

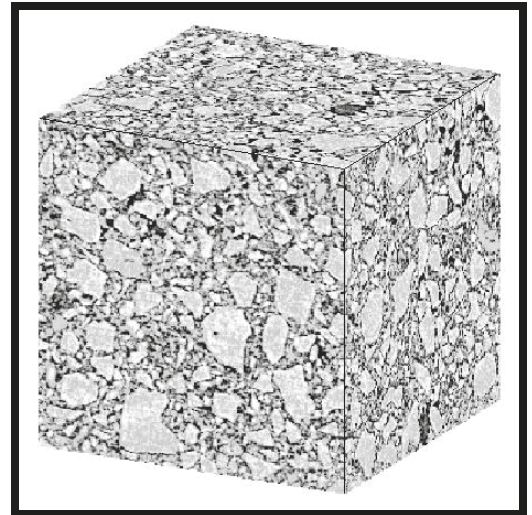
Cement: Types and Usage with Natural Stone

1.0 Introduction: The purpose of this paper is to inform designers and installers using natural stone of key characteristics of cements related to stone installation and assemblies. A second goal of the paper is to educate designers and installers regarding trends in the cement industry that can have significant impacts related to the use of natural stone.

Three trends are occurring today with cements used in natural stone applications that are of interest to designers and installers. The first is a movement toward performance based specifications for cements, mortars and grouts. The second trend is an increase in the use of blended materials and specially formulated products for cements, mortars and grouts. The third trend underway is a movement toward providing improved sustainability with respect to the production, installation and service life of building materials. The use of blended cements, combining recycled with finely ground siliceous (or siliceous and aluminous) materials with portland cements, will continue to increase. Blended cements provide the opportunity to produce a material with a significant recycled material content, as well as lowering the carbon dioxide emissions associated with production of the material.

2.0 Cement Basics

2.1 Composition: Portland cements are a type of hydraulic cement, composed primarily of hydraulic calcium silicates. The word “portland” is a generic term that had its origin in the early 19th century, referring to resemblance of quarried building stone near Portland, England. Hydraulic cements set and harden by reacting chemically with water and will do so under water. The reaction that occurs between hydraulic cements and water is known as hydration. Cement paste is formed during this reaction. When cement paste is combined with aggregates such as sand, gravel, crushed stone or other granular material, it binds the aggregates together. Compositions with a combination of fine and coarse aggregates are known as concrete. Compositions with fine aggregate only, typically sand, are known as grouts or mortars.



This image shows a volume rendering of a cement paste sample. The actual sample is less than one millimeter wide. (NIST image)

2.2 Types of Cement: Cement types are classified by composition in ASTM C150, “Standard Specification for Portland Cement”. Different types of cement are manufactured to meet physical and chemical requirements for specific purposes. Table 1 (see page 2) lists the six classifications of portland cements defined in ASTM C150.1.¹

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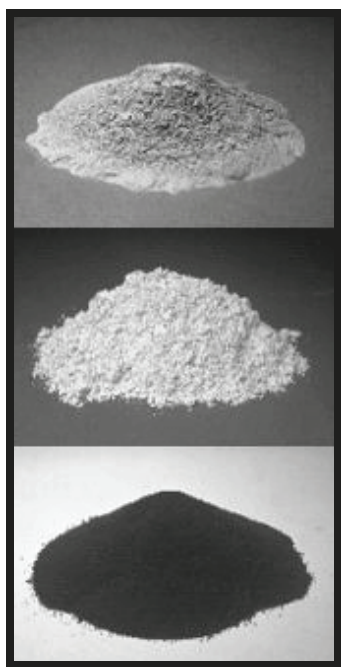
Table 1
Key ASTM Cement Specifications

Cement Specificat	General Purpose	Moderate Heat of Hydration	High Early	Low Heat of Hydration	Moderate Sulfate Resistance	High Sulfate Resistance
ASTM C150 Portland Cement	I	II (MH)	III	IV	II, II (MH)	V
ASTM C595 Blended Hydraulic Cements	IS (<70)	IS (<70) (MH)	-		IS (<70) (MS)	IS (<70) (HS)
	IP	IP (MH)	-	IP (LH)	IP (MS)	IP (HS)
	IT (P<S<70)	IT (P<S<70) (MH)	-	IT (P>S) (LH)	IT (P<S<70) (MS)	IT (P<S<70) (HS)
	IT (P>S)	IT (P>S) (MH)			IT (P>S) (MS)	IT (P>S) (HS)
ASTM C1157 Hydraulic Cements	GU	MH	HE	LH	MS	HS

Type I portland cement is a general purpose cement suited for all uses where the special properties of other types are not required. Type II and Type V portland cements are used where precaution against sulfate attack is important, such as contact with sulfate-bearing soils. Type II is used in applications where moderate sulfate exposure is anticipated, Type V is used where more severe sulfate action is anticipated. Type III portland cement provides higher strength than Type I at an early age, usually a week or less, and is often used in precast operations. It is chemically and physically similar to Type I cement, except that the cement particles in Type III have been ground finer than in Type I and additional calcium sulfate is usually added to control setting time. Type IV portland cement used to be employed where the rate and amount of heat generated from hydration had to be minimized. This characteristic meant that it developed strength at a slower rate than other cement types. It was used in large concrete structures such as dams where the temperature rise resulting from heat generation during hardening must be minimized. The use of Type IV cement has largely been replaced by blended cements, described below in more detail, and specialty concrete mixes for mass pours.²

White portland cement is compositionally similar to Type I or III, and is made in conformance with the ASTM C150 specifications for Type I or Type III. The manufacturing process for white cement is controlled to guarantee the finished product will be white. White portland cement is made of selected raw materials containing negligible amounts of iron and magnesium oxides which are the substances that give cement its gray color. White cement is often used where white grout or mortar is needed. It is required with light colored limestone, marble and onyx. It is also used to manufacture white masonry cement.²

2.3 Blended Hydraulic Cements: Blended hydraulic cements are produced by grinding together two or more types of cementitious raw materials. The primary materials typically used are portland cement, ground granulated blast-furnace slag, fly ash, silica fume, calcined clay, other pozzolans and hydrated lime. A pozzolan is a finely ground siliceous or siliceous and aluminous material, which by itself does not possess cementitious properties, but reacts in the presence of moisture and calcium hydroxide to form compounds with cementitious properties.



From top: Fly ash, Slag Cement and Silica Fume

ASTM C595, “Specification for Blended Hydraulic Cement,” defines three primary classes of blended cements:

Type IS	Portland blast-furnace slag cement
Type IP	Portland-pozzolan cement (Binary)
Type IT	Portland-pozzolan cement (Ternary)

Type IP cements are made with a blend of portland cement and one additional pozzolanic material. Type IT cements are made with portland cement and two additional pozzolanic materials blended with the cement. General purpose cements specified in ASTM C595 carry the designation IS, IP or IT. Other classifications for low or moderate heat of hydration and sulfate resistance are included in ASTM C595; the designations for these are included in Table 1.^{1,2}

2.4 Hydraulic Cement Classified in ASTM C1157, “Performance Specification for Hydraulic Cements”: As discussed earlier, there is a trend toward the use of performance specifications for cement and cement based materials. Historically, cement standards have been defined by material composition. ASTM C595 defines hydraulic cement classification primarily on the basis of material composition. ASTM C1157 de-

fines classification based on performance of the cement. Cement performance is defined using a variety of standardized test methods that evaluate strength, rate of strength development, heat of hydration and sulfate resistance. Cement categories defined in ASTM C1157 are:

Type GU	General Use
Type MH	Moderate heat of hydration
Type HE	High early strength
Type LH	Low heat of hydration
Type MS	Moderate sulfate resistance
Type HS	High sulfate resistance

Cement classifications for ASTM C1157 are illustrated in Table 1.¹

2.5 Masonry and Mortar Cements: Masonry and mortar cements are hydraulic cements designed for use in masonry construction. They are composed of portland cement or blended hydraulic cement and plasticizing materials such as finely ground limestone or lime. Other materials are typically introduced to improve properties such as workability, setting time, water retention and durability. These components are proportioned and packed under controlled conditions at a manufacturing facility to insure uniformity of the material and performance.²

Requirements for masonry cement are included in ASTM C91, “Standard Specification for Masonry Cement.” The specification classifies masonry cements under three types: Type N, Type S and Type M. White masonry cement and colored cements meeting ASTM C91 are also available.

The “Standard Specification for Mortar and Unit Masonry,” ASTM C270, defines specifications for mortars. Mortars, consistent with masonry cements, are classified using Type N, Type S and Type M. Type N mortar is produced using Type N masonry cement. Type S mortar is produced using Type S masonry cement, with Type N following the same pattern. Type N mortar is the most commonly used.

2.6 Water-Repellent Cements: Water-

repellent cements are usually made by adding a water-repellent additive, such as a sodium or aluminum stearate to cement clinker during final grinding. Manufactured in either white or gray color, water-repellent cements reduce liquid capillary water transmission, but do not stop water-vapor transmission. They are used in tile grouts and mortars.²

3.0 Mortars

3.1 Thick Bed Portland Cement Mortars:

Thick bed portland cement mortars for floors are typically composed of a mixture of portland cement and sand. A typical composition for floors includes one part portland cement to three parts sand. For walls, lime is added to the portland cement and sand mix. A typical mixture for a wall application is one part portland cement to five-to-seven parts sand to one half-to-one part lime. Portland cement mortar is suitable for most surfaces and ordinary types of installation. The thick bed, 1" to 1½" on walls and 1¼" on floors, facilitates accurate slopes or planes in the finished work. There are two equivalent methods recognized for installing stone tile with a portland cement setting bed on walls, ceilings and floors;

1. ANSI 108.1A requires that the stone be set on a mortar bed that is still plastic.
2. ANSI 108.1B requires the stone to be thin set on a cured mortar bed with dry set or latex-modified portland cement mortar or a two part, 100% solids epoxy.

Portland cement mortars can be reinforced with metal lath or mesh, backed with membranes, and applied on metal lath over open studding on walls or on rough floors. They are structurally strong, not affected by prolonged contact with water and can be used to plumb and square surfaces installed by others. Suitable backings, when properly prepared, are brick or concrete masonry units, concrete, wood or steel stud frame, rough wood floors, plywood floors, foam insulation board, gypsum board and gypsum plaster (dry interior applications only). Not all substrates are appropriate for all applications. See chapter 13,

"Installation", of the *Dimension Stone Design Manual*, 7.1 for a detailed discussion.

3.2 Thinset Mortar: Thinset mortar is a mixture of portland cement with sand and additives providing water retention. It is used as bond coat for setting stone. In some thinset mortars, calcium-aluminate cements are also used. Calcium-aluminate cement is produced using a specialized kiln process and results in a cement with a high percentage of monocalcium sulfate compared to conventional portland cements. Calcium-aluminate cements can be combined with other materials to provide good workability during installation and rapid strength gain following installation.

Thinset mortar is available as a factory sand mortar to which only water is added. Cured thinset mortar is not affected by prolonged contact with water, but does not form a vapor barrier. Thinset mortar has excellent water and impact resistance, can be cleaned with water, and is non-flammable and good for exterior work. It is not intended to be used in truing or leveling the substrate surfaces as tile is being installed.^{3,4,5}

Thinset mortar is suitable for use over a variety of surfaces. Stone should be properly placed into the mortar, which will be one layer as thin as 3/32" after tamping. When properly prepared and in sound structural condition, suitable backings include masonry, concrete, cementitious backer units, terrazzo, cured portland cement mortar beds, brick, ceramic tile and dimension stone.^{3,4,5}

3.3 Thinset Latex-Portland Cement

Mortar: Latex-portland cement mortar is a mixture of portland cement, sand and latex additives which is used as a bond coat for setting stone tile. Applications for latex-portland cement mortars are similar to those of thinset mortars. Latex-portland cement mortars typically have a lower stiffness than portland cement mortars. They are designed to improve adhesion, reduce water absorption and provide greater bond strength than conventional cement mortars.

Thinset latex-portland cement mortar is suitable for use over a variety of surfaces. Stone should be properly placed into the mortar, which will be one layer as thin as 3/32" after tamping. When properly prepared and in sound structural condition, suitable backings include masonry, concrete, gypsum board (dry interior applications only), cementitious backer units, terrazzo, cured portland cement mortar beds, brick, ceramic tile and dimension stone.^{3,4,5}

3.4 Latex Modified Mortars: The thinset and thinset latex mortars described above typically combine a polymer latex with a mixture of portland or calcium aluminate cement and other additives. Latex is an emulsion: a stabilized suspension of colloidal polymer beads in water. Most latexes have a solids content between 45 and 55 percent. The emulsion is stabilized with six or seven percent water-soluble, nonionic surfactants. Polymer modified mortars commonly use styrene-butadiene and acrylic latex formulations. Typical proportioning for a latex-modified mortar is shown in Table 2.^{6,7}

Table 2
Typical Proportions
Latex-Modified Mortar
(Yields approximately 3 cubic feet)

Ingredient	Amount
Cement	100 lb (45.4 kg)
Sand	290 lb (131.5 kg)
Latex	3.7 gal. (14.1 L)
Water	2.6 gal. (10.0 L)

When properly formulated the use of latex combined with portland or calcium aluminate cement results in a mortar with improved workability during placement, as well as improved durability and bond strength during the service life of the mortar. Both styrene-butadiene and acrylic latex formulations offer these performance advantages when properly formulated and installed.⁶

3.5 Limestone Setting Mortar: Cements used with limestone are white portland cement, complying with ASTM C150, or white masonry cement, complying with ASTM C91 are required per the Marble Institute of America's *Dimension Stone Design Manual*, 7.1, Chapter 13, Section 3.1.5. The Indiana Limestone Institute recommends a setting mortar mixture of one part portland cement, one part lime and six parts sand, or the use of a Type N mortar.

4.0 Grouts

4.1 Sand-Portland Cement Grout: Sand-portland cement grout is mixed on the job site. Typical proportions are:

- For joints up to 1/8 inch wide: one part portland cement to one part clean, fine graded sand (ASTM C144)
- For joints up to 1/2 inch wide: one part portland cement to two parts sand.
- For joints over 1/2 inch wide: one part portland cement to three parts sand.

Up to one part lime-to-five parts sand may also be added.^{3,4,5}

Sand-portland cement grout should be applied with caution over honed or polished stone because it may scratch the stone surface.

4.2 Commercial Portland Cement Grout: Commercial portland cement grouts are produced and blended by a manufacturer and delivered to the jobsite in bags. Liquid components, in addition to water, may be used and added at the jobsite. Commercial portland cement grout is available with sand preblended, or without sand. Other ingredients, such as polymer additives, may be included in the mix composition. These grout mixtures typically produce a dense, water resistant, uniformly colored material.^{3,4,5}

4.3 Polymer Modified Portland Cement Grout: Polymer modified portland cement grout is a mixture of cement based grout with polymer admixtures. The most common polymer types are latex and acrylic. These grouts are designed to be

used in many typical applications, including most commercial installations. The use of polymer additives in grouts can improve the ductility and durability of the grout. It can also reduce the permeability, which can make these grouts less absorptive than regular cement grouts. Polymer modified portland cement grouts are typically produced and blended by a manufacturer offsite, and delivered to the job site in bags. Liquid components, in addition to water, may be used and added at the job site. Polymer modified portland cement grout is available with sand preblended, or without sand.^{3,4,5}

5.0 Discussion and Conclusions: Three significant trends are underway regarding the use of cements in natural stone applications. The first is a movement toward performance based specifications for cements, mortars and grouts. Recent changes to ASTM C150, C595 and C1157 represent a movement toward a performance based approach for cement classification. The goal of performance based classification is to improve quality and consistency of material performance while enabling flexibility in the use of new materials, fostering innovation in material usage and improvements in performance.

The second trend is an increase in the use of blended materials and specially formulated products for cements, mortars and grouts. The increased use of blended cements offers the opportunity to improve product performance, reduce cost and enhance the sustainability of cements by using recycled and economical pozzolans in combination with traditional cements. Preblended mortars and grouts offer advantages in performance, speed and consistency of installation and in-service performance when compared to traditional, site mixed mortars and grouts. The trend of increased use of these materials will continue.

The third trend underway is a movement toward providing improved sustainability with respect to the production, installation and service life of building materials. The use of blended cements, which typically combine recycled and pozzolanic materials with port-land cements, will continue to

increase. Some pozzolans, such as blast-furnace slag, can be classified as a recycled material. Other pozzolans may be able to be combined with cement such that the amount of carbon dioxide produced in production of the blended cement is significantly reduced when compared to the use of a non-blended cement. Increasing the recycled content and reducing carbon dioxide emissions associated with production are both significant environmental benefits.

The trends described above have implications for designers and installers working with natural stone. Designers need to be aware of the material composition of the cements, mortars and grouts they are specifying, and insure that slabs, topping materials, mortars and grouts are compatible. Manufacturer's literature and cement specifications must be checked to insure that materials are compatible and the application is appropriate for the material specified. Installers must know the material composition of the substrate they are working over and follow the appropriate installation guide as well as manufacturer's literature regarding installation. With respect to installation, designers and installers must also be aware of the water absorption and moisture transport properties of slabs over which stone installations are applied. Hard troweling can create very dense surface layers on slabs that absorb very little water. This can create problems with bond on thin set mortars on these very dense, low absor-bency surfaces. Bond testing of the specified mortar over the installed slab should be conducted in these cases.

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