Mass Transit Ceramic Tile and Stone Technical Design Manual

Globally Proven Construction Solutions

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Mass Transit Ceramic Tile and Stone Technical Design Manual

MASS TRANSIT CERAMIC TILE AND STONE
TECHNICAL DESIGN MANUAL

LATICRETE Technical Service Staff

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MISCELLANEOUS:

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Authored by the LATICRETE International, Inc. Technical Services Staff

Section 1: Introduction

Hartsfield–Jackson Atlanta International Airport, Atlanta, Georgia

1.1 PREFACE

Airports, train stations and other mass transit facilities introduce millions of visitors and citizens to communities on a daily basis and often reflect the grand scale of architecture at the time of construction. It has been said that many of these prestigious facilities provide a glimpse into a city's personality and its qualities. Styles of mass transit architecture range from vintage baroque and gothic styles to more modern utilitarian styles. A renewed interest in mass transit projects is taking place on a global scale. Many countries recognize the benefits of expanding or creating public mass transit facilities. These benefits include; more efficient travel routes, less congestion on city streets, lower automobile emissions, less reliance on fuel oils, fewer accidents on roadways, realized land consumption savings, reduction of noise, and longer life cycles for transportation services. Public transportation involves more than moving people; it is a means to provide mobility that is safe and enjoyable for the passengers of the communities that are served.

Mass transit applications include, but are not limited to; airports, tunnels, train stations, rapid transit rail systems, commercial railway systems, tram, light rail, magnetic levitation, monorails, bus terminals, communal road service system, ferry and waterway service or a mix of various transportation modes. Many of the terminals, roadways, platforms, tunnels and building structures in and around these various facilities require floor and wall finish materials that can withstand the demands placed upon the application. In addition to the performance requirements, the finish material types must add a certain aesthetic value to the project. Historically, ceramic tile and stone finishes have provided this combination of performance and beauty in mass transit applications around the world.

LATICRETE International, Inc., a manufacturer of ceramic tile and stone installation systems, understands the demands that are placed on ceramic tile and stone installations in mass transit applications. Therefore, this technical manual has been created to provide guidelines and recommendations for the design, specification, and installation of ceramic, quarry, paver and stone tile floor and wall installations. Technical advances in materials, manufacturing, and construction methods have expanded the role of these types of application ever since the development of adhesive mortars in the 1950's. In keeping with their position as an industry leader, LATICRETE International is publishing this edition of the Mass Transit Ceramic Tile and Stone Applications Technical Design Manual. This manual will make state-of-the-art information and technology available to architects, engineers, construction professionals, tile contractors, and manufacturers in the ceramic tile, paver and stone industries. It is also the goal of this publication to encourage new ideas, research, and building regulations for the purpose of improving the future of this construction technology and the ceramic tile, paver and stone industries.

1.2 TILE AND STONE IN MASS TRANSIT FACILITIES

Prior to the advent of thin bed installation systems, bulky conventional thick bed methods were employed for the installation of ceramic tile, paver tile and stone applications. Adhesive technology has opened up an entirely new world of aesthetic and technical possibilities for tiling in all types of demanding applications. Mass transit applications present many challenges for the designer and the installer.

Many mass transit installations place tremendous stress on the tile or stone application creating a challenging environment not only for the finish tile or stone, but also for the installation system materials.

This design manual has been created with the intent to assist the design professional in assessing and specifying the correct installation system for the specific application.

The earth, and everyone on it benefits from the more efficient and environmentally sensitive use of materials, resulting from reduced weight, lower cost of material, and more efficient use of natural resources. The building construction process is made more efficient by utilizing modern technology and installation methods, which all reduce construction time, on-site labor costs, and provides better quality assurance. For example, in the not so distant future we will even see tile and stone installations in heavy traffic areas including mass transit applications where flooring systems will generate electrical power. An example of this futuristic technology can be found in the Tokyo Station of the East Japan Railway Company and on the dance floors of Bar Surya in London England. Even in early development of these systems, the floors can produce up to 1400 kW/second per day as passengers walk on the piezoelectric elements embedded in the flooring systems (e.g. stone flooring).

However, all these advantages of using the systems outlined in this manual can only be realized with a new approach to the design and construction of the areas that will receive the finish materials. Design and construction techniques must be adapted to the specific requirements and behavior of construction adhesive technology, as well as to the unique attributes of ceramic tile, pavers and stone finishes.

1.3 HISTORY OF CERAMIC TILE IN MASS TRANSIT FACILITIES

Ceramic tile has been used for centuries as a decorative and functional building material for buildings. Ceramic tile development can be traced to 4,000 B.C. in Egypt.

In the 1950's, Henry M. Rothberg, a chemical engineer who later founded LATICRETE International, invented a product and new methodology that would make direct adhesive installation of ceramic tile, stone, and thin brick applications physically and economically feasible. This development revolutionized both the ceramic tile and stone industries.

1.4 SUMMARY OF MUTUAL CONTENT

Ceramic tile, porcelain tile, pavers, quarry tile and stone must be designed and constructed with careful consideration of the complex interactions that occur between all components within the tile and stone assembly. This manual explores many of the issues that a design professional will encounter as specifications and details are prepared for these demanding, high performance applications.

The selection and preparation of a substrate is one of the most critical steps in the design and construction of a tile and stone assembly. Suitability and compatibility of the most common substrates is covered in this manual, along with comprehensive recommendations for preparation of the substrate including evaluation of level and plumb tolerances, surface defects, and the effect of climatic and site conditions on substrates.

Section 2 – Floor Constructs

This section is a primer on the theory and terminology of floor construction. Types of floor structures and construction are presented, together with commentary on applicability to the installation of ceramic tile, paver and stone finishes for mass transit applications.

Section 3 – Wall Constructs

A primer on the theory and terminology of wall construction. Types of wall structures and construction are presented, together with commentary on applicability to the installation of ceramic tile, paver and stone finishes for mass transit applications.

Section 4 – Comparison of Alternate Transit Flooring Systems

A comparison of other popular flooring systems, including seamless epoxy and polyaspartic floors, cement based terrazzo, resin-based terrazzo, decorative polished and stamped concrete are considered. Advantages and disadvantages of each type are discussed.

Section 5 – Types of Tile and Stone for Mass Transit Applications

Investigation and selection of the proper type of finish material is an important design and durability decision. Detailed criteria for the assessment and selection of ceramic tile, porcelain tile, pavers, quarry tile and stone are presented.

Section 6 – Types of Waterproofing Membranes

This section discusses the various types of waterproofing membranes that are available on the market, and their suitability for use in conjunction with tile and stone applications. Criteria on selection and use are also discussed.

Section 7 – Types of Mortars/Adhesives/Grouts

This section covers the process of assessing and determining the selection criteria for mortars, adhesives and grouts as well as specific performance functions of installation materials for mass transit applications.

Section 8 – Methods of Installation

This section covers the entire range of installation and construction techniques and methods, from the various types of installation procedures to the equipment required for the installation of mass transit tile and stone applications.

Section 9 – Maintenance and Protection

Cleaning, protection, and preventative maintenance procedures are presented to ensure long-term performance of a tiled system.

Section 10 – Industry Standards, Building Regulations and Specifications

Detailed information on applicable industry standards and building codes for ceramic tile and stone adhesives is provided. Sustainability is also discussed in this section.

Architectural details show typical tile and stone application assembly configurations used in mass transit projects and recommended design for such. Examples of these concepts are graphically depicted with various substrate/material combinations. Details include design recommendations for interface details such as penetrations, drain tie-ins, movement joint sealants, flashing, and waterproofing membranes. Please visit www.laticrete.com/ag for the complete library of LATICRETE details and specifications.

Section 2: Floor Constructs

Shanghai Hongqiao Airport, China

2.1 STRUCTURAL CONSIDERATIONS

Types of Structural Movement

It is essential that all floor applications be designed to accommodate all types of structural movement. Structural movement can transmit through the flooring assembly, accumulate, and then exert stress on the flooring, resulting in cracking, buckling, or loss of bond.

The different types of structural movement are individually quantifiable through mathematical calculations which, for mass transit floors, will mainly be restricted to concrete substrates. Fortunately, the structural theory used in most building codes dictates the use of "worst case" conditions; the calculated movements are of the highest possible magnitude in order to provide a safety factor when exposed to the most extreme, actual conditions.

Types of Structural Movement Include:

- Thermal Movement
- Creep
- Differential Settlement
- Seismic

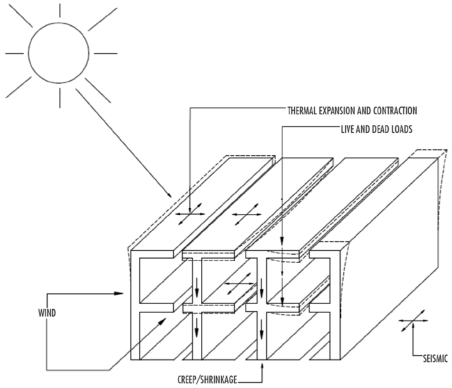


Figure 2.1 – Types of structural movement (Goldberg, 1998, p. 71).

Thermal Movement

Thermal movement is a term that refers to the expansion or contraction of a substance in response to changes in temperature. All materials react to changes in temperature. While all materials move in response to temperature, all materials can exhibit differences in both the speed of the reaction and the degree of movement when subjected to similar temperature changes. When two dissimilar materials react dramatically different in the same environment, the ability of a tile adhesive to maintain strong bond through such challenges can be tested. In situations where dissimilar materials meet and tile spans both materials, cracking or complete loss of bond may be the likely consequence. Allowing for movement within the substrate layer and the tile installation is critical to assure long term, problem-free installations.

There are two factors to consider in analyzing thermal movement:

1. The rates of expansion of different materials (i.e. linear coefficient of thermal expansion)
2. The anticipated temperature range exposure

Some building materials respond rapidly when exposed to temperature changes while concrete can respond more slowly. Some tile products have a higher tensile strength than concrete and may also respond to temperature changes at a different rate. Stresses applied to the tile installation and concrete, as a result of the rapid or continuous movement of dissimilar materials, can be that the concrete cracks horizontally just below the bond line and the system can fail at that point.

Thermal movement can be rapid and reoccurring. Rapid changes can be explained when normal conditions are introduced to extreme high temperatures (i.e. direct sunlight) or extreme cold (e.g. freezing conditions). Temperature changes do not have to be dramatic for movement to occur. Slower more repetitive temperature changes can be equally destructive. In these situations, there can be continuous stress at the bond line caused by such things as daily recurring temperature changes. These temperature changes, in conjunction with time, can fatigue the weaker material at the bond line. Over time the weaker material (i.e. concrete), may cause the same failure as if it were exposed to rapid temperature changes. The conditions that might cause loss of bond are not always obvious. Some conditions to be aware of are:

- Exterior Applications
- Interior Applications Exposed to Sunlight Through Windows, Curtain Walls, Doors and Skylights
- Rapid or Wide Changes in Ambient Temperature
- Application of Cold Water to Hot Surfaces (e.g. When Rain Showers Occur and Cool Down Exterior Applications That Have Been Exposed to Hot Conditions)

When selecting materials for a tile floor, be aware of the above conditions. Additionally, cleaning and disinfecting protocols requiring hot water or steam need to be considered, especially if the area being cleaned is normally kept cool, as in the case of controlled public environments.

In applications of extreme temperature change, it may be necessary to use a coarser aggregate than what is used in typical concrete. Thinner ceramic tile and stone bonding systems (e.g. 257 TITANIUM™) react well to thermal stress because they are often too thin to exhibit destructive energy at the bond line. In a conventional tug of war, tile installation materials are more at the mercy of the concrete properties than the other way around. However, if the application receives heavy vehicular traffic or extremely heavy loads, make sure the tile installation materials fit the service requirement of TCNA "Extra Heavy" when tested in accord with ASTM C627 (Standard Test Method for Evaluating Ceramic Floor Tile Installation Systems Using the Robinson-Type Floor Tester).

The primary goal in analyzing thermal movement is to determine both the cumulative and individual differential movement that occurs within and between components of the floor assembly.

For example, a porcelain tile has an average coefficient of linear expansion of between (4–8 x 10^{-6} mm/°C/mm) of length. Concrete has an average expansion rate of 9–10 x 10^{-6}mm/°C/mm. The surface temperature of a porcelain tile in an application exposed to direct sunlight may reach as high as 160°F (71°C); an ambient temperature in a moderately cold climate may be 0°F (-18°C) or colder. The temperature variation within this tile installation can vary by as much as 160°F (89°C). The temperature range of the concrete, insulated from the temperature extremes by the tile and tile installation mortars, as well as length of exposure, may only be 85°F (30°C). For a building that is 50 m wide, the differential movement can be calculated as follows:

Concrete 0.000010 mm x 50 m x 1000 mm x 30°C = 15 mm. Tile 0.000006 mm x 50 m x 1000 mm x 70°C = 21 mm.

Because the thermal expansion of the tile is greater, this figure is used. The general rule for determining the width of a movement joint is 2 – 3 times the anticipated movement, or 3 x 21 mm (.82") = 63 mm (2.5"). The minimum recommended width of any individual joint is 10 mm (3/8"), therefore, a minimum of 6 joints across a 50 m (154') floor, each 10 mm (3/8") in width is required just to control thermal movement under the most extreme conditions.

Linear Thermal Movement to Differential Porcelain Ceramic Tile Sizes		
Tile Size	Thermal Coefficient x Temp. Range x Tile Length	Linear Movement per Tile in mm
24" x 24" (600 x 600 mm)	8 x 10^{-6} (60°C) (600 mm)	0.288 mm
16" x 16" (400 x 400 mm)	8 x 10^{-6} (60°C) (400 mm)	0.192 mm
12" x 12" (300 x 300 mm)	8 x 10^{-6} (60°C) (300 mm)	0.144 mm
8" x 8" (200 x 200 mm)	8 x 10^{-6} (60°C) (200 mm)	0.096 mm
6" x 6" (150 x 150 mm)	8 x 10^{-6} (60°C) (150 mm)	0.072 mm
4" x 4" (100 x 100 mm)	8 x 10^{-6} (60°C) (100 mm)	0.048 mm

Figure 2.2 – Linear thermal movement of different porcelain ceramic tile sizes at normal maximum temperature range for temperate climate (Goldberg, 1998, p. 72).

Thermal Coefficient of Expansion of Concrete Based on Aggregate Type		
Aggregate Type	Coefficient of Expansion, millionths (10-6)	
(from one source)	per degree Fahrenheit	per degree Celsius
Quartz	6.6	11.9
Sandstone	6.5	11.7
Gravel	6.0	10.8
Granite	5.3	9.5
Basalt	4.8	8.6
Limestone	3.8	6.8
NOTE: Coefficient of Expansion of concretes made with aggregates from different sources may vary widely from these values, especially those for gravels, granites, and limestone. The coefficient for structural lightweight concrete varies from 3.9 to 6.1 millionths per degree Fahrenheit (7 to 11 millionths per degree Celsius), depending on the aggregate type and the amount of natural sand.		

Figure 2.3 – Controlling the thermal movement of concrete by aggregate type. (Goldberg, 1998, p. 74).

Creep

Deformation movement in concrete structures, also known as creep, occurs more slowly and can increase initial deflection by 2–3 times. Creep is the time dependent increase in strain of a solid body under constant or controlled stresses. The placement of movement joints is critical in the success of the structure. Also the realistic prediction of both the magnitude and rate of creep strain is an important requirement of the design process. While there are laboratory tests that can determine the deformation properties of concrete, it is often skipped because of the time consuming nature and high cost of the test. In cases where only a rough estimate of the creep is required, an estimate can be made on the basis of only a few parameters such as relative humidity, age of concrete and member dimensions. Ideally a compromise has to be sought between an estimate of the prediction procedure and the laboratory testing and mathematical and computer analyses.

Differential Settlement

Buildings structures and concrete placement pours used for access ways are typically designed to allow for a certain tolerance of movement in the foundation, known as differential settlement. In most cases, the effect of normal differential settlement movement on the flooring system is considered insignificant because much of the allowable settlement has occurred before the flooring system has been installed. Differential settlement of a building foundation and concrete that occurs beyond the allowable tolerances is considered a structural defect which can cause significant problems to any flooring system, including the tile or stone finish. At that point, one would need to address the root cause of the problem and come to a solution before the flooring system can be repaired. Patching the visible problem areas in the flooring system will not provide an adequate solution, and one can expect repetition of the same issues in the floor.

Controlling Stresses With Movement (Expansion) Joints

One of the primary means of controlling the stresses induced by building movement, concrete shrinkage and typical concrete curing is with movement joints (also known as expansion, dilatation, or control joints). All buildings and building materials move to varying degrees, and therefore the importance of movement joints cannot be understated. At some point in the life cycle of an interior floor, there will be a confluence of events or conditions that will rely on movement joints to maintain the integrity of the floor system. Maintaining integrity of the floor can be made as simple as preventing cracks in grout joints, to preventing complete adhesive bond failure of the tile. Proper design and construction of movement joints requires consideration of the following criteria:

- Location
- Frequency
- Size (Width:Depth Ratio)
- Type and Detailing of Sealant and Accessory Materials

Figure 2.4 – Result of stresses induced by concrete shrinkage and lack of movement joint control. As the concrete shrinks, expansion joints are required to relieve the stress. When expansion joints are omitted or are not sufficient, "tenting" of the tiles can occur, creating bond failure and cracking.

MOVEMENT JOINTS

Location of Movement Joints

The primary function of movement joints is to isolate the tile or stone from other fixed components of the structure, and to subdivide the substrate and finish materials into smaller areas thereby compensating for the cumulative effects of building movement (see section 10 for specifications and details). While each floor is unique, there are some universal rules for location of movement joints that apply to any floor installation. Many of the universal rules for movement joints can be found in the current edition of the Tile Council of North America's (TCNA) Handbook for Ceramic, Glass, and Stone Tile Installation, EJ-171.

Existing Structural Movement Joints

Movement joints may already be incorporated in the underlying structure to accommodate thermal, seismic or other load types. These movement joints must extend through to the surface of the tile or stone, and equally important, the width of the underlying joint must be maintained to the surface of the tile or stone.

Changes of Plane

Movement joints should be placed at all locations where there is a change in plane, such as outside and inside corners and changes in elevations (e.g. ramps).

Location – Dissimilar Materials

As stated earlier in this section, different materials have different rates and characteristics of movement. Movement joints must be located wherever the floor tile and underlying adhesive and leveling mortars meet a dissimilar material, such as metal, penetrations, and many different types of tile.

Frequency of Movement Joints

Guidelines for movement joints are up to a maximum of 25' (7.5 m) in every direction for interior applications, and 8' to 12' (2.4 m – 3.6 m) in every direction for exterior applications and any interior tile work exposed to direct sunlight or moisture, or, as stated in the current TCNA Handbook for Ceramic, Glass, and Stone Tile Installation EJ-171. The placement of movement joints need to be incorporated where tile work abuts restraining surfaces such as perimeter walls, dissimilar floors, curbs, columns, pipes, ceilings, and where changes occur in backing materials, but not at drain strainers. All expansion, control, construction, cold, and seismic joints in the structure should continue through the tile work, including such joints at vertical surfaces. Joints through tile work directly over structural joints must never be narrower than the structural joint.

Size of Movement Joints

The proper width of a movement joint is based on several criteria. Only taking thermal linear expansion of the tile in consideration, and not considering the frequency or size of the substrate -or- deflection, shrinkage, or expansion, the width movement joints is preferred to be around 1/4" (6 mm) for most applications. For exterior installs, joint 8' (2.4 m) on center the minimum width shall be 3/8" (9 mm) and joints 12' (3.7 m) on center shall have a width of 1/2" (12 mm). Change in plane interior application shall be the same as the grout but never less than 1/8"; any joint narrower than this makes the proper placement of backer rods and sealant materials impractical, and does not provide adequate movement allowance.

The width of a movement joint filled with sealant material must be 3 to 4 times wider than the anticipated movement in order to allow proper elongation and compression of the sealant. Similarly, the depth of the sealant material must not be greater than half the width of the joint to allow for proper functioning of the movement joint (width:depth ratio). For example, if 1/4" (6 mm) of cumulative movement is anticipated in the floor, the movement joint should be 3/4 – 1" (19 – 25 mm) wide and 3/8 – 1/2" (6 – 9 mm) deep (a rounded backup rod is inserted in the joint to control depth, and to keep the sealant from bonding to the substrate). Sealants are products that are designed to bond to two parallel surfaces (the sides/flanks of two tiles). Sealant bonding to 3 surfaces (the sides/flanks of two tiles and the substrate) means that the sealant can lose 75% of its effectiveness. So the backer rod, which the sealant does not bond to, is very important to the success of the sealant.

Sealants

Sealants should be a neutral cure, high performance (also known as Class A, or have a Shore-A hardness of 25 or greater), viscous liquid type capable of +/-25% movement. Silicone sealants can have the ability to compress to 50% of its original width and expand up to 100%. Floors exposed to heavy vehicular traffic may require a sealant with a higher A-Shore hardness as specified. Check with the sealant manufacturer for acceptability on each application.

Pre-fabricated movement joints, which typically consist of two L-shaped metal angles connected by a cured flexible material often may not meet the above movement capability required for a demanding horizontal application where extreme temperature changes occur. Similarly, the selection of non-corroding metal, such as stainless steel, is required to prevent corrosion by alkaline content of cement adhesive or galvanic reactions with other metals.

Pre-fabricated movement joints are commonly installed in advance of the tile, so it is critical to prevent excessive mortar from protruding through the punched openings in the metal joint. The hardened mortar may subsequently prevent proper bedding of the tile onto the floor in these areas.

Mechanical Properties

Sealants should have good elongation and compression characteristics, as well as tear resistance to respond to dynamic loads, thermal shock, and other rapid movement variations which are not unusual for floors subjected to heavy loads and use. Many floors in mass transit projects are exposed to extreme vibrations resulting from railway cars, heavy foot traffic, carts, vehicles and machinery and are therefore constantly under stress from these vibrations.

Compatibility

Some sealants may stain tile or stone. In addition, curing by-products may be corrosive to concrete, metals, or waterproofing membranes. There are many types and formulations of sealant products, so it is important to verify compatibility and acceptability for the intended use. Compatibility varies by manufacturer's formulations, and not by sealant or polymer type. For example, acetoxy silicones cure by releasing acetic acid and can be corrosive; neutral cure silicones do not exhibit this characteristic.

Fluid migration and resultant staining is another compatibility issue to consider with sealants. There is no correlation with polymer type (i.e. silicone vs. polyurethane) and fluid migration. Fluid migration is dependent solely on manufacturer's formulation and type of tile or stone. Dirt contamination is another common problem and can be associated with type of exposure, surface hardness, type of and length of cure, and formulation, but not the sealant polymer type. Performing a test area to determine compatibility is recommended to make sure that problems are not encountered in the field during installation.

Adhesion

Sealants must have good tensile adhesion to non-porous or porous tile surfaces, ideally without special priming or surface preparation.

Subjective Criteria

Color selection, ease of application, toxicity, odor, maintenance, life expectancy, and cost are some of the additional subjective criteria that do not affect performance, but do require consideration.

Types of Sealant

High performance sealants are synthetic, viscous liquid polymer compounds known as polymercaptan, polythioether, polysulfide, polyurethane, and silicone. Each type has advantages and disadvantages. As a general rule, polyurethane and silicone sealants are a good choice for ceramic tile, pavers and stone.

Polyurethanes and silicones are available in either one component cartridges, sausage packs, or pails; some polyurethanes come in two-component bulk packages, which require mixing and loading into a sealant applicator gun. Both types of sealants are typically available in a wide range of colors.

Installation of sealants and accessories into movement joints requires skilled labor familiar with sealant industry practices. The installation must start with a clean, dry and dust free surface. Some products or materials require use of a primer to improve adhesion or prevent fluid migration. If a primer is necessary, it should be installed before installation of backer rods and it may be necessary to protect underlying flashing or waterproofing to avoid deterioration by primer solvents. Any excess mortar, spacers or other restraining materials must be removed to preserve freedom of movement. If necessary, protect the tile or stone surface with masking tape to facilitate the cleaning process. The use of a suitable backer rod or bond breaking tape is typically used to prevent three-sided adhesion and to help regulate depth of the sealant. Once the sealant has been applied, it is necessary to tool or press the sealant to ensure contact with the tile edges; the backer rod also aids this process by transmitting the tooling force to the tile edges. Proper tooling of the sealant joint also gives the sealant a slightly concave surface profile consistent to the interior surface against the rounded backer rod. This allows even compression/elongation, and prevents a visually significant bulge of the sealant under maximum compression.

2.2 STRUCTURAL CONSIDERATIONS

Loads

Forces that act on structures are called loads, and there are two types of loads which are taken into consideration when designing structures; dead loads and live loads. Typically, dead loads are static in nature, which means they either do not change or change infrequently. Dead load is essentially the weight of the structure itself; anything permanently attached to the structure would be considered part of the dead load. This would include walls, floors (and flooring), roofs, columns, and so on.

Live loads are the weight of items in the building. Live loads are not static as they can change. Examples of live loads would be people, furniture, railway cars, trolleys, carts, vehicular traffic, etc… Live loads can have a profound effect on the success of a tile installation and on the long term performance of the entire structure. Suitable allowance must be made for all anticipated live loads with enough allowance to meet any additional loads placed on the system in the future. Anticipated live loads must be accounted for in mass transit applications. Design assumptions should be calculated on 'worst case scenarios'. In other words, structures must be designed to anticipate the confluence of all loads, including dead and live loads, and the potential affect on the structure.

Requirements of Building Design

Buildings, platforms, structural concrete pours, and tunnels must be designed for the specific use for which they will be utilized. The architect or engineer has to know what the structure is going to be used for in order to properly calculate the different live and dead loads involved. If a railway car platform were designed to be constructed for an elevated condition, the design professional would have to calculate the total anticipated live load. Suitable allowance must be made for all anticipated live loads with enough allowance to meet any additional loads placed on the system in the future. Adequate structural reinforcement is required for demanding mass transit applications. The American Concrete Institute (ACI) is a good source of information pertaining to the design of concrete pours and structures for mass transit projects.

In addition, The Tile Council of North America's (TCNA) – Handbook for Ceramic, Glass, and Stone Tile Installations provides a floor tiling installation guide that depicts which installation methods are appropriate for the performance level requirements of an application. The performance levels of specific installation methods are determined by ASTM Test Method C627 "Standard Test Method for Evaluating Ceramic Floor Tile Installation Systems Using the Robinson Type Floor Tester". The test method exposes a tiled floor construct to a 300 lb. (135kg) concentrated load which turns on three wheels. As the cycles increase, the wheel type is changed from hard rubber wheels to steel wheels. An installation method that passes all 14 cycles is considered "Extra Heavy". An installation method that passes cycles 1 through 12 is considered "Heavy" and an installation method that passes cycles 1 through 10 is considered "Moderate". Typically, mass transit floor applications require installation methods that comply with "Extra Heavy" or "Heavy" service ratings.

In some applications, "Moderate" service ratings may also be applicable. It is important to note that the Marble Institute of America, Inc. (MIA) references the TCNA Handbook for the installation of certain dimension stone. The MIA's Dimension Stone Design Manual also provides information on this matter.

Vibration and Noise

Mass transit applications are subjected to varying levels of vibration and noise. Railway cars, buses, automobiles, and other mechanized equipment moving in and around mass transit structures place stresses on building components, including the tile and stone constructs and their installation systems. In many cases, shock absorbing fasteners, sound barriers, shock absorbing mounts, ballast mats, resiliently supported ties, floating concrete slabs and other anti-vibration ballast materials and equipment is specified and utilized in an effort to help reduce the transfer of vibration and noise through a building's structure. Multi-story mass transit facilities are designed to integrate shopping, housing and various transportation modes within the same facility. The vibration that can occur from the elements within a structure can affect the long-term performance of building components that are not designed to accommodate these stresses. In addition, excessive vibration and noise can have an adverse impact on humans and their ability to carry out their daily functions.

The United States Federal Transit Administration (FTA) has an assessment manual entitled "Transit Noise and Vibration Impact Assessment Manual" on this matter. These guidelines specify how to measure, predict and evaluate noise and vibration levels from mass transit sources.

Noise and Vibration Basics

The A-weighted noise level measured in decibels (dBA) is the basic measure of sounds.

Lmax = Maximum noise level during a single event (without taking into account the duration, time of day or number of events that occur).

Ldn = The equivalent day-night noise levels. This measurement assesses the annoyance level at residences and hotels. This is a 24 hour measurement which includes penalties for events that occur in the evenings.

Leq = The hourly-equivalent noise levels. This measurement is used to assess annoyance from noise at locations with daytime use such as schools or libraries.

Some typical Ldn dBA ranges for various environments are as follows:	
Ambient noise levels in close proximity to freeways, urban transit and major airports	= 85 Ldn
Urban ambient noise	= 70 Ldn
Suburban ambient noise	= 60Ldn
Rural ambient noise	= 45 Ldn
Wilderness ambient noise	= 35 Ldn

Vibrations are the movements of building surfaces produced by the forces of mass transit vehicles which can transmit through rails, roadways, structures, soil and other building elements. The basic measure of vibration is vibration velocity level in decibels (VdB). Humans can feel vibrations in structures above 65 VdB. Typically, vibration levels over 100 VdB can start to fatigue structures and begin to cause minor damage.

It is a science onto itself to research, assess, predict and construct mass transit facilities to reduce vibration and noise impact on humans and building structures. A qualified noise engineering service or an engineering firm specializing in this discipline should be consulted for aviation, rail and other mass transit projects for a comprehensive noise and vibration assessment.

Ceramic tile and stone installations can resist the traditional vibration stresses when installed with high performance shock resistant installation materials. The LATICRETE Systems Materials referenced throughout this technical design manual are designed to hold up under the demanding stresses typically found in mass transit applications.

Deflection

Floor systems, over which the tile will be installed, shall be in conformance with the International Building Code (IBC) or applicable building codes for mass transit applications.

Historically, for ceramic tile and paver applications, the maximum allowable deflection should not exceed L/360 under total anticipated load and L/480 for stone installations. The Marble Institute of America sets the maximum allowable deflection standard at L/720.

The ceramic tile and stone industry abides by the following note on deflection: the owner should communicate in writing to the project design professional and general contractor the intended use of the tile (or stone) installation, in order to enable the project design professional and general contractor to make necessary allowances for the expected live load, concentrated loads, impact loads, and dead loads including the weight of the tile (or stone) and setting bed. The tile installer shall not be responsible for any floor framing or sub-floor installation not compliant with applicable building codes, unless the tile installer or tile contractor designs and installs the floor framing or sub-floor." (see section 10 Building Codes and Industry Standards for more information).

2.3 SUBSTRATE CONDITION AND PREPARATION

Evaluation of Substrate Condition

The first step in substrate preparation is the evaluation of the type of substrate and its surface condition. This includes the levelness (plane or flatness deviation), identification of general defects (e.g. structural cracks, shrinkage cracks, laitance, etc…), and the presence of curing compounds, form release agents, surface hardeners, and contamination. Concrete should have a wood float or light steel trowel finish for proper adhesion of thin-set mortars, renders, screeds or membranes. Over finishing a concrete surface can close the pores and may inhibit proper adhesion of thin-set mortars, renders, screeds and membranes.

The ability of a substrate to be wetted by an adhesive is essential to good adhesion and important in determining the performance of the adhesive in bonding to the substrate. This means that not only should the substrate possess a balance between porosity and texture, but also that the surface must be clean of any contamination such as dust or dirt that would prevent wetting and contact of an adhesive. The levelness tolerance or smoothness of a substrate surface also play an important role in allowing proper contact and wetting with an adhesive. Typically, the greater the surface area to which the adhesive is in contact, the better the adhesion.

Adhesive Compatibility

Compatibility plays an important role in determining adhesion between the substrate and the finish material being installed. The substrate material must be compatible not only with adhesive attachment, but also with the type of adhesive under consideration. This means that the substrate material must have good cohesive qualities to resist tensile and sheer stresses and not have adverse reactions with the proposed adhesive. Similarly, the tile or stone being installed must also be compatible with the adhesive.

A general consideration in determining compatibility with adhesives is as follows; the installation of any finish material with an adhesive will only be as good as the setting materials and the substrate to which the finish material will be bonded. The highest strength adhesives and most careful application with the best quality tile or stone will not overcome a weak or dirty substrate.

This section provides information on the identification of common substrate characteristics and defects, and the preventative and corrective actions necessary for proper surface preparation.

Site Visit and Conference

Prior to commencing ceramic tile or stone work, the contractor shall inspect surfaces to receive the tile or stone and any installation accessories (e.g. waterproofing membranes, crack-isolation membranes, vapor reduction membranes, etc.), and shall notify the architect, general contractor, or other designated authority in writing of any visually obvious defects or conditions that will prevent a satisfactory tile or stone installation. Installation work shall not proceed until satisfactory conditions are provided. Commencing installation of tile or stone work typically means acceptance of substrate conditions.

Job Site Conditions

The following items are examples of potential issues that may need to be addressed prior to commencing the installation:

Moisture Content of Concrete

Finishes and installation materials used in mass transit applications can be affected by moisture during the installation and curing phase. For example, the strength of cementitious adhesives can be reduced from constant exposure to wet or damp substrates. Some materials, such as waterproofing membranes, may not cure properly or may delaminate from a continually wet substrate. A damp substrate may also contribute to the formation of efflorescence.

There are generally three tests that are used to determine moisture content in concrete. The three tests are Calcium Chloride (ASTM F1869 – Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloors Using Anhydrous Calcium Chloride), Relative Humidity (ASTM F2170 – Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes) and Plastic Sheet Method (ASTM D4263 – Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method). The Calcium Chloride test involves placing a petri dish of calcium chloride (covered by a plastic dome adhered to the concrete) on the concrete and allowing the petri dish to remain in place between 60 – 72 hours. The calcium chloride absorbs any moisture vapor that transmits through the concrete within the plastic dome. The results of a calcium chloride test measures the amount of moisture absorbed and results are stated in pounds per 1,000 ft^2 (92.9 m^2) in a 24 hour period. The Relative Humidity test involves placing probes in the concrete and taking readings with a hygrometer. A relative humidity reading of 75% or below is acceptable for most tile/stone applications. The Plastic Sheet Method involves taping a 24" x 24" (600 mm x 600 mm) piece of plastic on the concrete and allowing the plastic to remain in place for 18 – 24 hours to determine if any moisture has accumulated under the plastic when it is removed. Both ASTM F 1869 and ASTM F2170 are quantitative tests (stating approximately how much moisture is present) while ASTM D 4263 is a qualitative test (stating that moisture is present but not how much), and all are a “snapshot” of moisture vapor emission during the testing period. Please refer to Section 2.5 for more information on moisture content in concrete.

For substrates scheduled to receive a waterproofing membrane, maximum amount of moisture in the concrete/mortar bed substrate should not exceed 5 lbs/1,000 ft^2/24 hours (283 µg/s•m^2) per ASTM F1869 or 75% relative humidity as measured with moisture probes. Consult with finish materials manufacturer to determine the maximum allowable moisture content for substrates under their finished material.

Figure 2.5 – ASTM F1869 calcium chloride test kit and ASTM F2170 Relative Humidity Meter.

Surface and Ambient Temperatures

During the placement of concrete and installation of other types of substrates, extreme cold or hot temperatures may cause numerous surface or internal defects, including shrinkage cracking, a weak surface layer of hardened concrete caused by premature evaporation, or frost damage. Once the concrete is cured, extreme temperatures of both the ambient air and surface of the substrate can also affect the normal properties of tile/stone adhesives.

Elevated ambient air and surface temperatures (>90°F [32°C]) will accelerate the setting of cement, latex cement and epoxy adhesives. Washing and dampening floors will serve to lower surface temperatures for latex cement mortars and epoxy adhesives. Shading the substrate, if exposed to sunlight, is also effective in lowering surface temperatures, but if ambient temperatures exceed 100°F (38°C), it is advisable to defer work with adhesives to a more suitable time. Humidity may also have an effect on the curing of membranes and portland cement based adhesives and grouts. Higher humidity will work to slow down cure rates while low humidity will accelerate the curing process.

Flatness and levelness

A flat substrate is an important concern for any tile/stone installation requiring a direct bond adhesive application. Acceptable tolerance is 1/4" in 10' (6 mm in 3 m) and

1/16" (1.5 mm in 300 mm) from the required plane to conform with the ANSI specifications for ceramic tile/stone installations (see ANSI A108.01 – General Requirements: Subsurfaces and Preparations by Other Trades – Current Version). Greater deviations prevent the proper installation of tile/stone into the adhesive, which may result in numerous problems, including loss of bond or lippage.

If levelness tolerance is exceeded, then it may be necessary to employ remedial work, such as re-construction, patching, grinding, or installation of a self-leveling underlayment (e.g. NXT® Level) or a mortar bed (e.g. 3701 Fortified Mortar Bed).

If the tolerance is within specifications, then the use of a medium bed mortar and a larger size notch trowel can alleviate any minor defects in the substrate. Please note that while a medium mortar may be used to correct minor substrate defects, it is important to stay within the product manufacturers guidelines for thickness of the setting material.

Concrete Curing – Age of Concrete

The age of a concrete substrate is important due to the fact that as concrete cures and loses moisture, it shrinks. A common misconception is that concrete completes shrinking in 28 days. This is not true. Thick sections of concrete may take over 2 years to reach the point of ultimate shrinkage. Under normal conditions, 28 days is the time that it typically takes for concrete to reach its full design strength. At that point, concrete will have maximum tensile strength and can better resist the effects of shrinkage and stress concentration.

Depending upon the curing techniques, exposure to humidity or moisture, there may be very little shrinkage in the first 28 days. Flexible adhesives, certain latex or polymer fortified thin-set mortars or (e.g. 254 Platinum or MULTIMAX™ Lite), can accommodate the shrinkage movement and stress that may occur in concrete less than 28 days old. In some cases it may be recommended to wait a minimum of 30–45 days to reduce the probability of concentrated stress on the adhesive interface. Some building regulations or codes may require longer waiting periods of up to 6 months. After this period, resistance to concentrated stress is provided by the tensile strength gain of the concrete, and its ability to shrink as a composite assembly. The effect of the remaining shrinkage is significantly reduced by its distribution over time and accommodated by the use of flexible adhesives.

Cracking

Freshly placed concrete undergoes a temperature rise from the heat generated by cement hydration, resulting in an increase in volume. As the concrete cools to the surrounding temperature, it contracts and is susceptible to what is termed “plastic shrinkage” cracking due to the low tensile strength within the first several hours after the pour.

Concrete also undergoes shrinkage as it dries out, and can crack from build-up of tensile stress. Rapid evaporation of moisture results in shrinkage at an early stage where the concrete does not have adequate tensile strength to resist even contraction. Concrete is most susceptible to drying shrinkage cracking within the first 28 days of placement during which it develops adequate tensile strength to resist a more evenly distributed and less rapid rate of shrinkage. It is for this reason that it is recommended to wait 30–45 days before direct application of adhesive mortars.

Plastic shrinkage occurs before concrete reaches its’ initial set, while drying shrinkage occurs after the concrete sets. These types of shrinkage cracks generally do not produce cracks larger than 1/8" (3 mm) in width.

Treating Shrinage Cracks

There are two different ways to treat shrinkage cracks. The first way is detailed in the LATICRETE Architectural Guidebook – ES-F125 (available at www.laticrete.com/ag) or the Tile Council of North America’s (TCNA) TCA Handbook for Ceramic Tile Installation – F125. This method only treats the individual crack and not the entire floor. Be sure to follow the LATICRETE Execution Statement and detail ES-F125 or the TCA Handbook for Ceramic Tile Installation – F125 for proper installation recommendations.

The second method of treating the shrinkage crack would be detailed in the LATICRETE Architectural Guidebook – ES-F125A (available at www.laticrete.com/ag) or the TCA Handbook for Ceramic Tile Installation – F125A. This method uses the anti-fracture membrane over the entire floor. Following this method will help to protect the finished installation from cracks currently in the concrete substrate and any cracks which may develop over time. Mass transit applications are generally subjected to greater incidents of vibration which can affect the finish materials. Therefore, the use of crack isolation/anti-fracture membranes is recommended for these applications.

Structural Cracks

There is no tile/stone installation practice or method for treating any crack over 1/8" (3 mm) wide or structural cracks that experience differential vertical movement. These cracks are considered structural in nature and would require determination of the cause of the crack. Once the cause of the structural movement is determined, it must be remedied prior to repairing the tile installation. Repair techniques can vary (i.e. epoxy injection and pinning systems) and a structural engineer should be consulted prior to any remediation or installation of a tile/stone system.

Excessive foundation settlement and movement can be caused by building on expansive clay, compressible or improperly compacted fill soils, or improper maintenance around foundations. Whatever the cause, settlement can destroy the value of a structure and even render it unsafe. In any case, water is the basic culprit in the vast majority of expansive soil problems. Specific components of certain soils tend to swell or shrink with variations in moisture. The extent of this movement varies from soil type to soil type.

When unstable soils are used as a base for a foundation, the tendency for movement is transmitted to the foundation. Since soil movement is rarely uniform, the foundation is subject to a vertical differential movement or upheaval. If all the soil beneath a foundation swells uniformly, there usually is no problem. Problems occur, however, when only part of the slab settles. Then, differential movement causes cracks or other damages. Once again this condition must be corrected before any tile/stone installation can occur.

Potential Bond Breaking Materials

A tile/stone installation is only as good as its adhesion to the substrate and the tile/stone. An adhesive, in any form, will bond to the first thing it comes in contact with. If that material is dirt, dust, paint, or any other impediment that is lying on a surface, then the adhesion to that substrate can be compromised. The importance of a good, clean surface cannot be over emphasized, regardless of the substrate or tile/stone adhesive.

Laitance

Laitance is a surface defect in concrete where a thin layer of weakened portland cement fines have migrated to the surface with excess “bleed” water or air from unconsolidated air pockets. Once the excess water evaporates, it leaves behind a thin layer of what appears to be a hard concrete surface, but in reality is weakened due to the high water to cement ratio at the surface. Laitance has a very low tensile strength, and therefore the adhesion of tile/stone will be limited by the low strength of the laitance.

Mechanical methods, including the use of chipping hammers, scarifying machines or high-pressure water blast, are recommended. Concrete should be removed until sound, clean concrete is encountered. Measurement of surface tensile strength and the absence of loose material are good indicators of sound concrete.

Abrasive blasting by means of dry, wet or bead/shot blast methods are preferred for the removal of laitance on new and fully cured concrete. Compressed air used in these methods must be oil free. Since wet abrasive blasting reintroduces moisture into the concrete, sufficient drying time must be allowed.

Curing Compounds and Sealers

Liquid curing compounds and sealers are topically applied spray-on materials, which are designed to keep moisture in the slab. The constant amount of water kept in the concrete by the curing compounds helps accelerate the curing time and improve the performance of the concrete. Curing compounds and concrete sealers are used more frequently in all types of construction, especially in fast track jobs. Unfortunately, all types of curing compounds, concrete sealers and surface hardeners (including form release agents) must be completely removed from the slab prior to the installation of tile/stone. The best method to remove these curing compounds from the surface would be to bead-blast or shot-blast the concrete surface.

There is a very simple and effective test to identify the presence of curing compounds, sealers or other bond breaking conditions. Simply sprinkle a few drops of water onto the substrate and see what happens. If water absorbs into the slab then it is usually suitable for the direct adhesion of tile. On the other hand, if the water beads up on the concrete surface (like water on a freshly waxed car) then there is something present on the concrete surface that can inhibit proper adhesion of the tile adhesive.

Substrate Preparation Equipment and Procedures

To determine if bond inhibiting contamination such as oil or curing compounds are present on concrete, conduct the following test: taking proper safety precautions, mix a 1:1 solution of aqueous hydrochloric (muriatic) acid and water, and place a few drops in various locations. If the solution causes foaming action, then the acid is allowed to react freely with the alkaline concrete, indicating that there is no likely contamination. If there is little or no reaction, chances are the surface is contaminated with oil or curing compounds. Acids do not affect or remove oily or waxy residue, so mechanical removal may be necessary.

Contamination Removal

Any surface to receive tile or stone finishes will always be exposed to varying degrees of contamination, especially normal construction dust and debris. Tile and stone is often included in the last phase of building construction. Multiple trades have been in the area and finished their certain part of construction (i.e. sheet rock, plumbing, painting, etc…). There is often paint, drywall compound, oil and other materials on the concrete from prior trades that need to be removed. One of the most difficult jobs for any installer is the preparation of the surface before the installation of the tile or stone commences. But, it is one of the most important steps, if not the most important step, in providing for a successful, long lasting tile installation. Cleaning the surface is mandatory before tile is placed, and sometimes multiple washings will have to take place before tiling. Just sweeping the floor is not good enough!

With most adhesives or cement leveling mortars/renders, such as latex cement mortars or moisture insensitive adhesives, the substrate can be damp during installation; however, it cannot be saturated. The objective is not to saturate the floor, but to make sure all the dust and debris is removed before tiling.

If contamination removal is required, or if surface damage or defects exist, bulk surface removal may be necessary to prepare the substrate. There are several methods of removal, but it is important to select a method that is appropriate to the substrate material and will not cause damage to the sound material below the surface. The following methods are recommended:

METHODS OF REMOVAL

Mechanical Chipping, Scarifying and Grinding

Mechanical chipping, scarifying or grinding methods are recommended only when substrate defects and/or contamination exist in isolated areas and require bulk surface removal greater than 1/4" (6 mm) in depth. Chipping with a pneumatic square tip chisel and grinding with an angle grinder are common mechanical removal techniques.

Figure 2.6 – Dustless grinding.

Shot-blasting

This is a surface preparation method, which uses proprietary equipment to pummel the surface of concrete with steel pellets at high velocity. The pellets are of varying size, and are circulated in a closed, self contained chamber, where the pellets and debris are separated. The debris is collected in one container and the pellets are re-circulated for continued use. This is the preferred method of substrate preparation when removal of a thin layer of concrete surface is required, especially the removal of surface films (e.g. curing compounds or sealers) or paint.

Figure 2.7 – Shot blasting machinery creates a concrete surface profile to improve adhesion and remove contaminants.

Water-Blasting

High-pressure water blasting using pressures over 3,000-10,000 psi (21-69 MPa) will remove the surface layer of concrete and expose aggregate to provide a clean, rough surface. Thorough rinsing of the surface with water after water blasting is necessary to remove any laitance. Water-blasting is only recommended on concrete because of the high-pressure. Proper allowance must be made to allow for the excess water in the slab to dry. This method is commonly used on vertical surfaces.

Acid Etching

Acid etching or cleaning is never recommended to clean a surface prior to receiving tile/stone. If an acid is not neutralized or cleaned properly after the cleaning takes place, it can continue to weaken the portland cement in the concrete and tile installation materials when in the presence of moisture. Acid must be neutralized with Tri-Sodium Phosphate or baking soda mixed with water and then completely rinsed to ensure all the acid is removed from the surface. Again, acid is not recommended for cleaning concrete, since it has an adverse affect on portland cement. A chemical reaction occurs when portland cement and acid are introduced to each other that can destroy the cement matrix. The interaction between the acid and the portland cement exposes the concrete aggregates and weakens the concrete.

Acid can also leave a white powdery substance on the surface which can act as a bond breaker for any tile/stone installation material. To avoid any potential problems it is best to avoid the use of acids as a substrate preparation method.

Final Surface (Residue) Cleaning

The final and most important step of substrate preparation is the final cleaning, not only of the residue from contamination and bulk removal processes described above, but also cleaning of loose particles and dust from airborne contamination.

The final cleaning is considered minimum preparation for all substrates. Final cleaning can be accomplished by pressurized water as mentioned above, but can also be accomplished with standard pressure water and some agitation to eliminate the bond breaking effect of dust films. In some cases, airborne contamination is constant, requiring frequent washing just prior to installation of cement leveling plaster/renders, adhesive mortars, or membranes.

There is no exception from this general rule; and the only variation is the drying time of the substrate prior to the application of the adhesive. Drying time is dependent on the type of adhesive being used. With most adhesives, the substrate can be damp, with no standing water. A surface film of water will inhibit grab and bond of even water insensitive cement and epoxy based adhesives. The use of a damp sponge just prior to installation of tile/stone is an industry accepted method to ensure that the substrate is cleaned of any dirt and construction dust on the properly prepared substrate.

Typical Concrete Surface Profiles to Accept Tile/Stone Finishes

Ideally concrete slabs should be finished to a wood float or light steel trowel finish when scheduled to receive tile, stone or associated installation materials (e.g. waterproofing membranes, anti-fracture membranes, sound control membranes, self-leveling underlayments, vapor reduction membranes, bonded mortar beds, etc…). However, at times a wood float or light steel trowel finish has not been achieved and additional mechanical abrasion is required. Mechanically abrading over troweled slabs (shiny or burnished slabs) opens up the concrete surface pores which improves the bond of the topping materials.

To what extent/amount of mechanical scarification or bead blasting is required in order to achieve the satisfactory results? Is there a point where there can be too much mechanical abrasion?

As a reference guide, the International Concrete Repair Institute (ICRI) has created a concrete surface profile (CSP) chart:

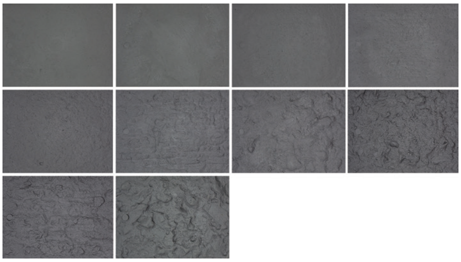


Figure 2.8 – Concrete Surface Profiles (CSP) ordered from 1 to 10 (ICRI, 1997).

- CSP 1 – Acid Etching
- CSP 2 – Grinding
- CSP 3 – Light Shot Blasting
- CSP 4 – Light Scarification
- CSP 5 – Medium Shot Blast
- CSP 6 – Medium Scarification
- CSP 7 – Heavy Abrasive Blast
- CSP 8 – Scabbling
- CSP 9 – Heavy Scarification

These models are replicates of concrete surfaces that represent the degrees of roughness ranging from CSP 1 (nearly smooth) to CSP 9 (very rough). Ordered in ascending roughness, surface profiles are meant to correspond to acid etching, grinding, light shot blasting, light scarification, medium shot blast, medium scarification, heavy abrasive blast, scabbing and heavy scarification.

If a floor is scarified to a point that it is too rough (e.g. CSP 6 or rougher), a LATICRETE® fortified underlayment can be used to correct the imperfections. Waterproofing or crack isolation membranes should be applied over smooth concrete slabs or slabs that has been smoothed or leveled with a LATICRETE fortified underlayment.

It is important to note that simply achieving the desired CSP rating does not necessarily indicate that all of the potential bond breaking or bond inhibiting materials have been thoroughly removed. All bond breaking and bond inhibiting materials must be removed regardless of the CSP rating of a concrete floor.

Contaminated Slab Alternative

On contaminated concrete slabs where it is not feasible to remove the top surface by a suitable method, an unbonded (wire-reinforced) mortar bed would be the best alternative. Please refer to the LATICRETE ES-F111available at www.laticrete.com/ag or in Section 10 for more information.

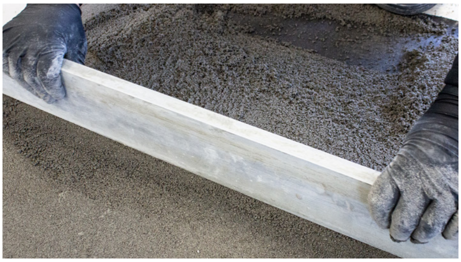


Figure 2.9 – Installation of an unbonded wire reinforced mortar bed.

ANSI A108.01 provides typical service ratings and mortar bed thickness for unbonded mortar bed applications. It is important to note that an unbonded mortar bed may not be appropriate for all application types in mass transit applications. Bonded mortar beds may be better suited for many of the applications that will be encountered in these applications.

	Extra Heavy / Heavy	Moderate
Thickness of Bed	2-1/2" (62 mm) minimum; 3-1/2" (87 mm) maximum	1-3/4" (44 mm) minimum; 2-1/2" (62 mm) maximum
Reinforcing Fabric	(Reference ANSI A108.02 Paragraph 3.7)	(Reference ANSI A108.02 Paragraph 3.7)
Placement of Reinforcing	Suspend reinforcing wire in middle of mortar bed	Suspend reinforcing wire in middle of mortar bed

Figure 2.10 – ANSI A108.01 General Requirements: sub-surfaces and preparations by other trades.

Service rating/thickness of wire reinforced mortar beds installed over a cleavage membrane, specify reinforcing and thickness. Mortar beds in excess of 3-1/2" (87 mm) thick may require heavier reinforcing, larger aggregate, richer mix, greater compaction and must be detailed by appropriate authority.

2.4 UNCOMMON SUBSTRATES

Asphaltic Waterproofing Membranes

Asphaltic (petroleum based) waterproofing placed over substrate surfaces are generally not compatible with tile installation adhesives. The presence of this type of waterproofing would dictate the method of installation that would have to be used. An unbonded wire reinforced mortar bed (ES-F111), available at www.laticrete.com/ag, would be the best option for installing over this type of waterproofing product. (See Section 10 for executions statement on this method).

Steel and Metal

Steel and metal substrates require an epoxy adhesive or the mechanical fastening of diamond metal lath to the steel and the installation of a mortar bed due to the high density and very low porosity of this type of material. Portland cement or latex portland cement adhesives, by themselves, do not develop adequate bond to metals without expensive preparation or special adhesive formulations.

There are two methods for the installation of tile over steel or metal substrates;

The preferred method would be to tack weld or mechanically fasten 3.4# diamond metal lath complying with the current revision of ANSI A108.1 (3.3 Requirements for lathing and Portland cement plastering), ANSI A108.02 (3.6) Metal lath, and A108.1A (1.0 – 1.2, 1.4 and 5.1).

Next, apply 3701 Fortified Mortar Bed; or, 226 Thick Bed Mortar gauged with 3701 Mortar Admix to float and fill in the wire lath. Float surface of scratch/leveling coat plumb, true and allow mortar to set until firm. Once the mortar bed is firm and dry the installation of the membrane (e.g. HYDRO BAN®, 9235 Waterproofing Membrane or Blue 92 Anti-Fracture Membrane), if specified can commence. Tile/stone can be installed directly to the membrane using 254 Platinum. Grout using an appropriate LATICRETE Grout (e.g. SPECTRALOCK® PRO Grout†) and use LATASIL™ for any movement or isolation joints.

The alternative (and most frequently used) method to set tile over a steel or metal substrate is as follows;

Make sure the steel or metal substrate is cleaned thoroughly, meets deflection ratings and can support the weight of the installation. Wash steel or metal with a strong detergent to ensure that all manufacturing oils are removed. Rinse completely and allow the steel or metal to air dry. If possible scuff up the surface to receive tile with sand paper or emery cloth and then re-wash the surface, rinse completely and allow to air dry. Once the surface is dry you may set the tile/stone using an epoxy adhesive (LATAPOXY® 300 Adhesive). Grout using a suitable LATICRETE Grout (e.g. SPECTRALOCK PRO Grout). Use LATASIL for movement and isolation joints.

The metal or steel substrate must be rigid enough to withstand the weight of the mortar bed, any membranes, setting materials, tile and grout.

(See Section 10 for an execution statement on these methods). Please refer to LATICRETE ES-S313 and ES-S314 at www.laticrete.com/ag or in Section 10 for more information.

Plywood

Plywood and other wood-based products generally have high water absorption rates, and undergo rates of volumetric swelling and subsequent shrinkage that make these materials unsuitable as a substrate types in mass transit applications. In addition, The Tile Council of North America (TCNA) classifies most plywood floor substrates as residential and light commercial use. Therefore, this classification would negate the use of plywood in many types of mass transit applications.

2.5 CONCRETE – SLAB-ON-GRADE

Placement of Concrete Slab

The vast majority of all mass transit tile installations are adhered directly to concrete. The most important factor for good, hard concrete is the water to cement ratio. Concrete needs water to hydrate and harden, but too much water can have a detrimental effect on concrete. Too little water will also affect the final performance of the concrete product. Understanding water and its effect on concrete is critical to achieving the desired results from a concrete slab. Water escapes from concrete via evaporation and also transpires through concrete from other sources and passes through as moisture vapor.

The water used to mix concrete must be clean (potable) and free of acids, alkalis, oils, or sulfates. This is necessary for proper hydration and curing of the concrete. There is a direct relationship between the strength characteristic of portland cement based concrete and the amount of water used per weight of cement. This is known as Abram's Law (Duff Abrams, 1918). Essentially, the lower the water to cement ratio the higher the resultant physical properties of the concrete will be. Rule of thumb – LESS WATER = BETTER CONCRETE.

Figure 2.11 – Placement and screeding of Concrete Slab

A properly designed concrete mixture will possess the desired workability for the fresh concrete and the required durability and strength for the hardened concrete. Typically, a mix is about 10 – 15% cement, 60 to 75% aggregate (fine and coarse combined), 15 to 20% water and 5 to 8% entrained air. The project engineer or design professional is responsible for specifying the actual concrete properties as required for each individual project.

Concrete will very often have an excess amount of water added to make the concrete easily workable. However, because portland cement only requires a certain percentage of its weight to hydrate, the excess water (water of convenience) will eventually escape. Much of the excess water will escape through capillary action (bleeding) while the concrete is in its plastic state during consolidation and finishing operations. Proper cure of concrete to attain the desired physical properties requires that moisture in concrete be maintained for a minimum of 3 to 7 days depending on temperature, humidity, type of cement, and type of admixtures used.

Typically, the first thing that a concrete contractor will do on a job site is perform a slump test to make sure that the concrete meets the slump criteria for that particular concrete. Unfortunately, many concrete contractors do not like the workability of concrete that passes the slump test. If this is the case, then the next words heard on the job site is "ADD MORE WATER". The concrete contractor may, without their knowledge, be affecting the final performance of the concrete. The fact is; if one extra gallon (3.8 L) of water is added to a cubic yard (1 m^3) of 3,000 psi (21 MPa) concrete then one or more of the following problems may occur;

1. Finished concrete can develop 5% less than its intended design strength,
2. Slump may increase by 1" (25 mm),
3. Compressive strength can be lowered by 150psi (1 MPa) or more,
4. The effect of 1/4 sack of concrete can be wasted,
5. Shrinkage potential increases,
6. Resistance to attack by de-icing salts is decreased, and
7. Freeze/thaw resistance can be decreased by 20%.

Importance of Vapor Retarders

Vapor retarders are necessary because concrete is a moisture and vapor permeable material. In fact, concrete can be thought of as being a very hard, dense sponge. Moisture vapor easily passes through concrete and can lead to problems with certain types of impervious tile, membranes, setting materials, and other types of flooring materials. In many cases, the vapor retarder is typically a 10 mil (.25 mm) thick polyethylene sheet placed directly under the concrete slab. Choosing the proper vapor retarder can be important since many polyethylene sheet materials are made with some recycled organic content. This organic content can decay over time leaving voids or holes through the sheeting; rendering it as an ineffective barrier. For better long term performance, architects and engineers are recommending 100% virgin polyethylene or 15 mil reinforced polyolefin as the vapor retarder. Proper placement and installation of the vapor retarder should also be specified by a qualified architect or engineer and shown in project details. No matter what material is used as the vapor retarder, it should conform to ASTM E 1745 (Standard Specification for Water Vapor Retarders Used in Contact with Soil or Granular Fill Under Concrete Slabs).

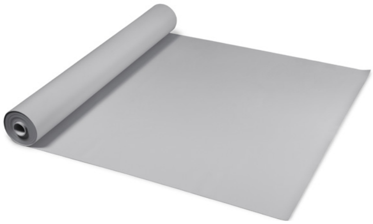


Figure 2.12 – Typical 15 mil thick sheet type vapor retarder – Photo Courtesy of Insulation Solutions, Inc.

A vapor retarder must have a maximum perm rating of 0.3 perms (0.2 metric perms) when tested by ASTM E 96 (Standard Test Method for Water Vapor Transmission of Materials).[6] To give you an example of what a perm is; 7003 perms translates to 1 lb/1,000 ft^2/24 hours (57 mg/s•m^2) of moisture vapor as determined using the calcium chloride test (ASTM F 1869 – Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride). This means that moisture vapor can transpire through the vapor retarder but at an extremely low rate. A properly specified and placed vapor retarder will not allow any passage of moisture vapor through penetrations in the slab or at the perimeter. Good detailing, seaming and sealing of the vapor retarder are necessary to ensure that the required performance is attained. A good, properly placed and installed vapor retarder can also help to limit radon infiltration through a slab and into the structure.

Placement of Vapor Retarder

ACI Committee 302, "Guide for Concrete Slabs that Receive Moisture-Sensitive Flooring Materials" (ACI 302.2R-06)" states in section 7.2 that some specifiers require concrete to be placed on the vapor retarder, and others require placement of a granular blotter layer between the concrete and the vapor retarder. As with many engineering decisions, the location of a vapor retarder is often a compromise between minimizing water vapor movement through the slab and providing the desired short- and long-term concrete properties. There are benefits and drawbacks to each method. Therefore, proper detailing is very important to not only the performance of a flooring system but to the potential health and safety of building occupants.

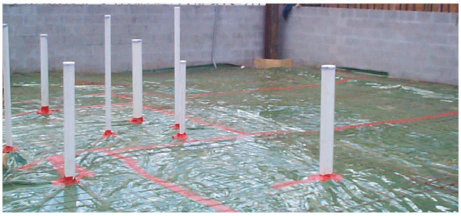


Figure 2.13 –Proper vapor retarder placement.

The original method places the vapor retarder directly onto the compacted soil. Next a 4" (100 mm) granular base blotter layer is placed on the vapor retarder with concrete poured on top. Based on the review of problem installations incorporating this method, it became clear that the fill course above the vapor retarder can take on water from rain, wet-curing, wet grinding or cutting, and cleaning. Unable to drain, the wet or saturated fill provides an additional source of water that contributes to moisture vapor emission from the slab. These moisture vapor emission rates can be well in excess of the 3 to 5 lb/1,000 ft^2/24 hr (170 – 283 mg/s•m^2) recommendation by many of the floor covering manufacturers.

As a result of these experiences, and the difficulty in adequately protecting the fill course from water during the construction process, caution is advised as to the use of the granular fill layer when moisture sensitive finishes are to be applied to the slab surface. The committees believe that when the use of a vapor retarder is required, the decision whether to locate the material in direct contact with the slab or beneath a layer of granular fill should be made on a case-by-case basis. Each proposed installation should be independently evaluated to consider the moisture sensitivity of subsequent floor finishes, anticipated project conditions and the potential effects of slab curling and cracking. It is also very important to lap up the vapor retarder onto the vertical plane and to seal off any penetrations through the sheeting to ensure maximum protection against vapor and moisture intrusion.

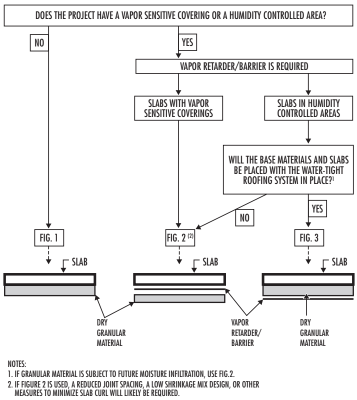


Figure 2.14 – Decision flow chart to determine if a vapor barrier is required and where it is to be placed. Chart courtesy of American Concrete Institute (ACI – 302.2R-06).

Figure 2.15 – Placement of vapor retarder over blotter layer / directly under the concrete pour. Notice the mechanic pulling the reinforcement wire to the middle of the concrete pour.

Drivers of Moisture Vapor

There are some very common reasons for having high moisture vapor emission problems in slabs. The most obvious would be a concrete slab without the placement of a vapor retarder. Without a vapor retarder there is nothing to prevent or limit any moisture underneath the slab from passing through the concrete. Soil capillarity can contribute as much as 12 gallons (45 L) per 1,000 ft^2 (92.9 m^2) per day to unprotected slabs from saturated shallow water tables. Broken pipes or leaking sewer lines can saturate the slab without obvious loss of water pressure. Some industrial applications have sump pumps underneath the slab to remove heavy chemicals and water used to clean machinery and floors. The pipes for these pumps can become corroded and eventually compromised by these chemicals and the soil underneath the slab can become saturated. Over-watered plant beds are another obvious contributor of water to building slabs as well.

When there is a vapor pressure differential, the higher pressure system will force moisture into the lower pressure system. Moisture vapor will consistently move from areas of high pressure to areas of low pressure. If sufficient moisture volume exists at the source and the concrete slab has low resistance to moisture, then the potential for floor covering or coating failure increases. Under the right conditions, there may also be sufficient moisture available to encourage the colonization of fungi. Indoor air quality and human health issues can be a far costlier outcome of excessive concrete moisture vapor emission than simply the loss of a floor.

TEMPERATURE F° (C°)	RELATIVE HUMIDITY %									
	100	90	80	70	60	50	40	30	20	10
100 (38)	0.948	0.854	0.758	0.663	0.569	0.474	0.379	0.284	0.189	0.095
90 (32)	0.639	0.621	0.551	0.482	0.414	0.344	0.275	0.209	0.138	0.069
80 (27)	0.506	0.455	0.405	0.357	0.303	0.253	0.202	0.152	0.101	0.051
75 (24)	0.429	0.386	0.343	0.300	0.258	0.214	0.172	0.129	0.086	0.043
70 (21)	0.362	0.326	0.290	0.253	0.217	0.181	0.145	0.108	0.072	0.036
65 (18)	0.305	0.274	0.244	0.213	0.183	0.152	0.122	0.091	0.061	0.030
60 (16)	0.256	0.230	0.205	0.179	0.153	0.128	0.102	0.077	0.051	0.026
55 (13)	0.214	0.192	0.171	0.149	0.128	0.107	0.085	0.064	0.042	0.021
50 (10)	0.178	0.160	0.142	0.124	0.107	0.089	0.071	0.053	0.036	0.018

Figure 2.16 – Chart Showing Static Pressures Based on Temperature and Relative Humidity (Moisture Vapor Intrusion into Building Envelopes from or Through Concrete Slabs).

Negative Hydrostatic Pressure

A common misconception points to negative hydrostatic pressure as the culprit floor covering failures.

Negative hydrostatic pressure can only occur when there is a physical water source higher than the slab. Therefore, it is very rare that a negative hydrostatic pressure condition exists on a project.

The chart (Figure 2.16) above helps to explain how temperature and humidity work to draw moisture into a structure through walls and concrete slabs. If the temperature of the soil under a structure is 55°F (13°C) and the relative humidity is 100% then the static pressure equals 0.214; if the building interior is at 70°F (21°C) and the humidity is 30% then the static pressure equals 0.108. This means that the moisture is driven into the building through the slab moving from the area of high pressure to the area of low pressure. Proper placement of a suitable vapor retarder can help to minimize moisture vapor transmission.

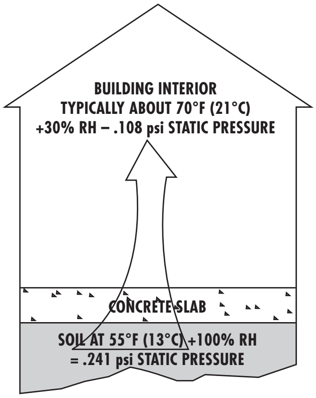


Figure 2.17 – Drawing showing movement of moisture vapor through a concrete slab.

Testing for Moisture in Concrete

Many variables affect the results of moisture and pH tests commonly used to determine the moisture related acceptability of concrete floors. Failure to run the test correctly can produce erroneous and misleading results.

Owners and contractors must understand that accurate floor tests must be conducted after the HVAC system is operating and the building has been at service conditions for 48 hours or longer. Most floors will not even begin to dry until the building has been enclosed and the HVAC system is running.

The building owner or general contractor should hire an independent testing agent to conduct floor moisture testing. Testers should be trained and certified. The test results should be reviewed by the design professional or a knowledgeable consultant to determine whether the floor is ready to receive an applied finish.

Most moisture tests, whether for moisture vapor emissions, relative humidity, or moisture content, measure a property that changes after the tile or other floor covering is installed. Concrete at the bottom of the slab in contact with the vapor retarder contains more moisture than the concrete at the surface. The moisture condition at the interface between the concrete and finish flooring changes because evaporation at the surface is hindered after the flooring is installed. This is true even if the vapor retarder is properly installed, the water to cement ratio is less than 0.50, and the floor is protected to prevent re-wetting. Water moves from the bottom of the slab toward the top driven by differences in vapor pressure between the high relative humidity at the bottom and the lower relative humidity at the top (as noted in Figure 2.15). Changes in temperature and relative humidity above and below the slab affect the static pressure and, in turn, the subsequent drive of the moisture vapor.

Current practice (if required) is for the tile installer to measure the moisture and pH of the floor and submit the results to the general contractor or construction manager. Too often these results are not transmitted to the design team, nor are the tests performed that the design team might have preferred. Moisture vapor emission rates are critical to the long term performance of a tile installation that incorporates a waterproofing or crack isolation membrane. Typical liquid applied waterproofing/anti-fracture membranes (e.g. HYDRO BAN®) require that the maximum amount of moisture in the concrete substrate not exceed 5 lbs/1,000 ft^2/24 hours (283 mg/s•m^2) per ASTM F1869 or 75% relative humidity as measured with moisture probes as per ASTM F2170.

High alkalinity in conjunction with a high moisture vapor emission rate may affect the long term performance of certain types of adhesives and "peel n' stick" asphaltic type membranes. These adhesives and membranes may soften and deteriorate when subjected to high alkalinity. Alkalinity can be measured by performing a standard concrete surface pH test in compliance with ASTM F710 (Standard Practice for Preparing Concrete Floors to Receive Resilient Flooring).

The design team should not leave the testing to the tile installer. Specifications should require the owner's testing agency conduct these tests and report the test results to the tile installer, general contractor or construction manager, and the design team. The specifications also should require that each test be conducted in accordance with ASTM standard test methods, or that any deviations from these methods be approved by the design team.

Commonly Used Moisture Test Procedures

Calcium ChlorideTest (ASTM F1869 – Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride)

A calcium chloride test measures Moisture Vapor Emission Rates (MVER) passing through or from concrete and gives results measured in pounds of moisture per 1,000 ft^2 (98.3 m^2) in a 24 hour period. Three calcium chloride tests should be conducted for the first 1,000 ft^2 (98.3 m^2) and one additional test per 1,000 ft^2 (98.3 m^2) within a 60 – 72 hour time frame or as required by design team. These tests are a "snapshot" for the specific time/date when the testing takes place and results can vary when calcium chloride tests are performed on different dates. Calcium chloride tests should only be performed after a building has been completely enclosed and the HVAC system has been operating for a prescribed length of time. Check with the manufacturer of the moisture test kit for complete instructions and recommendations.

Figure 2.18 – Calcium chloride test in place (Photo Courtesy of Vaprecision).

Relative Humidity Testing (ASTM F 2170 – Standard Test for Determining Relative Humidity in Concrete Floor Slabs Using In-Situ Probes)

Typically, relative humidity testing (also referred to as in situ testing) involves drilling a hole into the concrete and inserting a plastic sleeve. The sleeve is sealed and pressure is allowed to equalize for a prescribed length of time. A hygrometer probe is inserted into the sleeve and the reading is taken. Some relative humidity testers do not require drilling a hole. Testing equipment methodology and procedures may vary by manufacturer. Instructions for frequency and location of testing should be followed as recommended by design professional or engineer. Relative humidity testing can measure at selected depths of the concrete depending on the depth of the hole that is measured by the probe.

Figure 2.19 – In-Situ moisture testing.

The results of relative humidity testing are measured in percentages. Although there is no direct correlation between results based on ASTM F1869 testing and relative humidity testing, a reading of 75% roughly translates into 3 lbs/1,000 ft^2/24 hours (1.4kg/98.3 m^2/24 hours) as measured by a ASTM F1869 calcium chloride test (see 2.4.4.1). A reading of 80-85% roughly translates into 5 lbs/1,000 square feet/24 hours (283 mg/s•m^2).

Plastic Sheet Test (ASTM D 4263 – Standard Test for Determining Moisture in Concrete by the Plastic Sheet Method)

This test method is qualitative and only provides static results at the moment that the test is completed. This test method will not provide quantitative moisture level results and is strictly used to determine if moisture is present. This is generally considered an outdated method to measure moisture transmissions.

Figure 2.20 – ASTM D4263 – Plastic sheet method – 18" x 18" (45 cm x 45 cm) sheet of plastic is tightly taped to the substrate and allowed to sit undisturbed for 24 hours. If water or condensation is observed, then a measure of moisture vapor transmissions is present. This test will not provide a quantitative moisture vapor emission rate.

Efflorescence

Efflorescence is a white crystalline deposit that forms on or near the surface of concrete, masonry, grout and other cement based materials. It is the most common post-installation condition in tile, stone and brick masonry installations.

Efflorescence can range from a cosmetic annoyance that is easily removed, to a serious problem that could cause adhesive bond failure or require extensive corrective construction and aggressive removal procedures.

Efflorescence starts as salt, present in portland cement products, which is put into solution by the addition of water. The salt is then transported by capillary action (or gravity on walls) to a surface exposed to the air. The solution evaporates, the salts react with carbon dioxide and a white crystalline deposit remains. Efflorescence can also occur beneath the surface or within ceramic tile or brick.

Figure 2.21 – Presence of efflorescence on surface of concrete slab. Moisture migration through the slab can carry destructive salts to the surface of the concrete slab.

Efflorescence occurs when the three conditions listed below occur. While theoretically, efflorescence cannot occur if one condition does not exist, it is impractical to completely eliminate the confluence of these conditions.

Causes of Efflorescence

- Presence of Soluble Salts
- Presence of Water (for Extended Period)
- Transporting Force (Gravity, Capillary Action, Hydrostatic Pressure, Evaporation, etc…)

Presence of Soluble Salts

There are numerous sources of soluble salts listed in the Table below. There is always the potential for efflorescence when concrete and cement mortars, adhesives and grouts are exposed to the weather. Other sources of soluble salts can be monitored, controlled or completely eliminated. For more information on efflorescence please see Section 9.6.

Cement Hydration – The most common source of efflorescence is from portland cement based materials (e.g. concrete, cement plasters/renders, concrete masonry units, cement backer board units, and cement-based mortars, including latex cement adhesive mortars). One of the natural by-products from cement hydration (the chemical process of hardening) is calcium hydroxide, which is soluble in water. If portland cement based products are exposed to water for prolonged periods and evaporate slowly, the calcium hydroxide solution evaporates on the surface, combines with carbon dioxide and forms calcium carbonate, one of the many forms of efflorescence. Once the calcium hydroxide is transformed to calcium carbonate efflorescence, then it becomes insoluble in water, making stain removal difficult.

Calcium Carbonate Contamination – A common source of soluble salts is either direct or airborne salt-water contamination of mixing sand and the surface of the substrate. Mixing water can also be contaminated with high levels of soluble salts. Typically, water with less than 2,000 ppm of total dissolved solids will not have any significant effect on the hydration of portland cement, although lower concentrations can still cause some efflorescence.

Presence of Water

While it is difficult to control naturally occurring soluble salts in cementitious materials, proper design, construction and maintenance of a concrete floor and its finish materials can minimize water penetration. Without sufficient quantities of water, salts do not have adequate time to dissolve and precipitate to the surface of a concrete slab or tile installation, and efflorescence simply cannot occur. Using less "water of convenience" can also help to minimize the occurrence of efflorescence.

For exterior installations, rain and snow are the primary sources of water. For interior installations, the primary source is cleaning water. Broken pipes, poor soil drainage and inadequate rainwater evacuation can also contribute to high moisture levels within a building.

Sealers and Coatings

Water repellent coatings are commonly specified as a temporary and somewhat ineffective solution to fundamentally poor slab design and construction. In some cases, water repellents may actually contribute to, rather than prevent the formation of efflorescence. Water repellents cannot stop water from penetrating cracks or movement joints in the slab. As any infiltrated water travels to the surface by capillary action to evaporate, it is stopped by the repellent, where it evaporates through the coating (most sealers have some vapor permeability) and leaves behind the soluble salts to crystallize just below the surface of the water repellent. The collection of efflorescence under the repellent coating may cause spalling of the concrete.

Effects of Efflorescence

The initial occurrence of efflorescence is primarily considered an aesthetic nuisance. However, if the fundamental cause (typically water infiltration) is left uncorrected, continued efflorescence can become a functional defect and affect the integrity and safety of a tile/stone installation.

The primary concern is the potential for bond failure resulting from continued depletion of calcium and subsequent loss of strength of cementitious adhesives and underlying cement based components. The crystallization of soluble salts can exert more pressure on a tile/stone system than the volume expansion forces of ice formation.

Efflorescence Removal Methods and Materials

Prior to removal of efflorescence, it is highly recommended to analyze the cause of efflorescence and take corrective action to prevent recurrence. Analysis of the cause will also provide clues as to the type of efflorescence and recommended cleaning method without resorting to expensive chemical analysis.

Determine the age of the installation at the time the efflorescence appeared. In buildings less than one year old, the source of salts is usually from cementitious mortars and grouts, and the water source is commonly residual construction moisture. The appearance of efflorescence in an older building indicates a new water leak or new source of salts, such as from acid cleaning residue. Do not overlook condensation or leaking pipes as a water source. Location of the efflorescence will offer clues as to the entry source of water.

Chemical analysis of efflorescence can be conducted by a commercial testing laboratory using several techniques to accurately identify the types of minerals present. This procedure is recommended for buildings with an extensive problem, or where previous attempts to clean with minimally intrusive methods have failed.

Removal methods vary according to the type of efflorescence. Therefore, it is of critical importance to evaluate the cause and chemical composition of efflorescence prior to selecting a removal method.

Many efflorescence salts are water soluble and will disappear with normal weathering or dry brushing. Washing is only recommended when temperatures are warm so that wash water can evaporate quickly and not have the opportunity to dissolve more salts.

Efflorescence that cannot be removed with water and scrubbing requires chemical removal. The use of muriatic acid is a conventional cleaning method for stubborn efflorescence, however, even with careful preparation, acid etching can occur. There are less aggressive alternatives to muriatic acid, including a less aggressive sulfamic acid, available in powdered form. Sulfamic acid, dissolved in water to a concentration between 5–10%, should be strong enough to remove stubborn efflorescence without damage to the cementitious material.

Regardless of the cleaning method selected, the cleaning agent should not contribute additional soluble salts. For example, acid cleaning can deposit potassium chloride residue (a soluble salt) if not applied, neutralized and rinsed properly.

Acids should not be used on polished stone or glazed tile, because the acid solution can etch and dull the glaze or polished surface. Acids can react with compounds in the tile glaze and deposit brown stains on the tile surface which are insoluble and impossible to remove without ruining the tile.

Before applying any acid or cleaning solution, always test a small, inconspicuous area to determine if any adverse effects may occur. Just prior to application, saturate the surfaces with water to prevent acid residue from absorbing below the surface. While most acids quickly lose strength upon contact with a cementitious material and do not dissolve cement below the surface, saturating the surface is more important to prevent absorption of soluble salts residue (potassium chloride) which then cannot be surface neutralized and rinsed with water. This condition in itself can be a source of soluble salts and allow recurrence of the efflorescence problem intended to be corrected by the acid cleaning.

Application of acid solutions should be made to small areas less than 10 ft^2 ($1m^2$) and left to dwell for no more than 5 minutes before brushing with a stiff acid-resistant brush and immediately rinsing with water. Always follow the acid manufacturer's directions for diluting, mixing, application, initial rinsing, neutralization, and final rinsing techniques.

2.6 SUSPENDED CONCRETE SLABS

With advancements in concrete and concrete placement technology, the number of suspended (elevated) concrete slabs being placed is increasing around the world. There are numerous types of cast-in-place and pre-cast concrete floor systems available that can satisfy any structural, span or loading condition. Since the cost of a floor system is a major part of the structure, and the building cost, then selecting the most effective floor system is important to achieving overall performance of the building.

The ability to customize load capacity to suit the usage requirements, deflection, inherent fire-resistance, ease of installation, and the ability to create long spans makes concrete the material of choice for mass transit applications. The ability to finish the floor with a wide variety of finish materials (including tile and stone), permanently mount heavy machinery and the capability to stand up to extreme conditions are added benefits of concrete.

Defining the proper suspended slab type, reinforcement method, thickness, span, load bearing capacity, and all other performance requirements is the responsibility of a qualified design professional and/or structural engineer and is based on expected loads, usage, environment and much more.

We will take a look at 3 different types of suspended concrete slabs;

Cast-in-Place Concrete Slabs

The main components and expenses of cast-in-place concrete slabs are the concrete, reinforcement (either mild or post-tensioned) and formwork. A major emphasis of the need for reinforcement in suspended concrete slabs is the fact that concrete, while strong in compression, is weak in tensile and flexural strengths. Steel is strong under forces of tension, so combining concrete and steel together makes for an extremely strong and versatile building material. By combining the properties of reinforcing steel with concrete, you achieve a building material that can easily resist both compressive and tensile forces.

Benefits can also be achieved by using the reinforcing materials to place additional forces on the concrete to place it in compression. By compressing the concrete, additional tensile strength can be realized. This additional tensile strength (stiffness) can provide an architect with the ability to achieve longer spans with a thinner concrete slab. Another benefit of tensioning concrete raises the capability of the slab to resist the development of shrinkage cracks. In theory, the more the concrete is squeezed together, the less likely it is that concrete slab shrinkage cracks will develop.

Mild Reinforcement Concrete Slabs

Mild reinforced concrete slabs are poured in place, over framework, and around a steel reinforcement (rebar) grid. These rebar grids are most often assembled on site as defined by installation drawings with concrete poured around the reinforcing. This type of reinforcement is most often used in steel frame (deck) concrete slabs.

Post Tensioned Concrete Slabs

Post-tensioning is a method of stressing concrete in which tendons have tension applied after the concrete has hardened and the pre-stressing force is primarily applied through the end plates or anchorages. Unlike pre-tensioning, which can only be done at a pre-cast manufacturing facility, post-tensioning is performed in-situ on the job site.

Concrete slabs usually utilize ultra high-strength steel strands to provide post-tension forces to the slab. Typically, these steel strands have a tensile strength of 270,000 psi (1,860 MPa), are about 1/2" (12 mm) in diameter and are stressed to approximately 33,000 lbs (15,000 kg).

Fig. 2.22 – Post tensioned concrete slab. Notice the orange tensioning cables that will run throughout the concrete slab. Photo Courtesy of SunCoast Post Tensioning Company.

Figure 2.23 – Post tensioned concrete cables. Notice the orange tensioning cables that will run throughout the concrete slab. Photo Courtesy of SunCoast Post Tensioning Company.

Figure 2.24 – Post tensioned concrete slab tendon anchor. Anchor secures post tensioning cables running through the concrete slab. Photo Courtesy of SunCoast Post-Tensioning Company.

Reinforcing wire tendons are usually pre-manufactured at a plant, based on specific requirements, and delivered to the jobsite, ready to install. These tendons are laid out in forms in accordance with installation drawings that indicate how they are spaced, what their profile height should be, and where they will be stressed. After the concrete is poured and has reached required strength (up to 5,000 psi [34.5 MPa]) the tendons are stressed and anchored. These tendons, like rubber bands, want to return to their original length but are prevented from doing so by the anchorages. The fact that the tendons are kept in a permanently stressed state causes a force in compression to act on the concrete. The compression that results from the post-tensioning counteracts the tensile forces created by subsequent loading (machinery, people, equipment, flooring, etc…).

Pre-Tensioned (Pre-Cast) Concrete Slabs

While pre-tensioning is similar to post-tensioning in the fact that steel tendons are exerting stresses onto concrete to increase tensile strength, the method of placement is different. In post-tensioning, the steel tendons are stressed after the concrete hardens; in pre-tensioning, the steel tendons are stressed to 70 – 80% of their ultimate strength prior to the concrete being placed or (poured into the molds – in the case of pre-cast concrete) around the tendons. Once the concrete reaches the required strength, the stretching forces are released. As the steel reacts to return to its original length, the tensile stresses are translated into a compressive stress in the concrete.

Pre-tension concrete members must be poured at a production facility and shipped to the job site individually. Each member is then installed as required and supported by columns, beams or other structural member.

Pre-cast concrete planking is another form of pre-tensioned concrete. The pre-cast concrete planks are tensioned prior to the concrete being poured. The concrete planks are then slipped together and mortared in place. Typically, a 2" (50 mm) thick concrete topping slab is required to create a monolithic concrete slab that is suitable to receive a ceramic tile or paver finish.

Advantages of pre-stressed concrete slabs is shallower depth for the same deflection rating as a thicker slab and greater shear strengths than plain reinforced slabs of the same depth.

Figure 2.25 – Pre cast concrete planks. Planks rest and are supported by a flange attached to the steel girders. The planks are hoisted into place by a crane and mortared to the beams and to each other. Photo courtesy of Girder Slab Technologies LLC.

Steel Frame (Deck) Concrete Slabs

To achieve desired tensile strength in pre-tension and post-tension slabs, tendons are required that have stresses applied to them. In steel frame (deck) construction, the steel deck and additional mild steel reinforcing will provide the tensile strength required for the concrete slab. Post-tensioning is typically not necessary.

Modern profiled steel pan sheeting, specifically designed for the purpose, acts as both permanent formwork during concreting and tension reinforcement after the concrete has hardened. Shear connections are mechanical fasteners used to develop composite action between the steel beams and the concrete and maintains solid structural integrity. At this final stage the composite slab consists of a profiled steel sheet and an upper concrete topping which are interconnected in such a manner that horizontal shear forces can be resisted at the steel-concrete interface.

Composite floor construction has certain advantages over typical concrete construction;

1. It is used in very tall buildings,
2. It is lightweight and strong,
3. It is prefabricated, so it assembles quickly.

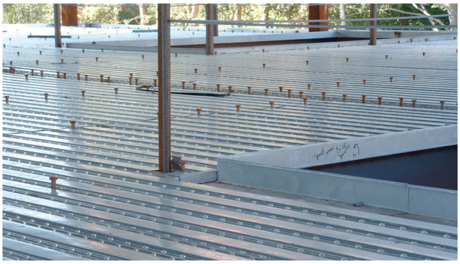


Figure 2.26 – Steel pan showing placement of shear connections and edge detail.

Figure 2.27 – Concrete pour over suspended composite steel pan floor construction.

Tile Installation Over Suspended Concrete Slabs

The TCNA recommends method F-111 for installation over a suspended concrete slab, or, for installations where an unbonded mortar bed is impractical, follow TCNA method F122 which requires an anti-fracture or waterproofing/ anti-fracture membrane.

Please reference www.laticrete.com/ag for further information on the LATICRETE recommended installation methods (ES-F111 and ES-F122) to comply with the above mentioned TCNA guidelines.

Concrete or Mortar Bed Substrates

Once the mortar bed (e.g. 226 Thick Bed Mortar mixed with 3701 Mortar Admix or 3701 Fortified Mortar Bed) hardens and is cured properly, most waterproofing membranes can be installed directly over the mortar bed. Follow the membrane (e.g. 9235 Waterproofing Membrane or HYDRO BAN®) installation instructions for proper cure time of the mortar bed prior to application of the membrane. When using an epoxy setting material or other epoxy membrane, full cure of the mortar bed is required.

A typical 2" (50 mm) thick mortar bed weighs roughly 24 lbs per square foot (95 kg per m^2).

Section 3: Wall Constructs

Metropolitan Transport Authority Murals: 86th Street Station, New York, New York

3.1 STRUCTURAL CONSIDERATIONS (WALLS AND TUNNELS)

As in Section 2 with floor applications, the same criteria for surface and structural considerations applies to wall applications. Basically, the wall constructs must be structurally sound, dimensionally stable, meet the maximum allowable standard for deflection of L/600 according to the International Building Code (IBC). (The MIA requires L/720 for stone applications) under total anticipated loads and be free from any bond breaking or bond inhibiting substances (please refer to Section 2.2 for more information on structural considerations and live and dead loads). Local code deflection requirement should be followed, if available. For more information on direct adhered ceramic tile, stone and thin brick exterior façade applications, please reference the "Direct Adhered Ceramic Tile, Stone and Thin Brick Façade" Technical Design Manual, by Richard P. Goldberg AIA, CSI available at www.laticrete.com.

3.2 WALL TYPES

Concrete Wall Types

One of the most common substrate types that will be found in mass transit applications is concrete. This section will examine the various concrete construction types that can be encountered and their common characteristics.

Tilt-Up Concrete

Tilt-up and tilt-wall are two terms used to describe the same process. For a tilt-up concrete building, the walls are created by assembling forms and pouring large slabs of concrete, called panels, directly at the job site. The concrete panels are then tilted up into position around the buildings slab to form the walls. Because the concrete tilt-wall forms are assembled and poured directly at the job site, no transportation of panels is required. A major benefit of this technique is that the size of the panels is only limited by the needs of the building and the strength of the concrete panels themselves.

Tilt-up construction panels can sometimes be extremely wide and/or tall. Tilt-up concrete panels have been as large as 69' (21 m) across and almost 93' (28.3 m) high. Thus, architects and tilt-up concrete contractors have a great deal of flexibility in planning and creating their buildings.

A tilt-up construction project begins with job site preparation and pouring the slab(s). During this phase of the project, workers install footings around the slab in preparation for the panels. The crew then assembles the panel forms on the slab. Normally, the form is created with wooden pieces that are joined together. The forms act like a mold for the cement panels. They provide the panel's exact shape and size, doorways and window openings, and ensure the panels meet design specifications and fit together properly. Next, workers tie in the steel grid of reinforcing bars into the form. Inserts and lift hooks are embedded for lifting the panels and then attaching them to the footings, the roof, and to each other.

Once the concrete panels have hardened and the forms have been removed, the crew connects the first panel to a crane with cables that hook into the inserts. Workers help to guide the concrete panel into position and the crane sets it into place. An experienced crew can erect as many as 30 panels in a single day.

Because concrete tilt-up walls are poured outdoors, contractors are at the mercy of climatic conditions. When temperatures drop below freezing, curing the concrete panels becomes more difficult and expensive. This makes this process attractive in warm climates. While tilt-up concrete buildings are built in northern areas, the window of time for temperate weather is smaller and less predictable. This can make construction schedules more difficult to meet.

Figure 3.1 – Tilt Up Concrete Panels erected into place. Photo courtesy of www.constructionphotographs.com.

Pre-Cast Concrete

The pre-cast concrete building process is similar to tilt-up construction, but it addresses the challenges presented by weather. For pre-cast concrete buildings, work crews do not set up forms at the job site to create the panels. Instead, workers pre cast concrete panels at a large manufacturing facility. Because the pre-cast concrete forms are poured indoors, this activity can take place regardless of the weather conditions. After curing, the pre-cast concrete panels are trucked to the job site. From this point, pre-cast concrete buildings are assembled in much the same manner as tilt-wall buildings.

The fact that pre-cast concrete walls are formed at a manufacturing facility resolves the weather issue, but presents a different limitation not found in tilt-up construction. Because the panels must be transported, sometimes over long distances, this places a substantial limitation on how wide or tall each panel can be. It would be impossible to load pre-cast panels that were 60' (20 m) wide or 90' (30 m) long onto trucks and transport them any distance. For a pre-cast construction project, the panels must be smaller and more manageable to allow trucks to haul them over the road to their final destination. This places certain design restrictions on architects and limits the applications where pre-cast construction can be used.

Cast-in-Place Concrete

Cast-in-place concrete is a common substrate for the direct adhesion of tile. Cast-in-place concrete is poured into forms (sprayed with form release agents) where steel reinforcing has previously been placed. The condition of vertically formed concrete is extremely variable, due to the numerous potential defects that can occur with mix design, additives, forming, placement, and curing. There may be concerns with poured-in-place concrete in relation to the long term performance of a tile installation.

Laitance

As noted in Section 2.3, laitance is a thin layer of weakened portland cement fines that have migrated to the surface of the concrete. This condition is especially prevalent in vertically formed concrete, where excess water migrates by gravity, aided by the vibration of concrete and pressure to the surface against the wall form. The excess water gets trapped by the form where is stays until the form is removed. Once the forms are removed and the water has had a chance to evaporate, it leaves behind a thin layer of what appears to be a hard concrete surface, but in reality is weakened due to the high water to cement ratio at the surface. Laitance has very low tensile strength, and therefore the adhesion of tile will be limited by the low strength of the laitance. Laitance should be removed from the concrete surface prior to the installation of tile.

Honeycombing

Honeycombing is a condition where concrete is not properly packed or consolidated by vibration during the pour, where steel reinforcement is too close to the form, where there is internal interference with the flow of concrete during the consolidation procedure, or where there is poor mix design. These conditions can result in voids in the surface or core of the concrete. Surface honeycombing defects must be properly prepared and patched using a bonding agent to ensure proper adhesion to the concrete prior to installation of the tile or other finish material.

Unintended Cold Joints

In vertical walls, cold joints are usually unintended, and can result in a weakened plane. This weakened plane is subject to random shrinkage cracking which could transfer to the surface of the tile installation. These conditions usually result from delays or equipment breakdowns and can be prevented by proper coordination of concrete delivery and proper maintenance and use of installation equipment.

Concrete Forms

Smooth formwork for concrete walls can result in a surface that is too smooth for direct adhesion of tile or stone with a portland cement based tile adhesive. A smooth surface provides little or no mechanical key for the initial grab required when applying wet cement based mortars. These surfaces do not typically facilitate absorption of cement paste and subsequent mechanical locking provided by the growth of cement crystals into the pores of the substrate. High-pressure water blast, mechanically grinding or vertical scarification can be used to achieve a better concrete surface to accept a direct adhered tile installation. Epoxy based tile installation materials (e.g. LATAPOXY® 300 Adhesive or LATAPOXY BIOGREEN™ 300 Adhesive) do not rely on open pore structure to achieve exceptional bond and may be a better choice for a smooth concrete finish.

Form Release Agents

There are a wide variety of form release agents on the market today. These products range from used motor oil and diesel fuel to sophisticated water based products. Any type of oil based or other potential bond breaking contaminant must be physically removed prior to the direct adhesion of tile.

Curing Compounds

The variety of materials and the unique characteristics of proprietary formulations require that you follow the same recommendations above for form release agents.

Concrete Additives

There are numerous concrete additives, which, depending on the properties they impart to the concrete, could be detrimental to the adhesion of the tile to the concrete wall. For example, super plasticizers are a type of concrete additive that allows extremely low water to cement ratios and resultant high strength, without sacrificing workability of the concrete. This type of additive can induce bleed water, and facilitate the formation of laitance. Similarly, additives that react with free minerals in the concrete produce an extremely dense and water-resistant pore structure (e.g. crystalline type additives) and may be detrimental to good adhesive bond. It is therefore imperative to communicate to the concrete subcontractor, and to write into the concrete specification, which areas of the concrete are scheduled to receive ceramic tile/stone finishes. This communication can help ensure that the concrete is fully compatible with the direct bond method of ceramic tile/stone installation using a latex fortified portland cement based or epoxy adhesive.

3.3 CONCRETE CURING

The installation of ceramic tile/stone over concrete can only begin once the concrete reaches satisfactory cure. As concrete cures, it loses moisture and shrinks. A common misconception is that concrete cures completely and all concrete shrinkage takes places within 28 days of placement. This is simply not true. Thick sections of concrete could take over 2 years to reach the point of ultimate cure. 28 days at 70°F (21°C) is the period of time it takes for concrete to reach its full design strength. At that point, concrete should reach its designed tensile strength, and can better resist the effects of shrinkage and stress concentration.

Depending on the humidity and exposure to moisture in the first 28 days, there may be very little shrinkage that occurs within that period. So while more flexible adhesives, like latex portland cement adhesive mortars can accommodate the shrinkage and stress that may occur in concrete less than 28 days old, it may be recommended to wait a minimum of 30–45 days to reduce the probability of concentrated stress on the adhesive interface with some settling materials. Some building regulations may require longer waiting periods (up to 6 months). After this period, resistance to concentrated stress is provided by the tensile strength gain of the concrete, and its ability to shrink as a composite assembly. The effect of remaining shrinkage is significantly reduced by its distribution over time and accommodated by the use of low modulus or flexible adhesives.

3.4 CONCRETE MASONRY UNIT (CMU)

Concrete masonry unit (CMU) construction is a suitable substrate for many ceramic tile/stone applications. When standard aggregate and density CMU is built to plumb and levelness tolerances (including the mortar joints), no further preparation is needed except for final water cleaning, unless there is a specific need or specification for an anti-fracture (e.g. Blue 92 Anti-Fracture Membrane) or waterproofing membrane (e.g. HYDRO BAN® or 9235 Waterproofing Membrane) which typically are installed directly to the CMU (following the manufacturer's installation instructions).

Both standard and lightweight aggregate concrete masonry units present several other material specific concerns. Typically, CMU walls are fairly porous. Therefore, care must be taken to prevent possible pre-mature absorption of moisture, required for proper hydration of latex portland cement adhesive mortars, into the CMU. The CMU walls should be wiped down with a damp sponge prior to the application of any membrane or adhesive mortar. This will increase the working time of the membrane or adhesive mortar and also provide a final cleaning of the wall. In some cases, where test panels may indicate poor adhesion at the CMU/adhesive interface, it is recommended to skim coat the CMU (1/8" {3 mm} maximum thickness) with a latex portland cement mortar (e.g. 257 TITANIUM™) to seal the rough surface texture of the CMU. With the proper latex portland cement mortar, the thin skim coat will harden quickly without risk of moisture suction. Another concern is the cohesion or tensile strength of the CMU material which may be less than the tensile bond strength of the adhesives; this is more of a concern with lightweight aggregate or cellular CMU.

Cellular or gas beton CMU (also commonly known as ytong or Aerated Autoclaved Concrete [AAC]), is manufactured with gases to entrain air spaces and reduce weight and density. Typically, AAC block does not have good tensile and shear strength (<7 kg/cm^2). Due to the low shear strength, slight shrinkage of conventional cement mortars may tear the surface and result in delamination. Similarly, the low density (40–50 lbs/ft^2 [500–600 kg/m^2]) of this material results in a coefficient of thermal expansion which is significantly different enough from typical cladding materials to cause concern about differential movement. The porous structure of this material also requires careful consideration to compensate for suction of hydration moisture from cement based adhesives. Most of the cellular or gas beton CMU block manufacturer's require the use of a latex portland cement based skim coat (e.g. 257 TITANIUM) prior to the installation of the tile adhesive mortar, cement based render or membrane.

3.5 FRAMED WALL SUBSTRATES

Light gauge metal (galvanized steel) studs are commonly used as a back-up wall structure for directed adhered cladding. The metal stud frame can employ a variety of sheathings, the type of sheathing dependent on whether the wall is a barrier wall requiring direct adhesion of the cladding material, or a cavity wall where the sheathing type does not affect adhesion. Metal stud walls can also be used for both pre-fabrication of panels, or construction in-place. Metal stud size and gauge are selected based on known structural properties required to resist live and dead loads. The predominant live load in external applications is wind, therefore stiffness usually controls size of metal studs. Empirical experience has shown that 6" (150 mm) wide, 16 gauge studs spaced 16" (400 mm) on center are appropriate for most applications. However, engineering calculations may show that other widths, and gauge are required. Deflection (measure of stiffness) of metal stud back-up wall construction for exterior facades should be limited to 1/600 of the unsupported span of the wall under live (wind) loads. Interior applications of ceramic tile should be limited to L/600 for stone applications. While these are the current allowable deflection standards for metal stud back-up walls, some studies on conventional masonry veneer cavity walls have shown cracking can occur on walls that have significantly less deflection. There have been no definitive studies conducted on metal stud barrier walls used for direct adhered cladding, but empirical evidence indicates that the composite action of rigid cladding materials, high strength adhesives, and proper specification of sheathing material and attachment method to metal studs does create a more rigid diaphragm compared to a metal stud back-up wall separated by a cavity. Metal stud framing typically requires lateral bracing to, or integration within the structural steel frame of a building. Bracing is dependent on the configuration and unsupported length of the stud frame.

Empirical experience also provens that integration within the structural steel system not only provides a stiffer metal stud wall by reducing the unbraced lengths of studs, but also improves accuracy and reduces errors by providing an established framework where studs are used as infill rather than the entire framework. There are a wide variety of sheathing materials to choose from for metal stud walls, ranging from low cost exterior gypsum sheathing or plywood for cavity wall sheathing, to cement backer board, or lath and cement plaster for barrier walls requiring direct adhesion of the cladding material. Gypsum sheathings historically have not been a very durable material for cavity walls, although new gypsum based sheathings with fiberglass facings and silicone impregnated cores have improved performance. Cement plaster is an ideal sheathing for exterior metal stud back-up walls. This sheathing provides a seamless substrate with no exposed fasteners, resulting in good water and corrosion resistance. The integral reinforcement also provides necessary stiffness, resistance to shrinkage cracking, and positive imbedded attachment points for anchorage to the metal stud frame. The attachment of the reinforcing in a cement plaster sheathing and resulting shear and pull-out resistance of the fasteners within the sheathing material is superior to that of pre-fabricated board sheathings such as gypsum or cement backer unit boards (CBU). This factor is important in more extreme climates where there is more significant thermal and moisture movement which can affect sheathings that are poorly fastened or have low shear or pull-out resistance to fasteners.

Cement backer unit boards (CBU), fiber cement and calcium silicate boards are other choices for metal stud back-up walls requiring direct adhesion of the cladding material. CBU board is pre-fabricated, and provides an efficient, cost effective cementitious substrate for adhesion of cladding materials. While CBU is technically water resistant, it requires waterproofing for exterior and interior wet area applications, as the minimal thickness and corrosion potential of fastener attachments increase the possibility for minor cracking, leaks, deterioration, and defects such as efflorescence.

Fiber cement underlayments can be sensitive to moisture, and requires waterproofing to resist dimensional instability that may be caused by both infiltrated rain water and condensation on the back side of the board. Check with the fiber cement underlayment manufacturer for use in exterior environments.

There are proprietary direct adhered wall systems which employ corrugated steel decking as sheathing and as a substrate for exterior cladding adhered with special structural silicone adhesives. Because these systems employ spot bonding rather than a continuous layer of adhesive, the combination of open space behind the cladding and the corrugation of the steel decking provide a cavity for drainage and ventilation. This cavity anticipates water penetration, and re-directs water back to the exterior wall surface. However, the underlying metal decking and framing are subject to corrosion facilitated by abrasion of galvanized coatings during construction. Leakage may also occur due the difficulty in waterproofing the steel and multiple connections/penetrations. Corrugated steel sheathing cavity walls have a limited service life similar to that of barrier walls.

Generally, the light weight and minimal thickness of most sheathing materials for metal stud barrier back-up walls make them more susceptible to differential structural movement and dimensional instability from thermal and moisture exposure. Therefore, careful engineering analysis of cladding-adhesive-sheathing material compatibility, and analysis of the anticipated behavior of the sheathing and its attachment are critically important.

Cementitious Backer Units (CBU)

There are a wide variety of product formulations in this category of substrates, such as pure portland cement, cement-fiber, and calcium silicate boards. Some of these boards are manufactured with an adhered layer of rigid insulation attached to the framed side of the board for use in vertical applications. This board type is designed for use on floors, walls, ceilings in wet or dry areas and is applied directly to wood or metal framing. Ceramic tile/stone can be bonded to it with latex/polymer modified portland cement mortar, or epoxy adhesive by following the backer board manufacturer's instructions.

The ceramic tile industry supplies the following installation instructions for CBU applications. It is important to note that many of the other board types, including coated glass mat water resistant gypsum backer board, fiber cement underlayments, fiber-reinforced water-resistant gypsum backer board and cementitious coated foam boards follow many of the same industry recognized installation instructions. However, the specific board manufacturer's installation instructions will take precedence over the general installation instructions.

1. Systems, including the framing system and panels, over which tile will be installed shall be in conformance with the International Building Code (IBC) for commercial and industrial applications, or applicable building codes.

The project design should include the intended use and necessary allowances for the expected live load, concentrated load, impact load, and dead load including the weight of the finish and installation materials.

2. All CBU must comply with American National Standards Institute Inc. (ANSI) “Standards for Test Methods and Specifications for Cementitious Backer Units (ANSI A118.9)” – and ASTM C1325 (Standard specification for non-asbestos fiber-mat reinforced dementitious backer units). CBU installation must comply with ANSI “Interior Installation of Cementitious Backer Units (ANSI A108.11)”.
3. Provide expansion movement/expansion joints for ceramic tile, stone and thin brick installations as per the current TCA Handbook for Ceramic Tile Installation – EJ171.
4. Consult with the CBU manufacturer for specific recommendations on installing their units. Generally speaking fasten the CBU with 7/8" (22 mm) minimum length, non-rusting, self-imbedded screws for wood studs (or appropriate fasteners for steel framing). Fasten the boards every 6" (150 mm) at the edges and every 8" (200 mm) in the field. Tape all the board joints with the alkali resistant 2" (50 mm) or 4" (100 mm) wide reinforcing mesh (provided by the CBU manufacturer) imbedded in the same thin-set mortar used to install the ceramic tile, stone or thin brick.
5. To prevent water leakage through the walls, especially in high water exposure areas apply a waterproofing membrane (e.g. 9235 Waterproofing Membrane or HYDRO BAN®) directly on the CBU. Please refer to membrane manufacturer’s written installation instructions. Some applications may require an additional vapor barrier installed behind the CBU.
6. Before applying the ceramic tile/stone it is essential that the CBU be wiped down with a damp sponge to remove dust and to increase working/adjustability time over hot, dry surfaces. This will ensure that the thin-set mortar (e.g. 257 TITANIUM™) has an opportunity to hydrate properly without the CBU absorbing the water. Apply the mortar or adhesive, using the flat side of the trowel to work the material into good contact with the CBU. Then comb on additional material with the notched side of the trowel. Spread only as much material as can be tiled in 15–20 minutes. Use the correct size notched trowel and “back butter” the tiles, if necessary, to achieve the correct coverage. It is recommended to pull tiles occasionally to ensure proper coverage is being achieved. Once the thin-set mortar or epoxy adhesive has cured for the appropriate amount of time, grouting can take place.

Coated Glass Mat Water-Resistant Gypsum Backer Board

Coated glass mat water resistant gypsum backer board should conform to ASTM C1178 (Standard Specification for Coated Glass Mat Water-Resistant Gypsum Backing Panel) and be suitable for use as a ceramic tile backer board. This type of board should only be recommended for use on walls and ceilings over wood or metal framing in mass transit applications. Ceramic tile/stone can be bonded to a coated glass mat water resistance gypsum backer board with latex/polymer modified portland cement mortar or an epoxy adhesive by following the backer board manufacturer’s instructions.

Waterproof Coated Lightweight Foam Backer Board

Waterproof coated lightweight foam backer board (e.g. HYDRO BAN Board) is a waterproof backer board constructed from extruded polystyrene and coated with waterproofing membrane which is designed as a substrate for ceramic tile walls in wet and dry areas and is applied directly to wood or metal framing. Ceramic tile can be adhered with a latex/polymer modified portland cement mortar or an epoxy adhesive. Follow the manufacturer's recommendations for installation instructions.

Fiber Cement Underlayment

A dispersed fiber-reinforced cement backer and underlayment designed for use on walls and ceilings in mass transit applications. This board is typically applied directly to wood or metal framing. Ceramic tile/stone can be bonded to it with latex/polymer modified portland cement mortar or an epoxy adhesive by following the backer board manufacturer’s installation instructions.

General interior installation and material specifications are contained in ANSI A108.11 and ASTM C1288 (Standard Specification for Discrete Non-Asbestos Fiber-Cement Interior Substrate Sheets).

Fiber-Reinforced Water-Resistant Gypsum Backer Board

Fiber-Reinforced Water-Resistant Gypsum Backer Board should conform to ASTM C1278 (Standard Specification for Fiber-Reinforced Gypsum Panel). This board is typically used on walls and ceilings, and is applied directly to wood or metal framing in mass transit applications. Ceramic tile/stone is adhered to this board with latex/polymer modified portland cement mortar or an epoxy adhesive by following the backer board manufacturer's recommendations.

Cementitious Coated Foam Board

Cementitious coated foam board is a waterproof backer board constructed from extruded polystyrene and coated with a cementitious coating which is designed as a substrate for ceramic tile walls in wet and dry areas and is applied directly to wood or metal framing. Ceramic tile/stone can be adhered with a latex/polymer modified portland cement mortar or an epoxy adhesive. Follow the manufacturer's recommendations for installation instructions.

3.6 SUBSTRATE CONDITION AND PREPARATION

Evaluation of Substrate Condition

As previously mentioned in Section 2.3, the first step in any installation is the evaluation of job site conditions. The extent of substrate preparation will not be known until the surface is examined for compliance with industry standards for substrate tolerances, plumb, surface defects and substrate contaminates.

In relation to the overall cost of the installation, preparation of the substrate is neither costly nor time consuming. However, proper preparation is the one of the most important steps that leads to a successful, long term tile/stone installation and helps prevent "call backs".

Adhesive Compatibility

As mentioned in Section 2.3, adhesive compatibility plays an important role in determining adhesion between the substrate and the tile/stone being installed. Both the substrate and the finish type must be compatible with the type of adhesive being used and recommended for use in the environment in which it will be installed. The ability of a substrate to be 'wetted out' by an adhesive is essential to good adhesion and important in determining the performance of the adhesive in bonding to the substrate. The highest strength adhesives and the most careful application to the best concrete wall will not overcome a dirty or contaminated substrate.

Site Visit and Conference

Prior to commencing ceramic tile/stone work, the tile contractor shall inspect surfaces to receive tile and accessories, and shall notify the architect, general contractor, or other designated authority in writing of any visually obvious defects or conditions that will prevent a satisfactory tile/stone installation. Installation work shall not proceed until satisfactory conditions are provided. Commencing installation of tile work deems acceptance of substrate conditions.

Substrate Preparation

Wall substrates scheduled to receive tile/stone will always be exposed to varying degrees of airborne contamination, exposure to other trades and site applied products. This can include, but is not limited to, form release agents, curing compounds, sealers, efflorescence, laitance, or any other potential bond inhibiting or bond breaking materials.

Therefore, any type of oily or other potential bond breaking contaminant must be removed prior to the installation of tile/stone on concrete walls. These types of contaminants may require mechanical scarification, grinding, shot blasting or other methods of mechanical removal.

It is important to note that if concrete walls are poured in place (cast in place), they had to be formed. Therefore, if they are formed, then it must be assumed that form release oils were used to coat the forms. The form release oils allow the forms to be stripped from the concrete after it has hardened. It must also be assumed that form release oils or other potential bond breakers exist in all of these conditions and must therefore proceed accordingly. This information is also appropriate for pre-cast tilt up concrete walls that may be treated with curing compounds during the casting phase.

The following methods can be utilized to prepare vertical substrates scheduled to receive ceramic tile/stone finishes:

Waterblasting

High-pressure water blasting using pressures over 3,000–10,000 psi (21–69 MPa) will remove the surface layer of concrete and expose aggregate to provide a clean, rough surface. Thorough rinsing of the surface with water after water blasting is necessary to remove any weakened cement paste (laitance) residue. Water blasting is only recommended on concrete because the high pressure will damage surfaces of thin, less dense materials such as cement boards or brick masonry.

Mechanical Chipping, Scarifying and Grinding

For preparation of walls, this method is recommended only when substrate defects and/or contamination exist in isolated areas and require bulk surface removal greater than 1/4"(6 mm) in depth. Chipping with a pneumatic square tip chisel, or grinding with an angle grinder are common scarifying techniques.

Shotblasting

This is a term for a surface preparation method which uses proprietary equipment to bombard the surface of concrete with pressurized steel pellets. The pellets, of varying diameters, are circulated in a closed, self-contained chamber which also removes the residue in one step. This is the preferred method of substrate preparation when removal of a thin layer of concrete surface is required, especially removal of surface films or existing painted concrete. However, only hand held equipment is currently available for vertical concrete, so preparing large areas with this method is inefficient.

Sandblasting/Gritblasting

The coatings industry now employs a new generation of cleaner, safer, and less intrusive grit-blasting which employs water soluble low-silica grit materials (sodium bicarbonate). Sandblasting is acceptable if other safer and less intrusive methods of bulk removal are not available.

In addition to the above mentioned methods, other methods to mechanically abrade contaminants from concrete also exist.

Figure 3.2 – High-pressure water washing.

Cracks

Plastic and Shrinkage Cracks

Freshly placed concrete undergoes a temperature rise from the heat generated by cement hydration, resulting in an increase in volume. As the concrete cools to the surrounding temperature, it contracts and is susceptible to what is termed "plastic shrinkage" cracking due to the low tensile strength within the first several hours or days after the concrete is placed. Plastic shrinkage can be controlled by reduction of aggregate temperature, cement content, size of pours/members, deferring concreting to cooler temperatures, damp curing, and the early removal of forms.

Concrete also undergoes shrinkage as it dries out, and can crack from build-up of tensile stresses. Rapid evaporation of moisture results in shrinkage at an early stage where the concrete does not have adequate tensile strength to resist contraction. Concrete is most susceptible to drying shrinkage cracks within the first 28 days of placement. After 28 days concrete typically develops adequate tensile strength to resist a more evenly distributed and less rapid rate of shrinkage. It is for this reason that it may be recommended to wait 30–45 days before application of adhesive mortars. Just like floors, treat any shrinkage cracks with an anti-fracture membrane (e.g. Blue 92 Anti-Fracture Membrane) to prevent the transmission of cracks through the finish surface.

Structural Cracks

Cracks that are greater than 1/8" (3 mm) in width, are displaced or not in plane, and occur throughout the cross section of a concrete wall or structural member, are an indication of a structural defect and must be corrected before the tile is adhered to the wall. Structural cracking on vertical applications can be repaired using low viscosity epoxy or methacrylate pressure injection methods. Once the cracks are stabilized and properly repaired, the tile/stone installation process can commence. Methods for corrective action vary depending on the severity of the structural cracks. Methods can range from simply routing out and patching the cracked areas to more sophisticated pinning and epoxy injection systems.

In-plane cracks that are 1/8" (3 mm) or less in width are typically non-structural shrinkage cracks. While these types of cracks do not require structural correction, they require suppression by means of a crack isolation membrane (e.g. Blue 92 Anti-Fracture Membrane for crack isolation; or, HYDRO BAN® or 9235 Waterproofing Membrane if crack isolation and waterproofing are required). The crack isolation membrane is applied to the crack with a 6" (150 mm) wide treatment (3" {75 mm} applied on either side of the crack). Next, another layer of the crack isolation membrane treatment, that is at least three times the width of the tile/stone, is applied over the previous layer (For more information on this method, please refer to LATICRETE ES-F125 at www.laticrete.com/ag). This treatment ensures that the tile/stone will sit directly on the membrane and will provide the full capabilities of the crack isolation membrane. An alternative method treats the entire vertical substrate with the crack isolation membrane to help prevent existing cracks and any future non-structural cracks from telegraphing through to the tile surface (for more information on this method, please refer to LATICRETE ES-F125A at www.laticrete.com/ag).

Plumb and Level

It is imperative to evaluate how plumb a wall is before applying tile/stone. The TCNA stipulates maximum variation in the substrate shall not exceed 1/4" in 10' (6 mm in 3 m) or 1/16" in 1' (1.5 mm in 300 mm) from the required plane for most tile/stone installations. At times, the design professional may specify a more stringent tolerance of 1/8" in 10' (3 mm in 3 m). If this variation is not achieved then a leveling coat or mortar bed may be necessary. For mass transit applications, concrete, concrete masonry units and cement backer units over steel framing are generally the vertical substrates most frequently used. At times, the substrate may require a skim coating of latex/polymer fortified thin-set mortar (e.g. 257 TITANIUM™) to fix any minor irregularities (<1/4" [6 mm] thickness), all the way up to a full render application that includes a scratch and brown coat (e.g. 3701 Fortified Mortar Bed) in order to make the walls plumb and true.

Although some walls may be plumb, they may not necessarily be level. Tile /stone installations can overcome a wall that is not perfectly level, however, there could be consequences to setting tile/stone on a wall that is not flat, the most serious being inadequate bond.

Tile and stone also have certain tolerances when it comes to their manufacturing process (ANSI A137.1). For example, the greater the tolerance for tile thickness, the greater the chances are that the tile wall will appear wavy and irregular in profile. The quality of the tile can also play an important role in the final appearance of the finish.

After the walls have been brought into compliance with industry substrate tolerance standards, the installation of tile/stone can commence. Prior to installing tile/stone on walls, it is important to clean the wall surface just prior to installing tile/stone so that dust and contaminants will not affect the bond of the installation.

Specialty and large and heavy tile mortars(e.g. MULTIMAX™ Lite) can alleviate small variations in the wall and tile tolerances without the need of a leveling coat or thick mortar bed. Follow the manufacturer's recommendation of thickness with these special setting materials.

Mass transit walls that employ the epoxy spot bonding method (e.g. LATAPOXY® 310 Stone Adhesive [see Details ES W260 and ES W215 in section 10 for more information]) generally tolerate greater deviations from a flat plane. Maximum deviation is a function of the recommended thickness and working properties of the adhesives such as sag resistance. Generally, this adhesive type can accommodate +/-1/2" (12 mm) from the finish plane for a maximum build up of 1" (25 mm). Follow the manufacturer's installation instructions when utilizing the epoxy spot bond method.

Surface and Ambient Temperature

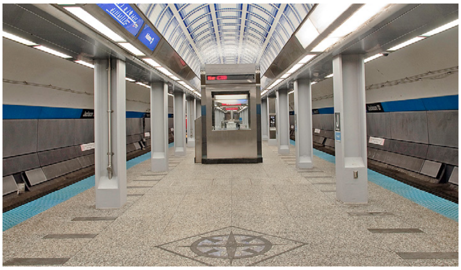
During the placement of concrete and installation of other substrate types, cold or hot temperatures may cause numerous surface or internal defects, including shrinkage cracking, a weak surface layer of hardened concrete caused by premature evaporation, or frost damage. Prior to curing, extreme temperatures of both the ambient air and surface of the substrate will also affect the normal properties of adhesive mortars.

Warmer ambient air and surface temperature will accelerate the setting of cement and epoxy adhesives. Cooler ambient air will cause the adhesives to cure for a longer period of time.

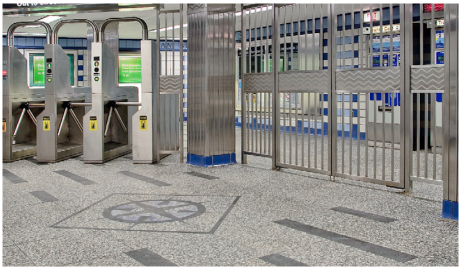
The two general rules are;

1. For every 18°F (10°C) below 70°F (21°C) cement based and epoxy based materials will take twice as long to cure, and
2. For every 18°F (10°C) above 70°F (21°C) cement based and epoxy based materials will take half as long to cure.

Washing and dampening walls as described previously will not only help to remove any loose contaminants off the wall, but it also serves to lower surface temperatures in warmer climates, and lower the absorption rate of the substrate. It is important to follow the manufacturer's recommendations for temperature ranges for all tile installation materials (see section 8.1 for more information on installing tile and stone in hot or cold weather conditions).



Chicago Department of Transportation Blue Line Project / Jackson & Van Buren Station, Chicago, IL. Troy T. Heinzeroth Photography, Studio 1701, West 19th St., Chicago, Illinois. 60608. Installed by W. R. WEIS Stone Systems, Chicago, IL.



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Section 4: Comparison of Alternate Mass Transit Flooring and Wall Cladding Systems

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LaPlaia Centro Commerciale, Cagliari, Italy

This section will provide general information on alternate systems (e.g. epoxy coatings, terrazzo, stamped concrete, polished concrete, metal wall panel cladding and more) which can be used in mass transit applications. It is important to note that mass transit tile/stone flooring systems are much more forgiving and require less overall maintenance than these alternate systems. The Tile Council of North America has conducted an extensive life cycle cost analysis comparing ceramic tile to other finish flooring types. See Section 5 for advantages in using ceramic tile/stone finishes in mass transit applications.

4.1 SEAMLESS RESINOUS FLOORING SYSTEMS

Generally speaking, resinous floors can be defined as "a floor which is finished with a resinous coating that is used as the wearing surface". These resinous flooring solutions offers a variety of unique designs and finishes for an increase aesthetic value while still offering increased chemical and abrasion resistance.

Gone are the days in which epoxy is the only choice to complete a resinous flooring install. Due to advances in technology, and modern day science, there are many options that can be offered to the customer for their resinous flooring install. These options consist of epoxies, polyaspartics, cementitious urethanes, MMAs (Methyl Methacrylate's), and others. Each of these products bring unique qualities to the application and we will briefly discuss the main options for mass transit below.

General Information on Epoxy Coatings

Epoxy Coatings

It is important to note that epoxy flooring installed within mass transit locations are 'epoxy coatings' which are much different than epoxy painted surfaces. For example, warehouses, labs, hospitals, automobile shops, car dealerships, loading docks, and many more applications use epoxy coatings. One manufacturer can define an epoxy floor by saying, "Multiple layers of epoxy placed on a floor surface, regardless of the kind of epoxy resins applied, provided that the total thickness of all layers is a minimum of 2 mm". This type of epoxy is considered an epoxy paint. Another manufacturer may call out for a specific epoxy material in a specific number of layers to a specific thickness. This is considered an epoxy coatings which carry their own definition. For the purposes of this Technical Design Manual and given they type of use these floors will be installed in, we will be discussing the latter option, Epoxy Coatings.

Each epoxy coating material has its own unique characteristics that help to define exactly how these materials can and should be used. A poor choice of epoxy coating, based on the needs of the application, can result in rapid degradation of the epoxy. An important note, however, is the fact that there can be a vast difference in performance properties with industrial epoxy coatings vs. 'watered down' epoxies that are less expensive and perform at decreased levels. These diluted epoxy coating materials do not perform as well as the more expensive industrial epoxy coating materials which are installed as recommended by the manufacturer. For example LATICRETE offers some 100% high solids epoxies that are formulated to have increased chemical resistance, resistance to yellowing and UV damage, and slip resistance to name a few. Please see the applicable product datasheet for additional information on LATICRETE Epoxy Products.

General Information on Polyaspartic Coatings

Polyaspartic Coatings

Polyaspartics are relatively new in the world of decorative concrete coatings, only being introduced in the early 1990s, but have been around in different forms in the coating industry for many years. Polyaspartic coating evolved from a class of material called polyurea, a durable fast drying material that has been used in many industrial applications as a corrosion resistant coating and repair material. Polyureas have two primary problems: Very fast setting (5-10 sec); and poor resistance to UV. Polyaspartics, a specific class of polyureas, have overcome these difficulties while maintaining the same strength, flexibility and chemical resistant properties.

LATICRETE now offers a variety of polyaspartic products with the introduction of our SPARTACOTE® line. These polyaspartic products include SPARTACOTE FLEX SB that is used in environment that can handle a strong solvent smell during installation and wants a rapid setting, fast drying system. For areas that requires low VOC and low odor, SPARTACOTE® FLEX PURE and SPARTACOTE FLEX XPL can be used. These products with the CLINICAL PLUS™ designation offers built in anti-microbial protection and also are low VOC with little to no odor. All of these low VOC/low odor materials allows for an application in existing areas that are occupied without having to shut down the entire business. For instance, in mass transit installations, an installer could section off an area of the floor (be it an train platform, lobby, or sitting area) to install the coating while the daily traffic commences just outside. Furthermore, a complete 3 coat system can be installed in a single day and returned to full service the next day. This is because of the unique fast drying capabilities of polyaspartic coatings, typically 1-3 hours between coats. This is very different from the standard epoxy coatings that could take 8-16 hours for each coat to dry or the urethanes coatings that can take 6-8 hours between coats. Additional benefits of polyaspartics are UV stability, color/gloss retention, no hot-tire pickup, high chemical resistance, and high abrasion & impact resistance. Please see the applicable product datasheet for additional information on LATICRETE polyaspartic products.

Figure 4.1 – La Plaia Centro Commerciale, Cagliari, Italy

Life Expectancy

The life expectancy of resinous floors are typically shorter than some other floor finishes. For instance quarry tile installation that have been installed over 50 years are still around in some transit stations where a resinous floor coating would have been replaced a few times within this same time frame. But in lieu of the forgoing more mass transit locations are more concerned with the aesthetics than longevity. The beauty of the location has become a top priority within these location. You are now seeing less quarry tiles being installed and more natural stone, porcelain & glass tiles and coatings become the norm.

The expected life of some resinous flooring systems are around ten years, but there are many variables that determine how long the coatings perform. Assuming that the correct coating material was chosen and was properly installed the installation may survive for ten years. However, the life span can be reduced for applications that are subject to harsh chemicals and aggressive cleaning regimens. One cleaning regimen, steam cleaning, must be considered when choosing and installing coating materials. Some coating materials may start to soften and lose adhesion when exposed to temperatures of 185°F (85°C) and higher.

Resinous Coating/Flooring Facts

Resinous coatings must be applied to concrete which has undergone proper surface preparation. The concrete can have no surface contamination or any type of additive applied before, during or after the concrete pour which can inhibit the bond of the coating materials. Since resinous coatings are typically vapor impermeable, they may be sensitive to moisture and high moisture vapor emission rates (MVER). Concrete must be allowed to cure for a minimum amount of time, have moisture content at or below certain levels, and have a continuing MVER level that does not exceed certain levels. If MVER levels excess the threshold of the resinous coating being applied the use of SPARTACOTE® Moisture Vapor Barrier is suggested. SPARTACOTE Moisture Vapor Barrier can reduces MVER from ≤25 to below 3 lbs/1000 ft^2/24hr (170 μg/(s • m^2). The manufacturer of the resinous coating material would be able to provide the information stating the required cure time of the concrete and the prescribed MVER levels. Tile can be installed directly to new concrete as soon as the installers can walk on the concrete by using 257 TITANIUM™.

For substrates scheduled to receive a waterproofing membrane, maximum amount of moisture in the concrete/mortar bed substrate should not exceed 5 lbs/1,000 ft^2/24 hours (283 μg/s•m^2) per ASTM F1869 or 75% relative humidity as measured with moisture probes. Consult with finish materials manufacturer to determine the maximum allowable moisture content for substrates under their finished material.

4.2 POLISHED CONCRETE FLOORS

Polished concrete is just as the name implies; concrete which is mechanically ground, chemically hardened (densified), sealed, and then polished. This process produces a dense concrete which in most cases, inhibits water, oil and other contaminants from penetrating the surface. Polished concrete does have its advantages when used within mass transit facilities. FGS PERMASHINE polished concrete system is a great option for a beautiful, aesthetically- pleasing floor that is durable and built to last. Regular maintenance of the flooring, when using this system, does not require the use of harsh abrasives, solvents or waxes. Areas that are suitable to receive this type of flooring would be the lobbies, waiting rooms, terminals and other areas in which the flooring doesn't have to be completely sealed.

Polished Concrete Limitations

As in the case of any floor finish, polished concrete is not suitable for all locations. Situations in which polished concrete will be exposed to acid based chemicals and aggressive cleaning regimens can cause the concrete to become pitted, start to powder or even crack. One of the most difficulties with this happening in any mass transit facility is the time required vs. time allotted to perform repairs. Concrete must be properly cured prior to be put back into service and in some locations time is very limited. It is also important to note that these floors, although abrasion resistant, also requires regular maintenance. Most sealers used for polished concrete are topical and are more likely to show wear in the high traffic areas causing the luster to dull. This mean that a recoat of the sealer or a regular maintenance coat of wax will be necessary more often. The process used to create a polished concrete floor eliminates the ability to directly bond a resinous coating or tiled flooring system to the concrete surface. If a different floor finish is sought in the future all sealers would have to be removed and the extremely hard, dense polished concrete surface would have to be profiled by grinding, shot-blasting, or beadblasting.

4.3 TERRAZZO FLOORS (CEMENT BASED AND RESIN BASED)

Terrazzo flooring is a composite material poured in place or pre-cast which is used for wall and floor finishes. Terrazzo can consist of marble, quartz, granite, glass and other types of aggregate chips mixed with a binder that is portland cement based, resin based or a hybrid of both types along with colored pigments. Poured in place terrazzo is cured and then ground and polished to the desired surface finish.

Various types of terrazzo are available which include:

Venetian – utilizes a large size chip.

Standard – the most common type of terrazzo which generally utilizes a small size chip.

Palladianna – utilizes thin random fractured slabs of marble.

Structural – cement based terrazzo topping placed over a minimum of 4" (100 mm) thick concrete slab.

Rustic – textured terrazzo finish in which the chips are exposed.

Resinous – generally an epoxy or polyester based binder mixed with small chips. Terrazzo can be applied as thin a 1/4" (6 mm).

Terrazzo floors can range in thickness from 2-1/2" (62 mm) for sand cushion terrazzo floors to as thin as 1/4" (6 mm) for resin based terrazzo pours. Epoxy resin, polyester resin and polyacrylate terrazzo types have certain chemical resistant properties.

Pre-cast terrazzo tiles can be installed using traditional tile setting methods as outlined by the TCNA and are then either grouted as traditional tile pavers or ground and polished in place. Pre-cast terrazzo is also used for stair treads/risers, window stools, base and thresholds (www.ntma.com).

One of the most desired features of terrazzo flooring is lack of "clicking noise" from luggage and carts rolling across the flooring finish. Terrazzo also has a very good life cycle cost that is similar to ceramic tile finishes. For more information on all types of terrazzo please visit www.mtma.com.

4.4 SAND SET AND BITUMEN SET PAVERS VERSUS MORTAR SET PAVERS

Brick, concrete, permeable, interlocking and stone pavers are a very popular paving option for exterior plazas, walkways, driveways and other mass transit applications. These pavers are very durable, offer many patterns and design options, are able to withstand vehicular traffic while maintaining their integrity in demanding exterior freeze / thaw climates. For the purposes of this comparison, the most common type; brick paving will be featured. Brick pavers should be specified to perform in the intended application according to the following industry standards:

Pedestrian paving brick – meeting ASTM C 902 "Standard Specification for Pedestrian and Light Traffic Paving Brick" (pedestrian – minimum. 2-5/8" [66 mm] thickness)

Light traffic paving brick – meeting ASTM C902 "Standard Specification for Pedestrian and Light Traffic Paving Brick" (pedestrian and residential vehicular – minimum. 2-3/8" [60 mm] thickness)

Heavy Vehicular paving brick – meeting ASTM C1272 "Standard Specification for Heavy Vehicular Paving Brick" (heavy vehicular traffic – minimum 3-1/8" [80 mm] thickness)

Weather classifications:

Class SX – exposed to water and freezing

Class MX – exposed to water but not freezing

Class NX – interior only

Traffic classifications:

Type I – sidewalks, driveways in public areas

Type II – residential sidewalks and driveways

Type III – floors and patios

For more information on brick pavers, consult The Brick Industry Association, Reston, VA; www.gobrick.com.

There are three basic types of setting options for these types of pavers in mass transit applications:

Sand Set – Type F

Bitumen Set – Type R

Fixed Mortar Set – Type R

There are advantages and disadvantages to the three methods. An architect or specifier will have to make an informed decision concerning the area of use and the amount of long-term maintenance that will be required for each of the systems. The following is a comparative analysis of the three methods:

Figure 4.2 – Sand Set Pavers

Sand Set Pavers

Sand set pavers have the lowest initial cost of the three options. The setting system can be altered depending on the level of traffic that will be exposed to the installation system. The installation starts with the grading and compaction of the soil under the pavers. A geo-textile drainage layer can be placed over the soil to help facilitate drainage. Next, a layer of gravel/trap rock (4" [101 mm]) is placed and compacted well over the soil (up to 95% of standard Proctor density as specified in ASTM D-698 "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 [600 kN-m/m^3])" or to ASTM D 1557 "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 [2,700 kN-m/m^3])" for areas subjected to vehicular traffic). The gravel/trap rock layer is then "rough screeded" to get the level of this layer close to the design level. This layer can be adjusted depending on how robust the setting system is intended to be. For example, heavy vehicular traffic will require 12–16" (300 mm–400 mm) of the gravel/trap rock base.

Pedestrian traffic areas generally require 4–6" (100–150 mm) of the gravel/trap rock base. This base layer serves as the support for the sand set paving system. In addition, the gravel base facilitates water runoff and drainage. Next, the sand layer is used to bed the pavers. The sand layer (meeting ASTM C33 "Standard Specification for Concrete Aggregate" or CSA A23.1 "Concrete Materials & Methods of Concrete Construction Methods of Test for Concrete" (coarse, clean masonry sand) can range in thickness from 3/4 - 1" (19 - 25 mm) thickness. The sand layer is placed compacted and screeded to the desired height. The pavers are then dropped into the sand layer. The pavers are tamped / compacted into place and finished to the desired height with a vibrating plate compactor capable of exerting 3,000 – 5,000 psi (21 – 34.5 MPa) of centrifugal compactions force operating at 75–90 hertz. A plastic or rubber mat should be used on the compactor to avoid paver damage. Generally, at least two passes are made to seat the pavers.

Traditional masonry sand is swept into the paver joints to fill the joints. This process also helps to secure the pavers into place. The pavers are then compacted again until the joints are full. Polymeric sand can also be used for this process and is generally worth the cost upgrade. The polymeric sand will harden and set firm to a degree once it is exposed to moisture. The polymeric sand stands up better to point loads within the joints are resists "wash-out" when compared to traditional sand swept joints. Possibly the most critical issue with sand set pavers is the edge restraints. Edge restraints can range from typical paver edging strips and spikes to poured concrete curbs and sidewalks. Most sand set paver issues arise from the fact that the edge restraints are not designed to withstand the "pushing" and "movement" that traffic will place on the system. The edges can push out which in turn causes the paving system to sink and start to experience issues with maintaining its designed level. It is to be expected that sand set pavers will require periodic ongoing maintenance to fix areas that have moved, dipped to vehicular patterns. Ongoing long-term maintenance costs should be factored into the life cycle analysis of sand set paving systems.

Advantages of Sand Set Pavers:

- Economical
- Low Initial Installation Cost
- Designed to Accommodate Minor Movement Without Failure
- Easily Repaired
- User Friendly Installation Materials
- No Off-Gassing of Installation Products
- Easy Access to Repair Underground Utilities
- Can be Designed as a Permeable Pavement

Disadvantages of Sand Set Pavers:

- May Require a Thicker Base for Heavy Duty Applications
- Edge Restraints Commonly Experience Problems with Movement and "Blow Out"
- Pavers Show Traffic Patterns
- Tree Roots Can Disturb Installation
- Drifting of Pavers Will Occur
- On-going Maintenance is Required
- Can Present Point Loading Issues Within the Joints
- Can Experience Erosion During Heavy Rain and Maintenance
- Highest Life Cycle Cost
- No Installation Warranties Apply
- Weeds Will Grow in Between the Joints
- Insects Will Build Nests and Disrupt the Appearance of the Paving System

Bitumen Set Pavers

The installation of bitumen set pavers is considered the middle ground as far as cost is concerned. A suitable concrete base or a 3–6" (75–150 mm) bituminous binder base placed over a compacted gravel base (8" [200 mm]) is required for this installation system. Once the concrete base is poured and properly cured, a layer of 3/4" (19 mm) asphaltic bitumen is placed over the slab followed by a 2% modified neoprene tack coat layer. This layer acts as an adhesive as the pavers are dropped into place. Once the pavers are set into place, the joints are filled in similar fashion to the sand set pavers with traditional masonry sand or polymeric sand. A bitumen layer is not considered a permanently fixed system in that the bitumen does allow some movement to take place. However, this method also requires good edge restraint to prevent paver separation and edge blow out. In addition, over time, vehicular traffic patterns can still reflect in the finish layer as the bitumen can experience long term fatigue.

Figure 4.3 – Bituminous Set Pavers

Advantages of Bitumen Set Pavers:

- Mid-grade Initial Installation Cost
- Designed to Accommodate Minor Movement

Disadvantages of Bitumen Set Pavers:

- Edge Restraints Commonly Experience Problems with "Blow Out"
- Pavers Can Show Traffic Patterns
- Drifting of Pavers Can Occur
- Little Tolerance for Paver Thickness Variations
- On-going Maintenance Is Required
- Can Present Point Loading Issues Within the Joints
- Sand Swept Joints Can Experience Erosion
- Bitumen Can Emit A 'Petroleum' Odor
- Bitumen is Not Considered to Be An Environmentally Friendly Product
- Bitumen Can Off-Gas (Volatile Organic Compound)
- Not Labor Friendly
- No Installation Warranty
- Weeds Will Grow in Between the Joints
- Insects Disrupt the Appearance of the Paving System

Mortar Set Pavers

Of the three installation types, the mortar set system is considered to be the most permanent. The mortar set system, typically requires a concrete base and gravel drainage layer beneath the concrete slab. Once the concrete slab is in place and properly cured (e.g. 28 days at 70°F [21°C]), the mortar setting system can be placed. See section 7.3 Thick Bed Method (bonded) or Thin-Bed Method for the installation methodology and product selection for this application.

Mortar set pavers are now permanently fixed in place and require very little long term maintenance. Of the three paver setting methods, mortar set pavers has the lowest life cycle cost.

Figure 4.4 – Mortar Set Pavers

Advantages of Mortar Set Pavers:

- Low or No Maintenance Required
- Low Life Cycle Cost
- Resistant to Point Loading
- Resistant to Fatigue
- Resistant to Edge Blow Out
- User Friendly Installation Materials
- Installation Materials Do Not Off Gas
- Long Term Manufacturer Performance Warranties
- No Weeds Will Grow in Between the Joints
- No Insect Damage

Disadvantages of Mortar Set Pavers:

- High Initial Installation Cost
- Repairs Are Difficult and Expensive

4.5 METAL WALL PANELS

Metal wall panels are typically used to clad and cover unsightly concrete pours and exposed utilities. In addition, metal panels are used as finish materials in metro and roadway tunnels. One of the advantages to the use of the metal panels is the speed of installation. There are certain drawbacks to the use of metal panels in many of these applications. The fabrication cost can be prohibitive. Replacement costs for damaged panels can be very high as the disassembly, fabrication and re-installation process can be very tedious. Corrosion is also a factor to consider when utilizing certain metal finishes. Ceramic tile finishes have many advantages over this cladding type.

Section 5: Types of Tiles for Mass Transit Applications

Delta Terminal, Hartsfield–Jackson Atlanta International Airport, Atlanta, Georgia

5.1 WHY USE CERAMIC TILE IN MASS TRANSIT APPLICATIONS

Mass transit floor applications can be exposed to some of the harshest and most extreme conditions of any system in a building structure. In general, many types of ceramic tile, porcelain tile, quarry tile, pavers, klinker tile, brick, and granite stone pavers are suitable for these applications. However, there is no standard formula or recommendation for the selection of these finishes types. Selection must be made by an assessment of the individual finish material's functional and aesthetic characteristics in relation to the performance requirements. A discussion of the aesthetic merits of different finish materials is highly subjective and beyond the technical focus of this manual.

Why select ceramic tile as the finish material for these applications?

Ceramic tile adds value to any structure, requires very little maintenance and costs less per square foot (m^2) than other permanent and long use flooring and wall options.

The following are some beneficial features of ceramic tile cited by the Tile Council of North America:

Low Life-Cycle Costs – ceramic tile costs less per year than all other flooring finishes over the life of a building. In fact, ceramic tile can cost up to 5 times less than other finish types over the life of a building.

Durability – maintains its original qualities and lasts longer than other cladding options

Water Resistant – ceramic tile installations can be waterproof and are suitable for use in areas exposed to wet or damp conditions.

Clean and Healthy – easy to clean and resistant to dirt, grime, mold and bacteria.

Green Product – ceramic tile is inherently green and an important part of sustainable construction. The use of ceramic tile can contribute towards Leadership in Energy and Environmental Design (LEED) credits and other green building certification programs.

Good Indoor Air Quality – ceramic tile is inherently good for the indoor environment. It has negligible volatile organic compound (VOC) emissions. Ceramic tile is virtually inert, with no off-gassing.

Low Maintenance – ceramic tile is virtually maintenance free, as it resists dirt, grime and stains.

Fade Resistant – properly rated ceramic tile will not fade in sunlight like the dyes used in other floor and wall cladding finishes.

Fire Resistant – non-combustible and will not give off toxic fumes when exposed to fire.

Exterior Use – fade-resistant, frost-resistant, durable, enhanced traction and low maintenance are all characteristic of ceramic tile finishes that makes it the preferred choice of specifiers and designers.

In fact, the LEED Reference Guide for Green Building Design and Construction states that mineral-based finish flooring such as tile, masonry terrazzo, and cut-stone without integral organic-based coatings and sealants…qualify for credit without any IAQ testing requirements. However, associated site-applied adhesives, grouts, finishes, and sealers must be compliant for a mineral based…flooring system to qualify for credit.

This section will focus primarily on the functional criteria necessary to determine whether a finish material's physical characteristics satisfy the performance requirements of a mass transit application's design and location. While every application can be unique, the following are criteria that can be used to determine general functional suitability of the finish materials:

5.2 SELECTION CRITERIA FOR FINISHED MATERIALS

- Low Water Absorption Rate
- Thermal Movement Compatibility With Adhesive and Substrate
- High Breaking Strength
- Chemical Resistance
- Thermal Movement and Shock Resistance
- Adhesive Compatibility
- Dimensional Stability (Heat and Moisture Insensitivity, Moisture Expansion)
- Frost Resistance (Where Required)
- Dimension and Surface Quality/Tolerance

Low Water Absorption Rate

The rate of water absorption is one of the most significant physical characteristics. This characteristic provides an indication of material structure and overall performance, and has significant influence on many other physical characteristics that are desirable for mass transit applications.

Water absorption, also known as porosity, is defined as a measure of the amount of water that can be absorbed through pores of a material. The absorption rate is measured as a percentage difference between tested dry and wet (saturated) weight of the material. Generally, the lower the water absorption rate the greater the frost, stain, chemical, abrasion and breaking strength resistance; all desirable qualities for a material exposed to heavy traffic and loads. Tile and stone absorption rates less than 3% would be considered suitable for mass transit floor and base applications. Quarry tile, brick pavers and stone should have an absorption rate of less than 3%. Porcelain tiles and pavers generally have an absorption rate of less than 0.5%.

Thermal Movement Compatibility

The tile or stone's rate of expansion and contraction due to temperature changes must be relatively compatible with the tile/stone adhesive mortar. Significant differences could cause excessive stress in the adhesive interface and lead to delamination or bond failure (see Section 7). Minor differences in thermal compatibility are acceptable and the selection of a suitable flexible adhesive (see Section 7) plays a critical role in distributing minor differential movement. Accurate prediction of thermal behavior is extremely complex, considering the rate and fluctuation of temperatures, thermal gradients and lag that exists, plus other potential factors. Figure 5.1 shows typical rates of thermal movement of materials commonly used.

High Breaking Strength (Modulus of Rupture)

The breaking strength resistance of a finish material is important primarily due to the type of handling that is necessary for installation within or on a structure. Once adhered in place to a suitable, rigid substrate, a properly installed tile or stone has up to ten times the breaking strength resistance compared to the unbonded tile or stone alone. The natural fragility and cleavage of many type of stone makes them particularly susceptible to breakage. Because the direct adhered method of installation allow relatively thin tile or stone to be used, a careful assessment of breaking strength relative to the tile or stone's thickness and dimension (facial area) will eliminate unforeseen call backs, high waste factors and increased costs.

MATERIAL	COEFFCIENT OF THERMAL EXPANSION (10–6 mm/mm/C°)
Ceramic Tile	4 – 8
Granite	8 – 10
Marble	4 – 7
Brick	5 – 8
Cement Mortar	10 – 13
Concrete	10 – 13
Lightweight Concrete	8 – 12
Gypsum	18 – 21
Concrete Block (CMU)	6 – 12
Cellular Concrete Block	8 – 12
Steel	10 – 18
Aluminum	24
Copper	17
Polystyrene Plastic	15 – 45
Glass	5 – 8
Wood – Parallel Fiber	4 – 6
Wood – Perpendicular Fiber	30 – 70

Figure 5.1 – Coefficient of linear thermal expansion for various materials.

Chemical Resistance

The finish materials must have good chemical resistance to prevent deterioration from environmental pollutants, spills, and chemicals that may be used in cleaning and maintenance not only of the tile or stone, but also other components of the buildings structure. Keep in mind the application, using a polished marble in an airport concourse would not be a great idea because inevitably someone will spill a cola based drink that will quickly etch the surface of the marble. Porcelain tile is a much better choice for these conditions.

Thermal Shock Resistance

Any tile or stone installation which may be exposed to a wide range of temperatures, and a rapid rate of temperature change, requires that the entire installation be able to accommodate the movement caused by thermal shock. Thermal shock refers to the rate and range of temperature fluctuation within short periods of time. For example, an airport granite facade in Texas, with a southern or western solar orientation, exposed to a sudden cool rainstorm can send the temperature of a cladding material plunging within a matter of minutes. The stresses caused by this sudden and rapid thermal movement may have a detrimental effect on the stone façade if proper knowledge of the thermal movement capabilities of the stone are not known and proper allowance for this movement are not taken into consideration.

Compatibility with Adhesive

The suitability of adhesives for the proposed application must be evaluated taking into consideration the criteria listed in Section 7 – Types of Mortars / Adhesives / Grouts. Part of that process is evaluating an adhesive's compatibility with the tile or stone composition, surface texture, and other physical characteristics, such as translucency. For example, lighter colored marble stones are translucent, and the transmission of color from the underlying adhesive can have significant aesthetic consequences. Similarly, adhesives should not stain the cladding material, or contribute indirectly to staining by solubility or reaction of chemicals with water. For example, certain silicone or urethane adhesives may be absorbed by stone causing permanent discoloration. Polymers of some latex additives which are not intended for exterior applications may be soluble in water and could cause staining problems. Another concern is a calcium chloride accelerant that may be used in some latex cement adhesive mortars. This additive could contribute soluble salts to the system and result in efflorescence after repeated water infiltration to the adhesive layer. Depending on the texture and porosity of the tile or stone's bonding surface, certain adhesives may require more or less dwell time in order to allow absorption of adhesive, a process known as "wetting out" a surface.

Dimensional Stability (Moisture and Heat Sensitivity)

Generally, the dense and compact nature of a low absorption material will impart good dimensional stability to a material, thereby making the finish material suitable for a mass transit application. However, there are certain exceptions where low absorption is not necessarily an indicator of dimensional stability. Certain types of marble and agglomerates, while water absorption rate may be favorable, exhibit internal crystal growth when exposed to moisture and can warp, spall or deteriorate rapidly when exposed to the weather in exterior applications. The plastic resins used in many agglomerates have a significantly higher rate of thermal expansion when exposed to the sun or other heat source. Similarly, clay brick can undergo permanent volume expansion after prolonged exposure to moisture.

Frost Resistance

Generally, frost resistance is a function of the water absorption characteristics of a tile or stone. Any cladding material with water absorption under 3% is typically considered frost (freeze) resistant. However, the pore structure of brick and certain stone may allow water absorption greater than 3% and still be considered frost resistant. Nonetheless, high water absorption will still reduce durability and resistance to weathering in general. Polishing of a stone surface can reduce surface porosity and increase resistance to weathering.

Dimension and Surface Quality

Ceramic tile and thin brick masonry are manufactured materials, and therefore dimensional and surface tolerances required for direct adhesion can be assured by selecting materials in compliance with established standards. For ceramic tile the applicable standards would be ISO 10545-2 "Determination of Dimension and Surface Quality" and ANSI A137.1, which incorporates ASTM C499 "Standard Test Method for Facial Dimensions and Thickness of Flat, Rectangular Ceramic Wall and Floor Tile". For thin brick, ASTM Standard C1088 Type TBX "Standard Specification for Thin Veneer Brick Units Made From Clay or Shale" governs dimension and surface quality. Stone is generally fabricated to specification for a variety of methods of installation. There are uniform standards for dimension and surface quality of stone tiles or slabs listed for individual varieties of stone in Section 5.10. It is recommended that the back side of an exterior cladding material have a key back or dovetail configuration in order to develop a mechanical lock with the bonding adhesive (or concrete in the case of negative cast pre-cast concrete panels). Grooved or rib-back tile or stone will also improve the factor of safety in the event of adhesive bond failure. Ceramic tile manufacturers currently offer this technology, primarily with ceramic tile manufactured by the extruded method. Porcelain tile manufacturers are expanding this concept to thinner (as thin as 1/8" [3 mm]) and larger module tiles (as large as 5' x 10' [1.5 x 3 m]) manufactured with the dust pressed method.

5.3 CERAMIC TILE

The beauty, durability, and functional qualities are shared by multiple floor finishes (e.g. terrazzo, resinous flooring, stained concrete, etc...) but ceramic tile is versatile and economical. As you might expect, there are an extraordinary number of different types and sizes of ceramic tile. Ceramic tile cladding can range in size from 3/4" x 3/4" (19 x 19 mm) nominal mosaics up to 5' x 10' (1.5 x 3 m) nominal porcelain stoneware tile. The raw materials for ceramic tile are a mixture of clay (to give plasticity), quartz sand (to give structural strength and act as an economical filler), and carbonates or feldspars (to provide fluxing/fusing action). Glazes are formed from sand, kaolinitic clay, prepared glasses (frit), and oxide based pigments to provide color. The raw materials are ground together with water added. The raw material for the majority of ceramic tiles used for mass transit applications are typically dried to a moisture content of 4–7% and shaped by the dust pressed method at pressures of 300 kg/cm^2 or higher. Some tiles used for mass transit facilities may be formed by the extrusion method, where clay with a moisture content of 15–20% is extruded through a die of desired shape. After forming, the raw tile or "bisque" is dried to remove excess water and fired in kilns operating at temperatures of 1,750 – 2,200°F (954 – 1200°C). This results in the vitrification or fusing of the clay and fillers, producing a tile product that is dense and non-porous. As mentioned previously, low water absorption is a key physical characteristic of external cladding materials, and has significant influence on the other physical characteristics.

Characteristics of Ceramic Tile

In order to select the most suitable type of ceramic tile or pavers for a mass transit application, and to understand the technical considerations for adhesive compatibility and installation, the specifier must have a general understanding of the classifications and physical properties of ceramic tile.

CLASSIFICATION OF CERAMIC TILE BY WATER ABSORPTION
ISO (International Standards Organization)
CEN (European Norms)

	Group I	Group II	Group III	Group IV
Absorption Shaping	≤3%	3 - ≤6%	6 - ≤10%	>10%
Group A Extrusion	Group A1	Group AIIa	Group AIIb	Group AIII
Group B Dust-Pressed	Group B1	Group BIIa	Group BIIb	Group BIII

Figure 5.2 – Classification of ceramic tile by water absorption. (EN or ISO Standards).

CLASSIFICATION OF CERAMIC TILE BY WATER ABSORPTION
ANSI Standards

Classification	Water Absorption
Non-vitreous	>7%
Semi-Vitreous	3 – 7%
Vitreous	0.5 – 3%
Impervious	<0.5%

Figure 5.3 – Classification of ceramic tile by water absorption (ANSI – American National Standard Specifications for the Installation of Ceramic Tile).

Water Absorption (Body of Tile)

The definition of water absorption is the measure of the amount of water that can be absorbed through pores of the ceramic tile. This characteristic is an indication of ceramic tiles' structure and overall performance. Water absorption is measured by ASTM C373 "Standard Test Method for Determination of Water Absorption and Associated Properties by Vacuum Method for Pressed Ceramic Tiles and Glass Tiles and Boil Method for Extruded Ceramic Tiles and Non-tile Ceramic Whiteware Products" and ISO 10545–3 "Determination of Water Absorption, Apparent Porosity, Apparent Relative Density, and Bulk Density" as a percentage difference between dry and wet weight of tile. The water absorption characteristics of ceramic tile have significant influence on many other physical characteristics that are important to proper performance in industrial applications. Water absorption of ceramic tile for mass transit (exterior and interior) applications should be 3% or less. However, precision manufacturing processes and advancements in technology now allow for production of porcelain tiles with under 0.05% (negligible) water absorption rates. While this creates an extremely durable product, it makes adhesion with traditional portland cement adhesives extremely difficult, because these types of adhesives rely on absorption of cement paste to provide mechanical locking of crystals within the pore structure of the tile body. Porcelain tiles require the additional adhesive power of latex thin-set mortars or epoxy adhesives in order to develop the high bond strength and flexibility required for mass transit applications. Currently, porcelain is the most popular ceramic tile choice for mass transit, commercial, industrial and other high traffic installations.

Thermal Shock

The definition of thermal shock is the resistance to internal stress when a tile undergoes rapid changes in temperature. The significance of this characteristic is that it provides an indication of good performance in demanding mass transit applications where there are constant cycles of thermal shock. Thermal shock is measured by ASTM C484 "Standard Test Method for Thermal Shock Resistance of Glazed Ceramic Tile" and ISO 10545-9 "Determination of Resistance to Thermal Shock" where there are no defects after 10 cycles of sudden temperature changes to and from 60 to 220°F (15 to 105°C). Many mass transit applications can experience sudden temperature changes on a repeated basis. Hot or cold liquid spills can subject the tile to thermal shock. Therefore, this consideration of thermal shock is critical in determining the suitability of a tile for the intended purposes.

Thermal Expansion/Contraction

The definition of thermal movement is the amount of expansion or contraction a tile undergoes from temperature changes. The significance of this characteristic is that tiles expand with temperature increases, and contract with temperature decreases. The measurement of a tile or stone's thermal coefficient of expansion provides the designer with the information necessary to determine compatibility of the tile with the substrate and adhesive materials, to calculate movement differentials, and for the design of movement (expansion) joints. Thermal expansion is measured by ASTM C372 "Standard Test Method for Linear Thermal Expansion of Porcelain Enamel and Glaze Frit and Fired Ceramic Whiteware Products by the Dilatometer Method", and ISO 10545–8 "Determination of Linear Thermal Expansion" and expressed as the linear coefficient of thermal expansion in units of in/in/°F (mm/m/°C).

Frost Resistance

Frost resistance measures the ability of the ceramic tile to resist the expansive action of freezing water. This characteristic is dependent on the tile absorption rate and the shape and size of pores. Frost resistance is measured by ASTM C1026 "Standard Test Method for Measuring the Resistance of Ceramic Tile to Freeze-Thaw Cycling" and ISO 10545-12 "Determination of Frost Resistance".

Breaking Strength (Modulus of Rupture)

Breaking strength primarily determines resistance to the handling and installation process. This characteristic is a measure of the tile material and not the tile itself. For example, if you compared two tiles of the same material with one being twice as thick, both would have the same unit breaking strength, but the thinner tile would require 75% less load or force to break. Impact resistance in service (fully adhered) is approximately 10 times greater than the minimum standard. Breaking strength is measured by ASTM C648 "Standard Test Method for Breaking Strength of Ceramic Tile" and ISO 10545-4 "Determination of Modulus of Rupture and Breaking Strength" which requires a minimum strength for all floor tile of 250 psi (1.75 MPa). Minimum breaking strength requirements for tile can be found in ANSI A137.1 "American National Standard Specifications for Ceramic Tile".

Moisture Expansion

Moisture expansion is the dimensional change of building materials as a result of changes in moisture. This is a significant characteristic for ceramic tile used in mass transit applications, because moisture expansion of clay is irreversible. It is measured by ASTM C370 "Standard Test Method for Moisture Expansion of Fired Whiteware Products" and ISO 10545–10 "Determination of Moisture Expansion". Moisture expansion is directly proportional to absorption; the lower the absorption, the greater resistance to moisture expansion and vice versa. In order to accommodate moisture expansion, there must be properly placed expansion joints within the installation itself to prevent heaving or failure due to the moisture expansion of the finish material.

Chemical and Stain Resistance

The definition of chemical resistance is the behavior of tile when it comes into contact with aggressive chemicals. Chemical resistance actually measures deterioration caused by two mechanisms; 1) chemical reaction resulting in alteration of tile, and, 2) penetration of a chemical or stain below the tile surface along with the difficulty of removal resulting in long term deterioration, or, effect on materials in contact with the surface. Chemical and stain resistance is measured by ISO 10545-13 "Determination of Chemical Resistance" by determining visual deterioration after exposure to standard chemical solutions (cleaning detergents, bleach, lactic and sulfuric acid, potassium hydroxide/alkali). The importance of this characteristic for mass transit applications is the resistance to deterioration and staining caused by exposure to various cleaning chemicals necessary for normal maintenance, or to fluids used for operation and maintenance of vehicles.

5.4 USE OF CERAMIC TILE IN ROADWAY AND METRO TUNNELS

Ceramic tile and stone have traditionally been used to line roadway tunnels, bridges and metro stations. In addition, to the aforementioned reasons, ceramic tile is also used for several of the following reasons in these specific applications:

Ease of Maintenance – ceramic tile is very easy to clean and maintain when compared to other finish types in these applications. In fact, ceramic tile can be used in virtually every climate type; including areas exposed to severe freeze/thaw conditions and areas of continued or intermittent submersion. Ceramic tile with an appropriate finish (generally glazed) will not allow small particles of dirt, debris, exhaust fumes and residue, roadway salts and other contaminants/pollutants to accumulate on its surface. Ceramic tile is generally very easy to clean (typically with high-pressure water wash, scrub brushes and neutral pH detergent) and will maintain its durability even under the harshest conditions.

Conforms to Contour of Tunnel Substrates – ceramic tile is a great choice to clad tunnel walls due to the fact that this finish can conform to cover almost any desired substrate shape. Tiles are typically used to clad tunnel walls and ceilings. The tiles can be installed to follow the contour of curves, multiple curves, cylindrical and other geometric shapes.

Easy to Repair – ceramic tiles can also be repaired in spot areas or over large areas as required. If localized damage occurs or repairs are required for any reason, then individual ceramic tiles can be removed and easily replaced when compared to other finish cladding types (e.g. metal panels).

Provides Safe Driving Conditions – light colored ceramic tile provides a very good reflective surface. In roadway tunnels, this makes for safer driving conditions using less artificial lighting. Municipal lighting within the tunnels, as well as the cars' headlights, reflect light off the ceramic tile clad walls, illuminating all areas of the tunnel.

Figure 5.4 – Robert C. Levy Tunnel, better known as the Broadway Tunnel in San Francisco, California.

Figure 5.5 – Holland Tunnel Dedication, November 12, 1927. Notice the ceramic tile clad walls and the ceramic mosaic tiles state murals. Photo courtesy of the Port Authority of New York and New Jersey.

Figure 5.6 – Tile Installation with Warning Tile at a train platform.

5.5 QUARRY TILE/KLINKER TILE

The durability and functional qualities of quarry tile make it one of the most suitable finishes for mass transit applications. As you might expect, there are an extraordinary number of different types and sizes of tile, only some types of tile have the physical characteristics required to be used in mass transit applications. Generally, quarry/klinker tile ranges in size from 4" x 8" (100 mm x 200 mm), to 6" x 6" (150 mm x 150 mm), to 8" x 8" (200 mm x 200 mm).

The raw materials for quarry tile are a mixture of clay (to give plasticity), quartz sand (to give structural strength and an economical filler), and carbonates or feldspars (to provide fluxing/fusing action). Glazes are formed from sand, kaolinitic clay, prepared glasses (frit), and oxide based pigments to provide color. The raw materials are ground together with water. The raw material for ceramic tiles are typically dried to a moisture content between 4–7% and shaped by the dust pressed method at pressures of 4,270 psi (29.5 MPa) or higher.

Some tiles used may be formed by the extrusion method, where clay with a moisture content of 15–20% is extruded through a die of desired shape. After forming, the raw tile or "bisque" is dried to remove excess water and fired in kilns operating at temperatures of 1,750–2,200°F (950–1,200°C). This results in vitrification or fusing of the clay and fillers, producing a tile product that is dense and non-porous. As mentioned previously, low water absorption is a key physical characteristic of tile for use in mass transit applications, and has significant influence on the other physical characteristics.

Klinker tiles are defined as red body tiles formed by either the extrusion process or dust pressing. Klinker tiles can also be referred to as red stoneware. This tile type can be glazed or unglazed and generally has a water absorption rate of less than 0.7%.

Figure 5.7 – Klinker tile at a train platform.

5.6 PORCELAIN TILE AND PAVERS

Porcelain pavers generally have a very low absorption rate just like porcelain tile (less than 0.5%).

Porcelain pavers are generally considered full body porcelain products which means the middle of the porcelain paver looks just like the outside of the porcelain paver. This works well in virtually all mass transit applications due to the fact that if a tile is chipped or broken, it is more difficult to notice the defect. Porcelain tiles also come in a variety of finish types ranging from polished (suitable for vertical applications) to matte and textured finishes (ideal for heavy traffic floor applications). Due to its dense nature, porcelain tiles are able to resist abrasive environments which can be found in demanding mass transit applications.

Figure 5.8 – Porcelain paver installation in Shinjuku Expressway Bus Terminal, Tokyo, Japan.

5.7 ABRASIVE TILE AND TREATMENTS

Abrasive tiles are used in areas to prevent slipping and where greater traction is required. Abrasive tiles are manufactured to have a high coefficient of friction or slip resistance built into the product. These types of tiles are frequently installed in mass transit, commercial and industrial applications, because of the potential amount of water, dirt, fluids and other debris, to help prevent pedestrians and facility personnel from being injured by slipping on a slick surface. In addition, abrasive tile is used on ramp areas to increase traction and reduce the potential for slip/fall accidents. Generally, corundum or metallic shavings are mixed in with the clay prior to the firing or extrusion process. These shavings become an integral part of the tile body. Abrasive tile can be manufactured in the form of quarry tile, klinker tile, dairy brick and porcelain pavers. In extreme cases where extra slip resistance is required, double abrasive tile can be used.

There are also treatments that will aid in slip resistance for tiles that do not have a high coefficient of friction. The treatments are typically spray applied to the tile. The treatment eventually becomes part of the tile itself. These treatments can last for years and can help to reduce the possibility of slip/fall accidents. Abrasive treatments usually require regular cleaning with non-abrasive cleaners. Dynamic coefficient of friction tests are performed according to ANSI A326.3 "Standard Test Method for Dynamic Coefficient of Friction of Hard Surface Flooring Materials". OSHA recommends a static C.O.F. of .50 minimum for dry surfaces. ADA recommends, on dry surfaces, a 0.60 for accessible routes and 0.80 for ramp surfaces. See Section 9 Protection and Sealing – Water Repellant Sealers and Coatings for more information on applying surface sealers to tile surfaces.

STATIC COEFFICIENT OF FRICTION RANGES	
Smooth	Dry 0.70 to 0.95 Wet 0.60 to 0.90
Abrasive	Dry 0.80 to 1.0 Wet 0.70 to 0.95

Figure 5.9 – Typical Static Coefficient of Friction Ranges – Courtesy of Summitville Tile Corporation.

5.8 DETECTABLE WARNING TILES

To comply with Americans with Disabilities Act (ADA) requirements (Accessibility Guidelines for Buildings and Facilities Federal Register Volume 56 No. 173, Section 4.29 dated September 1994 [ADDAG]), detectable warning tiles are mandated at railway tracks, ramps, landings and other critical areas to warn pedestrians that they are approaching an area that requires caution. These tiles are designed to trigger three senses; sight, sound and touch.

There Are 3 types of Warning Tiles:

Wet Set Concrete Type – embedded into wet concrete and fastened in place. Many of these tile types can be removed and replaced if damaged.

Surface Mount Type – this tile type is generally bedded in a latex fortified portland cement based mortar and is then fastened in place with masonry anchors.

Figure 5.10–ADA Compliant Detectable Warning Tile Installed next to a roadside pedestrian crossing.

Cast in Place Type – this tile type is similar to the wet set tile type in that it is embedded into wet concrete and fastened in place. However, this tile type is not removable.

The tile material composition should be UV resistant, color fast, scratch resistant and have excellent slip resistant characteristics. These dense co-polymer compound tiles are generally bright yellow in color and are designed to have a truncated dome pattern to alert pedestrians. The detectable warning tiles are generally installed within 6" to 8" (150–200 mm), or as specified, of curb lines, railway tracks and other critical areas.

5.9 NATURAL STONE AND AGGLOMERATES

There is a wide variety of stone and stone agglomerate tile used in building construction which are suitable for mass transit floor and wall installations. However, determining suitability of stone for use in heavy traffic mass transit projects requires more careful analysis than manufactured materials like ceramic tile because it is a heterogeneous, natural material. In fact, different pieces of the same type of stone will exhibit varying properties. Aside from aesthetic characteristics of color and texture, which again are not the focus of this manual, the porosity of stone is one of the key physical characteristics which determines the durability and suitability of the stone and agglomerates as a finish which can be used in mass transit projects. The effects of moisture on stone or stone agglomerates are varied. Moisture absorbed in a stone may be heated by solar radiation or frozen by cold temperatures and exert pressure in excess of the tensile strength of the stone (water increases 9% in volume when frozen!). Moisture will act also as a vehicle for transport of salts and contamination from other surfaces, from pollutants, or from weathering of the stone. Rupture or breaking strength is also an important characteristic of stone and agglomerates used in exterior applications. Good breaking strength is required to resist reflection of thermal or moisture (shrinkage) movement in the underlying substrates, and to resist potential breakage of stone during handling and installation. In order to select the most suitable type of stone for an application, and understand the technical requirements for adhesive installation of a particular stone, the specifier must have a general understanding of the classifications and physical properties of stone and stone agglomerates.

Types of Natural Stone – Geological Classification

Natural stone is classified geologically in three categories, also known as the "Three Great Classes" of natural stone:

Igneous – solidified rock from molten state

- Types – Granite, Basalt

Sedimentary – cementing, consolidation and crystallization of chemical solutions and biological deposits

- Types – Limestone, Sandstone

Metamorphic – change or alteration of solidified rock by heat, pressure, or intrusion of other rock

- Types – Marble, Slate, Quartzite, Serpentinite

Granite

Geologic and Commercial Classification

Granite is classified as an igneous stone, and has a primary mineral composition of feldspar and quartz. Black granite, also known as trap rock, has a completely different mineral composition than granite, but is commercially classified as granite. Black granite actually has a completely different mineral composition of hornblende and biotite and is not necessarily black in color. Some varieties of granite contain trace minerals which can cause discoloration or exfoliation after prolonged exposure to the weather.

Granite – Characteristics

Granite has a distinct crystalline appearance and is hard, dense, and resistant to scratches and acids. Of all the stone types, granite is the most suitable stone for direct adhered exterior/interior walls and floors in mass transit applications. This is because the density and hardness of granite impart stability and high breaking strength resistance (minimum requirement 1500 psi [10 MPa]) when fabricated in thin slabs or tiles that are necessary for cost effective installations. Laboratory research has also demonstrated that most granite fabricated in sections as thin as 7/16" (10 mm) have low moisture sensitivity and undergo minimum distortion or hysteresis growth when adhered with latex cement adhesive mortars. Granites used in building construction, especially exterior walls and floors, should have a maximum absorption rate of 0.40% by weight according to ASTM standards. The low absorption rate of most building granites require that cement adhesive mortars, which rely on absorption of cement paste and subsequent locking effect of crystal growth into the stone pores, utilize a latex additive or epoxy adhesives to insure proper adhesion. A latex additive will retard the evaporation of moisture needed to allow maximum absorption of cement paste and allow cement crystals to grow and produce a locking effect, and also impart pure adhesive bond. Because of the translucency of the minerals in some varieties, together with the thin widths typically used with the direct adhered method, some granite can darken temporarily from exposure to moisture (including the moisture in adhesive mortars). Granite may also darken permanently from reflection of dark or inconsistent coverage of underlying adhesives, or even darken or stain permanently from absorption of chemicals, such as the plasticizers, found in some (silicone) sealants. In selecting a thin granite for direct adhesion, it is recommended to avoid large grained granites relative to thickness; grain size should be less than 1/10 the stone thickness to maintain structural integrity of the vitrification between grain boundaries. While finishes of stone are primarily an aesthetic consideration, a textured (or thermal) finish is well suited for mass transit floor use and the preferred finish type. The thermal finish provides better slip resistance than other finish types. However, it should be noted that thermal finishes may require more maintenance as dirt and debris may be trapped within the stone finish. In addition, a thermal finish on granite induces thermal shock damage to the first 1/8" (3 mm) depth of the stone face, and should be taken into account by deducting this layer when calculating thickness specifications. Other common granite finishes are polished, honed, sandblasted and bush hammered. Commercially, granite is available in hundreds of varieties, differentiated primarily by color (a function of the mineral composition) and geographic origin.

Figure 5.11 – Granite Tiles typically found in an Airport or Train Station.

Limestone

Geologic and Commercial Classification

Limestone is classified as a sedimentary stone with a primary mineral composition of calcite and dolomite. Limestone is geologically categorized as either oolitic (granular composition) or dolomitic (non-granular composition), and are commercially categorized as a building stone according to American Society for Testing and Materials standard ASTM C 568 (Standard Specification for

Limestone Dimension Stone) by density properties:

Low Density – Category I

Medium Density – Category II

High Density – Category III

High density – Category III has an absorption rate of <3% and a minimum Modulus of Rupture of 1,000 psi (7 MPa), and is considered the best choice for interior floors and exterior walls, especially in colder climates (see characteristics below). Similar to other natural building stones, limestone is further differentiated by color (white, cream, buff or rose) and geographic origin. Special varieties of limestone include travertine, a limestone which is formed by the precipitation of minerals in hot springs. Travertine, while geologically classified as a limestone, is commercially classified as a marble (see marble) because it can be polished. Onyx is a type of translucent limestone which is formed by precipitation of calcite in cold water found in limestone caves.

Limestone – Characteristics

Limestone is characterized by the relatively loose cementing or consolidation of the minerals calcite and dolomite originating from biological deposits such as shells and sediments. As a general rule, lower density limestone (as classified above) has less desirable physical characteristics for exterior applications (especially in cold climates) such as a higher water absorption rate (7–12% by weight). Conversely, lower density limestone may possess better adhesive characteristics, especially with lower cost cement based adhesives. High density limestone has low absorption rates (<3% by weight) which impart good freeze thaw resistance and moisture stability.

Figure 5.12 – Limestone in New York's Grand Central Terminal Hallway.

Sandstone

Geologic and Commercial Classification

Sandstone is geologically classified as a sedimentary stone with a primary mineral composition of quartz. Sandstone is commercially categorized by mineral content (the percentage of quartz) according to the following three categories;

Sandstone (60% Quartz)

Quartzitic Sandstone (90% Quartz)

Quartzite (95% Quartz)

Sandstone is further classified by varieties according to their color and geographic origin. For example, bluestone is a dense, fine grained quartzite, and brownstone is loose, rough textured sandstone. Therefore, of all the sandstone types, dense species of bluestone and quartzite would be considered the only suitable sandstone types for demanding horizontal mass transit applications.

Sandstone – Characteristics

Sandstones are typically characterized by a loose or rough texture. Standard sandstone may have water absorption rates as high as 20% by weight, while quartzite, a more homogeneous composition of mainly quartz cemented with silica, has absorption <1% by weight. Sandstones (<60% quartz), are sensitive to weathering and cut relative to bedding planes.

Marble

Geologic and Commercial Classification

Marble is geologically classified as a metamorphic stone with a primary mineral composition of calcite and dolomite. Geologically, marble is actually a limestone that has been re-crystallized by heat, pressure, and intrusion of other minerals (thus the term "metamorphic"). The term "marble" is a commercial category of natural stone. Geologically marble is a metamorphic limestone of sufficient hardness which is capable of taking a polish. Commercially, there are over 8,000 varieties of marble, based on mineral content, color and geographic origin. According to American Society for Testing and Materials standard ASTM C 503 "Standard Specification for Marble Dimension Stone", there are four classifications of marble building stone for interior and exterior vertical cladding and heavy traffic floor installations:

Marble Classification

- Class I – Calcite
- Class II – Dolomite
- Class III – Serpentine
- Class IV – Travertine

The percentage of magnesium carbonate in marble generally determines its strength, color, texture and variety. Calcite marbles have <5% of magnesium carbonate, and dolomite marbles have >40% magnesium carbonate. Travertine is geologically a limestone, and serpentine is geologically an igneous stone, both capable of taking a polish, and therefore commercially classified as a marble. Stone industry organizations such as the Marble Institute of America further classify marble according to fabrication, handling and working qualities according to the following categories:

Marble – Fabrication and Working Quality Classification

- Group A – Sound Stone With Uniform Characteristics and Favorable Working Qualities
- Group B – Stone Similar to Group A; May Have Some Natural Faults
- Group C – Stone With Variations in Working Qualities, Containing Geological Flaws, Voids and Veins
- Group D – Contains Many of the Most Highly Colored, Veined, and Decorative Marbles With Substantial Natural Cleavage Faults

While fabrication classifications are not necessarily an indication of the physical properties or durability of stone, it is generally recommended that only Group A and Group B marble are suitable for use on a high traffic mass transit floor or for interior or exterior vertical cladding. This is especially true with the thinner stone modules typical with the direct adhered methods of installation. However, one of the advantages of the direct adhesion of stone is that the entire surface of the stone is adhered, which allows stone that may normally be too fragile for mechanical anchorage to be considered for direct adhesion.

Marble – Characteristics

Marble is a relatively soft stone (approximately 3 on the Mohs hardness scale), and the surface is easily scratched by abrasives or etched by acidic materials. Marble is not particularly durable as an exterior vertical / horizontal cladding in harsh climates or for floor applications in mass transit applications.

Figure 5.13 – Tile installed in old railroad station in Antwerp, Belgium.

Slate

Geologic and Commercial Classification

Slate is geologically classified as a metamorphic stone with a primary mineral composition of quartz and mica. According to ASTM C629 "Standard Specification for Slate Dimension Stone", slate is commercially classified as either:

Type I – Interior

Type II – Exterior

Slate is available in a variety of colors and from numerous geographic regions of the world.

Slate – Characteristics

Slate is characterized by a sheet-like structure with cleavage parallel to the grain. Slate is normally fabricated with a natural cleft surface, although some slates can be sanded smooth. There are a wide variety of slates, and even some type II slates do not have suitable characteristics for use in exterior or vertical applications. Relatively "young" slates typically have a high percentage of mica and, as a result, lower density. This characteristic results in easy parallel cleavage and susceptibility to cohesive shear failure when exposed to shear forces common in mass transit floor applications. The high percentage of mica can also result in a friable, dust-like surface which prevents good adhesion to the body of the slate, even after proper washing and preparation. Conversely, "old" slates have a dense, compact structure, and are better suited for direct adhesion. Only laboratory or field shear bond and tensile strength testing can ascertain suitability of slates for direct adhesion in all application types.

Agglomerate Stones

Classification

Agglomerate is a term used to describe a man-made stone slab or tile product that typically consists of natural stone pieces and/or aggregates held together in a synthetic binder (e.g. polyester resin or epoxy resin). While there is no geologic classification for agglomerates, many of these products have physical characteristics similar to the type of stone pieces used in the matrix, and are often commercially classified as granites or marbles. In some agglomerate products, the characteristics of the binder may have a dominant effect on the behavior and performance of the product. Polyester resins have a high thermal coefficient of expansion and can present problems of significant differential movement when installed on exterior facade.

Agglomerates – Characteristics

There are hundreds of proprietary agglomerate products on the market. Each of these roducts has its own physical characteristics dependent on the type of stone fragments or aggregates, type of binder, and percentage of each material. The most popular agglomerate tiles typically consist of natural stone pieces in a 4–8% polyester resin binder. It is important to verify the suitability of agglomerates for mass transit applications based on agglomerate stone hardness.

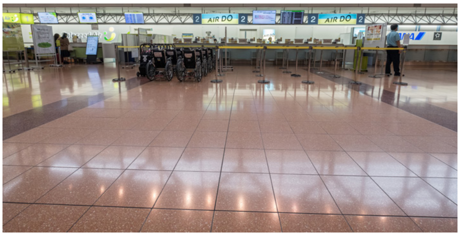


Figure 5.14 – Agglomerate Stone at an airport terminal in Japan.

5.10 COLOR, TEMPERATURE AND MOISTURE SENSITIVITY

Moisture Sensitivity of Stones

Modern stone fabrication technology now allows production of stone tiles as thin as 1/4–1/2" (6–13 mm). While this technology has made direct adhered stone technically feasible and affordable, it presents problems of moisture permeability and sensitivity that previously, were of little concern with traditional thick (2–4"/50–100 mm) stable slabs of natural stone. Known by the term "hysteresis," some thin stone (primarily marble) can bow or warp from crystal growth as a result of differential temperature or moisture change through its thickness. Some stone, especially dark, highly colored marbles and certain slates, contain minerals such as serpentine which are reactive with water. This simply means that crystal growth occurs on the side exposed to water, and the volume of the stone literally expands. This results in two problems that may occur if thin, moisture sensitive stone is installed using the direct adhered method:

Progress of installation – if water based cement or latex cement adhesive mortars are used, the side in contact with the adhesive may expand, and the outer surface will remain dry, resulting in differential movement with enough pressure to cause a thin stone to warp or distort from a flat plane. A thick section of stone would not be affected because the high ratio of unaffected or dry cross section to wet setting surface would not generate enough expansive force to overcome the resistance of the mass of stone.

The solution to this problem has been to either use accelerated latex cement adhesive mortars (e.g. 254R Platinum Rapid) which mechanically lock the surface of the stone before distortion by expansive forces begins, or in highly sensitive stones where reaction to moisture is rapid, to use a 100% solids, chemically reactive epoxy adhesive (e.g. LATAPOXY® 300 Adhesive or LATAPOXY BIOGREEN™ 300 Adhesive) which contains no water. However, these types of adhesives, and the labor techniques required, are typically more costly.

Post installation – Even if moisture sensitive stone is successfully installed in exterior mass transit applications, the stone may still be subject to cracking, spalling or adhesive bond failure from excessive volume expansion caused by exposure to constant high humidity or repeated cycles of rain.

Cladding Temperature and Color

A dark stone, such as black granite, or dark ceramic tile can become extremely hot from absorption of solar radiation. Color selection of a cladding material requires special consideration for expansion and contraction, as well as differential movement between the cooler underlying substrate. Dark colored tiles, stone or thin brick can easily reach a surface temperature of 170–190°F (80–90°C) with 3–4 hours of exposure to the sun in a hot, arid desert climate. When the sun sets, the ambient air temperature can drop to 60–70°F (15–20°C) in 1–2 hours, resulting in a temperature drop of 90°F (50°C) or more in the cladding material. This means that a dark stone, with an average coefficient of linear expansion of 7.3 x 10-6"/°F could expand and contract up to 7/8" (20 mm) over a distance of 100' (30 m) in as little as 2 hours!! This is not only a graphic example of the importance of movement joints, but also the importance of using a flexible, low modulus, high shear bond strength adhesive that can absorb the differential movement between the cladding material and the underlying substrate.

Material	% Of Solar Heat Absorbed
Black Matte Ceramic Tile	90%
Concrete	60%
Clay Brick	56%
Light Gray Ceramic Tile	46%
Aluminum	16%

Figure 5.15 – Heat Absorption of Cladding Materials.

5.11 EXPANSION AND CONTRACTION OF TILE FINISHES

Certain tile finishes can permanently increase in volume as a result of absorption of atmospheric moisture after removal from the kiln after firing. The total recommended design coefficient for moisture expansion as recommended by the Brick Institute of America is 3 – 4 x 10^{-4}" per inch of length. Factors affecting moisture expansion are:

Time of Exposure – 40% of the total expansion will occur within three months of firing and 50% will occur within one year of firing.

Time of Installation – moisture expansion will depend on the age of the tile and the remaining potential for expansion.

Temperature – the rate of expansion increases as temperatures rise and when moisture is present.

Humidity – the rate of expansion increases with relative humidity. Tile exposed to relative humidity of 70% can have moisture expansion rates two to four times as great.

In addition to permanent moisture expansion, brick will undergo reversible expansion and contraction due to changes in ambient air and surface temperatures. It is not uncommon for dark tile or stone surface temperatures to reach 170°F (75°C) on hot summer days and below freezing (32°F [0°C] or colder) on winter nights.

5.12 PANELIZED VERTICAL TILE AND STONE SYSTEMS

For mass transit installations of ceramic tile, stone, and thin brick, clad pre-cast concrete panels combine durability and tremendous design flexibility with the strength and economy of pre-cast concrete. The primary advantage of this type of backup wall construction is the economy of pre-fabricated, panelized construction. Pre-fabrication permits construction of panels well in advance of the normal sequencing of on-site construction of a building's exterior wall. Once the proper stage in the sequence of construction is reached, panels can be erected quickly, without weather or scaffolding erection delays. Pre-cast concrete also allows more stringent quality control afforded by plant production of both the batching and casting of the concrete, as well as the installation of the cladding material. The considerations for clad pre-cast concrete panels are generally the same as those for unfinished panels, with two exceptions; the method of installation for the cladding material, and investigation of differential thermal and moisture movement between the pre-cast concrete and the cladding material.

Pre-Cast Concrete Panels – Negative and Positive Cast Methods

There are two methods for installation of tile on pre-cast concrete panels; the negative cast, and the positive cast methods.

Negative cast panels involve the casting of the concrete and bonding of the cladding in one step. The cladding material is placed face down over the face of the panel mold; joint width and configuration are typically controlled by a grid to insure proper location, uniform jointing and secure fit during the casting operation. Joints are typically cast recessed, and pointed or grouted after the panel is cured and removed from the mold. This method requires the use of a cladding with a dovetail or key back configuration on the back of the tile (as shown in Figure 5.13) in order to provide a mechanical locking action between the cladding and the concrete. The mechanical bond strength afforded by the integral locking of the concrete to the back is often augmented by the use of latex portland cement slurry bond coats or polymeric bonding agents just prior to casting of the panel.

Positive cast panels are prefabricated in two separate processes. The pre-cast panel is cast, cured, and removed from the mold, and the cladding material is then installed using an adhesive in the production plant in similar fashion to in-situ construction. Installation of the cladding after erection and attachment to the structure on-site is viable, but this sequencing defeats the goal of economy and quality control provided by prefabrication.

Figure 5.16 – Tiled pre-cast vertical panels in Old Elbe Tunnel, Hamburg, Germany

Pre-Cast Concrete Panels – Differential Movement (Internal to Panel)

Differences in the physical characteristics of the pre-cast concrete and the cladding material make this type of back-up construction more susceptible to problems of panel bowing or excessive shear stress at the adhesive interface. Bowing of panels can occur from several mechanisms. In negative cast panels, the concrete shrinks as it hydrates and excess water evaporates. The cladding, being dimensionally stable, can restrain the shrinkage of the concrete. The result is compressive stress in the cladding, and tensile stress at the adhesive interface, with the potential for outward bowing of the cladding surface. The best techniques in preventing panel bowing is to control the concrete shrinkage and to provide the proper ratio of cross sectional area to stiffness (modulus of elasticity) of the panel. Avoid flat panels less than 5 – 6" (125 – 150 mm) thick; concrete as thin as 4" (100 mm) can be used in panels with small areas, or in panels where stiffness is increased by configuration or composite action with a thick cladding material. Concrete mix design and curing conditions can be adjusted to minimize shrinkage. Several other techniques, such as the amount, location, and type of (pre-stressing) reinforcement, or introduction of camber to the panel, have been developed to compensate for possible bowing caused by shrinkage. Differential movement caused by different coefficients of thermal expansion between the cladding material and the concrete can also result in panel bowing. The optimum condition is for the concrete to have a rate of thermal expansion that closely matches that of the cladding material. The thermal coefficient of expansion of concrete can be modified slightly by adjustment of aggregate type, size and proportion to provide compatibility with the cladding, and, minimize differential movement under temperature changes.

Pre-cast Glass Fiber Reinforced Concrete Wall Panels (GFRC)

Pre-cast glass fiber reinforced concrete (GFRC) is the term applied to a material which is fabricated from a cement aggregate slurry and reinforced with alkali resistant glass fibers. Mix composition and types of applications vary, but for installation of direct adhered cladding, GFRC panel consist of mix which contains 5% by weight of glass fibers combined with a portland cement-sand slurry which is spray applied onto a form. The form may contain a cladding material (negative cast method) to which a bond coat of latex portland cement is applied just prior to application of the GFRC material, or the panel is cast, cured and removed from the form for subsequent application of a cladding material in a separate process (positive cast method). A single skin GFRC panel is the most common type of panel construction. This type of panel has a thickness of approximately 1/2" (13 mm); however, it is recommended to increase the thickness of the GFRC panel, to approximately 1" (25 mm) to reduce and better resist differential movement stress. GFRC panels rely on a structural backing or stiffener of a steel stud framework. The steel frame is commonly separated from the GFRC by an air space and attached to the GFRC by means of 1/4" (6 mm) diameter rods called flex anchors, which are imbedded into the GFRC and welded to the framework. These anchors, while rigidly attached, have flexibility inherent by diameter and orientation of the rods, which allow some panel movement to accommodate thermal and moisture movement. Heavier panels, or those requiring seismic bracing, also require additional anchors known as gravity or seismic anchors, and are differentiated from flex anchors by their size, configuration, and connection orientation to the GFRC. It is very important to consider the additional weight of the cladding material during the design and engineering of a GFRC panel; you cannot install direct adhered cladding using the positive method unless the panel was engineered specifically for that purpose. Properly engineered and constructed GFRC panels have extremely high strength and good physical characteristics. However, due to the thin sections employed in GFRC panels, differential thermal and moisture movement can cause panel bowing, resulting in cracking. Because GFRC expands and contracts from wet-dry cycling, the adhesion of a cladding can result in a different rate of moisture gain or loss between the front and back of the panel, which, in turn, can induce bowing stress. Therefore, careful attention to detailing to prevent rain infiltration and condensation within the wall are important. Similarly, cladding materials with incompatible coefficients of thermal movement can induce stress. So thermal and moisture movement compatibility with cladding is important, as are low modulus adhesives and movement joints.

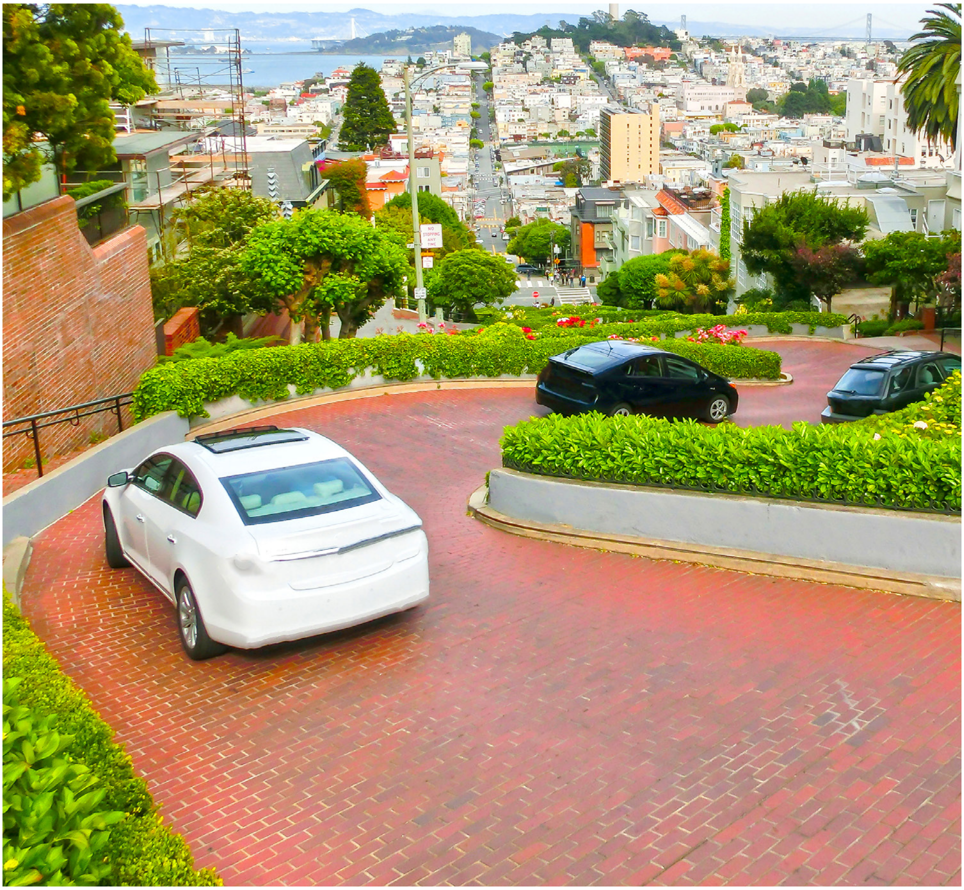
Pre-fabricated steel frame and cement backer unit (CBU) wall panels

Pre-fabricated steel frame and CBU wall panels rely on the same construction principles as in-situ light gauge steel stud construct. Another advantage of this type of wall construction is the economy of the pre-fabricated, panelized construction. In similar fashion to pre-cast concrete wall panels, pre-fabrication permits construction of panels well in advance of the normal sequencing of on-site construction of a building's exterior wall. Once the proper stage in the sequence of construction is reached, panels can be erected quickly, without weather or scaffolding erection delays. Pre-fabricated steel frame and CBU wall panels also allows more stringent quality control afforded by plant production in the sequencing of building elements (including fastening and taping of the CBU, air and vapor barrier placement, etc…) as well as the subsequent installation of the cladding material. Positive side waterproofing membrane is required for exterior panels. Thin, load bearing waterproofing membranes (e.g. 9235 Waterproofing Membrane or HYDRO BAN®) are generally specified to be installed directly under the cladding finish. A compatible latex-fortified portland cement thin bed adhesive mortar is used to adhere the cladding material to the waterproofed panel assembly. Critical detailing and sequencing is required when erecting the panels to:

1. Ensure that waterproofing integrity is maintained between adjacent panels
2. Proper expansion allowance is maintained with the appropriate flexible sealant while still maintaining waterproofing integrity (see Section 10 expansion joint with waterproofing looped into movement joint EJ-10 and EJ-11)
3. Waterproofing membrane "touch-ups" may be required after panels are erected into place

† United States Patent No.: 6881768 (and other Patents).

Section 6: Types of Membranes



Lombard Street – San Francisco, CA – Installation of thick bed quarry pavers on roadway utilizing the LATICRETE Thick Bed System.

6.1 OVERVIEW

There are various membrane types that can be specified within a ceramic tile/stone installation system, depending upon the requirements of the installation. The membrane types include;

- Waterproofing
- Crack isolation/Anti-Fracture
- Sound Control
- Combination of Two or More Element Types
- Adhesive Types That Incorporate Two or More Element Types

Waterproofing protection is one of the most practical steps to ensure the longevity of most mass transit tile and stone installations. It not only protects the spaces below and adjacent to the tile/stone installation, it also protects the setting bed, reinforcing wire (if used), concrete base and concrete reinforcing from potential damage and corrosion. Since damage to many flooring components can occur, it is no surprise that the majority of construction liability claims involve water damage that has resulted from the lack of, or an improperly installed, waterproofing membrane. Today's pressures of completing projects quickly often leads to tile and stone installations being rushed and installed improperly. The advanced technology that goes into waterproofing, crack isolation and sound control membranes allows the end user to take advantage of quicker curing times, which allows faster time to flood testing and ultimately allows the tile or stone installation to move forward in a more timely manner. The various membrane types of waterproofing, anti-fracture and sound control membranes include; peel and stick, trowel applied, liquid applied, and sheet good types.

The traditional asphaltic/bitumen based roofing type waterproofing membranes are omitted from this manual. However, it is important to note that if they were to be specified and used in a commercial flooring application, a full, wire-reinforced non-bonded thick bed mortar bed would be required. Direct bonding to these membrane types is not possible.

The most important factor in all types of membranes is to closely follow the membrane manufacturer's installation recommendations. This will significantly reduce the possibility of job site problems and potential failures. Adhering to industry standards is also paramount to the success of the tile and stone installation. Consideration should be given to membranes that carry plumbing and building code approval as well as being environmentally friendly (e.g. 9235 Waterproofing Membrane, HYDRO BAN®, Blue 92 Anti-Fracture Membrane, 125 TRI MAX™ and 170 Sound and Crack Isolation Mat).

Many crack isolation, sound control and waterproofing membranes can be applied over concrete, mortar beds, exterior glue plywood ,and cement backer board. Some membranes serve as both waterproofing and anti-fracture membranes in one (e.g. 9235 Waterproofing Membrane or HYDRO BAN).

The installation of waterproofing is covered under ANSI A108.13 "Installation of Load Bearing, Bonded Waterproofing Membranes for Thin-set Ceramic Tile and Dimension Stone". Crack isolation membranes and adhesives are covered under ANSI A108.17 "Installation of Crack Isolation Membranes for Thin-Set Ceramic Tile and Dimension Stone". The product standards for waterproofing can be found under ANSI A118.10 and the product standards for crack isolation membranes can be found under ANSI A118.12. Selection of membranes must take into account the conditions of a mass transit application including heavy traffic (pedestrian and/or vehicular), harsh cleaners, and, in many mass transit applications, excessive vibration.

6.2 SHEET MEMBRANES

Sheet membranes are typically made from chlorinated polyethylene, polyvinyl chloride, and other materials. These membranes (e.g. HYDRO BAN Sheet Membrane) are made in a variety of lengths and widths with supplemental options for tapes, corners and collar pieces to accommodate many different types of installations for quick and easy installs. Generally, these sheet membranes have a polyester or fiberglass scrim or netting bonded to both sides which allow it to be bonded to the substrate, and the tile or pavers to bond directly to the sheet membrane.

Typically, a latex portland cement mortar (meeting ANSI A118.4) is used to bond the membrane to the substrate and to bond tile/stone to the membrane. If time is a limiting factor, the use of a rapid setting adhesive can be used to bond the membrane (e.g. HYDRO BAN Sheet Membrane) to the substrate, which in turn allows the installation of tile or stone to take place quickly, without the loss of bond of the membrane to the substrate.

It is very important to consider the moisture vapor emission rate (MVER) and the alkalinity of the concrete slab prior to the installation of these products. A concrete slab or cement mortar bed with a high MVER rate and/or high alkalinity can create adhesion problems, and can possibly be destructive to the membrane and the overall installation. The sheet membrane manufacturer can provide information on the MVER and alkalinity limits of their products.

Sheet type membranes are pressed into contact with the substrate in an effort to eliminate air bubbles and voids under the membrane. Generally this can be done using a 75- or 100 (34–45kg) pound sheet vinyl roller or the flat side of a trowel. It is important to note that the substrate or setting bed surface must meet the same substrate smoothness criteria required for direct bond tile or stone applications. If the surface is not smooth and flat enough for tile or stone, then it is not smooth and flat enough for a membrane.

Precautions and concerns with sheet type membranes are as follows:

1. Trapping air below the membrane can cause air pockets to form and radically diminish the compressive strength of the overall tile system.
2. Overlapping and sealing the seams. The seams may require treatment with a suitable sealant or solvent.
3. Membrane thickness increases in the folds of inside and outside corners, seams and other transition areas. Additional flashing or skim coating treatment may be necessary to minimize the effects that this can have on the finish tile appearance.
4. High alkalinity can attack and adversely affect some sheet type membranes and the adhesive used to bond the membrane to the substrate.
5. High MVER – generally in excess of 5 lbs/1,000 ft^2/24 hours (283 mg/s m^2) can have a negative impact on the adhesion of sheet type membranes to the substrate. Always follow membrane manufacturer's guidelines for MVER.

6.3 PEEL AND STICK MEMBRANES

Peel and stick membranes are very similar to sheet type membranes in performance. The major difference between the two styles is that the peel and stick type does not rely on a separately applied adhesive layer to bond it to the substrate. These membranes are generally asphaltic based with a reinforcing fabric on the tile bonding side of the membrane and a removable paper type backing which exposes a tacky surface once it is peeled away. The installation of peel and stick membranes (e.g. FRACTURE BAN™) begins with priming the substrate with a primer specifically manufactured for the purpose. Primers can be either latex based types (e.g. FRACTURE BAN Primer) for interior installs or epoxy based materials (e.g. NXT® Epoxy Primer) for exterior installs).

Once the primer is in place and sufficiently dry, the removable film is peeled from the back side of the membrane and rolled onto the floor assuring a good bond and 100% contact with the substrate.

Precautions and concerns with sheet type membranes are as follows:

1. Careful consideration must be taken where the seams overlap. Spreading the tile mortar over the seam can be tricky and care should be taken to avoid humps where the tile lays over the seam.
2. These membranes are typically not intended for use as a waterproofing membrane. When a waterproofing membrane is required, use HYDRO BAN®.
3. Cleaning regimens also play a factor in whether peel and stick membranes should be used or not. Solvents typically have an adverse effect on peel and stick membranes. Consult the membrane manufacturer for specific applications, installation instructions and cautions.
4. Membrane thickness increases in the folds of inside and outside corners, seams and other transition areas.

Additional flashing or skim coating treatment may be necessary to minimize the effects that this can have on the finish tile appearance.

5. High alkalinity can attack and adversely affect some peel and stick type membrane and some adhesives which may be used to adhere the membrane to the substrate.
6. High MVER – generally in excess of 5 lbs/1000 ft^2/24 hours (283 mg/s m^2) can have a negative impact on the adhesion of peel and stick type membranes (follow membrane manufacturer's guidelines for MVER).

6.4 RECYCLED RUBBER MAT TYPE MEMBRANES

Recycled rubber mat membranes are primarily designed to be used under interior thin-bed adhesive floor installations as an acoustical underlayment that muffles impact noise through ceramic tile, stone and other hard surfacing materials. These mat types also minimize the transmission of non-structural cracks from the substrate to the tile or stone installation of up to 1/8" (3 mm).

An example of this category type is 170 Sound & Crack Isolation Mat. This mat is a 1/8" (3 mm) thick rubberized membrane comprised of 88.5% post-consumer recycled materials. This product achieves a ΔIIC rating of 20, per ASTM E2179 "Standard Test Method for Laboratory Measurement of the Effectiveness of Floor Coverings in Reducing Impact Sound Transmission Through Concrete Floors" while meeting ANSI A118.12 crack isolation requirements. It is important to note that this membrane type may not be suitable for most mass transit applications. These recycled rubber mat membranes may be subject to point load and compressive strength issues. Therefore, many of these mat types achieve only a "Residential" or "Light" service rating per ASTM C627 "Standard Test Method for Evaluating Ceramic Floor Tile Installation Systems Using the Robinson-Type Floor Tester". This means that recycled rubber mat membranes should only be used in residential or light commercial applications, and therefore, would not be appropriate for the majority of mass transit installations.

6.5 TROWELABLE MEMBRANES

Sound Control
Crack isolation
Waterproofing

Trowel applied membranes come in various forms, including special elastomeric co-polymer types, latex-fortified cement based types, epoxy resin types and urethane types. Great advances have been made in this category in recent years. Some of the trowel applied materials perform as the tile adhesive while providing crack isolation and sound control properties. For example, 125 TRI MAX™ provides crack isolation protection up to 1/8" (3 mm) in accord with ANSI A118.12 requirements and provides a ΔIIC rating of 15 (per ASTM E2179 "Standard Test Method for Laboratory Measurement of the Effectiveness of Floor Coverings in Reducing Impact Sound Transmission Through Concrete Floors") while acting as the tile adhesive mortar. 125 TRI MAX is ideal for interior applications where sound deadening, crack prevention or both are required.

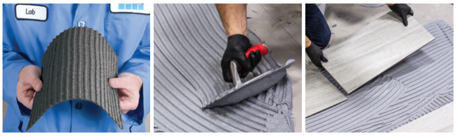


Figure 6.1 – Trowel applied sound and crack adhesive mortar applied to concrete substrate.

Some trowel applied waterproofing membranes include a reinforcing fabric which is used in corners, coves, and to tie into plumbing fixtures (including drains). After the typical pre-treatments are made to cracks and transition areas, the main application normally consists of keying the membrane into the substrate with the flat side of the trowel. This is immediately followed by combing the material in a singular direction, and then finally another pass with the flat side of trowel to smooth the surface. A few key elements are the notches in the trowel act as a gauging device for the membrane. Most membranes require a certain thickness of product to ensure complete waterproofing coverage. As with all waterproofing membranes, trowel applied membranes should be applied at a continuous thickness (as per membrane manufacturer's installation instructions) to ensure waterproofing integrity. The use a wet film gauge is recommended to assure acceptable uniform thickness.

Latex Cement Based Membranes

Latex cement based membranes are generally comprised of a liquid latex polymer that is mixed with a portland cement based powder. These products are generally very economical in cost and are easy to apply. However, the physical characteristics of these types of products generally restrict their use in demanding mass transit floor applications.

Epoxy Based Membranes

Epoxy membranes are normally 3 component systems consisting of an epoxy hardener, epoxy resin, and a filler powder. These products are generally highly chemical resistant, load bearing and suitable for mass transit applications. Some other advantages to epoxy based membranes waterproofing membranes are as follows:

- Flood Testing Can Be Performed in 24 Hours at 70°F (21°C)
- Adheres to Metal, Stainless Steel, and Pipe Penetrations
- Flexible and Able to Adhere to Many Substrates
- Can Be Used as a Flashing Membrane to Tie Into Other Types of Membranes or Surfaces When Required

An example of this category type of waterproofing membrane is LATAPOXY® Waterproof Flashing Mortar.

Urethane Based Membranes

Urethane waterproofing membranes are soft rubbery materials which are usually applied in a minimum thickness of 60 mils (1/16" [1.5 mm]) and may be as thick as 90–125 mils (1/11" – 1/8" [2.3 – 3mm]). Urethane membranes generally cure very slowly and the ultimate finish remains relatively soft and tacky after placement.

These membrane types are usually very chemical resistant and would hold up well under typical chemical attack. However, the disadvantages of the membranes will usually outweigh the advantages. For example, urethane membranes usually do not hold up well under the loads and stresses that mass transit installations experience. This membrane type can creep and deform excessively under load. Therefore, ceramic tile and pavers may not have sufficient support. Consequently, under heavy traffic and point loading, or even normal mass transit requirements, the installation could develop severe cracking of the joints, cracked or broken tiles, and/or loss of bond.

Many tile and stone installations utilizing a urethane based membrane, require a conventional, wire-reinforced, non-bonded thick mortar bed mortar be placed over soft urethane waterproofing membranes and over soft built-up asphaltic type waterproofing membranes.

6.6 LIQUID APPLIED MEMBRANES

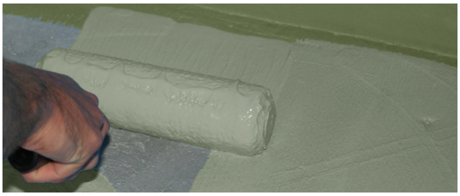
Liquid applied membranes offer an ideal solution to the demanding requirements of mass transit applications. In addition, to having "Heavy Duty" ratings as tested per ASTM C627 "Standard Test Method for Evaluating Ceramic Floor Tile Installation Systems Using the Robinson-Type Floor Tester", liquid applied waterproofing membranes are easy to install and provide many features and benefits. Two examples of liquid applied membranes include HYDRO BAN® and 9235 Waterproofing Membrane. Some of the features and benefits include:

- Can Provide Both Waterproofing and Anti-Fracture Protection
- Meet ANSI A118.10 Standards for Waterproofing
- Meet ANSI A118.12 Standards for Crack Isolation
- Plumbing Code Approved (IAPMO)
- GREENGUARD Approved for Low VOC Content
- Thin – Load Bearing and Shock Resistant
- Fully Compatible With the Entire Ceramic Tile, Stone or Paver Installation Materials
- Fully Formable to Fit Into Tight Areas
- Can Be Shaped to Follow Any Substrate Contour
- Flood Testing Can Vary According to the Membrane Type and Generally Ranges From 2 Hours to 7 Days at 70° F (21° C) – Check Installation Instructions For Each Waterproofing Membrane For Time to Flood Test
- Some Liquid Applied Waterproofing Membranes (e.g. HYDRO BAN) May Be Spray Applied With a Commercial, Airless Sprayer (See Section 8.5 For This Methodology).

Figure 6.2 – Liquid applied membrane applied to concrete substrate.

HYDRO BAN® is a cold liquid membrane which does not require fabric in the field, coves or corners.

9235 Waterproofing Membrane is a liquid applied, fabric reinforced membrane that is thin, load-bearing, and, like HYDRO BAN, is completely compatible with LATICRETE® latex thin-set mortars.



HYDRO BAN® Waterproofing Membrane

Section 7: Types Types of Mortars/Adhesives/Grouts

Pavers - NYC Bridge Walkway

7.1 ADHESIVE AND MORTAR PERFORMANCE AND SELECTION CRITERIA

The performance and use of ceramic tile and stone adhesives are regulated by country or region according to the prominent standards that govern the installation of ceramic tile and stone. Some of these standards are discussed in Section 10. Compliance may either be mandatory or voluntary in the respective countries, states, counties, or cities depending on whether the standard is incorporated into a building code.

Criteria for Selection of Adhesives and Mortars

- High Adhesive Strength (Tensile and Shear Bond)
- Water Resistant
- Flexible (Differential Movement)
- Permanent
- Fire and Temperature Resistant
- Non-toxic and User Friendly
- Good Working Properties (Open Time, Pot Life, Sag Resistance)

High Adhesive Strength (Tensile and Shear Bond Strength)

Shear stress occurs when a force is applied parallel to the face of the finish material. The greater the resistance to shear stress, the higher the shear strength result.

Tensile stress occurs when a force is applied to pull a material straight off of the substrate to the point where it loses bond. The greater the resistance to tensile stress, the higher the tensile strength result.

Tile and stone installations typically experience both shear forces, and rarely experience forces in tension (tensile). It is important to note that currently shear bond testing is limited to laboratory testing; although, equipment and methods are currently being developed to conduct shear bond testing in the field. On the other hand tensile bond testing can be performed in both laboratory conditions and in the field. Therefore, both tests are applicable and suitable to measure a material's bond strength.

The shearing force exerted by seismic activity is by far the most extreme force that an adhesive must be able to withstand. The shear stress exerted by an earthquake of a magnitude of 7 on the Richter Scale is approximately 215 psi (1.5 MPa) so this value is considered the minimum safe shear bond strength of an adhesive to both the surface of the finish materials and the substrate (Figure 7.1).

Figure 7.1 – High adhesive shear and tensile strength to resist seismic movement. Before photograph of the Bullock's building prior to the Northridge, CA earthquake in 1994. Tiles were installed on the exterior façade with 4237 Latex Additive mixed with 211 Powder over 9235 Waterproofing Membrane.

Figure 7.2 – High adhesive shear and tensile strength to resist seismic movement. Photograph of the Bullocks building after the Northridge, CA earthquake in 1994. Tiles remain adhered after severe shear stress from seismic activity and structural failure.

Water Resistance

For proper exterior and interior wet area performance, and in demanding mass transit applications, an adhesive must not be soluble in water after cured. The adhesive should also develop some water insensitivity within 24 hours so as not to require an unreasonable degree of protection against deterioration in the event of exposure to water.

Flexible (Differential Movement)

Adhesives must have a low modulus of elasticity, or flexibility, to withstand differential movement between the finish material and the underlying substrate and structure. Differential movement can be caused by uneven or sudden temperature changes, moisture expansion or shrinkage of the finish material, substrate or the structure, or, live loads such as wind or seismic activity (see Section 2 and 3).

Permanence

This criterion may seem obvious, but even if all other performance criteria are met, beware that some "old" technology cement, urethane or epoxy adhesives can deteriorate over time, depending on how they are chemically modified, even if they were properly installed. Some epoxies can become brittle with age, and some urethanes can undergo a phenomenon known as "reversion," where the adhesive may soften and revert back to its original viscous state. Certain polymeric modification of cement mortars work only to enhance the workability and curing process to improve the physical characteristics of cement, but do not contribute any significant lasting improvement to physical characteristics of the cement adhesive mortar.

Fire, Smoke and Temperature Resistance

When cured, adhesives must meet building codes and standard engineering requirements by not contributing any fuel or smoke in the event of a fire. In addition, the adhesive must maintain strength and physical properties during and after exposure to the high temperatures of a fire, or, from absorption of heat under normal service.

All metros and subways (like other confined, occupied spaces) utilizing ceramic tile and stone require installation materials that meet stringent fire/smoke/toxic fume limits. LATICRETE and LATAPOXY have been proven by time-tested installations around the world to provide superior levels of fire safety.

Non-Toxic and User Friendly

The adhesive should be non-hazardous during storage, installation, and disposal. This includes other materials which may be necessary for preparation or final cleaning. The adhesive should be non-toxic, non-flammable, low odor, easy to use, user friendly, and environmentally (VOC) compliant. It is always best to look for a third party endorsement for the installation materials in this regard (e.g. GREENGUARD). For example, LATICRETE International, Inc. manufacturers a wide variety of setting materials which are low VOC as certified by GREENGUARD. For more information, please visit our web site at www.laticrete.com/green.

Good Working Properties

The adhesive should have good working properties to ensure cost effectiveness and problem free installations. This means that adhesive must be easy to handle, mix, and apply without having to take extraordinary precautionary measures or waste time. Good initial adhesive grab to substrate and the finish material, long pot life, long open time (tacky, wet surface after spreading), vertical sag resistance (both the adhesive alone and with tile), and temperature insensitivity are all preferred working properties.

7.2 TYPES OF ADHESIVES AND MORTARS

Types of Adhesives

- Redispersible Polymer Modified Cement Mortar (Mixed With Water)
- Liquid Latex Fortified Cement Mortar (Latex in Lieu of Water)
- Modified Emulsion Epoxy Adhesives (Cement, Water, Epoxy Resins)
- Epoxy Resin Adhesives (100% Epoxy)

Latex/Polymer Fortified Cement Mortar

Latex/polymer fortified cement based adhesive mortar are available only as manufactured proprietary products. There are a wide variety of redispersible polymer fortified adhesive mortar products on the market. These materials typically are mixed with potable water; however, many redispersible polymer mortars can be mixed with liquid latex additive to improve performance (see latex fortified cement mortar). For example, LHT™ can be mixed with water for good performance, with 333 Super Flexible Additive for installations over exterior glue plywood (interior only), or with 3701 Mortar Admix for improved performance in interior applications, for exterior installations of for submerged applications. These mortars differ mainly by the type and quantity of polymer content. Performance characteristics may comply with either ANSI A118.1 (when mixed with water), or A118.4 and/or ANSI A118.11 (when mixed with a latex additive) standards. In addition, premium high strength redispersible polymer fortified mortars are available and suitable for use in mass transit applications. For example, 257 TITANIUM™ (for thin bed installations) and MULTIMAX™ Lite (for medium bed installations) are ideal for these areas. Performance characteristics of 257 TITANIUM™ and MULTIMAX™ Lite comply with ANSI A118.4, A118.11 and A118.15 standards. Please visit www.laticrete.com for more information on each LATICRETE product including mixing instructions.

Figure 7.3 – Mixing of liquid latex fortified portland cement medium bed mortar.

Types of Redispersible (Polymeric) Powders

- Modified Cellulose
- Polyvinyl Acetate Powder (PVA)
- Ethylene Vinyl Acetate Co-polymer Powder (EVA)
- Polyacrylate Powder

Many of the redispersible powder cement mortars available on the market may not be recommended for mass transit applications for a variety of reasons. Some of the polymers used, such as PVA's, may not be suitable for exterior applications because they may be water soluble and can re-emulsify after prolonged contact with moisture. This may cause polymer migration and result in staining, loss of flexibility, and loss of shear bond and compressive strengths. Some polymer fortified cement based mortars may also lack the compressive strength required for heavy traffic mass transit applications. Most products that conform to ANSI A118.1 adhesive standards contain only water retentive additives such as cellulose, which provides water retention for prolonged open time and improvement of working properties, but ultimately provides minimal improvement of strength or flexibility when compared to traditional cement mortar.

However, EVA modified mortars that conform to ANSI A118.4, ANSI A118.11 and ANSI A118.15 standards and are specially formulated for demanding applications (including exposure to freeze/ thaw conditions and are designed to be shock and impact resistant) will have the characteristics and physical properties required for mass transit applications (examples of suitable products i nclude, but are not limited to, 257 TITANIUM and 3701 Fortified Mortar Bed thick bed mortar).

While many redispersible polymer fortified cement based adhesives are economical and easy to use, it is recommended to verify suitability for use under the demanding requirements of mass transit applications with the manufacturer, and to request or conduct independent testing to verify the manufacturer's specified performance.

Liquid Latex Fortified Cement Mortar

There are a wide variety of proprietary liquid additives that can be used with both generic sand/cement mixes or with proprietary cement mortar powders. These include some products from the redispersible polymer fortified mortars, to prepare an adhesive for mass transit tile installations. As with redispersible polymer products, the liquid additives differ mainly by the type and quantity of polymer content. Therefore, suitability and performance characteristics for mass transit applications must be verified. 317 fortified with 3701 Mortar Admix is an example of these types of products. 226 Thick Bed Mortar gauged with the 3701 Mortar Admix also falls into this category.

Types of Liquid Additives

- Vinyl Acetate Dispersions
- Acrylic Dispersions
- Styrene-Butadiene Rubber (SBR)

Liquid latex fortified cement mortars are also a good choice for mass transit applications. However, as with redispersible polymer powder mortars, not all liquid additives mixed with cement based powders are suitable for these applications. The type and quantity of polymers, as well as other proprietary chemicals, will determine if latex fortified cement mortar is suitable for the conditions to which it will be subjected. A common and highly generalized misconception is that either acrylic or styrene butadiene rubber are superior to one another. This is simply not true. Both latexes can be formulated to have high adhesive strength, and be extremely flexible. Superior performance is achieved through the formulation of these two materials. It is recommended to verify the suitability of a latex fortified cement mortar for mass transit applications, and conduct or request independent testing to verify the manufacturer's specified performance.

Epoxy Resin Adhesives

Epoxy resin adhesives are typically three component systems, which consist of an epoxy resin, an epoxy hardener, and some type filler material, such as silica sand. Epoxy adhesives which conform to ANSI A118.3 contain 100% epoxy solids. LATAPOXY® 300 Adhesive is a high strength, 100% solids epoxy adhesive that works extremely well for mass transit applications. The use of LATAPOXY 300 Adhesive can ensure the long term performance of a mass transit floor exposed to extremely high traffic, severe weather conditions, harsh chemicals and cleaners, and thermal shock.

More economical versions of epoxy adhesives, known as modified epoxy emulsions, are available on the market. Modified epoxy emulsions, which conform to ANSI A118.8, consist of special epoxy resins and hardeners which are emulsified in water, and then mixed with a cementitious mortar. Modified epoxy adhesives combine the economy of cement based mortars and the added strength of epoxy adhesives. An example of a modified epoxy emulsion is LATAPOXY 210 Adhesive.

The advantages of epoxy adhesives are that they have exceptionally high adhesive strength (shear bond and tensile strength) to most any suitable substrate for a tile or stone installation, and more recent formulations have improved flexibility to accommodate different types of movement. While modified epoxy emulsions have lower strengths than 100% solid epoxy resin adhesives, they benefit from the higher temperature resistance and economy of portland cement adhesives. The primary disadvantages are that epoxy adhesives can be significantly more expensive, and the working qualities in cold or warm temperatures possible with many mass transit application conditions during construction, can limit production and further escalate costs. Sag resistance and temperature resistance are secondary limitations, depending on the requirements for the installation. Epoxy adhesives can bond to virtually any suitable, structurally sound substrate, so they are often recommended over more economical cement based systems when the tile or pavers must be adhered to unusual substrates such as steel, fiberglass or other metal substrates. In addition, 100% solids epoxy adhesive should be used when installing moisture sensitive stones, agglomerates, or resin-backed tile or stone.

Bonding Agents (Slurry Bond Coats)

Bonding of conventional cement mortar beds can be achieved by bonding agents or slurry bond coats. There are three main types of bonding agents: cement based slurries, latex emulsions (either latex alone or latex mixed with sand/cement), and epoxies. These materials should meet the requirements of ASTM C1059 "Standard Specification for Latex Agents for Bonding Fresh to Hardened Concrete" for latex bonding agents, and ASTM C881 "Standard Specification for Epoxy Resin Base Binding Systems for Concrete" for epoxies. Bonding agents are typically applied after substrate preparation and just prior to installation of leveling mortars or the tile and pavers. A thin coat, 1/8" (3 mm) maximum of slurry (mixed to a wet, creamy consistency) is vigorously brushed into the substrate surface (and/or onto the tile or paver) and installation is made while the slurry remains wet and tacky. Latex emulsions may be of the styrene butadiene rubber or acrylic type (see Liquid Latex Fortified Cement Mortar earlier in this section). Please note that polyvinyl acetates (PVA) bonding agents should not be used for this type of installation. 257 TITANIUM™ or 254 Platinum are often used as latex cement based slurry bond coats. Epoxy slurry bond coats should only be utilized in specialized or isolated conditions, because the epoxy can form a vapor barrier and cause delamination failure from entrapment of moisture vapor. It is a common misconception that bonding agents are a high-technology substitute for substrate preparation. This is not true; bonding agents or slurry bond coats are not designed to compensate for poor substrate preparation or conditions.

7.3 METHODS OF INSTALLATION

There are several methods generally used in the installation of tile and stone pavers in mass transit applications.

Application Methods for Mass Transit Installations

- Thin Bed Method
- Large and Heavy Tile Method (Formally known as the Bedium Bed Method)
- Thick Bed Method

Thin Bed Method

The thin bed method, also referred to as the adhesive method, is defined as an application of a tile adhesive layer ranging from a minimum of 1/8" (3 mm) to a maximum of approximately 1/4" (6 mm) thick which is in full contact with the tile or stone and substrate. The substrate must be properly prepared to be level and plumb prior to installation of the tile or stone. Please note that tile adhesives are not intended for leveling or correcting level and plumb deviations in the substrate. The adhesive can range from a pure or neat portland cement paste, to latex fortified cement adhesives and epoxy adhesives. The thickness of the adhesive layer is dependent on the type and size of the tile or stone paver, the substrate bonding surface texture, the configuration of the tile or stone paver (flat or ribbed back), and the variation in the thickness of the tile or stone. A "gauged" tile or stone paver is one with a consistent thickness and a specified tolerance for deviation; an ungauged finish material type is inconsistent in thickness and typically requires medium bed or thick bed methods for installation. Generally, most redispersible polymer and latex cement mortars (assuming that the formulation is first evaluated for suitability as an adhesive for the application) are suitable for use with the thin bed or adhesive method. Follow the adhesive manufacturer's guidelines for limitations on thickness, which varies based on formulation. Generally, thickness over 1/4" (6 mm) is not recommended for standard thin-bed or adhesive types of cement mortar mixes. Thickness over 1/4" (6 mm) typically require either a large and heavy tile mortar or modification of a site mix mortar with additional coarse sand.

Figure 7.4 – Tiler placing ceramic tile in position over adhesive with tile levelling system.

Large and Heavy Tile Method (formally known as Medium Bed Method)

Generally, thicknesses over 1/4" (6 mm) are not recommended for standard thin-bed or adhesive types of cement mortar mixes. Thickness over 1/4" (6 mm) typically require either a special formulation of powder containing a higher proportion of coarse sand, or modification of a site mix with additional coarse sand. These products are also known as large and heavy tile mortars. They are typically used when the required adhesive thickness ranges from 3/8" (9 mm) up to 3/4" (19 mm). Examples of medium bed mortars are MULTIMAX™ Lite or LHT™ Plus

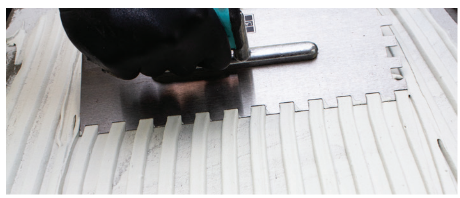


Figure 7.5 – Trowel applied medium bed mortar with a 3/4" (19 mm) square notch trowel used for large format tiles or stones. Trowel medium bed mortar in one direction holding trowel at a 45 degree angle. Notice the full ribbons of mortar that are left behind.

Recently there has been a trend to manufacture and install larger and larger tile. In the past, large format tile was considered to be 12" x 12" (300 mm x 300 mm) and was on the cutting edge of technology. Now, tile is available in sizes up to 4' x 4' (1220 mm x 1220 mm) porcelain and larger.

Some advantages of installing large format tile include;

- Narrow Grout Joints – Rectified, Large Format Tile Allows for Narrower Grout Joints
- Easier Maintenance – It is Typically Much Easier to Clean the Face of Tile Than It is to Clean Grout
- Room Size Perception – the Perception is That Large Tile Makes the Room in Which It is Installed Actually Appear to be Larger

However, there are three main concerns when installing large format tile and stone:

- Lippage
- Adhesive Mortar Coverage
- Curing/Protection

Lippage

The Tile Council of North America (TCNA) states that; "Lippage is a condition where one edge of a tile is higher than an adjacent tile, giving the finished surface an uneven appearance (See figure 7.4). This condition is inherent in all installation methods and may also be unavoidable due to tile tolerances, in accordance with ANSI A137.1."

With the increase in use of large format tile and stone on floors, the issue of lippage is becoming more commonplace. A tile or stone larger than 16" x 16" (400 mm x 400 mm) can now be considered large format.

Lippage, or the perception thereof, are influenced by many factors such as;

1. The allowable thickness variation of the tile modules when judged in accordance with manufacturing standards (ANSI A137.1).
2. The allowable warpage of the tile or stone modules.
3. The spacing or separation of each tile module, which would influence a gradual or abrupt change in elevation.
4. Angle of natural or manufactured light accentuating otherwise acceptable variance in modules.
5. Highly reflective surfaces of tile or stone modules accentuating otherwise acceptable variance in the modules.

The different components and factors which can lead to lippage problems are; Subsurface Tolerance: According to the TCNA, "Thin-set tile installations have a specified subsurface tolerance, for instance 1/4" in 10' (6 mm in 3 m) and 1/16" in 1'0" (1.5 mm in 300 mm), to conform with ANSI specifications. Because thin-set is not intended to be used in truing or leveling the work of others, the subsurface typically should not vary by more than 1/16" over 1'0" (1.5 mm in 300 mm), nor more than 1/32" (0.8 mm) between adjoining edges (e.g. plywood, cmu, cement backer board, etc…). Should the architect/designer require a more stringent tolerance (e.g. 1/8" in 10' {3 mm in 3 m}), the subsurface specification must reflect that tolerance, or the tile specification must include a separate requirement to bring the 1/4" (6 mm) subsurface tolerance into compliance with the 1/8" tolerance desired."

This becomes even more critical as the size of the tile or stone being installed increases. Mosaics on a floor can literally accept more variation in the substrate tolerance due to its small size; large format tile (16" x 16" [400 mm x 400 mm] or larger) requires a subsurface tolerance that is even more stringent than the industry accepted 1/4" in 10' (6 mm in 3 m). Essentially, the larger the tile or stone module, the greater the reflection of the unacceptable subsurface tolerance will show up as increased lippage in the finish. The subsurface tolerance is probably the tile contractor's biggest concern in regards to lippage, and, unless a procedure for leveling the floor is included in the contract, is not the fault of the installer. Substrates are often not suitably flat to achieve meeting both the owner's expectations and the industry tolerances for allowable lippage.

Grout Joint Width: With the advent of larger tile and stone module sizes comes the desire to have a smooth looking surface as well as one that is easier to maintain. Grout joints that are 1/8" (3 mm) or less in width are not uncommon for large format tile; a fact which can greatly exaggerate lippage issues. Subsurface tolerances outside of the allowable range or warping of the tile are much more noticeable when grout joints are tighter.

Tile Type	Tile Size	Joint Width	Allowable Lippage
Glazed Wall/ Mosaics	1" x 1" (25 x 25 mm) to 6" x 6" (150 x 150 mm)	1/16" to 1/8" (1.5 to 3 mm)	1/32" (0.8 mm)
Quarry	6" x 6" (150 x 150 mm) to 8" x 8" (200 x 200 mm)	1/4" (6 mm) or greater	1/16" (1.5 mm)
Paver	All	1/16" to less than 1/4" (1.5 mm to less than 6 mm)	1/32" (0.8 mm)
Paver	All	1/4" (6 mm) or greater	1/16" (1.5 mm)

Figure 7.6 – Chart depicting guidelines showing acceptable lippage for typical installations of tile (ANSI A137.01).

While narrow grout joints may be desirable and expected, joint should not be less than the minimum recommended width as shown in the chart above. Grout joints which are too narrow not only accentuate lippage within acceptable tolerances, it may also create problems in preventing the proper filling of the joint with grout, make it more difficult to keep the grout joint clean, and create potential visual problems when movement joints, within the tile or stone installation, are wider than the grout joints are required.

Further to this point, the ANSI Specifications for the Installation of Ceramic Tile states;
"To accommodate the range in facial dimensions of the tile supplied for a specific project, the actual grout joint size may, of necessity, vary from the grout joint size specified. The actual grout joint size shall be at least 3 times the actual range of facial dimensions of the tile supplied. For example, tile having a total variation of 1/16" in facial dimensions, a minimum 3/16" (4.5 mm) grout joint shall be used. Nominal centerline of all joints shall be straight and of even width, with due allowances for hand molded or rustic tiles. In no circumstance shall the grout joint be less than 1/16" (1.5 mm)."

Warpage: Warpage of tile is natural and is calculated as a percentage of the length of the edge or diagonal being tested. The tolerance range for warpage of tile varies based on size and type of tile, as well as whether the tile is natural, calibrated or rectified. Natural tile (referring to pressed floor tile only) is defined as tiles that are not sized or sorted mechanically. Calibrated tile is defined as tiles that have been sorted to meet a manufacturer's stated caliber range. Rectified tile is defined as tiles that have had all edges mechanically finished to achieve more precise facial dimensions. The following chart shows allowable warpage for several types of tile;

Tile Type	Warpage Edge Minimum	Warpage Edge Maximum	Warpage Diagonal Minimum	Warpage Diagonal Maximum
Mosaic	-1.00%	1.00%	-0.75%	0.75%
Quarry	-1.50% or -0.18" (-4.6 mm)#	1.50% or 0.18" (4.6 mm)#	-1.00% or -0.17" (-4.3 mm)#	1.00% or 0.17" (4.3 mm)#
Glazed Wall Tile (Calibrated)	-0.30% or -0.04" (-1.0 mm)#	0.30% or 0.05" (1.0 mm)#	-0.30% or -0.05" (-1.3 mm)#	0.30% or 0.07" (1.8 mm)#
Glazed Wall Tile (Rectified)	-0.30% or -0.04" (-1.0 mm)#	0.40% or 0.05" (1.3 mm)#	-0.30% or -0.05" (-1.3 mm)#	0.40% or 0.07" (1.8 mm)#
Pressed Floor Tile (Natural)	-1.00% or -0.12" (-3.1 mm)#	1.00% or 0.12" (3.1 mm)#	-0.75% or -0.13" (-3.3 mm)#	0.75% or 0.13" (3.3 mm)#
Pressed Floor Tile (Calibrated)	-0.75% or -0.08" (-1.3 mm)#	0.75% or 0.08" (1.3 mm)#	-0.50% or -0.08" (-2.0 mm)#	0.50% or 0.08" (2.0 mm)#
Pressed Floor Tile (Rectified)	-0.40% or -0.05” (-1.3 mm)#	0.40% or 0.05" (1.3 mm)#	-0.40% or -0.07" (-1.8 mm)#	0.40% or 0.07" (1.8 mm)#
Porcelain Tile (Calibrated)	-0.75% or -0.09" (-2.3 mm)#	0.75% or 0.09" (2.3 mm)#	-0.50% or 0.08" (-1.8 mm)#	0.50% or 0.08" (2.0 mm)#
Porcelain Tile (Rectified) smaller than 24" x 24" (600 mm x 600 mm)	-0.40% or -0.05" (-1.3 mm)#	0.40% or 0.05" (1.3 mm)#	-0.40% or -0.07" (-1.8 mm)#	0.40% or 0.07" (1.8 mm)#
Porcelain Tile (Rectified) larger than 24" x 24" (600 mm x 600 mm)	-0.40% or -0.05" (-1.8 mm)#	0.40% or 0.05" (1.8 mm)#	-0.40% or -0.07" (-1.8 mm)#	0.40% or 0.07" (1.8 mm)#

Whichever is less. For more information on the above chart please refer to ANSI A137.1-2008.

Figure 7.7 – Allowable warpage by tile type.

The test method used to determine warpage of tile is ASTM C485 “Standard Test Method for Measuring Warpage of Ceramic Tile” and is calculated by dividing the measured amount the tile deviates from flatness by the length of the edge or diagonal. In the rare instance where tile has a high percentage of warpage, the tile should not be considered commercially viable for floor installations. It should be known that all tiles are warped to some degree because shrinkage of tile is an inherent characteristic during the firing process. How a tile shrinks is dependent upon many factors and no two tiles are exactly alike, so tile cannot all shrink exactly the same.

Edge Treatment: The finished edge of the tile may also play a role in the final appearance of a floor in regards to lippage. Tile finished with a square edge is more likely to accentuate lippage as compared to a chamfered edge tile.

Moisture Sensitive Stone: There are some stone products (e.g. green marble, certain agglomerates, and others) which are dimensionally unstable when exposed to moisture. Exposure to moisture on one side of the stone, before or during installation, can cause the stone to curl at the edges and corners causing lippage problems. The use of LATAPOXY® 300 Adhesive is required for installation of moisture sensitive stone products.

Reflective (Polished) Surfaces: Installations with highly polished tile or stone modules may appear to have unacceptable lippage when their reflective surfaces make any unevenness visible. Any variation in the substrate, amount of setting material or warpage in the module, even within allowable tolerances will be visible in the finished installation. The use of a self-leveling underlayment (e.g. NXT® Level) or installation using the wet set method may help prevent some of the factors which can create lippage.

Lighting: Certain lighting conditions can emphasize acceptable lippage tolerances and make them appear significantly worse. As stated in the TCNA Handbook for Ceramic Tile Installation "Use of wall-washer and cove-type lighting, where the lights are located either at the wall/ceiling interface, or mounted directly on the wall, are popular techniques of producing dramatic room lighting effects. When proper backing surfaces, installation materials and methods, and location of light fixtures are not carefully coordinated, these lighting techniques may produce shadows and undesirable effects within the tile or stone. Similar shadows are created from side lighting interior walls and floors when light shines at angles through windows and doors." Lighting is an often overlooked factor when lippage issues are noticed. Please refer to NTCA "Lighting and Tile Installations" for more information.

Layout: Choosing the right pattern layout for tile or stone is important in regards to lippage. For instance, setting large, rectangular tile in a brick pattern (running bond) can be challenging. Extra attention must be given to subsurface preparation in trying to reconcile 6 junction points for each tile.

Overwhelmingly, the majority of lippage is caused by an uneven substrate or the improper application of adhesive mortar while trying to compensate for irregularities in the substrate. Generally, it is well worth the time and expense to flatten the floor first with a self-leveling underlayment (e.g. NXT Level), or, a properly screeded mortar bed (e.g. 3701 Fortified Mortar Bed).

There are a few methods to help prevent or minimize lippage issues during installation;

1. Uneven substrate surface – Make sure that the subfloor is within acceptable tolerances based on the tile size and layout pattern. Where applicable, check the floor preparation section of the specification and make sure the architect or designer is aware of any concerns. Use NXT Level or, 3701 Fortified Mortar Bed to make sure the substrate is flat enough to accept a large format tile or stone installation.
2. Insufficient or uneven thin-set / medium bed mortar coverage – Follow the National Tile Contractor's Association (NTCA) guideline E-29 "Bonding Large Size Tile for Coverage, Support and Reduced Lippage". The use of proper setting methods will help to ensure even mortar application and reduce setting material causes of lippage.
3. Varied tile thickness – Examine tile thickness or obtain a Master Grade Certificate from the tile manufacturer stating that they meet industry standards. Tiles which are of uneven thickness can be wet set into a mortar bed of 3701 Fortified Mortar Bed using a bond coat of 257 TITANIUM™, or a LHT mortar (e.g. MULTIMAX™ Lite) can be used with a larger sized notched trowel.
4. Warping caused by moisture sensitive stone – The only tried and true method to avoid this problem is to use a 100% solids epoxy setting material. LATAPOXY 300 Adhesive is ideal for installation of green marble, moisture sensitive agglomerate tile or other moisture sensitive tile or stone modules.

It is much easier to take the necessary steps to help avoid lippage before or during installation rather than after lippage has been noticed in a finished installation.

Adhesive Mortar Coverage

Complete bedding of large format tile or stone with the appropriate adhesive mortar is another area that requires attention. Lack of adhesive mortar coverage can lead to cracked tile and grout, and/or loss of bond to the tile or stone. Use the appropriate sized notch trowels (see figure 7.5 for trowelling technique) and tap or twist the tiles in place to properly bed the tile or stone. Large format tiles can be back buttered with additional thin set mortar to ensure that the appropriate coverage is achieved. In addition, the use of a medium bed mortar may be the more appropriate adhesive mortar for large format tiles and stone.

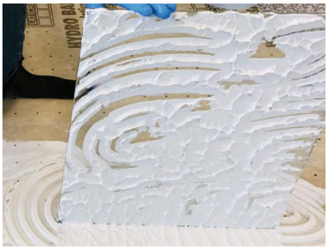


Figure 7.8 – Insufficient adhesive mortar coverage. Removal of a tile reveals many voids that are present in the hardened thin set mortar. Trowel ribbons are inconsistent which will also lead to poor coverage and mortar transfer to the backs of the large format tile/stone.

Figure 7.9 – Ceramic tile removed during the installation to verify proper coverage is being attained. Notice the lower right hand corner of the tile is lacking coverage. This could well lead to a cracked tile.

Size of the tile or stone will also determine exactly what tools are required to properly bed the tile. The simple logic is that the larger the tile, the larger the notch trowel size must be. A 1/4" x 1/4" (6 mm x 6 mm) square notch trowel might be fine for a 4 1/4" x 4 1/4" (100 mm x 100 mm) tile; but, it will not be suitable for installation of 20" x 20" (500 mm x 500 mm) tile. Tiles should be pulled up after they are installed (while the adhesive mortar is still fresh) to ensure that the desired coverage is achieved and that the surface of the tile/stone installation is flat and true. Industry standards require that a minimum coverage of 95% be attained for any dry or wet areas. General guidelines for trowel/tile size are depicted in figure 7.10.

3.16" x 5/32" (5 mm x 4 mm) v-notch	Mosaics to 4-1/4" x 4-1/4" (108 mm x 108 mm) wall tile	No back-buttering (required)
1/4" x 1/4" (6 mm x 6 mm) square notch	4" – 6" (10 mm – 150 mm) floor or wall tile	No back-buttering (required)
1/4" x 3/8" (6 mm x 9 mm) square notch	6" x 12" (150 mm x 300 mm) floor or wall tile	Back-butter 8" x 8" (200 mm x 200 mm tile or larger*
1/2" x 1/2" (12 mm x 12 mm) square or round notch	13" – 20" (300 mm – 500 mm) floor or wall tile	Back-butter*
3/4" x 3/4" (18 mm x 18 mm) round notch	20" (500 mm x 500 mm) or larger floor or wall tile	Back-butter*

Figure 7.10 – The chart above is intended as a guideline only and results should be checked during installation to make sure that proper coverage is achieved.

Choosing the best adhesive for the job is also important to assure a long-lasting installation. Some options are 257 TITANIUM™, MULTIMAX™ Lite (for non-sag installations on walls or medium bed mortar on floors), or for installations that require sound control and /or crack isolation, use 125 TRI MAX™. The practice of back-buttering is recommended for any tile that is larger than 8" x 8" (200 mm x 200 mm) to help achieve maximum coverage/bedding.

Curing / Protection

Another issue that must be dealt with when using large format tile and stone in mass transit applications is the issue of curing and protection. Larger tile and stones will require a longer cure time due to the fact that the mortar simply cannot cure quickly; especially under dense porcelain bodied tile. Most adhesive manufacturers will have varying suggestions on when an installation can be opened to other trades and traffic (including hand trucks, carts, scissor lifts, and other heavy machinery or vehicles). While there is no empirical data/formula that specifically address the cure rate in relation to the facial dimensions of tile, some manufacturers have had good experience in maintaining a minimum 3 day cure at 70°F (21°C) prior to exposing areas to heavy foot traffic or vehicular traffic. The floors should be covered/protected with a protection board if it is to be exposed to heavy traffic. It is important to note that even rapid setting latex fortified portland cement thin set mortars must be allowed to cure for a minimum of 3 days at 70°F (21°C). Although rapid setting mortars allow grouting and light foot traffic on newly tiled floors, heavy traffic and work can still damage the installation. In addition, allow for a longer cure period when temperatures are below 70°F (21°C), when relative humidity levels exceed 60%, or when large format porcelain bodied tiles are utilized.

The ceramic tile industry currently provides the following language in this regard: “After completion and cleaning, the obligation of the tile contractor ceases as to damage or injury which may be done to the tile work by others.” – ANSI A108.01 – Section 3.8 “To avoid damage to finished tile work, schedule floor installations to begin only after all structural work, building enclosure, and overhead finishing work, such as ceilings, painting, mechanical and electrical work, are completed. Keep all traffic off finished tile floor floors until they have fully cured. Builder shall provide up to 3/4" (19 mm) thick plywood or OSB protection over non-staining kraft paper to protect floors after installation materials have cured. Covering the floor with polyethylene or plywood which is in direct contact with the floor may adversely affect the curing process of grout and latex/ polymer modified portland cement mortar." – TCNA Handbook Language 2019 "Protecting New Tile Work".

Thick Bed Method (Floors)

Also known as the "wet-set" or "float and back-butter" method of installation, this method encompasses several different techniques. The most common thick bed technique is the "float and back butter" method. This method starts with the floating or screeding of the substrate with cement leveling mortar. The mortar bed can either be of the unbonded type or the bonded type. (See Section 10 for detailing of both methods).

Bonded Type

In the bonded type, a slurry bond coat consisting of 257 TITANIUM™ or, 254 Platinum is brush applied to the concrete substrate. While the slurry bond coat remains wet and workable, the mortar bed is placed, compacted and then screeded, leveled, and pitched as required.

Unbonded Type

In the unbonded type, a cleavage membrane is loose laid over the substrate. The cleavage membrane can take the form of 15 lb builders felt, 6 mil thick polyethylene sheeting, a waterproofing membrane, or any material which complies with ANSI A108.02 3.8. Half of the mortar bed thickness is placed over the cleavage membrane and lightly compacted. Next, 2" x 2" (50 mm x 50 mm) galvanized, welded wire mesh, or other mesh which complies with ANSI A108.02 3.7, is immediately placed as close to the top of the freshly placed mortar bed as possible. The wire mesh will allow the mortar bed to achieve maximum tensile strength resistance. The rest of the mortar bed is placed directly on top of the wire mesh and fresh mortar bed and then compacted, screeded, leveled, and pitched as required.

Figure 7.11 – Example of a non-bonded, wire reinforced mortar bed. Wire mesh is placed in the middle of the mortar bed and lapped together to ensure continuity. Notice that the mortar below the wire mesh has been compacted, thus ensuring that the entire mortar bed is compacted properly.

Once the mortar bed has been compacted, screeded, leveled, and pitched, the mortar bed can either be allowed to cure prior to installation of the tile or stone per ANSI A108.1B, or, the tiles or stone pavers can be installed into the fresh mortar bed (wet-set) per ANSI A 108.1A.

If a waterproofing or anti-fracture membrane is required, the mortar bed should be allowed to harden for at least 72 hours at 70°F (21° C), or as directed by the membrane's product data sheet or installation instructions. Cooler temperatures require longer cure time prior to installation of the waterproofing or crack isolation membrane.

Figure 7.12 – Example of wet-setting pavers using 254 Platinum Slurry and 3701 Fortified Mortar Bed

If the option to bond the tiles to the fresh mortar bed is desired, a bond coat is required on top of the fresh mortar bed. A trowel applied slurry bond coat consisting of 254 Platinum or 257 TITANIUM is preferred over the conventional dusting with dry portland cement and wetting with water method. The preferred method provides complete contact with the bonding slurry and reduces the chances of hollow and drummy sounding areas.

Figure 7.13 – Tile mechanic screeding a mortar bed.

The tile is then placed into the wet slurry bond coat and tapped into place and leveled with adjacent tile.

Once the tile or stone is installed, they can be grouted while the installation is fresh with conventional portland cement grouts or allowed to cure to receive the higher performing and recommended epoxy grouts (e.g. SPECTRALOCK® PRO Premium Grout†).

Wall Renders/Plasters

This method starts with the floating or rendering of the wall substrate with cement leveling plaster or mortar. Wall renders can be directly applied to properly prepared, suitable masonry or concrete surface or over substrates with properly fastened cleavage membrane (compliant with ANSI A108.02 3.8) and galvanized metal lath (compliant with ANSI A 108.02 3.6).

Figure 7.14 – Tile mechanic applying latex fortified cement based scratch coat to a block wall with a hawk and trowel.

Wall renders do not require the use of a bond coat beneath them as the mortar is mixed to a more plastic mix containing a higher liquid to mortar powder ratio. This consistency allows the cement paste to "wet out" the concrete/masonry substrate in a sufficient manner to achieve proper bond. Wall renders are generally applied in several lifts with each lift installed to a maximum 1/2" (13 mm) in thickness. The first lift is the scratch coat which is applied to the wall and is immediately scratched up with a small metal comb-like tool or trowel. The "scratching" roughens up the layer in order that the subsequent layer will achieve better mechanical bond. The scratch coat is allowed to harden and then the subsequent "brown" coat(s) are applied in the same 1/2" (13 mm) maximum lifts. If three or more lifts are required, the previous brown coat should be scratched up before it hardens. 3701 Fortified Mortar Bed; and, 226 Thick Bed Mortar gauged with 3701 Mortar Admix are pre-packaged thick bed / wall rendering mortars which will hold up to the rigors of demanding mass transit applications. The use of pre-packaged mortars eliminates inconsistencies in job site powder proportioning and raw material quality.

The rendering mortar can be hand applied by trowel or pumped and sprayed into place. Lath strips are placed into the mortars to establish the correct render depth (see figure 7.15).

Figure 7.15 – Latex fortified render is being applied to wall surface. Notice the lath strips that are set into the mortar. The lath strips are leveled and plumbed to establish the correct wall render depth. Once the render achieves a sufficient cure, the lath strips are carefully removed and the cavities are filled with mortar.

At this point, several installation options are available:

Float and Cover Method (One-Step)

While the second coat remains wet and workable, a layer of adhesive is applied to the bonding surface of the cladding (referred to as "back-buttering"), and the cladding is then fixed and beat in to proper contact and made level with adjacent cladding. The "one-step" or "buttering" technique involves thick layers of adhesive mortar (bedded thickness of 3/4" – 1-1/2" [19 – 38 mm]) which is applied over the entire surface of the cladding and the substrate with a flat, rather than a notched trowel. This method, can be used to correct plumb/level deviations, and adhere the cladding material in one procedure. As with the spot bonding method (see below), advance layout of plumb and level are critical and must be very accurate, because adjustments can be difficult to make. While using the thick bed method requires more skill, there can be a 30–50% cost saving over multiple applications of leveling mortars.

Butterball Method (One-Step)

Another variation of the buttering technique involves application of a large "butterball" of mortar to the back of the cladding, and the fixing and bedding the cladding into place. This technique requires significant attention to bedding of the cladding so that the mortar contacts and spreads over the entire surface of the cladding. This technique often results in an application which more closely resembles the spot bonding or dab method (see below) where such a method may not be suitable.

Traditional Method

Lastly, the scratch and brown coat layers can also be allowed to harden in the traditional manner. Then a waterproofing membrane (e.g. 9235 Waterproofing Membrane or HYDRO BAN®) can be applied to the hardened render. Alternatively, the tile or stone can be directly applied to a hardened render coat as well (see Section 10 for detailing of these wall render methods).

Epoxy Spot Bonding Method (Walls)

Also known as the "dab" method of installation, this method is where an epoxy adhesive (e.g. LATAPOXY® 310 Stone Adhesive) provides only partial coverage of the cladding and substrate bonding surface. The thickness and area of coverage are dependent primarily on the strength and working characteristics of the adhesive. The spot bonding method is highly specialized and restricted to certain types of adhesives, cladding materials and construction situations. In some respects, this method is similar to mechanical attachment of stone to facades. The wall must be plumb and level, for once the installation begins it is extremely difficult to make necessary adjustments. The misapplication of the spot bonding method can have serious consequences unless the architect and contractor acknowledge several important principles:

- Spot bonding is only suitable when using epoxy adhesives which have very high bonding strength and flexibility, and are manufactured specifically for the spot bond method. Some of these new technology epoxies and structural silicones may require supplemental mechanical anchoring
- Spot bonding should not be used in wet climates with cladding materials which are highly absorptive or which are moisture sensitive
- Spot bonding is not suitable for thin cladding materials which do not have the cohesive (tensile) or shear strength to resist the high stress concentrations inherent in localized attachment
- Back-up wall construction must make provisions for waterproofing and flashing the cavity between the substrate and the cladding surface
- Spot bonding may not be suitable for extreme climates or conditions

NOTE: Building regulations may only allow spot bonding as a supplement to mechanical anchoring and / or to interior applications only to reduce the size and complexity of mechanical anchor design. The use of spot bond adhesives may be restricted in height, tile or stone weight, and tile or stone facial dimensions without mechanical anchors; consult governing building codes or regulations for more information.

Figure 7.16 – Stone is prepared for installation by the epoxy spot bond method. Stone back is roughened at the adhesive connection points then washed and allowed to dry.

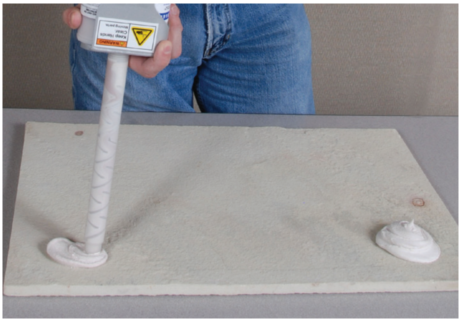


Figure 7.17 – Epoxy spot bond (e.g. LATAPOXY® 310 Stone Adhesive) adhesive is applied to the back of the stones with an automated epoxy mixer / applicator. A minimum of 10% adhesive coverage is generally required. The LATAPOXY 310 Stone Adhesive is available in standard grade (maximum working time of 45 minutes) or rapid grade (maximum working time of approximately 5 minutes).

Figure 7.18 – Stones are then placed, leveled and plumbed to the required finish.

Self-Leveling Mortars

In order to achieve the desired height where concrete slabs may be recessed, portland cement based self-leveling underlayment can be used. These products are highly polymerized and can be poured from feather edge up to 3" (76 mm) thick depending on the product formulation used. These products are installed very quickly and can be mixed and pumped into place. It is important to specify a product that can withstand the usage and exposure to the environment in which it will be subjected. Many traditional residential or light commercial grade self-leveling underlayments are not suitable for use in heavy duty mass transit applications. Consult with the self-leveling underlayment manufacturer for specific product recommendations. In all cases, a suitable primer must be used prior to the application of the self-leveling underlayment. The primer is designed to increase adhesion to the substrate. Once in place, strict adherence to cure times must be observed prior to the installation of membranes, epoxy adhesives and epoxy grouts. Please check with the membrane, adhesive or grout manufacturer for required moisture levels or underlayment cure times prior to installation.

Figure 7.19 – Application of self leveling underlayment over a primed concrete substrate.

7.4 TYPES OF GROUT AND JOINT FILLERS

Materials for Joint Grouting and Sealing

- Polymer Fortified Cement Grout
- Latex Cement Grout
- Modified Epoxy Emulsion Grout
- Epoxy Grout
- Furan Grouts
- Epoxy Grout (Industrial Frade)
- Silicone or Urethane Sealant

It is important to note that in many cases, renovations to existing tile floors are conducted in mass transit applications, solely to the grout joints. Therefore, replacement of tile and/or grout joints must often take place in areas where normal operations are being conducted. In applications where there is a high volume of traffic (vehicular or foot), and where cordoning off areas would impede this traffic for extended periods of time, it is critical that the grout, installation products and installation methods are suitable for the application. The use of rapid setting grouts and adhesives will limit the amount of time that an area must be restricted to traffic. The use of a suitable protection board can also allow grout to cure while bearing the weight of traffic. The health and safety of people who are in the vicinity of tile or stone repairs is also of the utmost concern, so the adhesives, grouts or other installation materials should be independently certified (e.g. GREENGUARD) low in volatile organic compounds (VOC). LATICRETE® Grouts contain no known carcinogens, mutagens and tetragens classified as hazardous substances, heavy metals or other toxic materials. LATICRETE offers a complete line of tile and stone installation materials which are certified by GREENGUARD as low VOC. For more information on low VOC LATICRETE products, and GREENGUARD certificates, please visit www.laticrete.com.

Polymer Fortified Cement Grout

Redispersible powder polymer fortified cement grouts mixed with water typically compensate for the reduced workability and premature evaporation of moisture inherent in conventional cement-sand-water grouts. Similar to some polymer fortified cement based adhesives, some proprietary grout formulations are not recommended for use in wet areas due to the polymer sensitivity to prolonged water exposure. These types of grout materials do not typically offer any chemical resistance characteristics. Products in the polymer fortified cement grout category range in performance capabilities and can be used in grout joint widths up to a 1/2" (12 mm). The better products offer greater color consistency, a measure of stain resistance, lower potential occurrence of efflorescence and increased compressive strength. The upper tier polymer fortified cement grouts are a suitable option for mass transit applications where epoxy based grouts are not used. An example of an upper tier polymer fortified cement grout is PERMACOLOR® Select^ Grout.

Figure 7.20 – Effects of inappropriate grout used on a demanding application. Notice not only the erosion of the grout joints, but also the adhesive mortar under the tile. In many floor applications, the use of an epoxy based adhesive and grout are required in order to ensure long-term performance.

Liquid Latex Fortified Cement Grout

Similar to the liquid latex fortified cement adhesive mortar category, latex fortified cement grout is a combination of either a proprietary pre-mixed sand, cement and pigment powder, or site mixed sand and cement powder with a ratio of approximately 1:2 by volume for joint widths to 1/2" (12 mm), gauged with a liquid latex or acrylic polymer additive. As with polymer fortified grouts, the liquid latex or acrylic additive must be formulated for wet areas. An example of this product type is 1500 Sanded Grout mixed with 1776 Grout Enhancer. These products also have very limited chemical resistance and are generally only used where no exposure to harsh chemicals will occur.

Modified Epoxy Emulsion

ANSI A118.8 compliant grouts essentially include emulsified epoxy resins and hardeners, pre-blended portland cement, and silica sand. Modified epoxy emulsions typically can be used as a tile setting mortar or grout. Note that not all manufacturers recommend this material be used for grouting. An example of a modified epoxy emulsion is LATAPOXY® 210 Adhesive.

Epoxy Grout

ANSI A118.3 compliant grouts are chemical resistant, water cleanable tile-setting and grouting epoxies. An epoxy composition, essentially a 100% solid system that is supplied in two or more parts to be mixed immediately before use as a setting adhesive or joint filling grout for ceramic tile, and that is partially emulsified by water, after mixing, in order to expedite cleaning from tile surfaces during application before the epoxy hardens. SPECTRALOCK® PRO Premium Grout† is an ANSI A118.3 compliant product. They offer both lower water absorption rates and improved chemical resistance when compared to traditional cement based grouts. This category grout type is an excellent choice for mass transit applications (e.g. airport terminal walkways, transit station walkways, bus terminals, subway and metro station platforms, restrooms, and other areas) that require easy to install, stain resistant and overall easy to maintain grouting products.

Epoxy Grout – Industrial Grade

Some epoxy grouts are specifically manufactured for high chemical and temperature resistance. SPECTRALOCK 2000 IG is a highly chemical resistant industrial grade epoxy grout for ceramic tile pavers, floor brick, packing house tile and stone. SPECTRALOCK 2000 IG is supplied as factory proportioned kits consisting of epoxy resin, hardener and chemical resistant silica filler. This product is ideal for use in environments such as mass transit terminal food service areas, fast food restaurants, cafeterias and maintenance areas. This material is water cleanable, fast curing, cures at low temperature, and meets USDA and USFDA requirements. This grout exceeds ANSI A118.3 and the much more stringent standard, ANSI A118.5 which applies to furan grouts. Ease of application, extremely high compressive strength and low water absorption rate makes this an excellent choice for use in demanding applications. There are no toxic fumes, in fact, SPECTRALOCK 2000 IG is GREENGUARD certified. This product is ideal for use in active food and beverage environments, as well as areas where harsh chemicals or high compressive strength are required.

Acceptable Epoxy Grout Appearance

Unlike portland cement based grouts, epoxy grouts will have a tendency to slump slightly in the grout joints. Due to their viscous nature, epoxy grouts may tend to flow under the tile and fill any voids in the adhesive mortar that may be present. This can be both a benefit and a problem. The benefit is that the grout can fill any voids to create a more solid base under the tile or stone. The drawback is that the grout joint can develop pinholes and voids in the finish surface, causing an uneven appearance in the grout joint. Careful attention must be given to bedding the tile properly to minimize the flow of the epoxy grout under the tile. This will help to alleviate the potential problems with sagging and pinholes.

In addition, the finished grout joint will have a slightly concave appearance. The American National Standard Institute Specifications (ANSI) for epoxy grouting of ceramic tile (ANSI A108.6 – 3.0.7) states, "Joints grouted with epoxy shall be filled to provide a contoured depression no deeper than 3/64" (1 mm) for a 1/4" (6 mm) wide joint, and 1/16" (2 mm) for a 3/8" (10 mm) wide joint. Figure 7.22 shows acceptable epoxy grout joint appearance criteria, as taken from the NTCA Reference Manual – 2nd Edition.

Figure 7.23 – Spreading of Epoxy Grout.

Silicone or Urethane Sealant

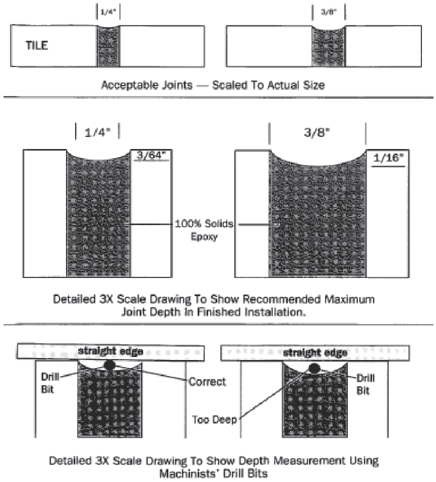
Sealants are typically used as filler only in movement joints and between dissimilar materials in an application where a high degree of adhesion and resistance to differential movement and tensile or compressive stress is required. Movement joints are intended for relief of significant stress build-up that may be transmitted over a larger area, and have the characteristics to resist much greater elongation or compression than more rigid materials like cement. These materials also adhere to dissimilar materials such as metal or wood to not only maintain a water barrier where a more rigid material may fail, but also to accommodate the significantly different thermal movement characteristics of dissimilar materials.

Horizontal mass transit installations may require a sealant with a high Durometer Hardness – Shore A to perform for long periods of time under heavy traffic loads. It is important to make sure that the specified sealant material is suitable for mass transit applications and is properly installed by a qualified professional.

Silicone and urethanes may also be used as a filler material for all joints in vertical cladding under certain conditions. In types of wall construction such as epoxy spot bonding, rigid grouts would have no support or composite action with an underlying adhesive mortar, and may crack and fail. In designs where narrow joints are unavoidable, highly flexible sealants are the recommended joint filler. See Sections 2.1 and Section 10.5 for more information on the use of flexible sealants in expansion joints.

Acceptable Joints When Grouting With 100% Solids Epoxy

This document compiled by the NTCA Technical Committee. Published by Tile Contractors Association, Inc. P.O. Box 13629, Jackson, MS 36236 USA



Epoxy grouting systems employing resin and hardener portions and silica filler are especially formulated for industrial, commercial and residential installations where impervious chemical resistant grout joints are of paramount importance. High temperature, chemical resistant formulas are also available. The grouts also provide high bond strength and impact resistance. They impart structural qualities to the tile when used both as a mortar and grout, especially over wood subfloors. Their use involves extra costs and special installation skills when compared to portland cement grouts.

While perfectly flushed epoxy grout joints are desirable, they are not obtainable using normal grouting procedures. The slightly concave epoxy grout joint, however, is superior in performance in every way when tested against other grouting materials.

The American National Standard Institute Specifications (A-3.313) states, "Joints grouted with epoxy shall be filled flush with the edges. Provide a contoured depression no deeper than 3/64" (1 mm) for 1/4" (6 mm) wide joint, and 1/16" (2 mm) for a 3/8" (10 mm) wide joint."

To measure a 100% solids epoxy grout joint, place a drill bit in the grout joint (a 3/64" bit for a 1/4" joint – a 1/16 bit for a 3/8" joint) and place a straight edge across the bit. If it touches or rocks on the respective drill bit, it meets or exceeds the ANSI specifications.

Figure 7.22 – Acceptable Epoxy Grout Joint Appearance. (NTCA Reference Manual – 2nd Edition)

LATAPOXY® 300 Adhesive Chemical Resistance Chart

Reagent Type at (70°F [21°C])	LATAPOXY® 300 Adhesive	
	Intermittent	Constant
Citric Acid 10%	R	R
Sulfuric Acid 10%	R	R
Hydrochloric Acid 10%	R	R
Lactic Acid 5%	R	R
Vinegar	R	NR
Acetic Acid 10%	R	NR
Nitric Acid 10%	R	R
Sodium Hydroxide 10%	R	R
Sodium Chloride 10%	R	R
Concentrated Detergents	R	R
Ammonium Hydroxide	R	R
Sugars	R	R
Gasoline	R	R
Cooking Oils	R	R
Turpentine	R	R
Mineral Spirits	R	R
Toluene	NR	NR
Xylene	NR	NR

R = Recommended   NR = Not Recommended

NOTE: LATAPOXY® 300 Adhesive
Heat Resistance: Intermittent – 250°F (120°C)
Continuous – 150°F (65°C)

NOTE: SPECTRALOCK® 2000 IG
Heat Resistance: Intermittent – 360°F (180°C)
Continuous – 185°F (80°C)

SPECTRALOCK® 2000 IG Grout Chemical Resistance Chart

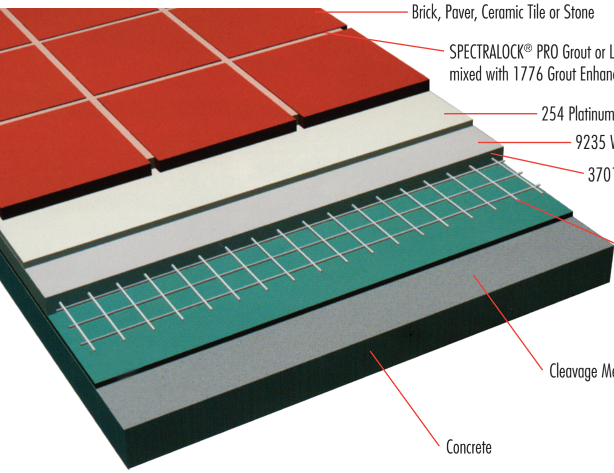
Reagent Type at (70°F [21°C])	SPECTRALOCK® 2000 IG		
	Intermittent	Constant	Splash Exposure
FOOD ACIDS			
Lactic to 10%	R	R	R
Acetic to 10%	R	R	R
Formic to 5%	R	R	R
Citric to 50%	R	R	R
Tartaric to50%	R	R	R
Tannic to 50%	R	R	R
Oleic to 100%	R	R	R
Phosphoric to 80%	R	R	R
MINERAL ACIDS			
Hydroflouric Acid[2] 10%	R	R	R
Sulfuric to 50%[2]	R	R	R
Nitric to 30%[2]	R	R	R
Hydrochloric to[2] 36.5%	R	R	R
CORROSIVE CLEANERS			
Sodium Hypochlorite[2] (Bleach) 3%	R	R	R
Sodium Hydroxide (Saturated)	R	R	R
SOLVENTS			
Xylene	R	R	R
Ethyl Alcohol	R	R	R
Mineral Spirits	R	R	R
Toluene	R	R	R
Methylene Chloride	NR	NR	NR
Gasoline	R	R	R

R = Recommended   NR = Not Recommended

Splash	Intermittent	Continuous
Minor spill wiped up quickly, such as in a laboratory	Exposure where clean-up takes place several times a day, as in a commercial kitchen. Use the "continuous" exposure recommendations for intermittent exposure to reagents at temperatures above 90°F (32°C).	Hazy exposure where clean-up is less frequent, such as in an industrial food plant.

Fig 7.21 – Chemical Resistance Charts for LATAPOXY 300 Adhesive and SPECTRALOCK 2000 IG.

7.5 TYPICAL RENDERS AND DETAILS FOR MASS TRANSIT APPLICATIONS



HYDRO BAN®

HYDRO BAN® is a thin, load bearing waterproofing/crack isolationmembrane that DOES NOT require the use of fabric in the field, coves or corners. HYRO BAN is a single component self-curing liquidrubber polymer that forms a flexible, seamless waterproofing membrane. HYDRO BAN bonds directly to a wide variety of substrates.

Used as an anti-fracture membrane, HYDRO BAN eliminates crack transmission of hairline shrinkage cracks in concrete slabs up through ceramic tile, terrazzo and stone floors installed with thin-set materials. Use to cover joints in plywood underlayments and cement backer boards or anywhere non structural cracks may occur.

Blue 92 Anti-Fracture Membrane can also be used when only the anti-fracture function is required.

HYDRO BAN adds no appreciable thickness to floor construction. Cold applied with a roller or brush, it is non-flammable and has no odor. "Extra Heavy" service rating per ASTM C627 (TCNA) and has IAPMO (UPC) approval as a shower pan liner.

NXT® Level

A cement-based underlayment for use in leveling interior substrates. NXT® Level produces a flat, smooth and hard surface for the installation of finished flooring. NXT Level can be placed from 1/8–3" (3–76 mm) in a single lift.

Mixed with water, NXT Level becomes a fluid material which produces a smooth, even surface with excellent durability. Ready for foot traffic in 4 hours, it can be covered with ceramic tile, vinyl tile, carpet, linoleum, wood parquet and traffic-bearing epoxy coatings.

3701 Fortified Mortar Bed

3701 Fortified Mortar is a polymer fortified blend of carefully selected polymers, portland cement and graded aggregates. 3701 Fortified Mortar does not require the use of latex admix, you only need to add water to produce thick bed mortar with exceptional strength. 3701 Fortified Mortar Bed can be used to repair, resurface and level walls and level, repair and slope to drains on floors.

LATAPOXY® 300 Adhesive

For installing green and other moisture sensitive marble and agglomerate tiles, LATAPOXY® 300 Adhesive is specially formulated to install quarry tiles, pavers, acid proof tiles and ceramic tiles. LATAPOXY 300 Adhesive is used in areas where cleaning agents would deteriorate normal installation materials. "Extra Heavy" service rating per ASTM C627 (TCNA) for commercial applications where the need for chemical and physical shock resistance is mandatory. Non-flammable, solvent-free and easily cleaned with cold water while fresh, LATAPOXY 300 Adhesive is designed for interior and exterior use in wet or dry areas.

Figure 7.24 – LATICRETE International, Inc. Unbonded Thick Bed System.

MULTIMAX™ Lite

MULTIMAX™ Lite is a patented, lightweight versatile polymer modified thin-set that provides maximum non-sag performance on walls. It allows for maximum buildup of up to 3/4" (19 mm) without shrinkage for floors and maximum coverage due to its lightweight creamy smooth consistency. In addition, MULTIMAX Lite is reinforced with fibers to provide maximum strength and durability. GreenGuard certified and now contains > 10% post-consumer recycled content.

MULTIMAX Lite can be applied over concrete, brick, block, masonry, gypsum wallboard, HYDRO BAN Board and cement backer board.

This product can also used as a high strength slurry bond coat.

257 TITANIUM™

257 TITANIUM™ is the ultimate, lightweight one-step polymer fortified, thinset mortar that provides unsurpassed strength, far exceeding all ANSI requirements. This exceptional bond strength is backed by the LATICRETE Warranty Systems*. No need to worry about tile and stone failure, even in the most difficult projects. 257 TITANIUM is ideal for interior and exterior applications on all suitable substrates, especially pools and fountains. In addition, 257 TITANIUM provides exceptional bond strength and easy workability making this multipurpose mortar ideal for difficult to bond porcelain tiles.

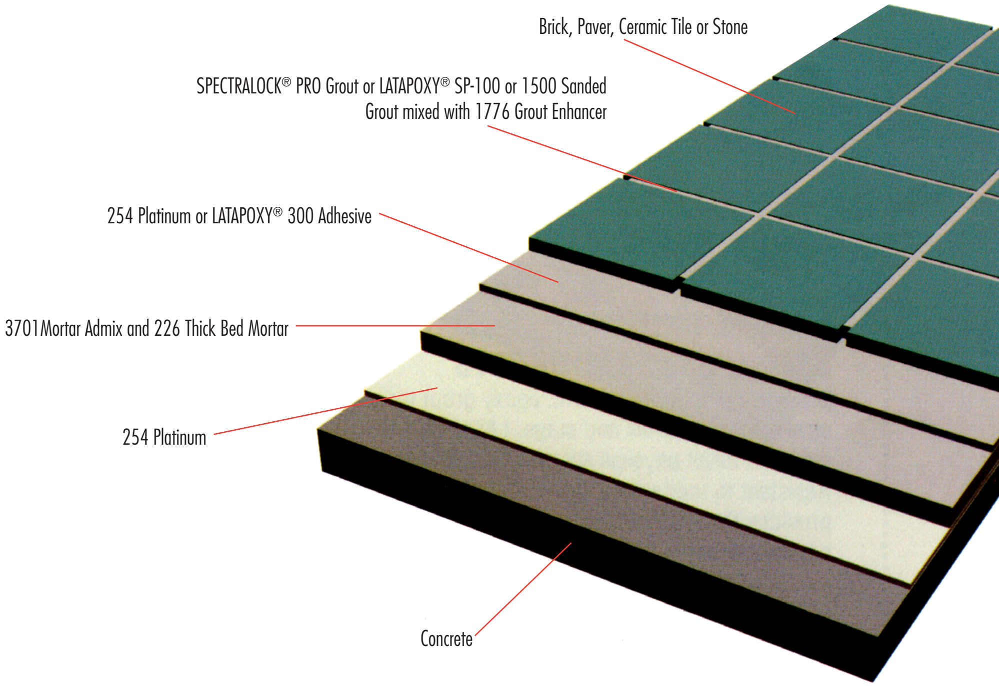
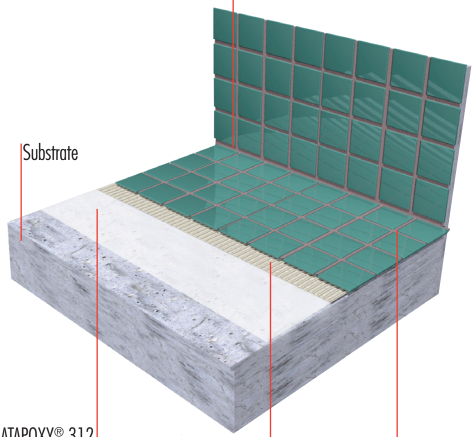


Figure 7.25 – LATICRETE International, Inc. Bonded Thick Bed System.

NXT® Vapor Reduction Coating

NXT Vapor Reduction Coating is a high performance roller applied epoxy membrane specifically designed to reduce the vapor transmission from the concrete slabs through to a finished floor surface to below 3 lbs per 1000 ft^2 (1.4 kg per 92.9 m^2) in 24 hours.

Backed by the LATICRETE® 25 Year System Warranty* and GREENGUARD certified for low VOCs, NXT Vapor Reduction Coating is compatible with a variety of LATICRETE adhesives, membranes and self-leveling mortars to assist in your flooring installation, whether it is ceramic tile, stone, vinyl, resinous coating, or other.



*See Data Sheet 025.0 for complete warranty information.

Figure 7.26 – LATICRETE International, Inc. – Vapor Reduction Membrane System – Utilized when a high moisture vapor emission rate condition exists on a project.

Commercial and Industrial Floors

LATICRETE offers a proven installation solution for both commercial floors in malls, restaurants or airports, and industrial floors such as dairies, breweries, and other high demand applications.

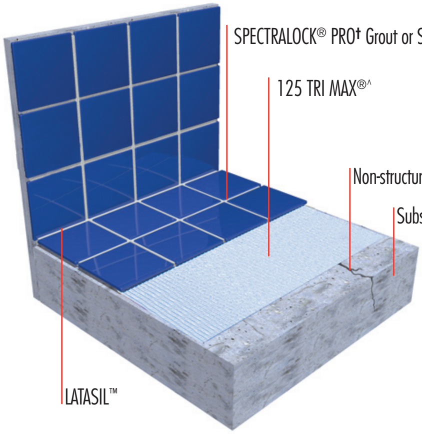
When non-structural shrinkage cracks area problem in the substrate, 125 TRI MAX® will help prevent transmission to the tile or stone finish as it meets the stringent ANSI A118.12 anti-fracture standard and has an "Extra Heavy" service rating per ASTM C627. 125 TRI MAX contains 36% post consumer recycled content contributing to LEED projects. If waterproofing protection is required in addition to anti-fracture performance, HYDRO BAN® is IAPMO and ICC approved for wet area installations providing you the highest possible protection and performance – all backed by a 25 Year System Warranty*.

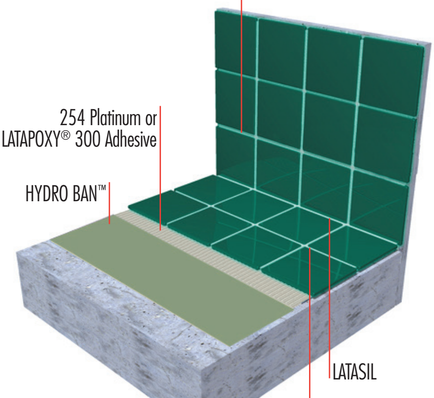
Next, adhering the tile or stone to the substrate or membrane is dependent upon the type of installation. For commercial floors, 257 TITANIUM™ offers maximum adhesion strength and meets ANSI A118.4 requirements, plus it is GREENGUARD certified. Suitable for porcelain, glass, stone or ceramic tile, 257 TITANIUM is part of our 25 Year System Warranty.

For industrial floors such as dairies or breweries where chemical resistance is critical, LATAPOXY® 300 Adhesive is recommended. LATAPOXY 300 Adhesive is a 100% solids high-strength epoxy adhesive, has an "Extra Heavy" service rating per ASTM C627, and exceeds ANSI A118.3 requirements.

For the grouting portion of the installation, LATICRETE offers high performing grouts for industrial or commercial applications. SPECTRALOCK® 2000 IG is a 100% solids epoxy grout required for industrial and commercial food processing applications. LATAPOXY 2000 exceeds ANSI A118.3 and ANSI A118.5 standards, is fast curing and ready for traffic in as little as 12 hours.

For commercial application grouting needs, SPECTRALOCK PRO Premium Grout† offers maximum stain resistance, color uniformity, and meets ANSI A118.3, plus it is GREENGUARD certified.





*See Data Sheet 025.0 for complete warranty information.

Figure 7.27 – LATICRETE International, Inc. – Thin Bed Installation Systems.

Masonry Veneer Installation Systems

Exterior Vertical installations of ceramic tile or stone require expertise, high performance products and a proven track record of success. Keeping up with the increasing popularity of adhered masonry veneers. Trust your installations to a complete productivity-boosting system designed to deliver superior long-term performance on masonry projects of all types including residential, commercial, and industrial application.

Exterior vertical installations of natural stone may be installed with our Veneer mortars like MVIS™ Hi-Bond Veneer Mortar or our ultimate non-sag MVIS Veneer Mortar. For those instances that requires an air or water barrier on the facade, the MVIS Air & Water Barrier can be installed. MVIS Air & Water Barrier is a liquid applied membrane that offers exceptional performance. It can be used as a stand alone air barrier when brick or stone is not being directly adhered to it or it can be used as a water barrier when stone is directly bonded to it. LATAPOXY® 310 Stone Adhesive is a high strength epoxy adhesive that is building code approved with over 15 years of global installations.

Community College of Southern Nevada, Las Vegas, NV

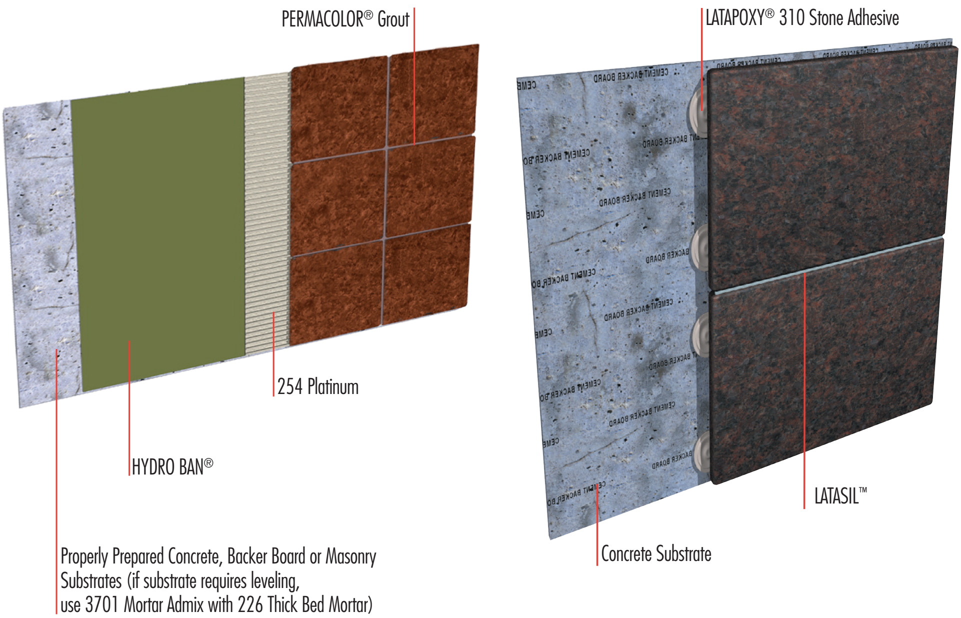


Figure 7.28 – LATICRETE International, Inc. – Vertical installations depicting direct bond and spot-bonding methods.

Plaza and Deck System

Terraces, Patios, Courtyards, and Decks

The LATICRETE Plaza and Deck System provides a thin, lightweight weather and frost resistant installation for exterior ceramic tile, pavers, brick, or stone applications. This system incorporates a waterproofing membrane and is designed for exterior use over occupied space and wood construction decks. An integral subsurface drainage component provides for elimination of infiltrated water.

The patented, lightweight LATICRETE Tile Drain Mat provides three times the drainage rate of a conventional 2" (50 mm) crushed gravel bed and reduces the potential for efflorescence. The mat is engineered to permit maximum load transfer to the structural deck while allowing lateral flow of infiltrated wter to flow easily to drains, scuppers, or gutters.

This unique system can be used over structurally sound and properly pitched substrates (concrete, pre-cast concrete planks, wood frame construction) that have been waterproofed with a primary roofing membrane. Recommended for new construction and renovation such as plazas, walkways, exposed decks, balconies, terraces, coutryards, and any exterior paving area subject to severe weather, frost, and moisture.

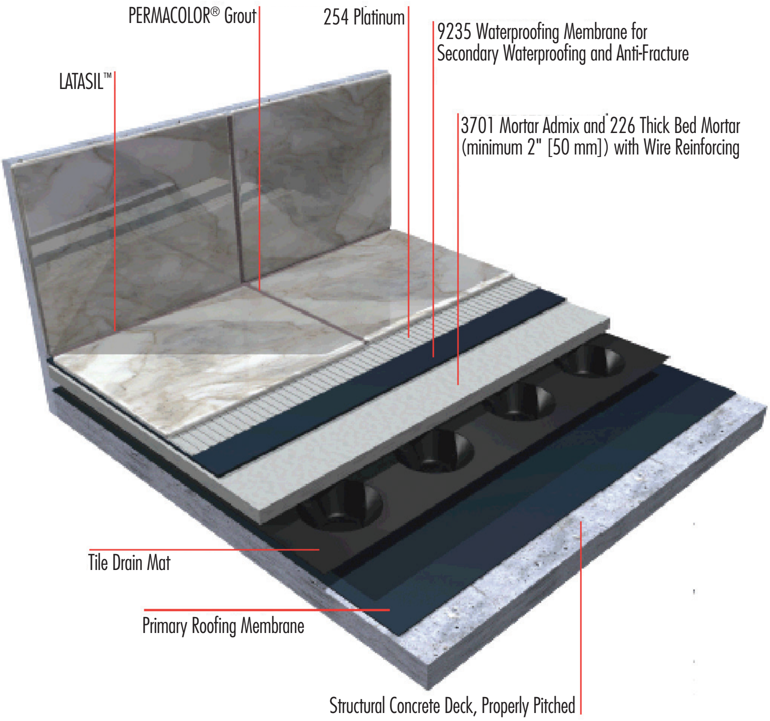


Figure 7.30 – LATICRETE International, Inc. – LATICRETE Plaza & Deck System for exterior applications over occupied space.

Expansion Joints (supplied by others)

A critical element to the functionality of the total floor system.

- Mechanical type — pre-formed stainless steel, with impact, chemical resistant, polyurethane filler
- Field applied type — pourable polyurethane. Fast curing with excellent chemical and impact resistance

Advantages

- Protects brick and tile edges from chipping (mechanical type)
- Provides for dynamic movement in the floor assembly — prevents cracking and delamination of tile

Waterproofing Membranes

Required to isolate areas above occupied space, and to prevent seepage into concrete subfloor.

- Liquid applied — safe, water-based liquid rubber applied with roller or squeegee, bonds directly to concrete subfloor

Advantages

- Safe, no flammables or solvents required for installation or clean-up
- Single source responsibility, compatible with all other components
- Breathable membrane, suitable over damp surfaces
- Thin — adds no appreciable thickness to floors or walls

Underlayments

Provide leveling and pitching capability over structural concrete slabs and masonry walls.

- Epoxy type — a three component, modified epoxy mortar for areas of extreme chemical exposure. Builds from 1/4" to 3/8" (6 mm to 10 mm)
- Latex type — portland cement-based mortar that produces a high impact-resistant bed. Builds from 1/4" to 2" (6 mm to 50 mm)
- Self-Leveling type — fluid, cement-based underlayment designed to level low areas. Builds from feather edge to 1" (25 mm)

Advantages

- Single source responsibility
- Provides all-important pitch to drains in critical cleaning and wash areas

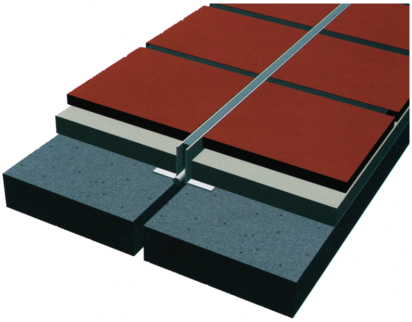


Fig 7.31 – LATICRETE International, Inc. Mass Transit Applications Systems Accessories and Components.

Section 8: Methods of Installation

Tiled train platform in Thailand

Figure 8.1 – Installation of Exterior Rated Ceramic Wall Tiles on the Ceiling of the Route 9A, New York, NY Roadway Tunnel Utilizing the Epoxy Spot Method – LATAPOXY® 310 Stone Adhesive

8.1 TRADTIONAL INSTALLATION EQUIPMENT AND PROCEDURES

The construction equipment and installation procedures required for each project in each region of the world are unique. With that said, it would not be possible to list all of the tools, equipment and procedures involved in the installation of mass transit tile applications. This section will present the most common tools, equipment and installation procedures required for each phase of the tile or stone installation. Tool and equipment requirements are determined by the phase of the installation shown below, and further defined by the type of construction, type of finish material, and the type of adhesive installation.

Installation Procedures, Tools and Equipment for Mass Transit Installations

- Substrate and Finish Material Surface Preparation (See Also Section 2.3)
- Access for Preparation and Installation (Rolling Scaffolds for Vertical Work)
- Mixing of Adhesives
- Installation of Adhesives
- Installation of Finish Material
- Installation of Grout/Sealants
- Clean-Up and Protection (See Section 9)

Weather and Substrate Protection

The optimum conditions for installation of ceramic tile and stone pavers are temperatures between 60° and 80°F (15° and 25°C), with 50% relative humidity. However, these conditions are atypical, so provisions must be made for variations in climatic conditions. Protection applies to the substrate, the installation of the adhesives and grouts, and also the storage and handling of the finish material.

As a general rule of thumb, follow the 18° Rule; For every 18°F (10°C) above 70°F (21°C) cement based and epoxy based materials cure twice as fast. For every 18°F (10°C) below 70°F (21°C) cement based and epoxy based materials take twice as long to cure.

Hot Temperatures

Protection or corrective action is required if either ambient air or surface temperatures of substrates and finishes go above certain thresholds during installation. Temperature thresholds vary with the types of adhesives, but generally, elevated ambient air (85–100°F [29–38°C]) and surface temperatures will accelerate setting of cement, latex cement, epoxy and silicone adhesives. Washing and dampening floors and walls will not only help to remove contaminants, but will also serve to lower surface temperatures by evaporative cooling of the substrate. Shading surfaces that may be in direct sunlight is also an effective method for lowering surface temperature, but if ambient temperatures exceed 100°F (38°C), it is advisable to defer work to a cooler period of day or the evening. If work cannot be deferred, it is also possible to cool additives (e.g. latex buckets or epoxy liquid pouches stored in cool water) in conjunction with the above techniques.

Conventional portland cement tile-setting beds, thin-set mortars, cement plasters and stuccos are often permanently damaged when subject to hot, dry temperatures or desert climates immediately after installation. High temperatures can quickly cause the water content of the mortar required for portland cement hydration, curing and strength development to evaporate. In addition, rapid drying can cause mortar to crack, crumble or lose bond. Waterproofing membranes, anti-fracture membranes, epoxy adhesives, epoxy grouts, epoxy waterproofing membranes and most other products will also be affected by hot working temperatures. Flash setting and reduced working time can result. It is important to note that surface temperature is more important than air temperature. Therefore, monitor the surface temperature of the installation. The use of premium latex-fortified mortars (e.g. 257 TITANIUM™ or MULTIMAX™ Lite) allows installations to be made at higher temperatures due to the fact that they have longer working properties. 3701 Mortar Admix in thin-sets, plasters, stuccos and other portland cement mortars allow work to continue in hot weather without costly delays or damage. Installations can be made in temperatures as high as 90°F (32°C) under normal circumstances. LATICRETE latex fortified mortars are not damaged by high temperatures and thermal shock after placement and eliminate the need for wet curing. Rapid setting materials will provide for greater challenges when working in high temperatures and should be used with caution.

Tips for working in hot temperatures:

1. For best results, always ship and store installation materials at temperatures between 40°– 90°F (5°– 32°C) to extend the shelf life and working time. Do not store products in direct sunlight. If installation materials are too warm, they should be cooled to the specified temperature range for that specific product.
2. Dampen or wet down substrate surfaces to not only clean the area, but to lower the temperature and lower the absorption rate of the substrate. Sweep off excess water just before mortar is applied. This step will extend the open time and working time of the installation materials.
3. Stir latex additives thoroughly before mixing with thin-sets, grouts, plasters, stuccos and other portland cement mortars.
4. Due to the rapid rate of moisture loss and portland cement dehydration at temperatures >90°F (>32°C), cover installations with polyethylene sheeting for 1–2 days to allow curing at a more normal rate.
5. Low humidity can also accelerate the curing process.
6. Tent off or provide shade when working in direct sunlight.
7. Work during cooler periods of the day (e.g. night, or early morning).
8. Use cool water (where required) when mixing with installation materials.
9. When possible, mix smaller batches of installation materials for optimum workability and immediate use.
10. An infrared or laser thermometer can be used to measure temperature of substrate, installation materials and finish materials.

Cold Temperatures

Conventional portland cement tile setting beds, thin-set mortars, grouts and cement plasters are often permanently damaged when subject to below freezing temperatures immediately after installation. The water content of a mortar turning into ice often results in the portland cement gel structure rupturing with significant loss in strength, flexibility and durability. Subsequent repairs to the damaged work and resulting site delays can be extremely costly.

Protection or corrective action is required if either ambient air or surface temperatures of substrates go below certain thresholds during installation. Temperature thresholds differ for various types of adhesives. Protection and corrective actions to elevate temperatures to optimum range typically involve enclosing or tenting of work areas, augmented by temporary heating. If temporary heating is employed, it is very important to vent units to the exterior of enclosures to prevent exposure to toxic fumes, and also to prevent build-up of carbon dioxide, which can cause carbonation of cementitious materials. Carbonation typically occurs when ambient temperatures during installation are around 40°F (5°C) and only affects exposed surfaces. The length of exposure is a function of temperature. Cement hydration stops at 32°F (0°C) or when water necessary for hydration freezes, while hydration is retarded (substantially slowed) when temperatures go below 40°F (5°C). Concentration of carbon dioxide can be elevated when temporary heating units are not properly vented outside of any protective enclosure during cold temperatures. As a general rule, temperatures should be maintained above 50°F (10°C) during installation of cement, epoxy, and silicone-based products. Some cement adhesive product formulations may allow installation in temperatures close to 32°F (0°C) and rising, however, at this critical ambient air temperature threshold, it is likely that surface temperatures are below freezing due to thermal lag, and hydration or other chemical reaction may not occur at the adhesive interface.

Figure 8.2 – Exterior façade work in temporarily heated, tented area in the middle of winter. LATICRETE Headquarters building, Bethany, CT.

Liquid Latex Fortified Mortars, Screeds and Plasters

The use of 3701 Mortar Admix in thin-sets, grouts, plasters, stuccos and other portland cement mortars allows work to continue in cold weather without costly delays or damage. Frost, ice and thermal shock do not damage LATICRETE® Latex Fortified Mortars after placement. Installations with these LATICRETE products can be made at temperatures as low as 35°F (2°C).

Rapid Setting Latex Fortified Mortars

The use of a premium rapid-setting thin-set mortar will also help to accelerate the setting time in cooler temperatures. 254R Platinum Rapid is ideal for this application. It allows work to take place in cool temperatures and return these areas back into service quickly.

Tips for working in cold temperatures

1. Work during warm periods of the day.
2. Ensure that the surface temperature is within the suggested temperature range for the LATICRETE or LATAPOXY® product being used during the installation and cure period. Consult the individual product data sheet and How-to-Install guide for more information.
3. Tent and heat areas that will be subjected to the elements or freezing temperatures during installation and cure periods.
4. For multiple story buildings – areas to receive tile and stone work may be heated from below to aid in "warming up" cold concrete slabs and rooms. Simply placing temporary heating units in areas under rooms scheduled to receive tile and stone finishes in multiple story buildings will help allow the natural rising of heat to warm up these areas.
5. Vent all temporary heating equipment in accord with OSHA (Occupational Safety and Health Administration) and local building code regulations.
6. For best results, always ship and store installation materials at temperatures above freezing so they will be ready to use when needed.
    a. If LATICRETE liquid latex admixtures and liquid membranes are ever frozen, allow them to thaw completely before use. Allow the products to come up to room temperature (i.e. 70°F [21°C]). Stir contents thoroughly before use or before mixing with thin-sets, grouts or other portland cement mortars.
    b. LATICRETE and LATAPOXY liquid pouches stored in cooler temperatures should be warmed by submerging the unopened pouches in warm water until the material is sufficiently tempered.
    c. Acclimate waterproofing membranes, crack isolation and sound control products to their respective usage temperature range prior to use.
    d. Store all polymer-fortified thin set mortars and grouting products in a warm area prior to use.

Protection

Due to the slow rate of portland cement hydration and strength development at low temperatures, protect installations from traffic for longer than normal periods. Keep all traffic off of finished work until full cure. For example, installations which will be subjected to vehicular traffic should cure for 3-7 days at 70°F (21°C) prior to vehicle traffic. Allow extended cure time, based on the 18° Rule, for installation in cooler temperatures. It is important to note that large format tile and stone will also require longer curing periods in cooler temperatures. Suitable protection should be included in the scope of work. For example, the Tile Council of North America (TCNA) of the

2008 TCA Handbook for Ceramic Tile Installation states "Protecting New Tile Work" states: "Builder shall provide up to 3/4" (19 mm) thick plywood or OSB protection over non-staining Kraft paper to protect floors after installation materials have cured". In addition, extended cure periods will be required for applications that include multiple layer build ups (e.g. mortar beds, waterproofing, sound control, crack isolation, epoxy grout, etc…). Each component must reach a proper cure prior to installing the subsequent installation product.

Dry, Windy Conditions

Dry and windy conditions can cause premature evaporation of water necessary for hydration in cementitious materials, and result in loss of strength. Latex additives are formulated to significantly reduce this drying effect by coating cement with a latex film. However, in extreme dry, windy conditions coupled with high temperatures >90°F (30°C), even latex additives do not provide adequate protection. It is recommended to provide temporary protection against rapid evaporation of moisture during hot, dry, windy conditions in the initial 36 hours after installation of cement mortars, screeds, plasters/renders and cement grouts, and to augment by damp curing with periodic daily water misting. Cement based adhesives are only susceptible to premature drying between the spreading of adhesive and the installation of the finish, and requires only temporary protection from dry and windy conditions during the open or exposed time of the adhesive.

Wet Conditions

Certain materials used in ceramic tile and stone assemblies can be moisture sensitive. For example, the strength of cementitious adhesives can be reduced from constant exposure to wet or damp substrates. Some materials, such as waterproofing membranes, may not cure properly or may delaminate from a continually wet or damp substrate. A damp substrate may also contribute to the formation of efflorescence (see section 2.5 efflorescence). This is a particular concern not only from normal rain exposure during construction, but also in areas of an installation which may be exposed to rising dampness at ground level, or, in areas where leaks from poor design or construction cause continual dampness in the substrate. When specifying liquid latex, or a dry redispersible polymer adhesive mortar, verify with the manufacturer that the polymer formulation is not water soluble. However, even formulations that are not soluble when dry are vulnerable to rain during the initial set period (typically 12–24 hours). Therefore, it is essential to provide protection from any significant rain or washing within this period to avoid loss of strength and prevent possible fluid or latex migration staining.

8.2 ACCESS FOR VERTICAL INSTALLATIONS (SCAFFOLDING)

The selection of scaffolding has a major impact on the productivity and resulting cost of installing vertical and overhead applications of tile and stone. The comfort and convenience for installers, as well as the ease of transport, assembly and handling of scaffolding all contribute to the efficiency and quality control.

Types of Scaffolding[1]

- Veneer Scaffolding
- Tubular Frame Scaffolding
- Adjustable Tower Scaffolding
- Powered Mast Climbing Work Platforms
- Multi-Point Suspended Scaffolding

Veneer Scaffolding

This is the simplest, most efficient, lightweight type of scaffolding. This equipment is used only for walls less than 10' (3 m) high. The system consists of a metal frame with adjustable, stabilizing legs that do not require cross-bracing, and wood or metal platform planks. Vertical adjustment can be made in small 3" (75 mm) increments.

Tubular Frame Scaffolding

This is the most common type of scaffolding, consisting of a tubular metal frame and cross-braces which give the system stability. This system is most efficient in applications under 30' (10 m) in height, because it is a stacked system. Some advantages are that the components of the system are very common, it adapts well to recesses and projections in walls, and it is the easiest type of system to enclose for hot or cold weather protection. Disadvantages are that this type of system can only be adjusted in large increments at each level of the frame, and that each successive level must be built before it can be stocked and occupied.


Figure 8.3– Example of tubular scaffolding.

Adjustable Tower Scaffolding
Most adjustable scaffolding consists of a base, towers, cross-braces, a carriage, a winch (hoisting) assembly, guardrails and a plank platform. These systems are most efficient on buildings up to 75' (23 m) in height, but can be used up to 100' (30 m). The hand operated winch raises the platform along the carriage towers. This system can be easily adjusted in any vertical increments, and the entire assembly can be lifted and transported by forklift to adjacent walls. Many proprietary designs provide separate loading/stocking and working platforms. Studies have shown that adjustable scaffolds can increase labor productivity by 20% over conventional frame scaffolding.

Powered Mast Climbing Work Platforms
Powered mast climbing work platforms are electrically or hydraulically powered and consist of a trailer base unit, a platform, and one or two tower masts on which the platform rides. Powered systems, depending on the components, can be used on buildings between 300–500' (91.5–152 m) in height, but the cost of frame erection makes them most efficient on buildings less than 100' (30 m) in height. Powered systems have all the advantages of adjustable scaffolding, as well as significant safety features such as built-in guard rails, safety stops, and speed controls. The primary disadvantages are the cost and the lack of availability in some regions of the world.

Multi-Point Suspended Scaffolding
Multi-Point Suspended Scaffolding is suspended from wire ropes attached to outrigger beams which are anchored to the roof or intermediate floor structure, or, to temporary structural counterweights. These systems are powered either by hand winches or power driven equipment. Suspended scaffolding is typically used for high-rise construction, and becomes cost-effective at building heights of 100–125' (30–38 m). Suspended scaffolding must be engineered for each construction site, usually by the scaffolding supplier and the building contractor's engineer. These systems have the same advantages as adjustable and mast climbing systems. In addition, there are no obstructions between the wall and the installers because suspended systems have no cross-bracing. Overhead protection is typically required by safety regulations due to work that progresses above, making overhead loading difficult unless the platform protection has a hatch opening.

8. 3 FINISH MATERIAL PREPARATION
Cleaning of the tile/stone back and substrate surface prevents contamination from inhibiting adhesive bond. Preparation and cleaning of substrates are covered in Section 2.3. While careful consideration is often given to the preparation of the substrate, preparation and cleaning of the finish material bonding surface is an often overlooked specification item or quality control checkpoint. Considerations are dependent on the type of finish material.

Types of Finish Materials
Ceramic and Porcelain Tile
The bonding surface of the tiles may be contaminated with dirt or dust from normal manufacturing, storage and handling. Porcelain tile may have a coating of a release agent (known by terms such as bauxite or engobe) which prevents fusion of the tile to kiln surfaces during the firing process. The type, amount, and degree of presence of the release agent will vary according to manufacturer, tile type or production batch. It is recommended to wipe each tile with a clean, damp towel or sponge just prior to installation to maximize adhesive bond. Cement-based, dry redispersible polymer cement or latex cement adhesive mortars can be applied to a damp, but not dripping wet surface (see Section 2.3 – Moisture Content of Concrete).

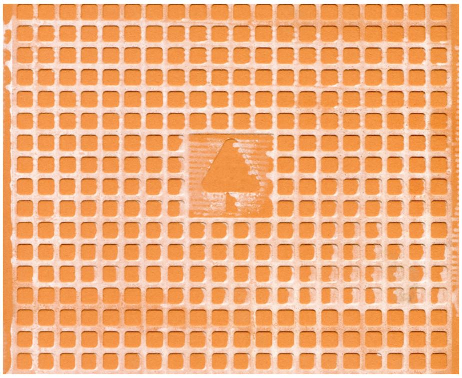


Figure 8.4 – Example of kiln release present on tile back.

Quarry Tile

Quarry tile typically has a rougher, more open pore structure and many have a ribbed back configuration which is manufactured specifically for demanding applications (e.g. mass transit, commercial or industrial floors). As a result, quarry tile is less susceptible to contamination due to the safety factor provided by both mechanical and adhesive bond. There are no specific cautions other than to remove normal dirt caused by storage and handling with normal cleaning techniques prior to installation.

Stone

Stone can be manufactured and supplied with a wide variety of finishes. In addition, the bonding side of the stone can be milled, cut or finished in various profiles. In similar fashion to ceramic and porcelain tiles, the backs of the stones must be free of any cutting/fabrication dust, or weak stone/water slurry. Stones must also be suitable for the intended use and should not contain elements that can inhibit its bond. Precautionary measures should be taken when installing moisture sensitive stones and agglomerates. (See section 7.2 Epoxy Adhesives).

Many stone types are being supplied with resin-backed mesh (e.g. polyester, epoxy, etc…), plastic, metal honeycombing, etc… in an effort to stabilize and prevent the stones from cracking during shipping, handling and installation. It is important to verify that the backings are well adhered, stable, and suitable for the intended purpose. If the backing loses adhesion to the stone itself, the stone installation will fail (see figure 8.5). The backing and backing adhesive must be water-resistant if the stone finish is exposed to moisture. In addition, the adhesive mortar must be compatible with the backing material. In many cases, an epoxy adhesive may be the only alternative for the installation of stones with these various backing types. Outside of any test reports to the contrary, an epoxy adhesive is the safe approach to installing stone with unusual or "non-natural" backing. Specifiers should be aware of the fact that an impervious epoxy adhesive and an impervious backed stone may create installation issues on exterior applications, in regards to condensation and diminished vapor drive through the stone finish. On the other hand, some backings are compatible with latex-fortified portland cement based mortars. These backings may include a layer of sand which has been broadcast into the resin to facilitate mechanical bond.

Figure 8.5 – Example of resin backed stone. Polyester resin mesh backing applied to the stone. Notice how easily the backing has peeled away from the stone itself.

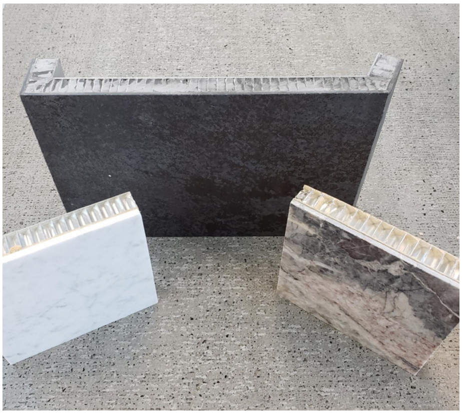


Figure 8.6 – Example of honeycombed metal backed stone fused to the stone. This stone type can only be installed with an epoxy adhesive.

8.4 ADHESIVE MIXING EQUIPMENT AND PROCEDURES

Equipment and tools required for mixing of adhesives are primarily dependent on the type of adhesive and construction site conditions, such as the size of project.

Types of Adhesives and Equipment

Latex Cement Based Adhesive Mortars

Manual Mixing

- Bucket, Trowel and Mixing Paddle

Mechanical Mixing

- Rotating Blade (Forced Action) Batch Mortar Mixer (Figure 8.8)
- Low Speed Drill (<300 rpm) and Non-Air Entraining Mixer Blade (Figure 8.7)

NOTE: Rotating drum type concrete mixers are not suitable for mixing adhesive mortars. In mixing cement adhesive mortars, always add the gauging liquid (water or latex additive) to the mixing container or batch mixer first. Begin mixing and add the dry cement based powder gradually until all powder is wet, then continue mixing continuously for approximately one minute or until mortar is wet and plastic. If using site prepared powder mixes of portland cement and sand, add the sand first until it is wet, and then add the cement powder. Take caution to prevent over-mixing by blending only until the mortar is wet and plastic in accordance with the manufacturer's instructions. Over-mixing can entrap air in the wet mortar and result in reduced density (high absorption will reduce freeze/thaw stability) and strength.

Epoxy Adhesive

Manual Mixing

- Bucket and Trowel

Mechanical Mixing

- Low Speed Drill (<300 rpm) and Non-Air Entraining Mixer Blade

The mixing instructions for epoxy adhesives vary according to the manufacturer's formulations. The most common epoxy adhesives are three component products, which involve mixing two liquid components (resin and hardener), and a powder component (silica filler). The liquids are mixed together and blended before adding the filler powder. There are several important considerations in mixing epoxies. First, the chemical reaction begins immediately upon mixing the epoxy resin and hardener; so the clock is running at this point. Because the "pot" or useful life of the adhesive may be relatively short (1 hour) and can be further reduced by ambient temperatures above 70°F (21°C), all preparation for mixing and installation of the epoxy adhesive should be made in advance. Mixing should also be made in quantities that can be installed within the stated pot life under installation conditions. Most epoxy adhesives cure by an exothermic (heat generating) chemical reaction, which begins with the mixing of the liquid components. The useful life of the epoxy not only begins before adding the filler powder, but the heat generated may accelerate the curing process in many formulations. Removal of the mixed epoxy from the mixing container is one technique used to dissipate heat generation and minimize set acceleration. Liquid components may also be cooled if anticipated ambient or surface temperatures will significantly exceed recommended use temperature range. Conversely, epoxy adhesive cure is retarded by cold temperatures, and the curing process can stop at temperatures below 40°F (5°C); the curing process should continue unaffected if temperatures are raised.

Figure 8.7 – Variety of Mixing Paddles used for Drill Type Mixers.

Mortar Beds/Renders (See Section 7.3)

- Aluminum Straight Edges and Screeds
- Concrete/Mortar Bed Finishing Trowel
- Wheelbarrows
- Square Edges Shovels
- Steel Rakes
- Walking Boards
- Mortar Bed/Tile Shoes
- Mortar Mixer

Figure 8.8 – Rotating Blade Type Mixer.

8.5 WATERPROOFING/CRACK ISOLATION MEMBRANES

The installation of waterproofing is covered under ANSI A108.13 "Installation of Load Bearing, Bonded, Waterproof Membranes for Thin-Set Ceramic Tile and Dimension Stone", and crack isolation is covered under ANSI A108.17 "Installation of Crack Isolation Membranes for Thin-Set Ceramic Tile and Dimension Stone". The product standards for waterproofing can be found under ANSI A118.10 "American National Standard Specification for Load Bearing, Bonded, Waterproof Membranes for Thin-Set Ceramic Tile and Dimension Stone Installation" and the product standards for crack isolation membranes can be found under ANSI A118.12 "American National Standard Specification for Crack Isolation Membranes for Thin-Set Ceramic Tile and Dimension Stone Installation". Liquid applied membranes are generally considered to be the best options in many applications. These membranes can be applied by brush, trowel or roller. In addition, some of these membrane types can also be applied by airless sprayer. For example, HYDRO BAN® can be effectively sprayed to increase productivity on large projects.

Spraying Liquid Applied Membranes

In addition to the conventional means of applying HYDRO BAN, (see Data Sheet 663.0 and How-To-Install Data Sheet 663.5) the airless spraying technique can be used as an alternate means of application.

The following are the guidelines for this procedure. Most airless spray units can be used to apply HYDRO BAN. This procedure will refer to the use of the Graco Ultra Max II 495 Airless Sprayer and the Graco Ultra Max 695 Airless Sprayer. These sprayers are designed for spraying the contents from a 5 gallon (19 L) pail. Many airless sprayers are similar in design and will accomplish the same purpose.

For more information on the spray application of HYDRO BAN, please refer to TDS 410 "Spraying HYDRO BAN" available at www.laticrete.com.

Graco Ultra Max II 495 Airless Sprayer

Graco Ultra Max 695 Airless Sprayer

Graco Ultra Max II 1595 Airless Sprayer

Description	Graco Part Number	Max Tip Size	Max GPM (LPM)	Max PSI (MPa)
Ultra Max II 495	17E857	0.025 (0.63 mm)	0.95 (3.6)	3300 (22.8)
Ultra Max 695	17E574	.0.031 (0.79 mm)	0.95 (3.6)	3300 (22.8)
Ultra Max II 1595	17E596	0.043 (1.09 mm)	1.35 (5.1)	3300 (22.8)

Figure 8.9 – Graco Airless Sprayers.

A good understanding of the equipment set up, delivery and cleanup procedures are required in order to effectively spray HYDRO BAN®.

Airless Spray Tip Characteristics: It is important to remember that the spray tip orifice size, in conjunction with the fan width size, determines the spray characteristics of the tip.

Examples: As the orifice size increases, while maintaining the same fan width size, the greater the volume of coating will be applied to the same area. Conversely, the larger the fan width size, while maintaining the same orifice size, will result in the same amount of material being applied over a greater surface area.

Tip Size: LTX521 – has an orifice of 0.021" (0.5mm) and a fan width of 10" (250 mm) holding the nozzle 12" (300 mm) away from the substrate.

Tip Size: LTX631 – has an orifice of 0.031" (0.8 mm) and a fan width of 12" (300 mm) holding the nozzle 12" (300 mm) from the substrate.

Figure 8.10 – Typical LTX Sprayer Nozzle.

The use of a spray tip with a smaller orifice will result in less membrane product being delivered to the substrate requiring multiple passes to ensure a complete coating with optimum thickness.

Understanding Spray Tip Wear

When beginning a project, choosing the right tip size and fan width will determine how effective the spraying process will be. The correct tip size will have a direct bearing on how much material is dispensed. However, spray tips will wear with normal use. Older, worn tips will increase delivery time and product consumption. Therefore, changing the spray tips often will result in greater productivity. Choosing the right spray tip is essential for ensuring a quality finish. It is important to replace a spray tip when it gets worn to ensure a precise spray pattern, maximum productivity and quality finish. When a tip wears, the orifice size increases and the fan width decreases. This causes more liquid to hit a smaller area, which wastes waterproofing membrane and slows productivity. The life of the spray tip varies by coating, so if a tip is worn, replace it. The life of the spray tip can be extended by spraying at the lowest pressure that effectively breaks up the coating into a complete spray pattern (atomized). Do not increase the pump pressure; it only wastes waterproofing membrane and causes unnecessary pump and tip component wear.

The example below demonstrates the spray pattern of new and worn spray tips. As wear occurs, the pattern size decreases and the orifice size increases. As a rule of thumb, it is best to replace the spray tips after spraying 30 –45 gallons (114–171 L) of HYDRO BAN®.

Figure 8.11 – Typical Spray Patters of Liquid Applied Membranes.

Spray Guns

Follow the specific airless sprayer and spray gun manufacturer's written instructions when using their equipment. Typically, a spray gun can be used for both vertical and horizontal applications. Some Spray Guns will allow filtering in the gun handle, and, if so equipped, the filter will need to be periodically cleaned or changed to ensure proper liquid flow through the spray gun and tip.

Application of HYDRO BAN®

Follow all surface preparation requirements outlined in Data Sheets 663.0 and 663.5. The airless sprayer should produce a maximum of 3,300 psi (22.8 MPa) with a flow rate of 0.95 to 1.6 GPM (3.6 to 6.0 LPM) using a 0.521or 0.631 reversible tip. Keep the unit filled with HYDRO BAN® to ensure continuous application of liquid. The hose length should not exceed 100' (30.5 m) in length and 3/8" (9 mm) in diameter. Apply a continuous film of HYDRO BAN with an overlapping spray. The wet film has a sage green appearance and dries to a darker olive green color. When the first coat has dried completely to a uniform olive green color, approximately 45 to 90 minutes at 70°F (21°C), visually inspect the coating for any voids or pinholes. Fill any defects with additional material and apply the second coat at right angles to the first. The wet membrane thickness should be checked periodically using a wet film gauge. Each wet coat should be 0.015 to 0.022" (0.4 – 0.6 mm) thick. The combined dried coating should be 0.020 to 0.030" (0.5 – 0.8 mm) thick or 0.029 to 0.043" (0.7 – 0.11 mm) wet.

Regardless of whether a liquid applied membrane is applied with hand tools (e.g. paint roller, brush or trowel) or by sprayer, check application thickness with a wet film gauge periodically during installation. This will help ensure that the HYDRO BAN is being applied correctly and that the appropriate thickness and coverage is achieved. Bounce back (rebound of unbonded spray) and overspray (spray onto adjacent surfaces) will consume more membrane liquid and affect coverage. To achieve the required film thickness, the coating must be free from pinholes and air bubbles. Do not back roll coating. Allow the HYDRO BAN to cure in accord with the instructions in Data Sheets 663.0 and 663.5 prior to the installation of the tile or stone finish. It is important to note that areas not scheduled to receive the HYDRO BAN should be taped off and protected from any potential overspray. Expansion and movement joints should be honored and treated as outlined in product Data Sheets 663.0 and 663.5.

Figure 8.12 – Wet film gauge.

NOTES: The operator of the spray equipment must have a working knowledge of the equipment used and be able to adapt to the project conditions as the spraying takes place. As the spray tips wear, adjustments will need to be made. Spray tip selection, pressure adjustments and hose length will have a direct bearing on the results achieved.

Spray Equipment Setup, Clean Up and Maintenance

Follow the airless sprayer manufacturer's instructions on set up, operation, clean up and maintenance of their equipment. The airless spraying unit should be flushed clean and be free from any contaminants prior to use with HYDRO BAN®.

Health and Safety

Follow all applicable health and safety requirement when applying HYDRO BAN. The use of protective clothing, safety glasses and a dual cartridge respirator are recommended when spraying. See SDS Sheet on HYDRO BAN (available at www.laticrete.com) for complete information.

Airless spray equipment can be purchased by contacting:

Graco, Inc.
The Paint Project Inc.
Sales/Distribution/Service
Industrial Spray Equipment & Systems
71 West St., P.O. Box 1141
Minneapolis, MN 5540-1141
Medfield, MA 02052 Tel. 800.690.2894
Tel +1.508.359.8003
Fax 800.334.6955 or, +1.508.359.8463
www.graco.com
e-mail bob@paintproject.com

8.6 FINISH MATERIAL INSTALLATION EQUIPMENT AND PROCEDURES

The basic concept of installing various finishes using the direct adhered method is the same. The entire surface of the finish material is adhered, and the basis for evaluating adhesion performance is by strength of a unit area; the size of the finish material is affected only by the logistics of construction and any legal/building code requirements. Adhesives are designed to bond at safety margins of about 250–400% greater than what is typically required by building codes. The reason for the high safety factor is, of course, to compensate for the unforeseen extreme forces such as seismic movement, weather conditions and the difficulty in the quality control of labor. Until sophisticated diagnostic quality control test methods become more readily available and cost-effective, it is foolish to expect maximum specification strength over the entire adhesive interface hidden from visual inspection.

Installation of Ceramic Tile and Stone Finishes

The following are the basic tools and equipment used for the installation of ceramic tile and stone finishes:

Equipment for Application and Bedding of Adhesives and Grout Joints

- Notched Steel Trowel
- Flat Steel Trowel
- Margin Trowel
- Hawk
- Metal Applicator Gun (for Silicone Sealant)
- Rubber Mallet
- Wood Beating Block
- Spacers, Shims and Wedges
- Grout Float (Cement or Epoxy)

Cutting/Fitting of Finish Materials

- Wet Saw (See Figure 8.13)
- Ceramic Tile Cutter and Accessories

Figure 8.13 – A commercial grade wet saw is ideal for cutting all types of tiles in mass transit applications.

Measurement
- Carpenter's Level
- Laser Level
- Straight Edge (4'/1200 mm)

Clean-Up
- Sponges and Towels
- Water Bucket
- Solvents (epoxy or silicones)

Safety Equipment
- Safety Glasses
- Rubber Gloves
- Dust Mask/Respirator
- Safety Belts and Harness

8.7 INSTALLATION PROCEDURE FOR FINISHES USING THIN BED ADHESIVES

Functions of a Notched Trowel
- Gauges the Proper Thickness of Adhesive
- Provides Proper Configuration of Adhesive
- Aids in Efficient Application of Adhesive

The notched steel trowel is the primary and most fundamentally critical installation tool for the thin bed method of installation. The proper thickness of the adhesive layer is dependent on the type and size of finish, the cladding and substrate bonding surface texture, and the configuration and tolerance from consistent tile or stone thickness. A "gauged" or "calibrated finish" is tile or stone with a consistent thickness and a specified tolerance for deviation. An "ungauged" cladding is not consistent in thickness. Even gauged tile and stone can experience thickness tolerances of up to 1/8" (3 mm).

Notched steel trowels are available in several sizes and configurations to control the thickness of the adhesive mortar. The configuration of the adhesive application is critical to the performance of the tile or stone installation. In addition to controlling the final thickness of adhesive, the notched configuration results in "ribbons" or "ribs" of adhesive separated by spaces that control bedding or setting of the finish into the adhesive. The spaces allow the ribs of adhesive to fold into one another to decrease the resistance to pressure required for proper contact, and provide a controlled method of filling all air voids while allowing for the escape of air parallel to the ribs. This function is critical in assuring full contact and coverage of adhesive, not only to ensure maximum bond strength, but also to eliminate air voids or channels, which can harbor or transport water.

Notch Chart

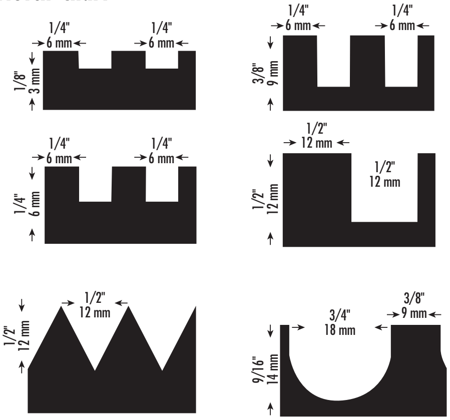


Figure 8.14 – Notched trowel sizes for installation of adhesive mortars.

It is important to maintain the specified notch depth and configuration of notched steel trowels throughout the project. The angle of the trowel during application of the mortar can have a significant effect on the height of adhesive ribs, which in turn can affect the height to width ratio (of the mortar "ribs") which is necessary for the control of mortar thickness and elimination of air voids. Therefore, it is recommended to prohibit the common use of severely worn trowels and to require frequent trowel cleaning, and specification of trowel angle during installation as part of the quality control measures. A flat steel trowel is a tool used in applying an initial thin layer of adhesive in positive contact with both the bonding surface of the tile/stone, also known as back-buttering, and the surface of the substrate. The opposite side of a notched trowel typically has a flat edge for this purpose. A rubber mallet, wood beating block, or hard rubber grout float (for smaller tiles) can be used to beat-in the tiles after they are placed to help assure full contact with the adhesive, and minimize voids in the adhesive layer (Figure 8.17).

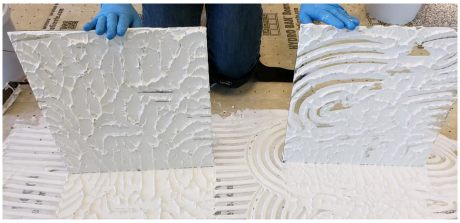


Figure 8.15 – Examples of incomplete bedding due to lack of sufficient mortar and /or incorrect trowel size selection and beat-in.

Thin Bed Installatin Procedure

The following is an abbreviated step by step process for the application of thin bed adhesive mortars. Follow the explicit manufacturer installation instructions for detailed information. For full installation specifications of thin bed, thick bed and membrane instructions– see section 10.

1. Apply a thin skim coat (1/16" [1.5 mm]) of thin-set or epoxy adhesive to the properly prepared dampened substrate with the flat side of the trowel; ensure good contact by scratching the edge of the trowel against the surface.
2. Additional thin-set or epoxy adhesive is then applied with the notched side of the trowel. Comb the mortar on the wall with the notched trowel holding it as close as possible to a 90° angle to the substrate. This will ensure the proper size of notches.

Figure 8.16 – A notched trowel has several important functions that contribute to a successful installation of ceramic tile and stone.

3. The ribs of thin-set or epoxy adhesive should be troweled in one direction only, and not in a swirl pattern. If additional thickness of adhesive is needed, add to the back of the finish using the same procedure as on the substrate, making sure that the direction of the combed mortar is identical to the one on the substrate, otherwise, you will end up with notches in two directions that disturb each other and consequently will not allow full contact between the mortar and the back of the tile/stone.
4. As a rule of thumb, tile/stone sizes larger than 8" x 8" (200 x 200 mm) should be back buttered. Back buttering not only improves the contact between the mortar and the back of the tile/stone, but also helps to ensure complete coverage. Another important consideration for back buttering is that if the tile/stone are not fully bedded by proper beat-in, the ribs of thin-set or epoxy adhesive, which are not flattened, are being sealed by the coat applied to the back of the tile/stone.
5. The tile/stone should be pressed into place, and either twisted and pressed into position, or for tile/stone sizes 12" x 12" (300 x 300 mm) and greater, slid into position with a back and forth motion perpendicular to the direction of the thin-set or epoxy adhesive ribs.
6. The final step is to beat-in with a rubber mallet to ensure thin-set or epoxy adhesive contact and make the surface level with adjacent tile/stone.

8.8 GROUT AND SEALANT MATERIALS, SELECTION, METHODS AND EQUIPMENT

Purpose of Grout or Sealant Joints

The joints or spaces between pieces of tile/stone serve several important purposes. Aesthetically, joints serve as a design element, primarily to lend a pleasing scale with any size tile/stone module. Functionally, joints minimize water infiltration, and compensate for manufacturing dimensional tolerances of the tile/stone. More importantly, though, joints lock the tile/stone into place and provide protection against various delaminating (shear) forces. Depending on the joint material, a joint may also act to dissipate shear stress caused by movement.

Compensate for Tile Thickness Tolerances

The joints between tile/stone compensate for allowable manufacturing or fabrication tolerances, so that consistent dimensions (from center to center of joints or full panel dimensions) can be maintained. As a result, joints must be wide enough to allow variations in the joint width to accommodate manufacturing or fabrication tolerances in the tile/stone without being evident.

Minimize Water Infiltration

Filled joints between tile/stone allow most surface water to be shed. This helps prevent infiltration of water, which can lead to saturation of the setting bed and substrate, freeze/thaw damage, strength loss, and efflorescence. Depending on the grout or sealant material used, and the quality of installation, no grout or tile/stone will be 100% effective against water penetration, so there may always be a small amount of water infiltration by capillary absorption. Therefore, the use of a waterproofing membrane is strongly recommended in mass transit applications exposed to water.

Dissipate Movement Stress

Probably the most important function of grout or sealant joints is to provide stress resistance and stress relief. The composite locking action with the adhesive layer allows the tile/stone finish to better resist shear and tensile stresses. Joints serve to provide stress relief of thermal and moisture movement that could cause delamination or bond failure if the edges of the tiles were butted tightly. Further isolation of movement is handled by separating sections of tile/stone with movement joints (see Section 2.1 – Movement Joints and Section 10 – Movement Joint Specifications and Details). This ensures that the grout or sealant joint will always fail first by relieving unusual compressive stress from expansion before it can overstress the tile/stone finish or adhesive interface. The dissipation of stress provides additional safety factor against dangerous delamination or bond failure.

Grout Installation Procedure

The following is an abbreviated step by step process for the installation of grout. Follow the explicit manufacturer installation instructions for detailed information. For full grout installation specifications – see Section 10.

1. Prior to grouting, it is essential to conduct a job site test panel (preferably as part of the pre-construction quality assurance procedures) to test the grouting installation and clean-up procedures under actual job site conditions. During this test, you may determine the need to apply a grout release or sealer to the tile/stone prior to grouting in order to aid in clean-up and prevent pigment stain and absorption of cement paste (especially latex cement or epoxy liquids) into the pores of the tile/stone. This test may also determine if additional adjustments are necessary, such as saturation of the finish with water to reduce temperature, lower absorption, and aid in installation and cleaning.
2. Wait a minimum of 24 hours after installation of tile/stone before grouting.
3. Before commencing with grouting, remove all temporary spacers or wedges and rake any loose excess adhesive mortar from joints. Remove any hardened thin-set or epoxy adhesive which is above half the depth of the tile/stone. Insert a temporary filler material (rope, foam rod) into the movement joints to protect from filling with hard grout material. Wipe the tile/stone surface with a sponge or towel dampened with water to remove dirt and to aid in cleanup.
4. Apply the grout joint material with a rubber grout float, making sure to pack joints full.

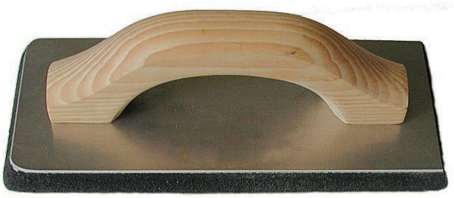


Figure 8.17 – Grout joint installation equipment – floats

5. Remove excess grout by squeegee action with the edge of the rubber grout float diagonal to the joints to prevent pulling of grout from the joints.
6. Allow grout to take an initial set, and then follow the appropriate clean-up process for the specific grout type used as stated in the manufacturer's written installation instructions.

7. Any remaining weakened grout haze or film should be removed within 24 hours using a damp sponge or towel. Temperature and grout type may require final cleaning sooner than 24 hours.

Silicone or Urethane Sealant

Installation procedures for sealant joint filler products are the same as for movement joints (see Section 2.1 – Movement Joints and Section 10 – Expansion Joint Specification and Details).

8.9 POST INSTALLATION CLEANING

Most clean-up should occur during the progress of the installation, for hardened adhesive and grout joint residue may require considerably more aggressive mechanical or chemical removal methods than required while still relatively fresh. Water based cement and latex cement adhesives clean easily with water while fresh, or may require minor scrubbing or careful scraping together with water within the first day. Epoxy and silicone adhesives and joint sealants may require more aggressive scrubbing techniques and chemicals if residue is greater than 24 hours in age.

8.10 MECHANICAL MEANS AND METHODS

As an alternative to the common traditional means and methods of installation, mass transit applications lend themselves to the use of mechanized means and methods due to the size and uniqueness of the application. In many cases, mechanized equipment can greatly improve productivity while lowering labor and installation costs. Generally, the set up and clean up time of the equipment factors into the decision whether to use the mechanized equipment. The following sections provide an alternative to the traditional means that are typically used in most ceramic tile/stone installations.

Power Screeds

Power screeds are used as an alternative to the conventional wood or aluminum straight edges methods of leveling and "pulling" of mortar beds. The power screeds run on small electric powered or gas powered engines which vibrate to help facilitate the screeding of the mortar bed. The power screed sits on aluminum ribbons which are set to the desired height. The power screed is pulled over the ribbons to compact and level the mortar bed faster and more efficiently than manual methods.

Figure 8.18 – Power Screed

Power Grouting

Power grouting is accomplished by using a mechanized grout spreading machine. The grout is spread by using rubber blades mounted on a powered rotating machine. This equipment will spread both latex fortified portland cement based and epoxy grouts in an effective manner. These machines pack the joints and strike the excess grout from the face of the tiles in one step. The rubber blades can be changed when excessive wear is noticed. The mechanized power-grouting machine has interchangeable pads to easily convert to the clean-up process. Traditional methods and equipment will still need to be used in small areas where the use of the mechanized equipment becomes impractical.

Figure 8.19 – Raimondi USA – Power Grouting and Accessories.

Figure 8.20 – Raimondi USA – Power Grouting Machine.

Figure 8.21 – Raimondi USA – Low Speed Power Mixing Tub.

Mortar Mixers and Pumps

Mortar mixers and pumps are used as an alternative to conventional mortar mixers. The pump and mixer apparatus effectively mixes and pumps the mortar through a 3" (75 mm) hose to the desired location. The strength and style of these machines varies greatly depending on the amount of mortar to be mixed, the distance to place the mortar, and the amount of mortar to be placed.

Fig. 8.22 – Mortar Mixer and Pump.

Figure 8.23 – Mortar is screeded with a vibrating screed to the desired height and pitched to falls and drains as required.

Figure 8.24 – Grout Spreading Process.

8.11 RENOVATIONS OF EXISTING MASS TRANSIT FACILITIES

Mass transit applications are expected to handle and stand up to demanding circumstances and situations, including 24 hour use, pedestrian and vehicular loads, as well as vibration and other loads that emanate from these facilities. In many cases, renovations of existing facilities are required when finishes experience wear, damage, falling out of code compliance, or just become outdated. Due to unique performance characteristics, tile and stone is used on a frequent basis to repair and renovate existing mass transit facilities.

Most if not all of the same principles that govern new installations of tile/stone apply to renovation applications. Section 10 includes various renovation options including details that depict new tile or stone installed over existing tile, stone, terrazzo, and other existing finish types. The versatility of tile and stone makes it a great choice for use in restoration projects. Provided that existing substrates are sound, well adhered and properly prepared, a restoration solution exists for the application. Suitable existing substrates include; concrete, terrazzo, existing ceramic tile and stone, resilient flooring and non-water soluble cut-back adhesive. The various high strength tile/stone adhesive types and installation accessories, including the use of anti-fracture and waterproofing products provide solutions for these demanding applications. In addition, rapid setting adhesives, membranes and grouting products can return newly renovated areas back to service in a relatively short period of time.

Figure 8.25 – Restoration of the 42nd Street Subway Station, New York, NY. Granite pavers installed with LATICRETE® 211 Powder mixed with LATICRETE 4237 Latex Additive over a mortar bed consisting of LATICRETE 226 Thick Bed Mortar mixed with LATICRETE 3701 Mortar Admix. Installation by Navillus Contracting Inc., Long Island City, NY.

Figure 8.26 – Restoration of the Route 9 Tunnel, New York, NY. Installation of new ceramic tile over existing concrete ceiling using LATAPOXY® 310 Stone Adhesive in the epoxy spot bond method. Installation by Navillus Contracting Inc., Long Island City, NY.

Figure 8.27 – Restoration of the St. George Ferry Terminal, New York, NY included the installation of new tile over existing cement based terrazzo and tiled floors.

Section 9: Maintenance and Protection

Airport terminal departure gates.

9.1 QUALITY ASSURANCE

The success of a tile and stone installation in a mass transit installation depends entirely on a thorough quality assurance program which is implemented at all levels of the project. Unfortunately, comprehensive quality assurance programs remain the most overlooked and ignored process in the design and construction of both the facility and the tile/stone installation.

There is an important distinction between the terms "quality assurance" and "quality control". The distinction is that quality assurance is preventative in nature and encompasses all of the procedures necessary to ensure a quality job. Quality control is typically corrective in nature, implemented during or after a procedure, and is only one component of a more comprehensive and planned quality assurance program.

A quality assurance program should include quality checks during the design, specification and bidding phases as well as during and after construction. One factor of tile/stone used in mass transit facilities is that the quality of the installation is only as good as each component, and its installation within the system. Therefore, choosing the proper products and installing them correctly is critical to the long-term performance of the installation.

A comprehensive quality program for the design and construction of tile/stone installations in mass transit applications should involve, but not be limited to the following:

Owner

- Define Scope of Work
- Organizational Requirements
- Quality Objectives

Design Professional

- Tile/Stone Installation System Product Component Design, Specification, Installation, and Inspection Procedure Training
- Pre-Installation Conference on Materials and Methods
- Identification of Construction Progress and Post Installation Inspection, Testing and Evaluation Requirements; Identify Resolution Methods for Non-Compliant Conditions
- Develop and Specify Post Installation Preventative Maintenance Programs

Construction Professional

- Substrate Preparation
- Control of Materials (Evaluation of Contract Document Performance Requirements, Material Suppliers, Delivery, Handling, and Records)
- Product Use Monitoring and Documentation (Pot Life, Curing, Protection and Batch Mixing)
- Setting or Fixing All Tile/Stone – Adhesion Monitoring (Spreading, Thickness, Open Time, Tackiness, Beat-In, and Coverage)

9.2 PREVENTATIVE AND CORRECTIVE MAINTENANCE

A systematic maintenance plan is a critical required final step, which is often overlooked. Industrial installations are demanding environments that are often exposed to harsh chemical cleaners, sanitizers, heavy foot traffic, vehicular traffic, extreme temperature variances, deicing salt applications, and much more. Without regular maintenance, any normal deterioration or degradation of a standard grout would be accelerated. The end result would be a loss of performance and shortening of the expected service life.

Facility maintenance is categorized according to how and when maintenance actions are taken. Preventative maintenance is planned and pro-active actions, which maintains specified performance and prevents potential defects or failures, are taken. Preventative maintenance includes anticipated routine actions and repairs, such as application of protective sealers or deteriorated sealant replacement, as well as unexpected repairs such as replacement of cracked tile or fixing water leaks that may manifest into structural problems later.

The benefits of preventative maintenance are well documented; prevention has been proven to increase expected service life, and cost a fraction of more extensive remedial action typically required once a problem occurs.

Corrective maintenance is remedial action, which repairs a defect after occurrence. Corrective maintenance is necessary to prevent further deterioration or total failure of a tile installation. Corrective action typically involves evaluation with either a non-destructive or destructive test procedure.

For exterior installations in freeze/thaw climates, the use of excessive deicing salts may have a negative impact on not only the structural steel reinforcing of concrete or mortar beds, but also on the integrity of the portland cement in these components. The use of a deicing compound that will not deteriorate or otherwise harm portland cement products is recommended.

9.3 PROTECTION AND SEALING – WATER REPELLANT SEALERS AND COATINGS

The purpose and performance of these materials is widely misunderstood by design and construction professionals. Generally, clear water repellant coatings can aid in retarding surface water absorption of porous materials, and reduce adhesion of staining materials. However, these sealing materials often give a false sense of security which is often due to a lack of understanding of the suitability, compatibility and performance in regards to conditions or to tile/stone type. Water repellents can reduce water leakage and deterioration in normally porous tile, stone and grouting materials, but they are not a cure to abnormal leakage caused by fundamental defects in detailing and construction.

There are several general principles for use and application of sealers. Water repellent sealers are not waterproof, and generally cannot bridge gaps or hairline cracks in grout joints or building material, so these materials are useless when used over cracks or very porous surfaces. Sealers suitable for use over slab-on-grade concrete must be vapor permeable and allow the floor to "breathe" or allow vapor to pass through the system. Sealers can also create functional or aesthetic defects that are intended to be prevented or corrected by their application.

As sealers age, wear out or weather, several other problems can occur. Effectiveness is typically reduced over time, so periodic reapplication (depending on the manufacturers formulation and recommendations) is necessary; typical effective service life ranges from 1 – 5 years. Sealers may also allow variable wetting of a portland cement grout or tile from poor application or weathering; this can produce a blotchy appearance. In some cases, the sealer can be reapplied; in others, it may be necessary to allow it to completely weather off, or be removed chemically to restore a uniform appearance. Check with the sealer manufacturer for complete information on the use and suitability of their products.

Compatibility of sealers is also important, not only with the materials to be sealed but also with adjacent and underlying components of the system. The appearance of certain tile/stone or grout can be affected by sealers. Poor application or poor quality products can darken or change the appearance of the tile/stone or grout. Application (or overspray) of sealers onto non-porous tile, such as porcelain, will result in visible residue or a dripping, wet appearance from sealers that do not absorb (e.g. urethanes or acrylics). Sealant joints, waterproofing membranes and metal are some of the system components, which might be affected by solvents in some formulations.

9.4 NON DESTRUCTIVE TESTING

Non-destructive testing (NDT) is the examination of an object or material with technology that does not affect its future usefulness. NDT is not only useful in that it can be used without destroying or damaging a facade cladding system, but certain techniques can provide accurate evaluation of this type of complex multilayered construction. Because NDT techniques allow inspection without interfering with construction progress and final usefulness, they provide balance between quality assurance and cost effectiveness. NDT incorporates many different technologies and equipment, and can be used to detect internal and external defects, determine material properties and composition, as well as measure geometric characteristics. NDT can be used in any phase of the construction of tile/stone cladding, including materials assessment, pre-construction test area assessment, quality control during progress of installation, and post-installation maintenance. Non-destructive testing of direct adhered cladding currently encompasses the following techniques:

Types of Non-destructive Testing

- Visual and Optical Testing (VT)
- Computer Modeling (Finite Element Analysis [FEA])
- Acoustic Impact Testing
- Thermographic Scanning
- Ultrasonic Testing (Pulse Velocity and Echo [UT])
- Radiography (RT)
- Moisture and Soluble Salt Content Testing

Visual Testing (VT)

As with any type of tile or stone installation, a systematic post-installation maintenance plan should be developed (and ideally implemented) by the design architect or engineer. Whether defects develop from exposure to normal service conditions, or exist from defective installation, they typically are hidden from view and do not manifest as problems until an advanced stage of deterioration or failure. Therefore, it is essential to develop, as a minimum, a systematic plan of visual inspections during pre-construction material and sample evaluation and during construction. Upon completion of the construction, the inspections should continue on a 2–3 year basis. Visual comparisons with reference samples, and observation for obvious signs of distress, (e.g. cracked tile or jointing material, signs of water leakage, etc…), should be accompanied by minimal acoustic impact (tap) testing or thermographic scanning. This will provide a quick, cost-effective qualitative record of installation conditions and serve as the basis for further testing if deemed necessary. In addition to inspecting the condition of the finish material, other critical components of the installation system, such as movement joints, should be inspected and assessed.

Computer Modeling (Finite Element Analysis)

Finite element analysis has been in use for several years as a design and diagnostic method to assist in determining the structural behavior of complex systems like direct adhered exterior cladding or mass transit tunnels. However, only recently has powerful computing technology become more widely available, allowing engineers to consider this design and testing technique as being cost effective.

Acoustic Impact (Tap) Testing

The Acoustic Impact Testing method is a simple and traditional test, born of common sense and necessity, which involves the tapping of finish materials with a hammer or other solid implement (e.g. golf ball). The frequency and damping characteristics of the resulting sound caused by impact can indicate defects such as delamination or missing areas of adhesive. The Acoustic Impact Test is purely qualitative; a solid, sharp, high frequency sound most likely indicates good adhesion, and a dull, reverberant, low frequency sound most likely indicates no contact or hollow areas caused by poor coverage of adhesive mortar. Tap testing only suggests that defects may exist, warranting further investigation using quantitative test methods such as ultrasonic pulse velocity testing. However, a general guideline is that if tapping of a tile/stone installation reveals more than 25% of an individual tile's area sounds hollow, the tile should be replaced, even though it may have functional adhesion. For installations on walls, tap testing is only useful for adhesive systems that require full coverage support and adhesion of the adhesive mortar. This testing system would not be applicable to systems employing spot bonding with epoxy (e.g. LATAPOXY® 310 Stone Adhesive) or silicone adhesives.

Advantages of Acoustic Impact (Tap) Testing

The primary advantage is that tapping is a cost-efficient test; no sophisticated equipment is necessary (a hammer or golf ball is recommended but any hard object will suffice), and the test is easily conducted during the progress of installation or at any point afterwards.

Limitations of Acoustic Impact (Tap) Testing

While tap testing of a large installation system is labor intensive, the primary limitation is the qualitative nature of the test results. Interpretation of soundings is very subjective, and requires experience to discern different sounds which can be influenced by factors such as mass or density of the cladding material, or the location of the defect within the composite installation system. Even with an experienced technician, isolated hollow soundings are not necessarily an indication of a condition that would adversely affect performance. Tap testing is recommended only as a general assessment technique to identify suspect defective areas for further testing using other more accurate and quantitative destructive or non-destructive test methods, such as tensile adhesion pull testing or ultrasonic testing.

Thermographic Scanning

Thermographic scanning, also known as infrared scanning, infrared photography or IR, has been used as a diagnostic technique for many years in other fields such as medicine and the aerospace industry. This technique is used primarily for identifying remote or inaccessible areas of heat loss or gain. Thermographic scanning has been applied in the construction industry for determining heat loss and gain from buildings, detection of water leakage, and more recently, for detection of structural defects in composite systems, such as delamination of tile and stone installations. The basic concept behind thermographic scanning is that all objects emit electromagnetic radiation in the infrared spectrum (invisible to humans). This invisible infrared radiation can be received and converted into electrical signals which are then deciphered as visual images (colors of line contours) which depict the temperature distributions on the surface of an object.

Advantages of Thermographic Scanning

The use of thermographic scanning as a quality assurance and post-installation diagnostic technique for identifying potential defects in mass transit tile systems is highly recommended. This is because the technique is safe, non-destructive, and does not require direct access to the finish material (which is important in testing on floors or walls where repairs may require blocking off large sections of high traffic areas). This makes it a very cost effective and time saving diagnostic method. Thermographic scanning is valuable not only for post installation defect diagnosis, but also as a quality assurance and preventative maintenance tool. Thermographic scanning can identify minor defects hidden from view that, in their present state, do not currently affect safety. These areas can be identified and documented for periodic monitoring and maintenance to prevent further deterioration. The use and results of thermographic scanning can be much more effective and concise if this technique is used to establish a reference thermographic image before construction begins. Sample panels can be constructed both according to specifications and with various defects, and then scanned to establish a reference thermal "pattern" that can be used as a quality assurance technique during and after construction.

Limitations of Thermographic Scanning

This technique has some significant limitations. Thermographic scanning cannot be used to pinpoint exact cause or locations of defects, and cannot quantify the nature of a defect. This method can only be used as a qualitative tool to provide a general assessment of the quality of the adhesion/cohesion of the outer finish layer. The reason is that thermographic scanning can only detect heat flow near the surface of the finish material, and therefore cannot easily detect defects in the underlying substrate. Therefore, thermographic scanning should only be used as an efficient, cost-effective method to identify and isolate potential defects from large areas for further, more conclusive testing using more quantitative methods. Conducting the test and subsequent interpretation of the images of heat flow is affected by many factors and must be made by qualified individuals trained to recognize false influences on thermal infrared images. Thermal images can be affected by factors such as viewing angle and distance of the test from the tile/stone installation as well as by extraneous factors that can affect measurement of heat flow, such as direct solar radiation, escape of internal heat (or cold), climate, air flow, and finish tile or stone texture.

Application of Thermographic Scanning to Exterior Façade or Wall Applications

Thermographic scanning can be used on mass transit facilities where the exterior tile or stone facade is exposed to daily cycles of heating and cooling from solar radiation, as well as changes in ambient air temperature. As the facade is warmed in the day, or cooled at night, heat loss or gain will be uniform through a continuous and homogeneous material such as tile or stone. Thermographic scanning detects potential defects by measuring the conduction of heat through the cladding and underlying wall assembly. Potential defects are identified as those areas where there is internal discontinuity, such as voids, cracks or separation (delamination) of materials. The areas of discontinuity will insulate and impede the conduction of heat across the air space. As a result, the thermal transmittance will be distorted at areas of defects and the temperature will differ from surrounding areas. During the day, this means that defective areas will stay cooler because the cladding (or underlying layers of the wall system) is insulated and does not allow heat to be conducted and absorbed by the underlying wall. Conversely, the loss of heat at night is impeded, and the defective areas will remain warmer than surrounding areas.

Test Procedures and Equipment for Thermography

The following basic equipment is necessary to conduct thermographic scanning:

Thermographic (Infrared) Scanning Equipment

- Infrared (IR) Detector

Processor Unit With Monitor and Recording System

- Interchangeable Lenses
- Tripod or Fixed Mounting (With Swivel Head)

The actual test procedures will vary accordingly with different types of equipment. Generally, the viewing angle should not be greater than 30 degrees from perpendicular to the surface of the cladding. Follow the IR detector's written instructions and contact IR detector manufacturer to answer any questions.

Ultrasonic Pulse Velocity

Ultrasonic Pulse Velocity is commonly used in building construction to identify and quantify structural defects. The basic concept of ultrasonic pulse velocity is that ultrasonic sound waves travel through solid materials at a known velocity (dependent on material density and elastic properties), and changes in velocity and direction can be measured at the interface between different materials. Ultrasonic pulse velocity is typically employed to determine the quality and uniformity of solid materials, such as underlying concrete floors or mortar beds in the case of mass transit facilities. Ultrasonic pulse velocity is used primarily for detection of delamination (loss of bond) or air voids (areas of missing adhesive). This test method can also be used for determining the uniformity of the underlying leveling mortars and concrete structure, as well as for locating cracks hidden from view. The test equipment, which is compact and easy to use, consists of an electronic display/pulse unit, and two transducers. The transducers can be placed for direct transmission through a wall assembly, or placed on the finish material surface for indirect or surface transmission (Figure 9-1).

Figure 9.1 – Ultrasonic pulse velocity equipment.

Advantages of Ultrasonic Pulse Velocity

The Ultrasonic Pulse Velocity method is recommended when accurate, quantitative information on voids, cracking, and delamination of finishes is required. The ultrasonic pulse is introduced locally at the cladding surface, and the sound waves are reflected back at any air voids such as cracks, missing areas of adhesive, or separation (delamination) of the cladding or other components of the wall system. This method can identify exact location, orientation, size and shape of air void defects, and can be used in conjunction with diagnostic tools such as thermographic scanning to locally verify areas with suspected defects.

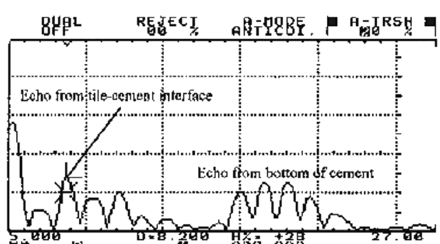


Figure 9.2 Reflected wave over good bonding.

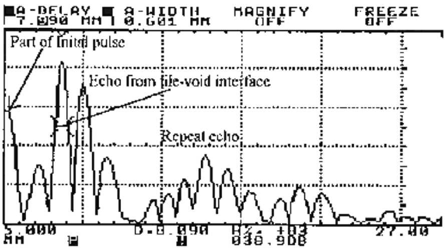


Figure 9.3 – Reflected wave over void.

Limitations of Ultrasonic Testing

The primary limitation is that ultrasonic testing requires direct access and full scale contact to the cladding surface, which makes testing of large areas cost prohibitive. As with thermographic scanning, there are external factors, such as the skill of the test interpreter or surface texture of the finish material, which could falsely influence echoes and be interpreted as improper thickness of adhesive. It is very important to consider that while the presence of voids can be accurately identified, the voids may not necessarily indicate present or potential failure of a tile or stone system. Therefore, the type, size and location of voids must be very carefully analyzed and interpreted to be an effective diagnostic tool.

Future Ultrasonic Test Methods

There are new ultrasonic test methods in development which use lasers to provide remote sensing capabilities of up to 100 meters, but these methods may currently be cost prohibitive for large areas. Current applications are being used for testing of polymer composites in the aerospace industry and in high temperature precision metal part fabrication. With the combination of remote sensing capabilities and accurate quantitative results, laser-ultrasonic testing may prove to be the diagnostic tool that will allow wide acceptance of tile and stone installation systems in the future.

Radiography (RT)

Radiography uses much the same technology as medical x-rays. Penetrating gamma or x-radiation can be directed through a construction component and onto a film located on the opposite side. The resulting shadowgraph shows the internal integrity of construction as indicated by density changes. Radiography in construction is expensive, requires direct access to both sides of an assembly, and requires clearing areas to prevent unwanted radiation exposure. Radiography is used primarily for further evaluation of potential structural defects identified by other less accurate techniques.

Moisture Content Testing

The effects of moisture sensitivity of installation system components, substrates, cladding materials and adhesives have been discussed in detail in this manual. Testing and measurement of the moisture content of materials is a valuable quality control and defect diagnosis technique. There are several test methods and types of equipment used in determining proper moisture content of material and installation assemblies. Test results not only provide valuable information to determine suitability of substrates to receive moisture sensitive claddings, adhesives and waterproofing membranes, but also to diagnose water infiltration or condensation that may have deteriorating effects on any component of a wall or floor assembly. There are basically two methods of testing for moisture content:

- Conductivity Test
- Hygrometer Test

Conductivity testing provides the average percentage of moisture content in a material. The moisture content is the weight of water expressed as a percentage of the dry weight of the material. In hard materials such as concrete or mortar, pins are driven into the material, or holes are drilled and filled with a special conductive gel. An electric moisture meter automatically senses and calculates moisture content. There are different thresholds of acceptable moisture content for different materials. Moisture content is calculated as follows:

$$\frac{\text{wet weight - dry weight x 100} = \text{\% M.C.}}{\text{dry weight}}$$

A heavy material such as concrete, will have a much lower percentage moisture content than a lighter material (e.g. wood) that has the same amount of water within it. This is because, as you can see from the formula, the divisor (dry weight) is a larger number for a heavier material. So a moisture content of 10% for wood is relatively dry, while in concrete 10% is considered damp. An additional problem with percentage moisture content is that the moisture content of building materials can vary through the cross section, meaning that materials can be both wet and dry at the same time (depending upon where the reading is taken. The general rule for percentage moisture content is that readings less than 10% in cementitious materials are safe for application of water sensitive claddings, membranes or adhesives.

Salt Contamination Testing

The presence of soluble salts on a substrate can be evaluated using either chemical testing or proprietary electronic test equipment. The primary reason for detecting the presence of salts is the potential danger of bond failure resulting from continued depletion of calcium that may occur from the formation of efflorescence, and the subsequent strength loss of cementitious materials. The crystallization of soluble salts, especially those that form in the adhesive/cladding interface, can exert more pressure than the volumetric expansion forces caused by ice formation. This mechanism may result in spalling of the cladding material, degradation of the setting bed or bond failure of the adhesive. Salt contamination can also accelerate the setting of cement mortars. Flash setting may result in reduction or failure of adhesive bond strength.

9.5 DESTRUCTIVE TESTING

Tensile Pull Strength Testing

Tensile pull strength testing, also known as pull-off or uniaxial tensile adhesion testing, measures the amount of force required to be applied perpendicular to the cladding plane until failure. Failure may occur at an adhesive interface, or cohesively within a material such as the substrate or the tile/stone; in other words, the adhesive interface is stronger than the material being adhered. Tensile stress in a direct adhered finish is typically considered non-consequential, or, a force rarely if ever applied to a tile installation system. Shear stress parallel to the cladding plane is by far of greater concern. However, buckling or warpage outside of the tile plane caused by thermal or moisture movement can cause tensile failure, and is therefore, a valid qualitative measure of in-service performance. Tensile pull strength testing is a destructive method and can be conducted with a variety of equipment each using slightly different methods.

There are several standards that address tensile pull test methodology;

- International Standard ISO 13007-2 Provides Test Procedures Specific to Ceramic Tile Installations
- European Standards EN 12004 Provides Test Procedures Specific to Ceramic Tile Installations
- British Standards BS 5980 Provides Test Procedures Specific to Ceramic Tile
- ASTM D 4541 "Standard Test Method For Pull-Off Strength of Coatings Using Portable Adhesion Testers"
- American Concrete Institute ACI 503–30 "Field Test For Surface Soundness and Adhesion"

These test methods provide additional information on this type of testing. The most common tensile pull strength test method involves securing a 2" (50 mm) diameter metal disc to the surface to be tested with a two component epoxy resin adhesive. This method will provide pure surface strength of the cladding material. The epoxy typically has significantly greater adhesive strength than the materials being tested. If an adhesive interface below the surface requires testing, it is necessary to isolate the cladding by core drilling or sawing through the finish material. The disc is then attached to a self-contained hydraulic pull tester and a force is applied to the surface until failure (separation) is induced.

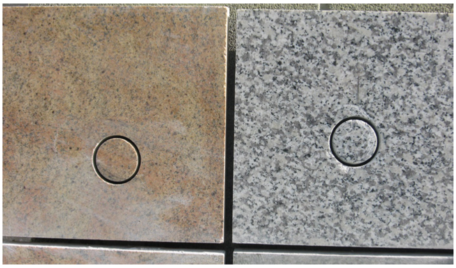


Figure 9.4 – Stone cladding is core drilled in preparation for the tensile pull test.

Figure 9.5 – 2" (50 mm) diameter metal disc to be adhered to the stone surface with a two component epoxy resin adhesive.

Figure 9.6 – Metal disc is held or mounted in place until epoxy resin is cured.

Figure 9.7 – Portable tensile pull testing equipment is attached to the metal disc. Test equipments exerts a "pulling" force on the disc and cored stone section (to the point of failure) to measure its tensile bond strength.

Figure 9.8 – View of cored stone and adhesive section. In this instance, failure occurred at the waterproofing membrane to substrate interface at approximately ~143 psi (1 MPa) (very good results).

Figure 9.9 – View of cored stone remaining on vertical wall surface.

Results are measured and expressed in N/mm^2 or Megapascals (MPa). There are several difficulties in interpreting results from tensile pull testing. First and foremost, the results are best used as a qualitative rather than quantitative assessment of the bond between two materials. Since the effective area of adhesive contact is uncertain, the force required to separate the surfaces may give no clue as to the strength of the adhesive bond at the points where contact does occur. There must be adequate sampling in order to qualify the results. Also, results are reported as force per unit area, and should be interpreted as average stress rather than uniform stress across the contact area. Stress distribution is rarely uniform across an adhesive assembly. Results are also greatly influenced by other factors such as core size or alignment of the test equipment to the surface. Test results are also difficult to interpret because there are no uniform standards for tensile adhesive strength of finish material or of the cohesive strength of plasters or mortars.

European and ISO Norms require minimum tensile pull strength of 0.5 MPa (72.5 psi) to meet the lower classification (C1) and minimum tensile pull strength of 1 MPa (145 psi) to meet the higher classification (C2) for direct adhered cladding. Demanding applications (e.g. mass transit facilities) typically require the higher classification to be reached.

Some standards require as high as 1.5 MPa (218 psi), or as low as .35 MPa (50 psi). For example, transit authorities that have oversight and jurisdiction over their projects will put into place a quality control program which obliges the installation contractor to conduct a specified amount of tensile pull tests which achieve a prescribed minimum threshold.

An important note; tensile pull strength results are not to be confused or compared with shear bond strength commonly provided by tile installation material manufacturers as a measure of adhesive mortar performance with certain tile/substrate combinations. While there is no direct correlation between the two tests, studies have indicated that tensile pull strength is approximately 57% of the direct shear bond strength. One of the benefits of a tensile pull test is that it provides not only a measurement of adhesion strength between materials, but also confirms the quality of the tensile or cohesive strength of the adhered materials (cohesive qualities of adhered materials may be weaker than the adhesive bond between them).

The Portland Cement Association has also determined that the tensile strength of concrete is approximately 8 to 12% of its compressive strength. A tensile pull test conducted over 2,000 psi (14 MPa) compressive strength adhesive mortar should yield results of 160 – 240 psi (1.1 – 1.65 MPa); however, this is only an approximate measure of a cement mortar's cohesive strength. An example is where a pull test induces failure within the cement plaster/render layer. This is very common when high strength cladding and adhesive mortars are employed, only to be sacrificed by a poor quality plaster/render mix and installation. Similarly, a fragile cladding material such as a "young" slate stone will typically fail cohesively along the parallel cleavage plane of the stone during a tensile pull test.

In-situ Shear Bond Strength Testing

The different types of movement presented in Section 2 can cause differential movement parallel to the tile plane. Shear bond strength testing is a common method used to determine the amount of force required to be applied parallel to the plane of the tile surface to induce failure at the adhesive interface. This test is more meaningful than an adhesion or tensile pull strength test because tile/stone installations are exposed primarily to shear stresses. However, tensile testing is also important to gauge resistance to out of plane buckling. Unfortunately, shear bond strength testing is cost effective only as a laboratory test using core samples from mock-ups or the actual construction, and not as an "in-situ" or in service test. While equipment for conducting in-situ shear bond tests exists (hydraulic flat jacks) difficulty remains in configuring equipment to induce stress parallel to the cladding plane. Technology is currently being developed that will create reliable and effective in-situ shear bond testing that will deliver linear and consistent results. In-situ shear bond testing will provide design professionals with information that will help them to more reliably specify tile/stone installations where it may have been questioned in the past.

Core Drilling

This test method involves the use of specially designed electric or hydraulically operated drills with carbide or diamond tipped core drill bits that can extract a core up to 6" (150 mm) in diameter to various depths. Equipment to drill cores up to 24" (600 mm) in diameter are available, but the size and logistics of operating this equipment may be cost prohibitive and does not add any value over smaller diameter cores. The purpose of core drilling may be to visually examine the cross section of an installation assembly for any obvious material or construction defects, to subject the sample to laboratory testing of compressive or tensile strength, or to chemical analysis. Selection of equipment specifically designed for this purpose will prevent percussive damage to adjacent areas and minimize damage from binding. In order to minimize difficult to repair destruction to in-service installations caused by this technique, it is recommended that this test method be employed primarily in evaluating specifically installed test panels in advance of full scale construction.

9.6 TYPES, CAUSES AND REMEDIATION OF DEFECTS

Defects in a tile or stone installation system can generally be classified according to type and location. The type of defect can be either aesthetic or functional. Aesthetic defects affect the appearance of an installation, but do not typically affect the safety. Some aesthetic defects, such as efflorescence, can ultimately lead to functional defects if the fundamental cause is not identified and remedied. Functional defects, such as bond failure, affect appearance and human safety, as well as the integrity and safety of other components of the installation system. Common aesthetic and functional defects are listed below:

Common Types of Defects

Aesthetic Defects

- Staining
- Efflorescence

Functional Defects

- Cracking
- Delamination and Bond Failure
- Movement and Grout Joint Failure

The location of the defect is also critical in evaluation and recommendation of corrective action. A direct adhered installation system consists of three distinct layers:

Locations of Defects

- Tile/Stone Layer
- Adhesive layer
- Substrate or Back-Up Wall Layer

Most common defects can occur at the interface between each layer, or within any of the three layers. Evaluation of these areas hidden from direct view and contact is often one of the most difficult aspects of quality assurance for any tile/stone installation system. Careful analysis of defects is very important, for in many cases, the symptoms manifest in locations other than the point of origin. Cracking and efflorescence are perfect examples, as they typically manifest on the surface of the cladding, yet may originate from poor moisture mitigation detailing and construction.

Staining and Weathering

Staining and weathering are primarily aesthetic defects, although prolonged exposure to weather and certain types of staining, such as that caused by atmospheric pollution or efflorescence, can lead to functional defects and subsequent deterioration or failure of the cladding materials.

Causes of Staining and Weathering

- Water Exposure and Infiltration
- Solar Exposure
- Corrosion of Metal Components
- Biological Growth
- Atmospheric Pollution
- Efflorescence (Soluble Salt Migration)
- Fluid Migration (Adhesives, Sealants)

Corrosion of Metal Components

Concrete reinforcing (rebar) or steel wire mesh is often incorporated into concrete, cement leveling mortars/plasters/renders to help reinforce the component, or to isolate poor surface conditions or incompatible substrate materials. Smooth concrete surfaces, friable surfaces (e.g. cellular CMU (AAC), deteriorated or contaminated surfaces, or substrates which may undergo significant differential movement are examples where wire mesh in mortars should be employed. It is important to note that a corrosion-resistant metal or galvanized coating should be used for both the mesh as well as the fasteners (if required). Corrosion of the fastener is a common mode of failure in wire mesh applications, and can result in staining. Rust staining can also be a symptom of the early stages of failure of structural attachment or the entire tile/stone system.

Efflorescence

Efflorescence is in effect a type of staining. Efflorescence staining is a white crystalline deposit that forms on or near the surface of concrete, masonry, and cement based materials. It is the most common post-installation defect in ceramic tile, stone, and brick systems. Efflorescence can range from a cosmetic annoyance that is easily removed, to a serious problem that could cause adhesive bond failure or require extensive corrective construction and aggressive removal procedures. Efflorescence starts as a salt (present in all portland cement products) which is dissolved by water; the salt solution is then transported by gravity or by capillary action to a surface exposed to carbon dioxide in the air, where the water evaporates and leaves behind the crystalline salt deposit. Efflorescence can also occur beneath the surface or within ceramic tile, stone, or brick units. Occasionally, staining on tile/stone installations, especially on direct adhered facades is misdiagnosed as efflorescence. Vanadium and molybdenum compounds in ceramic tile and manganese compounds in brick can be dissolved by acid cleaning, leaving behind an insoluble deposit. Efflorescence occurs from the occurrence of the three simultaneous conditions listed below. While theoretically efflorescence will occur if one condition does not exist, it is impracticable to completely eliminate the confluence of these conditions in any tile/stone installation. However, the conditions that cause efflorescence can be controlled and the symptoms minimized, to the point where deposits are not visible, or are easily removed and non-recurring.

Causes of Efflorescence

- Presence of Soluble Salts
- Presence of Water (For Extended Period)
- Transporting Force (Gravity, Capillary Action, Hydrostatic Pressure, Evaporation)

Presence of Soluble Salts

There are numerous sources of soluble salts listed in Figure 9.10. There is always the potential for efflorescence when concrete and cement mortars, adhesives and grouts are exposed to the weather or to water. Other sources of soluble salts can be monitored, controlled or completely eliminated.

COMMON SOURCES OF EFFLORESCENCE	
Principal Efflorescing Salt	Most Probable Source
Calcium Sulfate (CaSO4)	Brick
Sodium Sulfate (Na2SO4)	Cement-Brick Reactions
Potassium Sulfate (K2SO4)	Cement-Brick Reactions
Calcium Carbonate (CaCO3)	Mortar or Concrete Backing
Sodium Carbonate (Na2CO3)	Mortar
Potassium Carbonate (K2CO3)	Mortar
Sodium Chloride (NaCl)	Acid Cleaning
Vanadyl Sulfate (VOSO4)	Brick
Vanadyl Chloride (VOCl2)	Acid Cleaning
Manganese Oxide (Mn3O4)	Brick
Iron Oxide (Fe2O3)	Iron In Contact or Brick with Black Core
Iron Hydroxide (Fe(OH)3)	Iron In Contact or Brick with Black Core
Calcium Hydroxide (Ca(OH)2)	Cement

Figure 9.10 – Sources of soluble salts.

Efflorescence – Sources of Soluble Salts

- Hydration of Cementitious Materials (Calcium Hydroxide)
- Calcium Chloride Contamination (Deicing Salts, Sand)
- Mixing Water (Water Softeners)
- Cement Accelerator or Anti-Freeze Admixtures (Calcium Chloride)
- Acid Etching and Cleaning Residue (Chlorides)
- Lime in Mortars (Calcium Sulfate)

Cement Hydration – The most common source of soluble salts is from cementitious materials, such as concrete, cement plasters/renders, concrete masonry units, cement backer board, and cement based mortars, including latex cement adhesive mortars. One of the natural by-products from cement hydration (the chemical process of hardening) is calcium hydroxide, which is soluble in water. If cementitious materials are exposed to water for prolonged periods and evaporate slowly, the calcium hydroxide solution moves with the water to the surface of the installation, reacts with carbon dioxide in the air, and forms calcium carbonate (CaCO3), one of many forms of efflorescence. Once the calcium hydroxide is transformed to calcium carbonate, it is no longer soluble in water, making removal difficult.

Calcium Chloride Contamination – Common sources of soluble salts on exterior mass transit tile/stone installations are deicing salts. Mixing water can also be contaminated with high levels of soluble salts. Figure 9.11 shows the analysis of samples from 6 different city water supplies as compared to sea water. Typically, water with less than 2,000 ppm of total dissolved solids will not have any significant effect on the hydration of portland cement, although lower concentrations can still cause some efflorescence.

TYPICAL ANALYSIS OF CITY WATER SUPPLIES AND SEAWATER							
Parts Per Million							
Analysis #	1	2	3	4	5	6	Seawater*
Silica (SiO_2)	2.4	0.0	6.5	9.4	22.0	3.0	0.0
Iron (Fe)	0.1	0.0	0.0	0.2	0.1	0.0	0.0
Calcium (Ca)	5.8	15.3	29.5	96.0	3.0	1.3	50 - 480
Magnesium (Mg)	1.4	5.5	7.8	27.0	2.4	0.3	260 – 1,410
Sodium (Na)	1.7	16.1	2.3	183.0	215.0	1.4	2,190 – 12,200
Potassium (K)	0.7	0.0	1.6	18.0	9.8	0.2	70 – 550
Bicarbonate (HCO_3)	14.0	35.8	122.0	334.0	549.0	4.1	0.0
Sulfate (SO_4)	9.7	59.9	5.3	121.0	11.0	2.6	580 – 2,810
Chloride (Cl)	2.0	3.0	1.4	280.0	22.0	1.0	3,960 – 20,000
Nitrate (NO_3)	0.5	0.0	1.6	0.2	0.5	0.0	0.0
Total dissolved solids	31.0	250.0	125.0	983.0	564.0	19.0	35000.0
* Different seas contain different amounts of dissolved salts.							

Figure 9.11 – Analysis of city water and seawater samples for soluble salt levels.

Acid etching (see "Removal of Efflorescence")

Lime in Mortars

Unhydrated lime used in leveling mortars/renders contains calcium sulfate, which is a soluble salt. Uncontrolled water penetration through unprotected openings, cracks or incorrectly constructed joints may allow sufficient saturation of lime mortars to dissolve these salts in large quantities. The benefit of the autogenous or "self-healing" qualities of lime mortars has long been the subject of debate in the masonry industry. The very chemical reaction which can seal hairline cracks in lime mortars can also cause efflorescence.

Presence of Water

While you cannot control naturally occurring soluble salts in cementitious materials, proper design, construction and maintenance of exterior installation systems can control and minimize the installation components from water penetration. Without sufficient quantities and periods of exposure to water, salts do not have adequate time to dissolve and precipitate to the surface of an installation, and efflorescence simply cannot occur. Rain and snow are the principal sources of water.

Several wall construction types are designed (barrier, cavity, and pressure equalized rain screen walls) to control or prevent water penetration. Each type of wall is designed to minimize efflorescence by either providing barriers against water penetration, minimizing water contact with potential contaminants, or controlling the flow of water that contacts contaminated materials.

Proper architectural detailing and materials are necessary to help prevent water infiltration. For example, waterproofing, proper pitch to drains, properly placed and installed drains, leaders, and other factors will contribute to quick and easy removal of water. The simple truth is; if there is less water, there is less chance of problems caused by water.

Sealers and Coatings

Water repellent coatings are commonly specified as a temporary and somewhat ineffective solution to fundamentally poor design and/or construction. In some cases, water repellents may actually contribute to, rather than prevent the formation of efflorescence. Water repellents cannot stop water from penetrating the hairline cracks in the surface of cladding, or from penetrating through improperly designed or constructed joints and openings. Water repellents do not prevent water infiltration caused by poor design or construction. As the infiltrated water travels to the surface by capillary action to evaporate, it is stopped by the repellent, where it then evaporates through the coating (most sealers have some vapor permeability) and leaves behind the soluble salts to crystallize just below the surface of the tile or stone. The collection of efflorescence under the water repellent coating may cause spalling of the finish material, or may result in gross accumulation of efflorescence.

Effects of Efflorescence

The initial occurrence of efflorescence is primarily considered an aesthetic defect. However, if the fundamental cause (typically water infiltration) is left uncorrected, continued efflorescence can become a functional defect and affect the integrity and safety of an installation system (e.g. direct adhered façade). The primary danger is potential bond failure resulting from continued depletion of calcium and subsequent loss of strength of cementitious adhesives and underlying cementitious components. The crystallization of soluble salts, especially those that form in the adhesive-cladding interface, or within the cladding material can exert more pressure than the volume expansion forces caused by ice formation. This mechanism may also result in spalling or bond failure.

Fluid Migration

Fluid migration from sealant joint materials is a common source of staining in stone installations. This defect most often occurs with certain types of silicone sealants, but can also be caused by some types of soluble polymers found in mortar additives. This problem is more a function of a manufacturer's formulation than polymer type. There is no correlation with a particular polymer type (i.e., silicone vs. polyurethane), because the problem is typically caused by plasticizer additives and not the polymers. Fluid streaking though, depends on both formulation and sealant polymer type. There are several new generation silicones on the market, (such as LATASIL™) which have specifically addressed and overcome the above aesthetic problems associated with sealants used as both movement joints and fillers between tile and stone.

Fluid migration may also be known as "latex migration" when referring to staining caused by water soluble latex additives. It is recommended to verify that a manufacturer's polymer formulation for a liquid latex additive or a dry redispersible polymer powder is not water soluble. Similarly, all exterior installations of tile or stone which use latex cement adhesive mortars must be protected from significant rain exposure during the initial setting period (typically 12–24 hours). It is during this time when latex polymers may be subject to fluid migration or leaching.

Stain Removal Methods and Materials

Traditional stain cleaning methods for tile or stone installations include washing with water and detergents, and use of mild hydrochloric (muriatic) acid or fluoric acid solutions. Acid cleaning is less desirable today, not only due to environmental and safety concerns, but also due to the lack of skilled labor. As a result, there are several new, less invasive methods available on the market today for removal of efflorescence and staining. Less aggressive chemical cleaning compounds, such as mild ammonium bifluoride cleaning agents, with pH values of 4.5–4.7, are well suited to ceramic tile, stone and brick cladding and have been proven over the past 25 years. These cleaning agents are used in conjunction with high-pressure (1700 psi [120 kg/cm^2]) hot water 180°F (80°C) to achieve maximum cleaning effect. The advantages of high-pressure hot water are the mechanical effect of the water pressure, minimal use of water, quick drying, and the high dissolving power of hot water 180°F (80°C) water, which has 16 times the dissolving power compared to 70°F (21°C) water. Another less aggressive cleaning method, known as "soft" cleaning, was invented over 40 years ago, but only recently has this method been more widely available and cost-effective. These types of systems use proprietary equipment that deliver a very fine, safe powder (limestone and aluminum silicate crystals) at low pressures (60 psi [4 kg/cm^2]). The equipment also reduces the temperature of the compressed air at 200°F (93°C) to condense and separate out any water in the air; no water, chemicals or detergents are used. Proprietary equipment may also include enclosures which contain dust and flush residue. Soft cleaning systems are effective on a variety of soiling, stains, and efflorescence.

Efflorescence Removal Methods and Materials

Prior to removal of efflorescence, it is highly recommended to analyze the cause of efflorescence and take corrective action to prevent reoccurrence. Analysis of the cause will also provide clues as to the type of efflorescence and recommended cleaning method without resorting to expensive chemical analysis.

Determining the age of the installation at the time efflorescence appeared would be an important first step. In buildings less than one year old, the source of the salt is usually from cementitious mortars and grouts, and the source of water is commonly residual construction moisture, rain/snow, or exposure to water in showers, tubs or steam rooms. The appearance of efflorescence in an older building indicates a new water leak or new source of salts, such as deicing salts or acid cleaner residue. Do not overlook condensation within a wall cavity or leaking pipes as a sudden source of water. Also, location of efflorescence can offer clues as to the entry source of water.

Chemical analysis of efflorescence can be conducted by a suitably equipped commercial testing laboratory using x-ray diffraction and petrographic analysis to accurately identify the types of minerals present. This procedure is recommended for buildings with an extensive problem, or where previous attempts to clean with minimally intrusive methods have failed. Removal methods can vary according to the type of efflorescence. Therefore, it is of critical importance to evaluate the cause and chemical composition of efflorescence prior to selecting a removal method. Salts which cause efflorescence are water soluble and may disappear with normal weathering or from dry brushing. Washing is only recommended in warm weather so that the wash water can evaporate quickly and not have the opportunity to put more salts into solution, thereby exacerbating the problem.

Efflorescence which cannot be removed with water and scrubbing will require chemical removal. Using muriatic acid is a conventional cleaning method for stubborn efflorescence, however, even with careful preparation, cladding and grout joints can get etched and damaged. There are less aggressive alternatives to muriatic acid, and several are described in the previous section on stain removal. Other methods use phosphoric acid or sulfamic acids which are less aggressive than muriatic acid. These acids, properly mixed with water (per acid manufacturer's written instructions) should be strong enough to remove stubborn efflorescence without damage to the cladding or grout joint materials. Regardless of the cleaning method selected, the cleaning agent should not contribute additional soluble salts. For example, acid cleaning can deposit potassium chloride residue (a soluble salt) if not applied, neutralized and rinsed properly. Calcium carbonate efflorescence is a type of efflorescence where the calcium salts combine with carbon dioxide in the air and form a hard, crusty deposit which is insoluble in water. However, long term exposure to air and rain water will gradually transform this residue to calcium hydrogen carbonate, which is soluble in water. So long term weathering can help eliminate this type of efflorescence. Unfortunately, if the condition is not acceptable in the long term, and water or mild chemical cleaning proves ineffective, it may be necessary to wash the surface with a dilute solution (5–10%) of hydrochloric (muriatic) acid.

Aqueous solutions of acids are commercially available for ease of handling and prevention of dilution errors. For integrally pigmented grouts, a 2% maximum solution is recommended, otherwise, surface etching will reveal aggregate and wash away color at the surface. Acids should not be used on glazed tiles or polished stone, for the acid solution may etch and dull the glaze or polished surface, or react with compounds in the glaze and redeposit brown stains on the cladding which are insoluble and impossible to remove without ruining the tile. Before applying any acid solution, always test a small, inconspicuous area to determine any adverse effect. Just prior to application, saturate the surfaces with water to prevent acid residue from absorbing below the surface. While most acids quickly lose strength upon contact with a cementitious material, and should not dissolve cement below the surface, saturating the surface is more important to prevent absorption of soluble salt residue (potassium chloride) which then cannot be surface neutralized and rinsed with water. This condition in itself can be a source of soluble salts and allow recurrence of the efflorescence problem intended to be corrected by the acid cleaning. Application of acid solutions should be made to small areas less than 10 ft^2 (1 m^2) and left to dwell for no more than 5 minutes before abrading with a stiff, acid resistant brush and immediately rinsed with water. Acid solutions can also be neutralized with a 10% solution of ammonia or potassium hydroxide.

Functional Defects – Cracking

Cracking is a broad term applied to the distinct separation of a material through its cross section. Cracks may be structural and affect the safety of an installation, or may disfigure the appearance of the installation and allow wind, rain or dirt to penetrate. In a tile/stone installation assembly, cracking may occur in the tile/stone material, in the rigid joint filler material (grout), or in any one of the underlying installation system components hidden from view. In many cases, cracks develop in one component of the assembly, but are transmitted by composite action of the adhered assembly to other components.

Identifying Types and Causes of Cracking

While the mechanisms that cause cracking are quite complex, for purposes of this manual, types of cracking in tile/stone installation systems can be categorized according to the cause of cracking as follows:

- Structural Cracks
- Surface Cracks

Structural cracks are typically the result of fundamental defects in design or construction, or from corrosion of underlying structural concrete reinforcing bars or leveling mortar wire mesh reinforcement. Structural cracking is typically difficult and costly to remedy. These types of cracks are typically wide (over an 1/8" [3 mm]), are not localized at one particular tile or piece of cladding, and usually coincide with structural components or interfaces with adjacent or underlying materials/components of the installation assembly. In most cases, the cause of structural cracking can be identified by first analyzing the mechanisms of different types of structural movement (see Sections 2 and 3). Each type of structural movement manifests in typical locations. Types of structural movement are also associated with typical physical characteristics of cracking. For example, a diagonal crack originating at a corner of a window head and radiating or stepping through joints diagonally (re-entrant crack) would most likely be caused by lack of vertical movement joints to control shrinkage or creep, or by deflection or other structural inadequacy of the window lintel that supports the underlying wall at the window opening.

Physical Characteristics of Structural Cracks

- Geometry – Vertical, Horizontal, Diagonal, Stepped Through Joints, Radiating
- Orientation – Straight, Multi-Directional
- Position – Origin, Termination
- Size – Length, Width

The remedies for structural cracks should focus first on the identification and repair of the fundamental cause of the cracking, and then on the repair of the cracks. For example, removal and replacement of cracked tiles caused by lack of movement joints will not prevent recurrence of cracking if the cause is not corrected. In some cases, localized structural cracking can be repaired without major reconstruction if the cracking was caused by unusual or non-recurring movement. An example could be a seismic event that exceeded the design loads for the structure. The probability of recurrence is low, so repairs to cracking of underlying structural elements could be made with epoxy injection techniques, and the cladding could be locally replaced. Conversely, other situations that cause structural cracking, such as structural movement caused by poor soil composition and compaction, may not be remedied unless the cause of the problem is corrected. Repairs to the tile installation without addressing the cause of the problem can certainly lead to reoccurrence of the same problem.

Surface Cracking

Surface cracking is typically localized cracking that only occurs on the surface of the tile/stone, or in the filler joint (grout) material. These cracks are typically considered as non-structural in origin. Surface cracking can be caused by unintended impact with foreign objects (point loads), defective installation, or from normal weathering and deterioration (e.g. freeze-thaw cycling over a period of time). Surface cracking can also be a minor manifestation of structural movement, such as expansion or shrinkage.

This type of cracking can usually be repaired by simple replacement. In many cases, surface cracking, especially in filler (grout) joint material, poses no safety risk (this should be verified by testing), and the tile or stone may be left in place and behavior of the cracking monitored. While benign cracking may not be a safety risk, it does present other problems such as water infiltration. Water infiltration could lead to sub-surface efflorescence (cryptoflorescence) or spalling, which ultimately may pose a safety risk of bond failure. So neglect of benign surface cracking must be weighed against the risks under certain conditions.

Delamination and Bond Failure

Delamination and bond failure are, in effect, synonymous terms. Technically, there are subtle differences, but for the purposes of this manual, these terms both mean that either the tile/stone adhesive interface, or one of the underlying adhesive/substrate interfaces has physically separated. For vertical applications, this defect is the number one concern and fear of owners, architects, building officials, and construction contractors when considering tile or stone cladding. The result of delamination or bond failure on, for example, a wall is typically pieces or sections of cladding or other components of the wall which fall off and pose a serious risk to public safety. Delamination and bond failure can be categorized as either adhesive or cohesive.

Adhesive bond failure occurs at the interface of the adhesive to the tile/stone or the adhesive to the substrate. In fact, any tile or stone installation material that bonds to a surface (e.g. membranes, self-leveling underlayments, etc…) may lose interface to the substrate which is in effect an adhesive failure; adhesive bond failure does not necessarily have to involve an adhesive). Cohesive failure is a structural failure within a homogeneous material itself, such as a concrete wall surface or a cement render/plaster which separates internally. Bond failure is most commonly caused by defective design or installation, and is rarely caused by defective tile/stone or installation products. Prevention relies on implementation and enforcement of a comprehensive quality assurance program for both design and installation (see Section 9.1 – Quality Control and Assurance). A systematic preventive maintenance program provides an added factor of safety to check any oversights of the quality assurance program and prevent catastrophic bond failure.

Common Causes – Adhesive Bond Failure

- Contaminated Tile/Stone Surfaces
- Contaminated Substrate Surfaces
- Partial Adhesive Coverage
- Improper Setting (Bedding) Pressure
- Improper Mixing/Application of Adhesive
- Improper Specification of Adhesive
- Differential Movement (Shear, Expansion, Shrinkage)

Proper methods and materials to prevent the above defects are described in Sections 2 and 3 – Structural Considerations, Section 2 and 3 – Substrate Preparation, Section 5 Types of Tile/Stone, and Sections 7 and 8 – Types of Mortars/Adhesives and Grouts and Methods of Installation. The following information provides a logical sequence of evaluating the cause of bond failure.

Delamination and Adhesive Bond Failure Evaluation by Location

Failure at the interface between tile/stone and adhesive – Adhesive failure can occur with tile/stone which have smooth backs and which offers little texture to assist in improving mechanical adhesion between the adhesive and tile. Glass tile, pressed porcelain (vitrified) ceramic tile and certain types of stone can fail in this way, especially if the tile/stone has very low or no absorption. High strength adhesives that rely primarily on pure adhesive strength rather than mechanical bond are recommended for extremely dense and impervious material. Adhesive failure is rare with the extruded ceramic tile, or quarry tile/pavers since these types of tile typically have grooves at the back which provide a larger surface area to improve mechanical adhesion with high performance mortars, traditional cement mortars or lower strength latex cement adhesive mortars. Failure at the tile/adhesive interface can also result from dust/contamination on the back surface of the tile/stone, improper adhesive coverage, or poor bedding of the tile into the adhesive. Industry standards for exterior and interior wet area tile/stone installation require 95% adhesive coverage as well as back-buttering

(ANSI A108.5). However, these requirements are difficult to achieve on installations which do not employ proper equipment and quality assurance programs during the progress of installation.

Failure at the interface between adhesive and substrate – All too often the substrate is not properly prepared and does not induce good bond to be formed with the adhesive bedding mortar. This type of failure is more common on dense, smooth substrates with low or no water absorption. Very often dirt, grease, form release agents, curing compounds, or other surface contaminants are responsible for poor adhesion on concrete. In some instances, the substrate is treated to improve the bond between the substrate and the adhesive mortar. Skim/parge coats or slurry/slush coats (i.e. cement/sand slurries with or without latex additive), are sometimes applied to the substrate to improve adhesion of the setting mortar. Skim and slurry bond coats should be applied properly and should either employ a latex additive or be sufficiently cured to achieve adequate hardness and bond strength. Keep in mind that the substrate should be properly prepared to receive the skim coat or adhesion failure can occur as well.

Failure at the interface between cement leveling mortar bed / plaster and adhesive – In many projects where pitch to drain is required, the slab has been recessed, or, the floor or wall requires leveling or repair the substrate often receives a cement mortar bed / plaster before the adhesive mortar is applied. Failure at the mortar & plaster/ adhesive mortar interface is not uncommon. There can be numerous reasons for failure; poor mortar bed/plaster material, poor preparation or poor installation methods. The mortar bed / plaster / render should be of good quality and it should be applied over either a wet latex cement slurry bond coat (for floors), over a hardened rough texture bond coat (for walls – spritz, dash or spatter dash coat), or over a hardened rough texture flat skim coat to provide a mechanical key for the adhesive mortar. Failure between the substrate and leveling bed is not considered a tile/ stone failure, but it leads to failure of the tile/stone and should therefore be installed and prepared properly.

Vertical Applications

Thick layers of cement plaster/render to correct excessive plumb and level tolerance (i.e., bad workmanship) are not uncommon and are responsible for many failures. A single coat of cement plaster/render should be no thicker than 1/2" (13 mm). If a thick layer of leveling mortar is required to level off an uneven surface, the cement plaster/render should be applied in successive lifts (coats), each coat should be cured, scratched and prepared to receive the next coat.

A diamond metal lath (complying with ASTM C847 and ANSI A108.02 3.6) is often incorporated into cement leveling plasters/renders and attached to the structure or back-up wall construction, over a suitable cleavage membrane, to isolate poor surface conditions or incompatible substrate materials. Smooth concrete surfaces, friable surfaces such as cellular CMU (AAC), deteriorated or contaminated surfaces, or substrates which may undergo significant differential movement are examples where metal lath should be employed. It is important that a corrosion-resistant metal or galvanized coating is important for both the lath as well as the fasteners. Corrosion of the fastener is the most common mode of failure in wire lath applications, and can result in failure of any of the tile or installation components, or, the entire wall system.

Corrective Action for Delamination

In most cases, the only remedy to delamination is removal and re-installation of the defective cladding system or components of the cladding system. However, epoxy injection techniques can be employed under certain conditions. First, epoxy injection may be used if the delamination or void is thin and restricted enough so that adequate sealing of the delamination area is feasible in order to allow pressure build-up for proper delivery, distribution and performance of the epoxy. There also must be adequate access to the delamination to allow multiple "ports" or points of injection. Epoxy injection products are typically low viscosity materials used for structural repair of extremely fine hairline cracks. For larger volume repairs, special higher viscosity epoxy gel formulations may be necessary. Contact the manufacturer of the injected epoxy material for more information and for proper usage.

Other Mechanisms of Adhesion Failure

Adhesion failure is usually a result of a combination or confluence of factors and is rarely caused by a single mechanism. Variations in moisture content, variations in temperature, creep of a structure, the use of unsuitable or poor quality installation materials, and poor workmanship may all be contributing factors to a failure. Identification of the origin or fundamental cause of failure is often difficult because the stresses may occur within any component of the system, but the loss of adhesion normally occurs at the weakest interface. For example, a ceramic tile on which the bonding surface has not been cleaned may result in reduced adhesion, but the lack of movement joints may be the actual mechanism that induces stress beyond the capability of the adhesive to bond to the contaminated tile back. It is typically indeterminate whether the dirty tile would have failed if movement joints were constructed properly, or, if the lack of movement joints would have caused the failure even if the tile were cleaned and installed properly. The following dimensional movements are usually involved and they can all act together or in opposition to cause the failure:

Moisture Expansion of Tiles

Reversible expansion and contraction due to wetting and drying of tiles are relatively small and can for all practical purposes be disregarded in this context, except perhaps where large areas are involved or where freeze/thaw conditions exist. The irreversible expansion of ceramic tiles and clay products, referred to as moisture expansion, can be relatively large. This rather slow process takes place over a long period of time and begins the moment the tile leaves the kiln. Tile with a low moisture expansion rate, not more than about 0.03%, should be used for any wet or exterior installations. There have been cases in which tile removed from installations where failure had occurred showed moisture expansion was as high as 7%. Semi-vitrified or fully vitrified tiles have a low moisture expansion and should not fail as a result of moisture expansion of the tile.

Thermal Expansion of Tiles

The thermal expansion of porcelain (vitrified) tiles is relatively small, but when large surfaces are exposed to large temperature differences, significant total and differential dimensional movement can occur, leading to stress. The thermal expansion of glass tiles can be higher than that of ceramic tile, stone or porcelain tile.

Shrinkage of Cement Mortars

Adhesive mortars and cement plasters/renders usually shrink more than the fully cured concrete substrate. To avoid or minimize stresses due to the shrinkage of mortars, it is necessary to use mortars which have low drying shrinkage. This can be achieved by using a proprietary, pre-mixed and bagged mortar powder, both for cement mortars/renders and adhesive mortars. If site mixed mortars are specified, use clean, well-graded sand and a good quality cement. Use a liquid to powder cement ratio which is appropriate for the type of application and environmental conditions. Fine sands which contain a high percentage of clay produce mortars with a high drying shrinkage. Mortars which are rich in cement or have too much gauging liquid added may also experience higher drying shrinkage. Mortars with high drying shrinkage also typically exhibit large dimensional changes during cycles of wetting and drying.

Differential Movements Between Structure and Tile/Stone

All structures creep from the weight (dead load) of the structure, and from imposed live loads, causing shortening or shrinkage of columns and walls, as well as deflection of beams and floors. These movements in the structure induce compressive stresses in adhesive mortars and cladding and are very often a contributing factor towards failure of tile/stone systems (especially vertical systems). Bulging or tenting of the tile/stone from the substrate is a common symptom of differential movement.

Efflorescence or Cryptoflorescence

The primary concern with excessive efflorescence (visible) or cryptoflorescence (hidden) is the potential for adhesive bond failure resulting from continued depletion of calcium and the subsequent loss of strength of the cementitious adhesive and any underlying cement based components. The crystallization of soluble salts, especially those that form at the adhesive/cladding interface, or within the tile/stone material (see sealers and coatings, this section) can exacerbate calcium depletion by exerting expansive stresses. The formation of salt crystals can exert more pressure on the installation than the volume expansion forces caused by ice formation (ice occupies 9% more volume than the volume of the original water). This mechanism may result in spalling of the tile/stone material or adhesive bond failure.

Expansion of Cementitious Materials Due to Sulfate Attack

Reaction between sulfates and aluminates in portland cement can occur in wet environments. This reaction is accompanied by large volume increases which can lead to the disruption of concrete, cement plaster, cement mortar and adhesive mortars and can cause failure at any cementitious interface within the installation system.

Sealant and Grout Joint Failure

Sealants are widely misused and are a common source and cause of defects in tile/stone installation systems, especially at movement or expansion joints. Sealants are a critical bridge at perimeter interfaces between cladding and other installation system components, and at cladding or movement joints, yet they are routinely designed, specified, and installed improperly. It is essential to understand that sealants cannot be relied upon to provide the only means of protection against water and air infiltration, especially in installations where the sealant joint may be the only line of defense. Even with proper back-up protection, compliance with installation guidelines is required to ensure proper elongation and compression without peeling or loss of adhesion (see Section 2 – Movement Joints). Failure of sealant joints, while posing no direct safety risk, will allow water, air, and dirt to infiltrate behind the cladding material. Water infiltration presents several problems, especially in exterior systems:

1. Potential freeze-thaw problems if voids are present
2. Reduction of adhesive strength from long term water saturation
3. Increased probability of efflorescence and staining

A preventative maintenance program should include periodic visual inspection of sealant joints for deterioration, loss of adhesion, peeling, or other defects described in Section 2. Failure (or impending failure) of sealant joints as indicated by extreme compression or elongation is a signal of excessive stress within the tile or stone system and the potential problem of cracking or adhesive bond failure. Joints between cladding that are filled with relatively rigid cementitious grout are often designed to provide stress relief of thermal and moisture movement. This condition is considered normal and does not have any significant effect on the performance of the tile system because the primary purpose of grout joints are to separate and fill the joints rather than to hold the cladding together. Hairline cracking is best minimized by the use of joint materials such as latex portland cement grouts which provide enough resiliency, relative to a more brittle material, to absorb much of the compressive stresses from expansion without crushing, and absorb tensile stresses at the cladding edges from contraction. In most countries, standards and regulations require a minimum grout joint width of 1/4" (6 mm) for joints between cladding to allow the pieces of cladding to move as single or isolated units, rather than monolithic units. Further, and more efficient, isolation of stresses is handled by separating sections of cladding with movement joints. This ensures that the grout or sealant joint will always fail first by relieving unusual compressive stress from expansion before it can overstress the cladding or adhesive interface. The dissipation of stress provides an additional safety factor against dangerous delamination or bond failure. Excessive cracking, deterioration, or fallout of grout material is commonly caused by a combination of several factors:

- Excessive Movement
- Partial Filling of Narrow or Deep Joints
- Improper Installation Practices
- Poor Quality Grout

Grout cracking from excessive movement is primarily a design consideration, and is prevented by following good architectural and structural design practices. Partial filling is prevented by proper joint width to depth ratio, and insuring proper tools and installation practices. Accepted installation practices, including protection against hot, dry conditions, and types of grout mix designs to prevent defects are described in Section 7.4. The TCNA provides a guideline for the proper design, placement and construction of movement joints in the TCNA Handbook for Ceramic Tile Installation, EJ-171.

9.7 ALTERNATIVE TO USING SEALERS

Use a low absorption tile/stone (e.g. porcelain tile, quarry tile, granite) and an epoxy grout (e.g. SPECTRALOCK® PRO Premium Grout† or SPECTRALOCK 2000 IG). These installation system materials never require sealing and can greatly lower the long-term, overall cost usually required to maintain the tile/stone installation.

Section 10: Industry Standards, Building Regulations and Specifications

Camden Town Station, London Underground, London, UK
Architect: London Underground Limited, London, UK

10.1 BACKGROUND

Significant progress has been made on adopting a uniformly accepted building code and industry standards. However, the scope and content of existing standards varies substantially from country to country. Even the best standards for tile/stone applications have had a difficult time keeping pace with new construction adhesive technology and new ceramic tile and stone products available in the marketplace. In many countries, the absence of standards specific to ceramic tile/stone installations requires the adaptation of industry standards for the performance and use of ceramic tile and stone adhesives.

Fortunately, the trend in the United States and other countries is the development of a single model building code. The United States has adopted the International Building Code. This code, has eased the regulatory problems associated with multiple building codes on which thousands of country, state and local jurisdictions base their individual building codes. In addition, the International Standards Organization (ISO) standards for ceramic tile are moving in this direction to create a common global building code.

10.2 SUSTAINABILITY AND MASS TRANSIT

Mass transit infrastructure requires a long life cycle. In many cases, these facilities are being designed and constructed to last over a century and therefore must be supported with first rate building components and installation assemblies. Therefore, service life and product durability should be factored into the selection of mass transit building components. In addition, easily maintainable finish materials (e.g. tile or resinous coatings) should be considered and specified for mass transit projects. Facility maintenance has a direct impact on environmental sustainability. In other words, safe, easy to maintain finish materials in these demanding applications equate to lower maintenance costs, longer life cycles with minimal impact on the environment and the economy. Ceramic tile and stone finishes along with low maintenance epoxy grouting systems are a natural fit for these applications. The use of these finish materials allow for minimal levels of maintenance while providing high quality and durable performance.

Greater emphasis will continue to be placed on the benefits of mass transit based mobility. To this end, an immediate need currently exists in an effort to implement best practices for the construction of sustainable mass transit systems. Many modal and intermodal mass transit systems connect various modes of transportation systems within given communities including, water transit, rail, air, and bus service. These transportation hubs provide passengers with safe travel options to reach their final destination and are becoming the preferred means of travel. In addition, many mass transit centers allow travel minded people convenient access to residential areas, retail shops, hotels and restaurants. Mass transit hubs are often at the center of urban redevelopment projects and are key community components that generate and maintain urban renewal. Proper planning, design and construction of mass transit systems will provide greater impetus for people to choose these alternatives to driving.

Sustainable building products are no longer just an added benefit to product selection and use. In many regions of the world green building codes and other green building practices are mandated for projects that receive federal or government funding. For example, in the United States federally funded projects must comply with green building standards and achieve a designated green rating under the United States Green Building Council LEED program. Therefore, the selection and use of building products that comply with these standards is mandatory. Fortunately, ceramic tile/stone and the installation materials typically fit in very nicely with these requirements. In addition, requirements and standards for the interior environment and other key areas are also set forth. Many finishes and their installation components can off gas volatile organic compounds. These can include chemicals, odors from fibers, or fumes from building materials as they are curing and drying. Many of the building materials used in today's construction methods do contain products that can cause some of the problems mentioned at the outset.

Third party green building certification organizations (e.g. GREENGUARD) help specifiers and designers to choose products that comply with the latest green building standards and codes. Many of the products manufactured by LATICRETE International, Inc. are independently certified by GREENGUARD as low VOC compliant.

LATICRETE product GREENGUARD certificates are available on the LATICRETE web site at www.laticrete.com/green or at www.greenguard.org. LATICRETE has also introduced the LATICRETE LEED Project Certification Assistant to help tile contractors, distributors, architects, and specifiers easily obtain all of the information required for LEED certification. Please visit www.laticrete.com to use this excellent tool.

Background on the Green Building Movement

The term "green" when used in discussions that concern buildings and construction; signifies healthy and environmentally friendly products and buildings. The respiratory and allergic reactions of building occupants can, in many instances, be traced back to the VOC emission of some of the products within the structure. In one study, it was determined that people are indoors approximately 90% of the time. With that in mind, good indoor air quality is vitally important. The design community has long recognized this fact and has inspired federal and state organizations to create programs that are designed to target the issue of indoor air quality. There are literally dozens of programs currently running that have established guidelines to address this issue. For example, note what the State of California EPA had to say on the matter of finish materials and adhesives that contain formaldehyde (a known polluter of indoor air), "One of the most common pollutants found in indoor air is formaldehyde, a carcinogen often emitted by pressed-wood products, adhesives and fabrics. It can cause severe headaches, sensory irritation, nausea, rashes and cancer." In testing, the State of California EPA OEHHA has identified up to 60 hazardous substances, including formaldehyde that are commonly used in buildings. The project specifications for the Capitol Area East End Complex have established maximum modeled indoor air chemical concentrations for those compounds and formaldehyde." (Air Quality Sciences, 2002, p.25). More and more end users and design professionals are recognizing that a healthy building environment is an essential part of the community. Hand in hand with the health issues of our buildings comes the sustainability and quality of building materials used. What does this actually mean? Simply put, sustainability can be defined as how long will the products used in a structure last before they have to be replaced or repaired. For example, how long will the ceramic tile or stone finish last on a wall as opposed to a coat of paint or an application of vinyl wall covering? The health and sustainability issues go hand in hand, since the frequency in which finishes are replaced directly impact the indoor air quality of buildings. Therefore, the use of environmentally friendly and sustainable products makes great sense.

Environmentally Friendly Products

In today's construction marketplace, the phrase 'environmentally friendly product' is thrown around on such a frequent basis, that the term 'green washing' has been coined. Environmentally friendly products are products that do not harm the space that humans occupy, and, do not have any adverse impact on the ecology or environment during their harvesting, manufacturing, installation, curing/drying and while in service. In making the determination for whether a product is environmentally friendly or not; the following questions should be asked:

- Does the Material Break Down Over Time?
- What is the Life of the Product?
- Will It Off-Gas and for How Long?
- How Often Does it Need to Be Replaced?

For example, there are some materials in the plastics family that just do not break down easily. They can stay in landfills for hundreds of years. There are several types of flooring products that fall into this category (e.g. vinyl composition tile, linoleum, rubber flooring). In addition, when these types of flooring materials are installed with a urethane type adhesive; they can be potentially dangerous to the environment for many years when they are discarded. What is great about ceramic tile and stone is that they are mainly composed of basic materials that are found in the earth. There is not much that needs to be done to a slab of marble, limestone, slate, sandstone, granite or quartz; except maybe to alter its finish. That is easily accomplished by polishing the surface to a glimmering mirror like finish or just a bit to a softer honed finish. As far as ceramic tile, the ingredients that go into it are mainly clay and shale that are then pressed or extruded into shape and then fired in high temperatures to achieve a very dense and durable finish. Manufacturers of ceramic tile have become so effective in their production processes, that the cost of ceramic and porcelain tiles is actually coming down, as opposed to the cost of other types of flooring and wall finishes where the costs continue to increase. Therefore, vinyl flooring, carpeting and similar finishes that were considered inexpensive alternatives to ceramic tile and stone are actually at an even greater disadvantage. When a design professional was looking for an inexpensive alternative, they accepted the drawbacks of off gassing and short life cycles associated with these other types of finishes (e.g. vinyl composition tile, linoleum, carpet, rubber, paint, wall covering). They no longer have to compromise since ceramic and porcelain tiles are durable, dense, sustainable, long-lasting (50 years or more) and easy to maintain.

Ceramic tile and stone is also considered environmentally clean. If for any reason tile or stone is removed (and this is usually only because it looks dated), it can be buried in a land fill and will not harm the ecology or the environment. Unlike the adhesive mortars that are used to install resilient and wood floors or carpeting; tile and stone adhesives are typically portland cement based and do not pose any danger to the environment. The vast majority of cement based adhesives are inert once they harden and do not off-gas or emit any volatile organic compounds (VOC).

Volatile Organic Compounds (VOC)

Volatile organic compounds are carbon compounds that participate in atmospheric photochemical reactions which vaporize at normal room temperatures. These compounds are considered as harmful to building occupants when excessive levels are reached. This is what may cause a person to develop reactions to the materials in a building. It is the off gassing of the volatile organic compounds that creates respiratory or allergic reactions. Some of the ingredients in building materials which are considered as a VOC are formaldehyde, styrene, ozone, total aldehydes, and 4-phenylcyclohexene compounds. These ingredients exist in over 2000 chemicals. Ceramic tile/stone and their installation materials have many advantages in the area of low volatile organic compound emission. The LEED Reference Guide for Green Building Design and Construction states that tile adhesives should have a maximum VOC content of 65 g/L less water.

Advantages of Ceramic Tile and Stone

When a comparison is made of the volatile organic compounds contained in floor and wall finishing products, it is obvious to see why ceramic tile and stone is the better finish choice over the others. To demonstrate this fact, compare the following types of finishes and their volatile organic compound content (California Department of Health Services, 2004, p.3, 6, 7):

Ceramic Tile	0.00 grams/liter
Stone	0.00 grams/liter
Resilient Flooring	600 grams/liter
Carpeting (after 24 hours of installation): With polypropylene backing With polyvinyl chloride backing With polyurethane backing	399 grams/liter 602 grams/liter 83 grams/liter
Wood floors treated with a lacquer finish	350 grams/liter
Latex based paint	250 grams/liter (water based)
Vinyl wall covering	400 grams/liter
Fabric wall covering	400 grams/liter

In addition to the finishes mentioned above, the adhesives used for the application of the materials can also contribute to the total volatile organic compounds (TVOC) in a building environment. The following are the typical volatile organic compounds for the flooring and adhesives used for some of finishes listed above.

Ceramic tile and stone installed with a LATICRETE redispersible polymer fortified portland cement based mortar: 0.00 grams/liter Multipurpose carpet and resilient flooring adhesives including a typical carpet or resilient flooring material: Multipurpose latex adhesive 976 grams per liter Synthetic "low V.O.C." adhesive 698 grams per liter When compared against the other types of finishes;

ceramic tile and stone contributes to a healthier building environment. Now manufacturers and promoters of the other finish types will state that the off gassing of the volatile organic compounds will diminish as time passes and that is true to an extent. There have been many strides made to manufacture these types of finishes and adhesives with lower volatile organic compound content. Several of the larger watchdog agencies have set stricter guidelines to ensure that this happens (e.g. South Coast Air Quality Management District). However, these types of finishes are still significantly higher in volatile organic compound content when compared to ceramic tile and stone. In addition, these other finishes do not have the durability and sustainability that ceramic tile and stone has. In fact, carpeting and resilient flooring are typically replaced every six to ten years due to wear and tear. In comparison, ceramic tile and stone has greater sustainability and can last for the entire life of a structure (or longer).

Therefore, in the long run, ceramic tile is actually more economical than other flooring or wall finish materials. The following chart reflects this fact. Chart 1 compares the overall costs (including initial installation cost, maintenance cost per year and life cycle cost) of ceramic tile with other finish materials over a 50 year period. This chart is based on expected life (in years) of 50 years for tile and hardwood, 25 years for laminate, 10 years for VCT, and 6 years for carpet. Actual installations may vary.

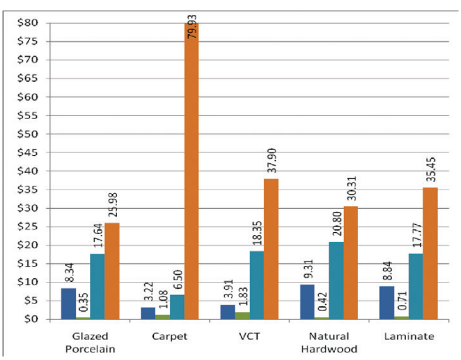


Figure 10.1 – Average costs ($USD) for various finish types based on $1'^2$ (300 x 300 mm) over the expected 50 year life of a tile installation. Source: Tile Council of North America, Tile Is The Natural Choice: Environmental and Cost Evaluation, 2009 TCA Handbook for Ceramic Tile Installation.

Evidence of tile and stone's sustainability is the fact that these finishes have been in place on some structures for hundreds, and in some cases for thousands of years. Can other finish materials make the same claim? Ceramic tile and stone are also good protection against mold and mildew. Tile and stone are not food sources for mold and mildew, whereas many of the other finish types are either made from ingredients that are organic (food sources for mold) or incorporate installation material which are a food source for mold under the right conditions. In addition, ceramic tile and stone are inherently water resistant, whereas these other finish types, absorb and degrade when exposed to moisture, further adding to the mold issue. A building owner certainly would rather have finishes in their structures that are resistant to the threat of mold and mildew. Therefore, ceramic tile and stone is the natural choice to be used as a finish material that will provide long lasting benefits. These benefits include a long in service life cycle, no negative contribution to indoor air quality and are very easy to maintain. When compared to other finish materials, the clear choice is to use ceramic tile and stone as a finish material in today's healthy building environments.

10.3 BUILDING CODES AND REGULATIONS

Building codes are mandatory standards, which either prescribe or set minimum performance criteria for construction in order to protect the health and welfare of the public, and make sure that buildings are constructed to accepted requirements. Building codes are usually conceived by private, non-governmental organizations that have no legal enforcement powers; these powers rest in the local building departments who enact and enforce these standards. Building codes typically are conceived in two distinct formats; a "prescriptive" and "performance". The 2009 International Building Code (IBC) sets forth a level of performance that ceramic tile installations must meet. The IBC references the American National Standards Institute (ANSI) Specification for the Installation of Ceramic Tile for the prescriptive and performance criteria. General Ceramic Tile Building Codes fall under Section 21 Masonry, sub section 2103 Masonry Construction Materials. The ANSI A108 Series deals with the installation methodology of the various products and the ANSI A118 Series deals with the actual product design and minimum performance levels. It is important to remember that the ANSI standards set the minimum performance levels for ceramic tile installation products. Mass transit applications are much more demanding and will require products that exceed the minimum industry standards. The manufacturers of the installation products can provide detailed information on how to achieve maximum performance from the ceramic tile or stone installation for any application (including mass transit). In addition, the 2009 IBC sets forth the substrate and structural design requirements for all applications including the appropriate live, dead, impact, and total load as well as deflection criteria. This information can be found in chapter 16 of the 2009 IBC; Structural Design. It is important to note that the intended use of a given area dictates the structural requirement. In many cases, L/360 is the maximum allowable standard for deflection, total load and impact load for ceramic tile applications and L/720 for stone installations over wood structures as set forth by the Marble Institute of America (MIA). The design professional must take all of the building environment factors in consideration when designing the structure to ensure that the ceramic tile/stone floor and wall areas will stand up to the stresses of the application.

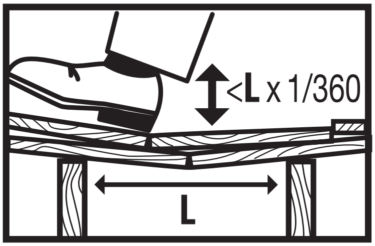


Figure 10.2 – Deflection is the maximum allowable deformation of the substrate under total anticipated weight load that is acceptable before a failure in the tile/stone assembly occurs.

Other applicable standards and regulations for mass transit applications are as follows:

National Fire Protection Association (NFPA) 415-2008 – Standard on Airport Terminal Buildings, Fueling Ramp Drainage, and Loading Walkways, 2008 Edition – Contributes to the improvement of airport safety and specifies the minimum fire protection requirements for the construction and protection of airport terminal buildings including interior finishes. It specifies the minimum requirements for the design and maintenance of the drainage system of an aircraft fueling ramp to control the flow of fuel that can be spilled on a ramp and to minimize the resulting possible danger. In addition it contains the minimum requirements for the design, construction, and fire protection of aircraft loading walkways between the terminal building and aircraft.

10.4 INDUSTRY STANDARDS

Industry standards are methods for the design, specification, construction, and testing of building materials and construction assemblies that are developed by "public consensus" organizations. Industry standards typically are much more comprehensive and concise than building codes, and recognize the latest technology in a given field of construction. As a result, it is common practice today that building codes are based primarily on the industry standards that are developed by specialist public consensus organizations. Examples of such organizations in the United States are the Tile Council of North America (TCNA), the American National Standards for the Installation of Ceramic Tile approved by the American National Standards Institute (ANSI) and the American Society for Testing Materials (ASTM). An example of the standards which are applicable in Europe includes European Union Norms or EuroNorms (EN). The International Standards Organization (ISO) is a global standard concept that is gaining momentum. There are distinct differences between building codes and industry standards. However, for the purposes of this manual, building codes and standards will be presented without distinction between mandatory (legal) or voluntary compliance.

10.5 SAMPLE SPECIFICATION

The following is an example of a typical 3 part CSI Master Format Specification for a ceramic tile/stone application:

10.6 SAMPLE MASS TRANSIT APPLICATION DETAILS

The following index and list of details are examples of typical installations for mass transit ceramic tile and stone applications:

FLOORS:

ES-F101 – Concrete – Bonded Thick Bed Mortar

ES-F102 – Concrete – Thin Bed

ES-F103 – Concrete – Exterior Plaza & Deck System

ES-F111 – Concrete-Slab on Grade or Suspended – Unbonded Thick Bed

ES-F112 – Concrete – Bonded Mortar Bed

ES-F113 – Concrete – Thin Bed with Epoxy Grout

ES-F114 – Concrete – Thick Bed with Epoxy Grout

ES-F115 – Concrete – Thin Bed with Epoxy Grout

ES-F115B – Concrete – Thin Bed with Epoxy Grout and Waterproofing

ES-F205 – Concrete With Cementitious Self-Leveling Underlayment

ES-F121 – Concrete – Unbonded Thick Bed Mortar With Waterproofing

ES-F122 – Concrete – Thin Bed With Waterproofing

ES-F125 – Concrete – Crack Isolation Membrane (Partial Coverage)

ES-F125A – Concrete – Crack Isolation Membrane (Full Coverage)

ES-RH110 – Radiant Heat on Concrete

ES-F133A – Concrete Slab – Chemical Resistant Thin Bed

ES-F134A – Concrete Slab – Chemical Resistant Thick Bed

WALLS:

ES – W201 (I) – Bonded Leveling Bed Over Concrete/ CMU With Lath

ES – W201 (E) – Bonded Leveling Bed Over Concrete/ CMU With Lath and Waterproofing

ES – W202 (I) – Thin Bed Over Concrete/CMU

ES – W202 (E) – Thin Bed Over Concrete/CMU With Waterproofing

ES – W211 (I) – Bonded Leveling Over Concrete/CMU

ES – W211 (E) – Bonded Leveling Over Concrete/CMU

ES – W221 (I) – Lath and Plaster Method Over Concrete/CMU

ES – W221 (E) – Lath and Plaster Method Over Concrete/CMU With Waterproofing

ES – W241 (I) – Lath and Plaster Method Over Steel Framing

ES – W241 (E) – Lath and Plaster Method Over Steel Framing With Waterproofing

ES – W244 (I) – Thin Bed Method Over Cement Backer Board

ES – W244 (E) – Thin Bed Over Cement Backer Board With Waterproofing

ES – W302 – Structural Glazed Block With Epoxy Grout

ES – W260 – Epoxy Spot Bond Method Over Cement Backer Board

ES – W215 – Epoxy Spot Bond Method Over Concrete Masonry Units or Concrete

RENOVATIONS:

ES – TR301 – New Tile or Stone Over Existing Terrazzo Floors

ES – TR302 – New Tile or Stone Over Existing Resilient or Non –Water Soluble Cut Back Adhesive Floors

ES – TR712 – New Tile or Stone Over Existing Ceramic Tile or Stone Floors

ES – TR713(D) – New Tile or Stone Over Existing Ceramic Tile or Stone Walls

MISCELLANEOUS:

ES-S313 – Installation of Tile/stone Over Steel Substrates – Direct Bond – Epoxy Thin Bed Adhesive

ES-S314 – Installation of Tile/stone Over Steel Substrates – Thick Bed (Wire Lath, Plaster and Waterproofing Membrane)

ES-WP300 – Waterproofing Membrane – Typical Pipe Penetration

ES-WP301 – Waterproofing Membrane – Typical Drain Detail

ES-WP302 – Drain Detail – Exploded View

EXPANSION JOINT DETAILS:

EJ171-07 – Movement Joint Design Essentials (Insert all appropriate EJ Details)

EJ-01 – Typical Expansion Joint – Thick Bed Unbonded

EJ-02 - Typical Expansion Joint – Thick Bed Bonded

EJ-03 – Typical Isolation/Expansion Joint – Thin Bed

EJ-04 – Typical Control Joint – Thin Bed

EJ-05 – Typical Perimeter Joint – Thin Bed

EJ-06 – Typical Generic Movement Joint

EJ-07 – Typical Expansion Joint – Thin Bed

EJ-08 – Expansion Joint With Waterproofing Membrane Below Thick Bed

EJ-09 – Control Joint With Anti-Fracture Membrane

EJ-10 – Expansion Joint With Waterproofing Membrane Above Thick Bed

EJ-11 – Expansion Joint With Waterproofing Membrane – Thin Bed

EJ-14 – Cold Joint

EJ-15 – Movement Joint With Waterproofing Membrane – Unbonded Thick Bed

NOTE: For complete application information and limitations consult related Product Data Sheets and Execution Statements related to the following depicted details, and applicable industry standards. Complete execution statements/specifications and details are available at www.laticrete.com/ag

Expansion Joint Details:

EJ-171-09 – Expansion Joint Essentials

Expansion and Control Joints: Provide control or expansion joints as located in contract drawings and in full conformity, especially in width and depth, with architectural details.

1. Substrate joints must carry through, full width, to surface of tile, brick or stone.
2. Install expansion joints in tile, brick or stone work over construction/cold joints or control joints in substrates.
3. Install expansion joints where tile, brick or stone abut restraining surfaces (such as perimeter walls, curbs, columns, etc…), changes in plane and corners.
4. Joint width and spacing depends on application – follow TCA "Handbook for Ceramic Tile Installation" Detail "EJ-171 Expansion Joints" or consult sealant manufacturer for recommendation based on project parameters.
5. Joint width: ≥1/8" (3 mm) and ≤1" (25 mm).
6. Joint width: depth ~2:1 but joint depth must be ≥1/8" (3 mm) and ≤1/2" (13 mm).
7. Layout (field defined by joints): 1:1 length: width is optimum but must be ≤ 2:1.

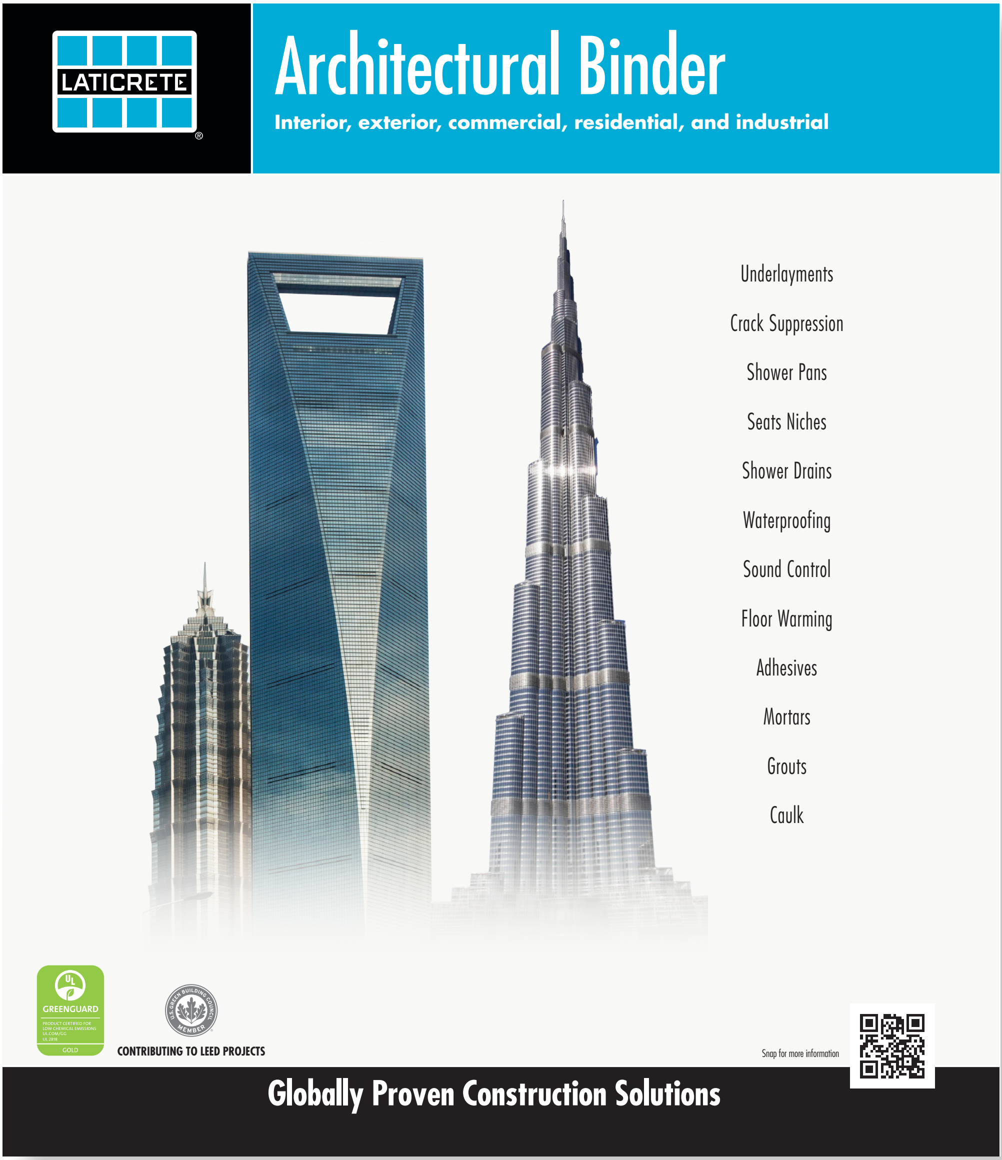
Remove all contaminants and foreign material from joint spaces/surfaces, such as dirt, dust, oil, water, frost, setting/grouting materials, sealers and old sealant/backer. Use LATICRETE® LATASIL™ 9118 Primer for underwater and permanent wet area applications, or for porous stone (e.g. limestone, sandstone etc…) installations. Install appropriate Backing Material (e.g. closed cell backer rod) based on expansion joint design and as specified in § 07920. Apply masking tape to face of tile, brick or stone veneer. Use caulking gun, or other applicator, to completely fill joints with sealant. Within 5–10 minutes of filling joint, 'tool' sealant surface to a smooth finish. Remove masking tape immediately after tooling joint. Wipe smears or excess sealant off the face of non-glazed tile, brick, stone or other absorptive surfaces immediately.

Use the following LATICRETE® System Materials

LATASIL™

LATASIL 9118 Primer

10.7 LATICRETE® ARCHITECTURAL GUIDEBOOK



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Section 11: Appendix

Shanghai Pudong International Airport, Shanghai, China

11.1 GLOSSARY OF CERAMIC TILE AND STONE INDUSTRY TERMS

ABSORPTION: The relationship of the weight of water absorbed to the weight of the dry specimen, expressed in percentages.

ACCELERATORS: Materials used to speed up the setting of mortar.

ACOUSTICAL SEALANT: A sealant with acoustical properties used to seal the joints in the construction of sound rated ceramic tile installations.

ACRYLIC: A general class of resinous polymers used as additives for thin-set mortar and grout. See Portland Cement Mortar or Grout.

ADMIXTURE: A material other than water, aggregates, or hydraulic cement, used as an ingredient of grout or mortar and which is added immediately before or during its mixing.

AGGLOMERATED PRODUCT: A man made stone product generally consisting of either crushed natural marble, natural granite or quartz chips with a matrix of resins and mineral pigments. The product is available in assorted tile sizes as well as large slabs.

AGGREGATE: Granular material such as sand, gravel, or crushed stone, used with a cementing medium to form a hydraulic-cement or mortar.

APRON: Trim or facing on the side or in front of a countertop, table edge or windowsill.

BACK-BUTTER: The spreading of a bond coat to the backs of ceramic tile just before the tile is placed.

BACK WALL: The wall facing an observer, who is standing at the entrance to a room, shower or tub shower.

BACKING: Any material used as a base over which ceramic tile is to be installed. See Substrate.

BENCH MARK: Permanent reference point or mark.

BOND COAT: A material used between the back of the tile and the prepared surface. Suitable bond coats include pure Portland cement, dry-set Portland cement mortar, latex Portland cement mortar, organic adhesive and epoxy mortar or adhesive.

BOND STRENGTH: A bond coat's ability to resist separating from the tile and setting bed. Measured in pounds per square inch (psi).

BOX SCREED: Essentially a box screed is a jig used to apply mortar onto the back side of large-sized ceramic, marble and granite tiles which may vary in thickness, in order to achieve a uniform unit of thickness of the tile and mortar combined.

BUTTONBACK TILE: Tile that has projections on the bondable side. Many of these projections are round and therefore the term "buttonback". Some projections are quite thick and can also be other shapes, such as square.

CAP: A trim tile with a convex radius on one edge. This tile is used for finishing the top of a wainscot or for turning an outside corner.

CEMENT GROUT: A cementitious mixture of Portland cement, sand or other ingredients and water, to produce a water resistant, uniformly colored material used to fill the joints between tile units.

CEMENTIOUS: Having the properties of cement.

CHALK LINE: Usually a cotton cord coated with chalk. The cord is pulled taut and snapped to mark a straight line. The chalk line is used to align spots or screeds and to align tiles.

CHEMICAL RESISTANCE: The resistance offered by products to physical or chemical reactions as a result of contact with or immersion in various solvents, acids, alkalis, salts, etc.

CLEAVAGE MEMBRANES: A membrane that provides a separation and slip-sheet between the mortar setting bed and the backing or base surface.

CLINKER (KLINKER): Red body formed by either the extrusion process or dust pressing. Sometimes referred to as red stoneware. This tile can be glazed or unglazed with a water absorption of 0.7%.

COLD JOINT: Any point in concrete construction where a pour was terminated and the surface lost its plasticity before work was continued.

COLORED GROUT: Commercially prepared grout consisting of carefully graded aggregate, Portland cement, water dispersing agents, plasticizers and color fast pigments.

COMPACTION: The process whereby the volume of freshly placed mortar or concrete is reduced to the minimum practical space usually by vibration, centrifugation, tamping or some combination of these; to mold it within forms or molds and around imbedded parts and reinforcement and to eliminate voids other than entrained air.

COMPRESSIVE STRENGTH: A material's ability to withstand a load measured in psi.

CONDUCTIVE MORTAR: A tile mortar to which specific electrical conductivity is imparted through the use of conductive additives.

COPING: The material or units used to form a cap or finish on top of a wall, pier, pilaster or chimney.

COVE: A trim tile unit having one edge with a concave radius. A cove is used to form a junction between the bottom wall course and the floor or to form an inside corner.

COVE BASE (SANITARY): A trim tile having a concave radius on one edge and a convex radius on the opposite edge. This base is used as the only course of tile above the floor tile.

CRAWLING: A parting and contraction of the glaze on the surface of ceramic ware during drying or firing, which results in unglazed areas bordered by coalesced glaze.

CRAZING: The cracking that occurs in fired glazes or other ceramic coatings due to critical tensile stresses (minute surface cracks).

CREEP: The timed dependent increase in strain of a solid body under constant or controlled stresses.

CURING: Maintenance of humidity and temperature of the freshly placed mortar or grout during some definite period following the placing or finishing, to assure satisfactory hydration of Portland cement and proper hardening of the mortar or grout.

CUSHION-EDGED TILE: Tile on which the facial edges have a distinct curvature that results in a slightly recessed joint.

DASH COAT: A first coat of mortar sometimes applied to a smooth surface with a whisk broom or fiber brush in such a manner as to provide a good mechanical key for subsequent mortar coats.

DOT-MOUNTED TILE: Tile packaged in sheet format and held together by plastic or rubber dots between the joints.

DRY-SET MORTAR: A mixture of Portland cement with sand and additives imparting water retentivity, which is used as a bond coat for setting tile. Normally, when this mortar is used, neither the tile nor the walls have to be soaked during installation.

EFFLORESCENCE: The residue deposited on the surface of a material (usually the grout joint) by crystallization of soluble salts.

ELASTOMERIC: Any of various elastic substances resembling rubber.

EPOXY ADHESIVE: An adhesive system employing epoxy hardener portions.

EPOXY GROUT: A mortar system employing epoxy resin and epoxy hardener portions.

EPOXY MORTAR: A system employing epoxy resins and hardener portions, often containing coarse silica filler and which is usually formulated for mass transit, industrial and commercial installations where chemical resistance is of paramount importance.

EPOXY RESIN: An epoxy composition used as a chemical resistant setting adhesive or chemical resistant grout.

EXPANSION JOINT: A joint through the tile, mortar and reinforcing wire down to the substrate.

EXTRUDED TILE: A tile unit that is formed when plastic clay mixtures are forced through a pug mill opening (die) of suitable configuration, resulting in a continuous ribbon of formed clay. A wire cutter or similar cut-off device is then used to cut the ribbon into appropriate lengths and widths of tile.

FAN OR FANNING: Spacing tile joints to widen certain areas so they will conform to a section that is not parallel.

FLOAT COAT: The final mortar coat over which the neat coat, pure coat or skim coat is applied.

FLOAT STRIP: A strip of wood about 1/4 inch thick and 1-1/4" wide. It is used as a guide to align mortar surfaces.

FLOATING: A method of using a straightedge to align mortar with float strips or screeds. Specialists use this technique when they are setting glass mosaic murals.

FURAN GROUT: An intimate mixture of a Furan resin, selected fillers and an acid catalyst. Fillers are generally carbon, silica or combination thereof into which the acid catalyst, or setting agent, may be incorporated. When combined, the components form a trowelable material for buttering or pointing tile.

FURAN RESIN: A chemical resistant acid catalyzed condensation reaction product from furfural alcohol, furfural or combinations thereof.

FURRING: Stripping used to build out a surface such as a studded wall. Strips of suitable size are added to the studs to accommodate vent pipes, shower pans, tubs or other fixtures.

GLASS MESH MORTAR UNIT/CEMENTITIOUS BACKER UNIT: A backer board designed for use with ceramic tile in wet areas. It can be used in place of metal lath, Portland cement scratch coat and mortar bed.

GRADE: A predetermined degree of slope that a finished floor should have.

GRADES: Grades of tile recognized in ANSI standard specifications for ceramic tile.

GROUT: A cementitious or other type material used for filling joints between tile.

GROUTING: The process of filling tile joints with grout.

GROUT SAW: The grout saw is saw-toothed carbide steel blade mounted on a wooden handle. It is used to remove old grout. It is also used in patching work. Care should be taken as it can easily damage adjacent tiles. The carbide steel blade is brittle and it will shatter if it is dropped or abused.

HARD SCREED: A mortar screed that has become firm.

HORIZONTAL BROKEN JOINTS: A style of laying tile with each course offset one-half its length.

HOT-MOPPED PAN: A type of shower pan made of altering layers of hot asphalt and tarpaper.

IMPERVIOUS TILE: Tile with water absorption of 0.5 percent or less.

IN/OUT CORNERS: Trim tile for turning a right-angle inside or outside a wall corner.

L CUT: A piece of tile cut or shaped to the letter "L".

LAITANCE: A layer of weak and non-durable material containing cement and fines from aggregates, brought by bleeding water to the top of over wet concrete, the amount of which is generally increased by overworking or over-manipulating concrete at the surface by improper finishing or by job traffic.

LATEX-PORTLAND CEMENT GROUT: Combines Portland cement grout with a special latex additive.

LATEX-PORTLAND CEMENT MORTAR: A mixture of Portland cement, sand and a special latex additive that is used as a bond coat for setting tile.

LATH: Metal mesh which acts as a backing or reinforcing agent for the scratch coat or mortar.

LAYOUT LINES: Lines chalked on a substrate to guide in accurately setting tile.

LAYOUT STICK: A long strip of wood marked at the appropriate joint intervals for the tile to be used. It is used to check the length, width or height of the tile work. Common names for this item are "idiot stick" or "story pole".

LEG: A tile wall running alongside a bathtub or abutment. This term is sometimes used to describe a narrow strip of tile floor.

LUGS: Protuberances attached to tiles to maintain even spacing for grout lines.

MARBLE TILE: Marble cut into tiles, usually 3/8" – 3/4" thick. Available in various finishes; including polished, honed and split face.

MASTER GRADE CERTIFICATE: A certificate which states that the tile listed in the shipment and described on the certificate are made in accordance with ANSI A137.1.

MASTIC: Tile adhesives.

MORTAR BED: The layer of mortar on which tile is set. The final coat of mortar on a wall, floor or ceiling is called a mortar bed.

MUD: A slang term for mortar.

NEAT CEMENT: Portland cement mixed with water to a desired creamy consistency. See Pure Coat.

NOMINAL SIZES: The approximate facial size or thickness of tile, expressed in inches or fractions of an inch.

NON-VITREOUS TILE: Tile with water absorption of more than 7.0 percent.

NOTCHED TROWEL: A trowel with a serrated or notched edge. It is used for the application of a gauged amount of tile mortar or adhesive in ridges of a specific thickness.

OPEN TIME: The period of time during which the bond coat retains its ability to adhere to the tile and bond the tile to the substrate.

ORGANIC ADHESIVE: A prepared organic material, ready to use with no further addition of liquid or powder, which cures or sets by evaporation.

PAPER AND WIRE: Tarpaper and wire mesh (or metal lath) that are used as a backing for the installation of tile.

PENCIL ROD: Reinforcing rod with a diameter of no greater than 1/4" (6 mm).

PINHOLES: Imperfections in the surface of a ceramic body or glaze, or in the surface of a grout.

PLASTER: A cementitious material or combination of cementitious material and aggregate that, when mixed with a suitable amount of water, forms a plastic mass or paste which when applied to a surface, adheres to it and subsequently hardens, preserving in a rigid state the form or texture imposed during the period of plasticity; also the placed and hardened mixture.

PLUMB: Perpendicular to a true level.

PLUMB SCRATCH: An additional scratch coat that has been applied to obtain a uniform setting bed on a plumb vertical plane.

POT LIFE: The period of time during which a material maintains its workable properties after it has been mixed.

PREFLOAT: The term used to describe mortar that has been placed and allowed to harden prior to bonding tile to it with thin-set materials.

PSI: Pounds per square inch.

PURE COAT: Neat cement applies to the mortar bed.

RACK: A metal grid that is used to properly space and align tiles.

RAKE OR RAKE LINE: The inclination from a horizontal direction.

RECEPTOR: Waterproof base for a shower stall.

REFERENCE LINES: A pair of lines chalked on a substrate that intersect at 90 degree angle and establish the starting point for plotting a grid of layout lines to guide in accurately setting tile.

RETURN: The ending of a small splash wall or wainscot at right angles to the major wall.

RODDING: A method of using a straightedge to align mortar with the float strips or screeds. This technique also is called floating, dragging or pulling.

ROUGHING IN: The act of preparing a surface by applying tar paper and metal lath (or wire mesh). Sometimes called "wiring".

RUBBER TROWEL: The rubber trowel used for grouting. A nonporous, synthetic rubber-faced float with an aluminum back and wood handle. This trowel is used to force material into tile joints, remove excess grout and form a smooth grout finish.

RUBBING STONE: A carborundum stone that is used to smooth the rough edges on tile.

RUNNING BOND: Stretchers overlapping one another by one-half unit, with vertical joint in alternate courses.

SAG: A term used when a wall surface has developed a slide.

SANDBLASTING: A method of scarifying the surface of concrete or masonry to provide a bondable surface. Compressed air is used to propel a stream of wet or dry sand onto the surface.

SAND-PORTLAND CEMENT GROUT: A site mixed grout of portland cement, fine graded sand, lime and water.

SCARIFY: A mechanical means of roughing a surface to obtain a better bond.

SCRATCH COAT: A mixture of Portland cement, sand and water applied as the first coat of mortar on a wall or ceiling. Its surface usually is scratched or roughened so that it will bond properly with subsequent coats of mortar.

SCRATCHER: Any serrated or sharply tined object that is used to roughen the surface of one coat of mortar to provide a mechanical key for the next coat.

SCREED OR SCREED STRIP: Strips of wood, metal, mortar or other material used as guides on which a straightedge is worked to obtain a true mortar surface.

SCULPTURED TILE: Tile with a decorative design of high and low areas molded into its face.

SEALANT: An elastomeric material used to fill and seal expansion and control joints. This material prevents the passage of moisture and allows the horizontal and lateral movement at the expansion and control joints.

SELF-SPACING TILE: Tile with lugs, spacers or protuberances on the sides that automatically space the tile for the grout joint.

SET-UP TIME: The time adhesive or mortar, spread on a surface takes to cure or harden.

SETTING BED: The layer of mortar on which the tile is set. The final coat of mortar on a wall or ceiling may also be called a setting bed.

SHELF LIFE: The maximum period of time that an item can be stored before it is used.

SHOWER PAN: A waterproof shower floor membrane made from metal, layers of built-up roofing or single or multiple elastomeric membranes.

SILICONE GROUT: An engineered elastomeric grout system for interior use.

SINK ANGLE: Trim shape used on a drain-board at the corners of the kitchen sink. This trim shape, which is AU 106, is also called a "Butterfly".

SLAKE: Allowing the mixtures of mortar, thin-set mortar or grout to stand for a brief period of time after the ingredients have been thoroughly combined and before the final mixing has occurs. Slaking enables the moisture in the mix to penetrate lumps in the dry components, making it easier to complete the mixing procedure.

SLIDE: A fresh tile wall that has sagged. This condition may be caused by excessive mortar, insufficient lime in the mortar or excessive moisture in the mortar. A slide may also result if the surface is slick or if the mortar is too soft.

SLOT CUT: Description of a tile that has been cut to fit around pipes or switch boxes. This tile is usually in the shape of the letter "H" or the letter "L".

SLURRY COAT: A pure coat of a very soft consistency.

SOLDIER COURSE: Oblong tile laid with the long side vertical and all joints in alignment.

SPACERS: Plastic, rubber, wood or rope used in wall or floor installations to separate tiles. Manufactured spacers are available in thickness' 1/16" to 1/2" (1.5 mm to 12 mm).

SPACING MIX: A dry or dampened mixture of one part Portland cement and one part extra-fine sand. This mix is used as a filler in the joints of mounted tile.

SPANDREL: That part of a wall between the head of a window and the sill of the window above it.

SPLASH WALLS: The walls of a tile drain board or bathtub.

SPLIT L CUT: An improper "L" cut that is made by splitting a tile instead of cutting it.

SPOTS: Small pieces of tile placed on a wall or floor surface to align the screeds or setting bed. Spots of casting plaster also may be used.

STANDARD GRADE CERAMIC TILE: Highest grade of all types of ceramic tile.

STATIC COEFFICIENT OF FRICTION (C.O.F.): Slip resistance. The degree of slip resistance presented in a quantitative number that expresses the degree of slip resistance. Slip resistance is evaluated by the horizontal pull method (ASTM C1028). There is no current ANSI requirement. A coefficient of friction of 0.5 and above is the recognized industry standard for a slip resistant floor.

STORY POLE: A measuring stick created for a particular tile installation whose unit of measure is the width of a single tile and grout joint rather than inches. This tool gives tile setters a quick, efficient means of determining how many tiles will fit in a given area and where to position layout lines.

STONED: Use of a carborundum stone to smooth rough edges caused by cutting.

STRAIGHT JOINT: The usual style of laying tile where all the joints are in alignment.

STRAIGHTEDGE: A straight piece of wood or metal that is used to rod mortar and to align tile.

STRETCHER: Trim shapes of tile between trim angles.

STRIKING JOINTS: A process of removing excess grout from the joints by wiping them with a sponge or cloth, or by scraping them with a curved instrument.

STRUCTURAL DEFECTS: Cracks or laminations in the tile body that detract from the aesthetic appearances and/or structural soundness of the installation.

SUBFLOOR: A rough floor – plywood or boards – laid over joists and on which an underlayment or substrate is installed.

SUBSTRATE: The underlying support for ceramic tile installations.

TCNA: Tile Council of North America.

TERRACOTTA: Hard baked tile of variable color and water absorption. Usually unglazed, this product requires a sealer to prevent staining. Used mainly on interior floors. Sometimes referred to as Cotto.

THICK-BED MORTAR: A thick layer of mortar (more than 3/4" (19 mm) that is used for leveling.

THIS-SET: The term used to describe the installation of tile with all materials except Portland cement mortar, which is the only recognized thick-bed method.

3-4-5- TRIANGLE: A triangle with sides in the proportion of 3:4:5, which produces one 90-degree corner. Plotting a 3-4-5 triangle is a method used to establish a pair of square reference lines on a large surface. These lines can be used to determine if the installation site is square and to create a grid of layout lines for setting tile.

TIE WIRE: The 18-gauge galvanized wire used for a variety of purposes in construction work.

TRIM UNITS: Units of various shapes consisting of items such as bases, caps, corners, moldings and angles necessary to achieve installations of the desired sanitary and architectural design.

URETHANE: An elastomeric polymer with excellent chemical and water resistance. Single component (moisture cure) and 2-part (chemical cure) systems are available. Both types may be applies in a fluid state and cure (polymerize) after installation. Typical tile industry applications include sealants, caulks, waterproofing membranes and high performance flexible adhesives.

V-CAP TRIM: V-shaped trim tile used on the front edge of a countertop. The tile's top surface is gently curved upward at the front edge to prevent water from running onto the floor.

VERTICAL BROKEN JOINT: Style of laying tile with each vertical row of tile offset for one-half its length.

VITRIFICATION: The condition resulting when kiln temperatures are sufficient to fuse grains and close pores of a clay product.

WATERPROOFING MEMBRANE: A covering applied to a substrate before tiling to protect the substrate and framing from damage by water. May be applied below mortar beds or directly beneath this-set tiles.

WET AREAS: Tile surfaces that are either soaked, saturated or subjected to moisture or liquids (usually water) such as gang showers, tub enclosures, showers, laundries, saunas, steam rooms, swimming pools and exterior areas.

11.2 RESOURCES GUIDE – TRADE ORGANIZATIONS AND TECHNICAL RESOURCES

Technical Design Manual

Direct Adhered Ceramic Tile, Stone and Thin Brick Facades
Technical Design Manual
Richard Goldberg, Architect AIA, CSI
c/o LATICRETE International, Inc.
1 LATICRETE Park North
Bethany, CT 06524
+1.203.393.0010
www.laticrete.com

Ceramic Tile Materials and Methods

Tile Council of North America, Inc. (TCNA)
100 Clemson Research Blvd.
Anderson, SC 29625
+1.864.646.8453
www.tcnatile.com

Terrazzo, Tile & Marble Association of Canada (TTMAC)
163 Buttermill Avenue, Unit 8
Concord, Ontario, Canada L4K 3X8
+1.905.660.9640
www.ttmac.com

Ceramic Tile Institute of America, Inc. (CTIOA)
12061 Jefferson Blvd
Culver City, CA 90230
+1.310.574.7800
www.ctioa.org

Tile Contractors Association of America (TCAA)
9153 Tahoe Circle
Strongsville, OH 44136-1412
800.655.8453
www.tcaainc.org

National Tile Contractors Association (NTCA)
P.O. Box 13629
Jackson, MS 39236
+1.601.939.2071
www.tile-assn.com

International Masonry Institute (IMI)
BAC/IMI National Training Center
17101 Science Drive
Bowie, MD 20715
+1.410.280.1305
www.imiweb.org

Natural Stone Methods and Materials

Natural Stone Institute (NSI)
380 E. Lorain Street
Oberlin, OH 44074
+1.440.250.9222
www.marble-institute.com
Masonry Institute of America
1315 Storm Parkway
Torrance, CA 90501-5041
+1.310.257.9000
www.naturalstoneinstitute.org

Thin Brick Masonry Materials and Methods

Brick Institute of America (BIA)
12007 Sunrise Valley Drive
Suite 430
Reston, VA 20191
+1.703.620.0010
www.bia.org

National Concrete Masonry Association (NCMA)
13750 Sunrise Valley Dr.
Herndon, VA 20171
+1.703.713.1900
www.ncma.org

Concrete, Pre-Cast Concrete

Portland Cement Association
5420 Old Orchard Rd.
Skokie, IL 60077
+1.847.966.6200
www.cement.org

Pre-cast/Pre-stressed Concrete Institute (PCI)
200 West Adams Street
Suite 2100
Chicago, IL 60606
+1.312.786.0300
www.pci.org

Wire Reinforcement Institute (WRI)
942 Main St.
Hartford, CT 06103
+1.860.240.9545
www.wirereinforcement.org

American Concrete Institute (ACI)
38800 Country Club Dr.
Farmington Hills, MI 48331-3439
+1.248.848.3700
www.concrete.org

Test Standards and Building Codes

American Society for Testing & Materials International (ASTM)
100 Barr Harbor Dr.
P.O. Box C700
West Conshohocken, PA 19428-2959
+1.610.832.9500
www.astm.org

Materials and Methods Standards Association (MMSA)
P.O. Box 350
Grand Haven, MI 49417-0350
+1.616.842.7844
www.mmsausa.com

International Code Council (ICC)
4051 West Flossmoor Rd.
Country Club Hills, IL 60478
888.422.7233
www.iccsafe.org

United States Green Building Council (USGBC)
1015 18th St., NW
Suite 508
Washington DC 20036
+1.202.828.7422
www.usgbc.org

American National Standards Institute (ANSI)
1899 L Street, NW, 11th Floor
Washington, DC 20036
+1.202.293.8020
www.ansi.org

International Organization for Standardization (ISO)
Chemin de Blandonnet 8
CP-401 1214 Vermier, Geneva
Switzerland
+41 22 749 01 11
www.iso.org

National Institute of Building Sciences (NIBS)
1090 Vermont Ave., NW
Suite 700
Washington, DC 20005-4905
+1.202.289.7800
www.nibs.org

Sealants, Waterproofing and Adhesives

Sealant, Waterproofing & Restoration Institute (SWRI)
400 Admital Blvd
Kansas City, MO 64106
+1.816.472.7974
www.swrionline.org

Adhesive & Sealant Council, Inc.
510 King Strewet
Suite 418
Alexandria, VA 22314
+1.301.986.9700
www.ascouncil.org

Cement Plaster/Render

International Institute for Lath & Plaster
P.O. Box 3922
Palm Desert, CA 92260-3922
+1.760.837.9094
www.iilp.org

Expansion Joints

Expansion Joints Manufacturers Association
25 North Broadway
Tarrytown, NY 10591
Fax: 914.332.1541
www.ejma.org

Swimming Pools and Spas
The Association of Pool and Spa Professionals (APSP)
2111 Eisenhower Ave.
Suite 500
Alexandria, VA 22314-4695
+1.703.838.0083
Fax: 703.549.0493
www.apsp.org

Plumbing
American Society of Mechanical Engineers (ASME)
Two Park Ave.
New York, NY 10016-5990
800.843.2763 (USA/Canada)
001.800.843.2763 (Mexico)
973.882.1170 (Outside North America)
www.asme.org