



Standard Guide for Selection of Dimension Stone¹

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INTRODUCTION

Natural stone, while being perhaps the oldest building material known to man, can also be one of the most difficult of all building materials to properly evaluate, select, and specify. Every natural stone product is unique, having its own physical properties and performance capabilities. Responsible stone selection involves extensive and objective evaluation of both the stone material and the application in which it is required to perform.

This guide presents a cursory review of the different stone types commonly used in construction, common applications, available finishes, and factors affecting product costs. It is intended to be used in combination with good judgment, responsible engineering analysis, local building codes, and any other available resources. It is not a “how-to” or a “step-by-step” guide, and has been prepared with the assumption that the user has some familiarity in the use of natural stone prior to utilizing this guide.

Past performance is the best test of a dimension stone’s durability. Yet because the physical properties of a natural stone can vary within a single deposit, even stones with a history of satisfactory performance may need to be tested to ascertain the quality of the current production stock. Common physical property tests include absorption, density, compressive strength, modulus of rupture, flexural strength, abrasion resistance, and anchor strength. Additional tests may also be required depending on the material and application.

In a high proportion of the cases, failure of a natural stone in service is a result of improper application, rather than the inherent properties of the stone. Placing stones in unsuitable environments, faulty fabrication, installation, or construction practices, and incompatible associated materials are frequent causes of stone system failures (for example, high-porosity stones in subgrade applications, inadequate anchorage or expansion space, mortars leaching alkalis, inappropriate strength mortars, staining grouts, voids in setting beds, and pavement stones with inadequate resistance to abrasion).

In selection of natural dimension stone products, the application as well as the aesthetic appeal must be considered. While aesthetics are important to the design, the selection of the proper stone material, thickness, anchorage, and related components is necessary to ensure meeting the performance and durability requirements of the design.

1. Scope

1.1 This guide is intended to be used by architects, engineers, specifiers, contractors, and material suppliers who design, select, specify, install, purchase, fabricate, or supply natural stone products for construction applications.

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1.2 *Consensus Standard*—This guide is an industry consensus standard drafted in a cooperative effort among engineers, architects, geologists, producers, and installers of natural stone.

2. Referenced Documents

2.1 *ASTM Standards*:²

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard’s Document Summary page on the ASTM website.

- C97 Test Methods for Absorption and Bulk Specific Gravity of Dimension Stone
- C99 Test Method for Modulus of Rupture of Dimension Stone
- C119 Terminology Relating to Dimension Stone
- C120 Test Methods of Flexure Testing of Slate (Breaking Load, Modulus of Rupture, Modulus of Elasticity)
- C121 Test Method for Water Absorption of Slate
- C170 Test Method for Compressive Strength of Dimension Stone
- C217 Test Method for Weather Resistance of Slate
- C241 Test Method for Abrasion Resistance of Stone Subjected to Foot Traffic
- C295 Guide for Petrographic Examination of Aggregates for Concrete
- C406 Specification for Roofing Slate
- C503 Specification for Marble Dimension Stone
- C568 Specification for Limestone Dimension Stone
- C615 Specification for Granite Dimension Stone
- C616 Specification for Quartz-Based Dimension Stone
- C629 Specification for Slate Dimension Stone
- C880 Test Method for Flexural Strength of Dimension Stone
- C856 Practice for Petrographic Examination of Hardened Concrete
- C1201 Test Method for Structural Performance of Exterior Dimension Stone Cladding Systems by Uniform Static Air Pressure Difference
- C1242 Guide for Selection, Design, and Installation of Dimension Stone Attachment Systems
- C1352 Test Method for Flexural Modulus of Elasticity of Dimension Stone
- C1353 Test Method for Abrasion Resistance of Dimension Stone Subjected to Foot Traffic Using a Rotary Platform Abraser
- C1354 Test Method for Strength of Individual Stone Anchors in Dimension Stone
- C1526 Specification for Serpentine Dimension Stone
- C1527 Specification for Travertine Dimension Stone
- C1721 Guide for Petrographic Examination of Dimension Stone
- D2203 Test Method for Staining from Sealants

2.2 Provisions of dimension stone handbooks, manuals, and specifications should be reviewed for compatibility with the principles outlined in this guide.

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminology C119.

4. Significance and Use

4.1 *Related Components*—Natural stone is only one component of a building's construction. All related materials and assemblies need to be evaluated to ensure compatible interactive behavior with the stone product.

4.2 *Applicable Codes*—Every stone application shall comply with applicable building codes.

EXTERIOR APPLICATIONS OF DIMENSION STONE

5. Introduction

5.1 Natural stones have long been used and admired for their beauty and permanence. As a natural material, each piece of stone has features and physical characteristics that make it unique. The rich variation in color and texture, as well as its ability to age gracefully in the exterior environment, have made stone one of the most popular materials for construction, sculpture, and monuments.

5.2 Varieties of stone possess certain properties making it suitable for a specific application. Stone geology (mineral content and structure), compressive strength, flexural strength, resistance to absorption and erosion, as well as its ability to be worked, vary widely by stone type. These are all key characteristics that dictate the best use of the material and must be considered during the process of stone selection.

6. Exterior Applications

6.1 There are several major categories of exterior applications for stone; each of these is introduced below.

7. Load-Bearing Masonry

7.1 Load-bearing masonry is perhaps the oldest form of stone construction. Its defining feature is the transferring of structural load vertically by relying on the compressive strength of the stone to support itself and other imposed loads. Due to the weight of the stone itself, structures built in this manner tend to be of limited height. As the height of the structure increases, the wall thickness at the structure's base must increase, thus requiring large individual stones, or multiple wythes of stone. The costs of such walls are typically higher than other systems, due to the large amount of stone and labor involved.

8. Cladding

8.1 In response to the limitations and expense of load-bearing masonry, stone cladding systems were developed. Cladding systems can offer the appearance of load-bearing masonry but without the mass and expense. Cladding systems also offer a wide variety of applications, allowing greater architectural innovation.

8.2 When stone is used as cladding, it is exposed to unique loading characteristics that can require complex structural analysis and detailing in order to be used successfully. Materials other than stone are also often integrated into cladding systems, requiring consideration of their material properties as well as compatibility with the stone components.

9. Building Trim

9.1 Stone has been and continues to be used in architecture to accent other building materials, or to perform a specific purpose. Stone is often integrated into wall systems as decorative belt courses, window sills, lintels, arches, or water tables. Stone can add an element of interest to buildings, in addition to performing as a durable wall component with a specific and well-defined purpose.

10. Pavements

10.1 From cobblestone streets to modern plazas, stone is used to carry vehicle and pedestrian traffic. Modern systems include those bearing on pedestals and traditional sand or cement-based setting bed systems.

10.2 Materials used for steps must have a high resistance to abrasion and provide a surface with adequate slip resistance for public safety. Many varieties of dimension stones, with appropriate finish, will satisfy both of these requirements.

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11.2 Steps are manufactured from dimension stones as “cubic,” in which the tread and riser faces are of one piece of stone, and also “veneered” in which multiple pieces of thin stone material are placed over a concrete or steel frame to form the tread and riser surfaces.

12. Coping

12.1 Wall systems that are fully exposed to the environment, such as roof parapet walls, balcony and terrace enclosure walls, and planter walls, are particularly susceptible to water penetration. Stone coping and wall caps are often used to help protect the underlying wall system from excessive moisture penetration and associated distress.

12.2 Copings and wall caps can also add a visual accent to the wall system, improving the appearance of the wall system by defining changes in the wall configuration.

12.3 Stone copings and wall caps are typically jointed, therefore, protection of the wall system is also reliant on proper treatment of the joints.

13. Roofing

13.1 Roofing applications for natural stone are typically limited to slate, a variety of stone that can be quarried and fabricated into thin, shingle-shaped elements. Dense, nonporous stones can provide a durable, water-resistant roof system that effectively utilizes the unique physical characteristics of the material.

14. Ornamental, Sculpture, and Monumental Elements

14.1 Many varieties of stone possess characteristics that make them a desirable material for sculpting and carving. Most stone varieties can be worked by hand or power tools into unique shapes and representations, including engravings and reliefs. Properly selected stones can demonstrate resistance to environmental effects, thereby providing a sense of permanence to monuments and decorative sculpted items.

INTERIOR APPLICATIONS OF DIMENSION STONE

15. Interior Applications

15.1 Stone is often used at the interior of buildings due to its exceptional durability, beauty, and classical appearance. Due to

the lack of environmental exposure, these applications are usually more forgiving of the material and allow for a broader range of stone varieties to be used. The major categories of interior use are discussed briefly below.

16. Flooring

16.1 Stone floors are typically highly durable, low maintenance, and aesthetically pleasing. When using stone as flooring, one must make sure that the finish is appropriate for its intended use; stone used for flooring should be abrasion resistant and have a finish that is not slippery to foot traffic when wet.

16.2 Joint conditions in floor installations are also critical; while interior flooring is not subject to the same temperature fluctuations as exterior installations, the joint system should include expansion joints that will accommodate cyclic variations in the stone dimensions over time, particularly if there is a substantial heat load from sunlight exposure or below floor-heating elements.

16.3 Stone flooring and the joint materials should also be relatively impervious to moisture; it is not unusual for interior floors to be cleaned with water and detergents on a daily basis. Excessive moisture in the flooring system can lead to discoloration of the joint materials and the stone, particularly if the stone flooring material is absorptive. Moisture can become trapped below highly polished finishes and appear as a stain. Some stone types used as flooring may need to be treated at the edges and bottom surface as well as the top surface to limit absorption-related concerns. However, component compatibility should be researched or tested prior to treating these surfaces to inhibit bond performance between the stone, adhesive, and grout. Only cleaning procedures and products (including waxes and cleaning agents) that are approved for use by the stone supplier should be used. Unapproved methods may stain or damage the stone or damage the stone finish.

17. Stairs

17.1 The use of stone for stair treads and risers leads to an attractive, durable, and low maintenance way to address interior elevation changes. Stone selected for stairs should be able to withstand constant foot traffic with minimal surface abrasion, erosion or damage. It should also be naturally slip-resistant due to the stone type or the finish selected.

18. Cladding

18.1 Stone used as interior wall cladding should be designed and installed in a similar manner to exterior wall cladding; however, loading considerations are different with an interior application. When considering stone anchorage options for an interior application, one should include (at a minimum) a nominal differential pressure on interior stone resulting from variations in building pressurization due to mechanical system performance and air loss through the building enclosure; however, it is likely that seismic requirements will control an interior application when compared to the comparatively low lateral loads generated from building pressurization.

19. Ornament and Sculpture

19.1 Stone used as decorative elements in an interior application have the distinct advantage of not being exposed to environmental forces such as temperature fluctuations, wind, water, and atmospheric pollutants. Therefore, the variety of stone suitable for interior applications can include many stone types that would otherwise not be appropriate due to their reduced resistance to environmental forces.

20. Wet Areas

20.1 Stone panels and tiles are commonly used for shower stall linings, urinal screens, and toilet partitions. Proper attention to water flow, waterproofing, corrosion resistance of attachment hardware, and base material is as critical in these applications as it would be in an exterior application.

21. Furnishings

21.1 Stone is widely used for countertops in kitchens, wet bars, and bathrooms. Normally, stone with lower absorption properties are recommended, though virtually any stone can be used if properly treated with impregnating repellents for exposure to moisture. Such repellents may alter the color or gloss levels of the stone surface, and typically have a reapplication interval specified by the manufacturer. While repellents will offer some degree of protection against moisture and staining, they will not protect acid sensitive stones against etching due to acid exposure.

21.2 Stone can also be used for table tops and table supports. Flexural strength is critical in these applications, along with consideration of the additional load to the floor structure from stone furniture when compared to other materials commonly used.

COMMON DIMENSION STONE TYPES

22. General

22.1 By strict geological definitions, hundreds of rock types are used as dimension stones. The commercial definitions of these rock types are much broader, allowing materials with similar performance and behavioral characteristics to be grouped together. Therefore, stones of different scientific geological definitions will be included in the same commercially-defined group. Using these broad commercial definitions, most materials used as dimension stone will fall under one of seven classifications: Granite, Marble, Limestone, Quartz-Based, Slate, Serpentine, or Travertine.

22.2 The finish applied to a stone may have more bearing on its suitability for use than the type of stone. While polished or honed surfaces are often used for cladding materials, these finishes are not recommended for walking surfaces because they do not demonstrate the frictional properties necessary for safe pedestrian ambulation. Refer to Section 43 for more detailed discussions of finish types.

22.3 Most dimension stones are known by an industry trade name. In many cases, a particular stone will be given different trade names by different fabricators or brokers. Therefore, the trade name alone may not be adequate to identify the selected

material. Including the origin (quarry location) and quarry owner in the specification will help minimize confusion in material identification.

22.4 For major projects, sufficient inventory of block material is rarely available at any one fabricator's facility. Supply of raw block material from the quarry to the fabricator will usually occur concurrently with fabrication throughout the duration of the project. The production capacity of the quarry, in addition to any transportation difficulties must be carefully evaluated to ensure uninterrupted delivery of material throughout the project's construction.

22.5 Quarries of all dimension stone types will have unique capabilities and limitations. Natural fissures and fracture planes in the quarry will limit available piece size and yield. The supplier of the material must be consulted during the design phase of the project to ensure that the project requirements can be satisfied by the specified material. Specific grades (for example, select, monumental, structural, architectural, quarry-run, clear, variegated) may be identified in the material to further define the color range or clarity of the stock quality.

22.6 Fabricators of natural stone products use a variety of machinery from worldwide sources. The stone products themselves exhibit vastly different strength and workability properties, as well as widely varying availability of raw stock sizes and qualities. As a result of these variables in product and machinery, there is less standardization of stone product offerings and sizes than are typically found in the supply of other construction components. The thicknesses of the stone slabs will generally adhere to standard offerings, and detailing materials to correspond with recognized industry standard slab thicknesses will benefit the project in both economy and delivery. Table 1 lists common slab thickness found in the dimension stone industry, with a brief description of the applications in which they are typically employed.

SPECIFIC DIMENSION STONE TYPES

23. Granite

23.1 Commercially, "granite" includes any visibly granular, igneous rock consisting mostly of feldspars and quartz, and accompanied by one or more dark minerals. Typically, feldspar is the most abundant mineral found in granites and, because of this, the color of the granite is largely governed by the color of this mineral. The color can be modified by quartz, hornblende, mica, or any other mineral in significant quantity. Granites are available in a wide array of colors including pink, gray, white, red, black, brown, buff, green, and blue. Dark granular igneous rocks, classified petrographically as gabbro, anorthosite, basalt, or diabase, are also included in the granite group and often referred to as "black granites".

23.2 The majority of materials in the granite group are granular or crystalline in appearance, with the grain size varying between 2 or 3 mm up to 25 mm or larger. Some of the materials included in the granite group will show a layering, or plate-like structure, due to recrystallization, folding, or other changes while the rock was in a plastic or semi-molten state. Such metamorphic rocks are called granite gneisses.



TABLE 1 Common Thickness and Application Chart

Thickness	Granite	Marble	Limestone	Quartz-Based	Slate	Serpentine	Travertine
5 mm ($\frac{3}{16}$ in.)	Not offered, except as veneers with a reinforced backer	Not offered, except as veneers with a reinforced backer	Not offered, except as veneers with a reinforced backer	Not offered, except as veneers with a reinforced backer	Used as roofing slate, also some thin-set tiles supplied in 6 mm ($\frac{1}{4}$ in.) thicknesses.	Not offered, except as veneers with a reinforced backer	Not offered, except as veneers with a reinforced backer
10 mm ($\frac{3}{8}$ in.) 13 mm ($\frac{1}{2}$ in.)	"Thin-set" tiles for interior use only	"Thin-set" tiles for interior use only	Thin-set" tiles for interior use only	"Thin-set" tiles for interior use only	"Thin-set" tiles for interior use only. Also commonly used for blackboards and countertop inserts. 13 mm & 15 mm materials are also used as flooring, baseboard, thresholds, and furniture applications	"Thin-set" tiles for interior use only	"Thin-set" tiles for interior use only
20 mm ($\frac{3}{4}$ in.)	Interior flooring, interior walls, countertops	Interior flooring, interior walls, countertops	Interior flooring, interior walls, countertops	Interior flooring, interior walls	Used as interior flooring, baseboard, window stools, hearths, interior wall veneer, and countertops	Interior flooring, interior walls, countertops	Interior flooring, interior walls, countertops
25 mm (1 in.)	Not generally used	Not generally used	Not generally used	Not generally used	Common thickness for flooring, window stools/sills, treads & risers, wall caps, hearths & mantels, countertops, and sanitary partitions.	Not generally used	Not generally used
30 mm ($1\frac{1}{4}$ in.)	Interior Walls and Countertops. Considered the minimum thickness for exterior applications, horizontal or vertical, although design loads may require thicker material.	Interior Walls and Countertops. Considered the minimum thickness for exterior applications, horizontal or vertical, although design loads may require thicker material.	Used in interior flooring applications or limited vertical application in higher density limestones, countertops	Generally the minimum thickness available for interior flooring or exterior pavement.	Interior Walls and Countertops. Considered the minimum thickness for exterior applications, horizontal or vertical, although design loads may require thicker material.	Interior Walls and Countertops. Considered the minimum thickness for exterior applications, horizontal or vertical, although design loads may require thicker material.	Interior Walls and Countertops. Considered the minimum thickness for exterior applications, horizontal or vertical, although design loads may require thicker material.
40 mm ($1\frac{5}{8}$ in.)	Used in exterior cladding applications when design loads marginally exceed capacity of 30 mm	Used in exterior walls & pavements	Commonly used thickness for interior flooring & wall veneer in high-density limestones.	Not commonly used	Exterior cladding	Used in exterior walls & pavements	Used in exterior walls & pavements



TABLE 1 Continued

Thickness	Granite	Marble	Limestone	Quartz-Based	Slate	Serpentine	Travertine
50 mm (2 in.)	Used in Exterior cladding applications when necessitated by pavement, design loads, spans, or flexural strengths. Also used when reveals are machined into stone face.	Commonly used in exterior walls or pavement.	Generally the minimum thickness used for any application of low or medium density limestone. Also the minimum thickness for exterior applications of high-density limestone.	Used in flooring & pavement applications. Used in limited cladding applications with small panel sizes and modest design loads.	Slate slabs are generally available in several increments in this range – Thickness of 38, 45, 50, 57, 63, & 70 mm (1½ in., 1¾ in., 2 in., 2¼ in., 2½ in., & 2¾ in.) can be obtained from most fabricators. These thicknesses are used for exterior cladding, treads, & coping.	Commonly used in exterior walls or pavement.	Commonly used in exterior walls or pavement.
80 mm (3 in.)	Used in exterior cladding when extremely large piece sizes are used, or when deep reveals are cut into stone face. Also used in exterior pavement subjected to passenger vehicle traffic. Commonly used in exterior window sill applications.	Thickness greater than 50 mm in Marble are referred to as “cubic” material. These thicknesses are generally applied in monument, sculpture, or decorative work, and are not normally offered as a “standard” thickness	Common thickness for exterior cladding applications, although design loads, spans, or material strengths may dictate thicker panels. Also commonly used in coping & sill applications	Common exterior cladding thickness	Used for copings, and also for cemetery markers.	Thickness greater than 50 mm in Serpentine are referred to as “cubic” material. These thicknesses are generally applied in monument, sculpture, or decorative work, and are not normally offered as a “standard” thickness	Thickness greater than 50 mm in Travertine are referred to as “cubic” material. These thicknesses are generally applied in monument, sculpture, or decorative work, and are not normally offered as a “standard” thickness
100 mm (4 in.)	Used in Landscape or Sitework applications such as copings & fountains		Used in exterior cladding when required to meet design loads or because of decorative reveals machined into stone face.	Used as coping, water tables, and belt courses – often will be supplied as 125 mm (5 in.).	Cubic material is available from slate producers, although not frequently used.		
150 mm (6 in.)	Used in Landscape or Sitework applications such as curbs, copings, steps, & fountains		Slab thickness greater than 100 mm are not considered “standard”, but are available on a project-specific basis for ornamental or sculpture type work. Also found in classical architectural detailing.	Used as coping, water tables, belt courses, steps, & curbs			
200 mm (8 in.)	Used in Landscape or Sitework applications such as curbs, copings, steps, & fountains			Referred to as “Cubic” material, these thicknesses are available on a job-specific basis for ornamental, landscape, and rustic applications.			
Greater than 200 mm (8 in.)	These thicknesses are not considered “standards”, but are available on a project-specific basis for sculpture, ornamental or monumental type applications						

23.3 Granites with uniform mineral distribution will show remarkable homogeneity within the quarry and will have minimal variation of color, texture, or veining pattern from block to block. Other granites will display considerable color variation between blocks, or even within one block.

23.4 Some granites are nearly isotropic, meaning that they have similar appearance and performance characteristics regardless of the direction the material is cut. More commonly, a granite will demonstrate some degree of anisotropic behavior, ranging from mild to pronounced. Such granites frequently require sawing in a specific direction in which to obtain the required visual and performance properties.

23.5 Granite materials are used in a variety of architectural, memorial, and industrial dimension stone applications. A list of common applications follows:

Architectural:

Exterior cladding/curtainwall

Interior cladding

Exterior paving

Interior flooring

Furniture & countertops

Curbs

Steps

Retaining walls

Coping

Window sills/stools

Memorial:

Monuments/Markers

Mausoleums

Industrial:

Picking tanks

Surface plates/Precision machine bases

Paper press rolls

23.6 The physical properties of granite are determined in accordance with a variety of ASTM test procedures. Minimum and maximum values for the material's physical requirements are listed in Specification **C615**.

24. Marble

24.1 Geologically, marble is a metamorphic rock resulting from recrystallization of limestone. Within this geological definition, the term marble is correctly applied only to rocks comprising crystallized grains of calcite (calcium carbonate) or dolomite (calcium magnesium carbonate), or both. Commercially, the term "marble" is applied not only to rocks meeting this definition, but also to rocks ranging from pure carbonate to those containing little carbonate, yet having compositions and textures that allow them to be polished. While sometimes loosely included in the definition of commercial marble, polishable limestones, travertines, and serpentine can be better evaluated under their correct stone type definition and appropriate specifications.

24.2 A geologic marble of pure calcite or dolomite would be white in color. Marble colors, veining, clouds, mottling, and shading are caused by substances included in minor amounts during formation. Iron oxides make the pinks, yellows, browns,

and reds. Most grays, blue-grays, and blacks are of carbonaceous origin. Greens are the results of micas, chlorites, and silicates.

24.3 While marble has been used architecturally for many centuries and is one of man's oldest building materials, not all marbles are suitable for exterior use. The marble's texture is governed by the size, shape, and mutual relations of the component grains or crystals. Texture is often a factor in the material's ability to resist weathering effects. Marbles with a fine-grained, equigranular texture tend to be less weather-resistant than those with a medium to large grained, inequigranular texture, because the latter usually has an interlocking texture (grains with irregular boundaries, that interlock by mutual penetration).

24.4 Marble materials are used in a variety of architectural and memorial dimension stone applications. A list of common applications follows:

Architectural:

Exterior cladding/curtainwall

Interior cladding

Exterior paving

Interior flooring

Furniture & countertops

Steps

Coping

Window sills/stools

Memorial:

Monuments/markers

Mausoleums

Civic memorials

24.5 The physical properties of marble are determined in accordance with variety of ASTM test procedures. Minimum and maximum values for the material's physical requirements are listed in Specification **C503**.

24.6 The Marble Institute of America classifies marbles into four soundness groups. The basis of this classification is simply the usual fabrication and handling practices involved in working with the material. Practical experience with each material has deemed such practices to be both necessary and acceptable. The classification has no bearing on the cost of the material. The four groups are listed below:

24.6.1 *Group A*—Sound marbles with uniform and favorable working qualities; containing no geological flaws or voids.

24.6.2 *Group B*—Marbles similar in character to Group A marbles, but with less favorable working qualities; may have natural faults; a limited amount of waxing, sticking, and filling may be required.

24.6.3 *Group C*—Marbles with some variations in working qualities; geological flaws, voids, veins, and lines of separation are common. It is standard practice to repair these variations by waxing, sticking, filling, or cementing. Liners and other types of reinforcement are used when necessary.

24.6.4 *Group D*—Marbles similar to Group C marbles, but containing a larger proportion of natural faults, maximum variations of working qualities, and requiring more of the same

methods of finishing and reinforcing. This group comprises many of the highly-colored marbles prized for their decorative values.

24.7 Most dimension stones return to their original volume after exposure to high or low temperatures. However, some marbles exhibit a phenomenon known as ‘hysteresis’, or a permanent volume change after exposure to thermal and moisture cycling. Hysteresis typically manifests itself as a bowing of the marble panels, often suggesting a pillowed effect. In addition to the bowing, the face of the panels becomes more porous, making the surface more vulnerable to attack by corrosive agents and freeze/thaw deterioration. Before selecting marble that is subject to hysteresis for a project, careful research should be conducted to determine the minimum thickness required to prevent failure of the cladding system.

24.8 Marble is a suitable and durable material for use when properly selected, designed, and installed. The ultimate test for any specific marble is its past historical performance on existing structures. Some marbles, particularly those included in the groups B, C and D classifications, are not suitable for exterior use.

25. Limestone

25.1 Limestone is a commercial rock term embracing both limestone and dolomite. It is a sedimentary rock composed principally of calcium carbonate (the mineral calcite) or the double carbonate of calcium and magnesium (the mineral dolomite), or a mixture of the two. Limestones, like all sedimentary rocks, contain organic matter and other natural characteristics that affect their appearance and properties. The amount, kind, and distribution of these natural characteristics may affect the suitability of the rock for commercial use. Limestones are known to exist in all geologic time periods and on all continents of the earth, but those that have properties of superior dimension stones are relatively rare.

25.2 Limestones are found in hues of white, brown, gray, yellow, red, or black, but those used commercially are commonly light earth tones of gray, buff, reddish or yellowish buff, or mixtures of these colors. The appearance of the stone is affected not only by color, but also by its texture, stratification, and finish. Texture is determined by the size, shape, and arrangement of component grains, skeletal minerals, and crystals. Stratification refers to the composition, thickness, and arrangement of component beds. Finish is brought about by milling or fabrication. Limestones range in texture from those so fine-grained that they lack visible particles, to coarse-grained, in which individual fossil shells may be apparent.

25.3 Some limestones are “anisotropic”, or directionally specific in their physical and visual properties, and have a preferred splitting direction. However, many widely-used limestones do not display a preferential direction of splitting, and are referred to as “freestones”.

25.4 Limestone materials have been used for hundreds of years in a variety of architectural dimension stone applications in all climates. A list of common applications follows:

Exterior cladding

Paving and steps
Window lintels and sills
Wall copings
Interior cladding, base and mouldings
Interior flooring
Hearths, mantels, fireplace surrounds
Columns
Balustrades
Carvings, decorative trim

25.5 The physical properties of limestone are determined in accordance with a variety of ASTM test procedures. Minimum and maximum values for the material’s physical requirements are listed in Specification **C568**. This specification classifies dimension limestones into three separate categories according to density.

25.6 Because of the varying physical properties found within limestones, a single variety may not be suitable for all applications. As with all materials, specifiers should verify that the stone under consideration is suitable for the intended application. For large projects, availability of stone type, dimensional capability, production, and historical performance of the limestone should be checked to ensure that project requirements can be met. Limestone used in older buildings may no longer be quarried today, but stone of similar color and texture may be found.

26. Quartz-Based

26.1 The term “Quartz-Based” is a general commercial term including a variety of rocks, all of which consist of high contents of quartz and silica. The grains of quartz are commonly cemented together by silica or calcium carbonate. This dimension stone classification includes an extremely wide variety of materials, with a wide range of physical and mechanical properties. Sandstone, bluestone, brownstone, quartzite, and meta-quartzite are examples of materials included in this group.

26.2 Quartz-based stones of sedimentary origin will typically have pronounced bedding planes producing considerable anisotropic properties. This will generally affect both the appearance and performance of the material. Quarrying methods will be tailored to take advantage of this feature, using the natural separation planes, or rift, of the stone to determine the separation planes of the blocks.

26.3 Composition varies widely within this group, from materials that feature coarse, well-defined visible grains of quartz, to those having very fine, tightly-bonded particles appearing nearly homogeneous in structure. The grain size controls the degree of finish that can be obtained, with the finer grain sizes allowing more refined, smoother finishes.

26.4 Quartz-based stones are found in a variety of colors. Shades of light buff to dark blue gray are most common. Quartz-Based materials are used in a variety of architectural dimension stone applications. A list of common applications follows:

Exterior cladding/curtainwall
Interior cladding
Interior flooring & steps

Exterior paving & steps
Coping
Window sills
Water tables/belt courses

26.5 The physical properties of quartz-based stones are determined in accordance with a variety of ASTM test procedures. Minimum and maximum values for the material's physical requirements are listed in Specification **C616**. In this specification, three sub-categories of Sandstone, Quartzitic Sandstone, and Quartzite are listed with separate sets of properties for each.

27. Slate

27.1 Slate is a microcrystalline, metamorphic rock commonly derived from shale. The shales from which slates originate were deposited previously as clay beds. Slates are composed mostly of micas, chlorite, and quartz.

27.2 Slates are always “anisotropic” or “directionally specific” in their properties. The micaceous minerals have a subparallel orientation resulting in very pronounced cleavage planes within the rock. This enables most slates to be split into thin, strong sheets. As a result of this property, slate is the only dimension stone type to be commonly used as roofing.

27.3 Slates vary in color from the monochromatic tones of black and gray to green, red, blue, purple, yellow, brown, buff, and mottled varieties. Gray and blue slates are so colored due to the presence of carbonaceous material, while most other colors are due to the presence of iron compounds.

27.4 Slate is typically a very dense material displaying favorable resistance to abrasion and chemical attack. For centuries, the bulk of slate production has been used in roofing and pavement applications, where its service lives have been well documented. Common applications of slate are listed below:

- Roofing
- Paving/flooring, and thresholds
- Exterior spandrel, cladding, curtainwall, and fascia
- Treads, risers, and stringers
- Countertops, vanities, laboratory tops
- Exterior window sills / interior window stools
- Hearths, mantels, fireplace surrounds
- Baseboard, wainscot, and miscellaneous Trim
- Sanitary partitions
- Blackboards

27.5 An important property of a slate material is its permanence of color. Some slates maintain their original color for years, while others change color shades after relatively short exposures to weather. Such changes are often due to the presence of small quantities of iron-magnesia carbonates, which decompose readily and form a yellow hydrous iron oxide called “limonite”. Therefore, slates are of two types; “unfading” and “fading”. There is currently no reliable test method available to predetermine a slate's susceptibility to fading. Evaluation of the material's historical performance in existing exterior applications is used to predict the color permanence of slate.

27.6 Slate is available from quarries throughout the world. Domestically, the primary deposits of black slates are indigenous to Pennsylvania and Virginia, while the red, green, purple, and mottled slate colors are found in the New York-Vermont slate belt. For large projects, the dimensional capability, production, and historical performance of the slate to be specified should be determined.

28. Serpentine

28.1 Serpentinite rocks, being principally made of the mineral serpentine, are mostly or entirely hydrated magnesium silicate ($\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$). Stones in this classification are generally green or grey in color, and may have a “soapy” or “greasy” feel to their surface. These materials will oftentimes be referred to as “serpentine marbles”, but this is an incorrect reference, as serpentines are not marbles.

28.2 Most stones in this group are suitable for exterior application and will maintain their finish quality when exposed to natural weathering effects. Some serpentines are known to fade when used in exterior applications.

28.3 Serpentine materials are used in a variety of architectural and memorial dimension stone applications. A list of common applications follows:

Architectural:

- Exterior cladding/curtainwall
- Interior cladding
- Exterior paving
- Interior flooring
- Furniture & countertops
- Steps
- Coping
- Window sills/stools

Memorial:

- Monuments/markers
- Mausoleums
- Civic memorials

28.4 The physical properties of serpentine are determined in accordance with variety of ASTM test procedures. Minimum and maximum values for the material's physical requirements are listed in Specification **C1526**.

28.5 The Marble Institute of America classifies marbles into four soundness groups, and many serpentines are included in this classification system to document common reinforcement and repair techniques used in these stones. Refer to the marble section of this document for further discussion of this system.

28.6 Some serpentines are vulnerable to warping when exposed to water-based setting bed materials. Research is required to determine is specific procedures or polymer-based setting compounds are required.

29. Travertine

29.1 Travertine is a porous, or cellularly layered, partly crystalline calcite rock generally formed from warm or hot mineral-rich springs in a land environment. This formation history is distinctly different from that of most limestone varieties, which are accumulation of calcareous organic debris deposited on the sea bottom. Travertine is popular amongst

designers for its rather soft, earthy color tones and distinct veining patterns. The sedimentary origin of travertine makes it a profoundly anisotropic material, and it can be marketed as either a “veiny” (cut in a direction so the veins of alternating colors are visible in the finished face of the stone panel) or “fleuri” (cut in a direction parallel to the nearly planar veins, to leave a random, “flowery” effect on the finished face of the stone) direction.

29.2 The most noted feature of travertine is undoubtedly the presence of voids, or holes within the stone. These holes are commonly filled with a cementitious or resinous filler to increase durability and facilitate maintenance of the material. There is no standard limiting the size or frequency of these holes, and their presence is not a defect of the material, but rather a natural trait of this particular stone group.

29.3 Travertine materials are among the softest of any dimension stone variety, and as such, are easily worked in both factory and field settings. Many stones in this group demonstrate relatively low resistance to abrasion. Abrasion resistance of this material should be verified before specifying for high abrasion applications, such as flooring in high traffic regions or steps.

29.4 A limited number of travertine materials are suitable for exterior use, particularly in horizontal applications subject to freeze/thaw cycling where the high porosity of the stone can be problematic in saturated conditions.

29.5 Travertine is used in a variety of architectural and memorial dimension stone applications. A list of common applications follows:

Architectural:

- Exterior cladding/curtainwall
- Interior cladding
- Interior flooring
- Furniture & countertops
- Window sills/stools

29.6 The physical properties of travertine are determined in accordance with variety of ASTM test procedures. Minimum and maximum values for the material’s physical requirements are listed in Specification **C1527**.

29.7 The Marble Institute of America classifies marbles into four soundness groups, and many travertines are included in this classification system to document common reinforcement and repair techniques used in these stones. Refer to the marble section of this document for further discussion of this system.

BUDGET (COMPONENTS OF MATERIAL COST)

30. Introduction

30.1 The total cost of an exterior stone application is the sum of the costs of many different components found in that system. An understanding of the primary cost components is beneficial in developing cost-effective designs.

31. Testing

31.1 The extent of laboratory and field testing required for a specific project is controlled by many factors, including the

type and variability of the stone material, the type of anchorage, and the available performance history of any of the components.

31.2 The required testing cost can vary from zero to several hundred thousand dollars for a given project. On smaller projects, it is often more cost-effective to over-design the system, rather than to engage in an extensive testing program in hopes of utilizing all components to their fullest allowable capacity.

32. Engineering

32.1 The engineering authority responsible for the stone design may also administer related activities. Such activities may include shop drawings, testing programs, product/supplier observations, or other activities, or combination thereof.

32.2 Engineering should be provided by professionals experienced in the design of stone facades. While this cost may be a significant component of the total cost, a specialist can normally provide superior design details, and achieve an economically reasonable long-term envelope design. Some economies may be achieved by including resources provided by suppliers such as fabricators and anchorage manufacturers employing design specialists who can provide technical support.

33. Shop Drawings

33.1 A shop drawing is a highly detailed drawing that shows the net stone dimensions, joint dimensions, anchor locations and orientations, and relationship details with other building components. Because stone products are usually shop-fabricated to the greatest extent possible, shop drawings are normally required on all stone projects. The cost of providing these construction documents is a relatively small, but often overlooked cost of the cladding system.

33.2 Shop drawings are often provided by the fabricator of the material, but they may be provided by an independent party. When provided by an independent party, it is imperative that the supplier of this service is familiar with the capabilities and limitations of both the product and the fabricator’s machinery, and that the stone fabricator review the drawings prior to submittal.

34. Quarrying

34.1 The cost of extraction is highly variable amongst dimension stone types. The uniformity and continuity of the stone deposit affect yields, which is a primary factor in determining the unit cost of the material. Access to the quarry site, local labor availability, mineral rights royalties, and reclamation responsibilities are also factors in raw product costs.

35. Transportation to the Fabricating Facility

35.1 Fabrication yields of stone products are quite low, often below 50 %. The cost of transporting the raw quarry blocks to the fabrication site then becomes very significant, as it includes both the freight cost of the usable and the unusable portions of the material.

35.2 This transport can be intercontinental, requiring both inland and marine transport of the material.

36. Fabrication

36.1 The sawing of slabs from the block is normally the first operation to be completed at the fabrication site, and is typically one of the largest components of the fabrication costs for dimension stone products.

36.2 Applying the face finish is normally done immediately after the cutting of the slabs.

36.3 Cutting the slabs to the required finished size of the building panels is in itself, a relatively low cost operation. It is at this step, however, where the yield of the material is determined. Establishing typical sizes, or “modules” in the building design that maximize the use of the typical sizes of the stone slabs for the selected material will significantly reduce costs.

36.4 Edge treatments, such as polished edges, chamfers, or rustications, are applied after the panel is cut to size. The cost of edge treatments varies greatly with the type of treatment specified as well as the equipment available to the fabricator. Modern machinery specifically tooled to complete a common task will do so very efficiently.

36.5 Preparations in the stone panel to accommodate anchorage hardware can be done in the field during installation, but cost and quality control favor completion of this activity in the fabricator’s facility. Researching the fabricator’s standard profiles and locations of anchorage preparations, and designing hardware to interface with these standards, will result in cost savings to the project.

36.6 The project may require specialty items, such as the carving of text or graphics, profile cutting, or multiple finishes on one piece of stone. These items can have significant impact on cost.

36.7 Packaging, also referred to as “bundling” or “crating” of the finished material is done by the fabricator. The sophistication, and therefore the cost, of the packaging can be affected by the mode of transport (that is, truck, rail, marine), handling considerations at the project site, or anticipation of extended storage of the material.

37. Anchorage and Support Hardware

37.1 Anchorage hardware may be supplied by the fabricator, the installer, or a third party.

37.2 It is likely that the supplier of the anchorage hardware offers some standard configurations to accommodate common attachment requirements. Utilization of these standard hardware items will help reduce costs.

38. Transportation to the Project Site

38.1 The cost of transportation from the fabricator’s facility to the project is generally governed by the distance between the two sites.

38.2 This transport can be intercontinental, requiring both inland and marine transport of the material.

38.3 Fabrication schedules and project site conditions may dictate the need for temporary off-site storage of the material, which will result in additional handling and cost.

39. Installation

39.1 The installation of the dimension stone entails too many variables to be adequately addressed within the scope of this guide. The designer is advised to contact local installing contractors for estimates of the installation costs, based on previously completed, similar projects.

40. Joint Treatment

40.1 The caulking or pointing of the stone joints is commonly included in the installation costs. On some projects, it may be contracted to another party.

41. Cleaning and Protection

41.1 Because there is other construction activity on the project site occurring after the stone installation, it is normally a requirement to have the finished stone installation protected from damage by other trades and cleaned prior to acceptance by the owner.

FINISHES

42. Introduction

42.1 Available finishes will vary between producers. The finishes listed herein are the most commonly found finishes in the industry.

42.2 Many fabricators have marketed variations of standard finishes, often by modifying the finish with high water pressure jetting or abrasive brushes. Most often, these finishes will be proprietary finishes available from a single source. It is best to consult with the manufacturer before specifying a material/finish combination to ascertain its availability prior to specifying it.

42.3 **Table 2** has been created to reference the applicability of the various finishes to the various stone material types.

43. Finishes

43.1 A list of the most commonly available finishes is included in this section with the industry standard name.

43.1.1 *Polish*—A polished finish is a smooth, glossy and highly reflective finish produced by mechanical abrasion and buffing.

43.1.2 *Hone*—A honed finish is a smooth, nonreflective finish produced by varying degrees of mechanical abrasion.

43.1.3 *Thermal (or Flamed)*—This finish is produced in granite, granite-like, quartz-based, and dolomitic limestone materials by a brief exposure to a high temperature flame. The process results in an exfoliation of the surface, creating a textured finish.

43.1.4 *Sanded (or Sandblasted)*—Also referred to as “dusted,” sanded finish is produced by “sand-blasting” the material with abrasive particles at high velocities. The resultant finish is a finely textured surface, which is generally lighter in appearance than the untreated stone. Visual characteristics such as color and veining are not as prominent through this finish.

TABLE 2 Applicability of Finishes for Various Stone Types

	Granite	Marble	Limestone	Quartz-Based	Slate
Polish	X	X	X ^A		
Hone	X	X	X	X	X
Thermal (flamed)	X ^B		X ^C	X	X
Sanded (sand blasted)	X	X	X	X	X
Bush-hammered	X	X	X	X	X
Split	X	X	X	X	
Rock-face	X	X	X	X	
Smooth			X	X	X
Sawn	X ^D		X	X	X
Natural cleft	X ^E		X	X	X
Sand rubbed		X			X
Machine gaged			X		X
Natural strata	X		X	X	

^A A polished finish is not achievable in all limestone varieties.

^B There are some stones included in the granite group that are not capable of taking a thermal finish.

^C In limestone, thermal finish applicability is generally limited to dolomitic limestone varieties.

^D Sawn finishes in granites are typically treated with some type of additional enhancement, that is, water or sand blasting.

^E Natural cleft is more commonly referred to as split finish in granites.

43.1.5 Bushhammer—This finish is made with a pneumatic hammer and a carbide tipped head having numerous points. The resultant finish is a textured surface with a relief of up to several millimetres. The direction of the finish application may or may not be visible in the final product.

43.1.6 6/8 Cut (or 6/8 Point)—This finish is made with a pneumatic hammer and a carbide tipped chisel having 6 or 8 closely spaced straight blades. As the pneumatic hammer traverses that stone, the chisel is rotated 10 to 30° producing a “herringbone” effect.

43.1.7 Split (or Splitface)—Split finish refers to the natural cleft surface left when the rock is broken. The breaking of the stone is done with driven wedges. Material with split surfaces is usually supplied in low course heights and laid in a bonded pattern similar to brick masonry.

43.1.8 Rockface (or Hand-Hewn, or Rock-Pitched, or Pitched)—These terms describe a finish which is an embellishment to a split surface. The split surfaces are “hand-pitched” with carbide tipped chisels to produce a protruding or “pillowed” profile.

43.1.9 Smooth (also referred to as “Machine Smooth,” or “Diamond Ground”)—As its name suggests, it is a smooth surface with a minimum of surface interruption. This finish can be achieved by either sanding or grinding.

43.1.10 Sawn—Sawn finish is a general term describing a surface that has been chat, shot, sand, or diamond sawn. It is comparatively rougher than “honed” or “smooth.”

43.1.11 Natural Cleft—The natural cleft surface is achieved by splitting the material along its natural cleavage plane. While available in some other stone types, natural cleft finishes are most commonly associated with slate.

43.1.12 Sand Rubbed (or Abrasive)—A nonreflective, matte finish with a slight grain or stipple pattern visible on the surface.

43.1.13 Machine Gaged—Machine gaged defines a surface that has been ground smooth with circular abrasive heads. The degree of smoothness may vary from one producer to another.

Slight, circular patterned swirl marks may be visible in some material having this finish.

43.1.14 Natural Strata (or Quarry Face)—A rough, uneven finish, similar to splitface, but the surface of the stone is left as it naturally occurs at the top layer of the sedimentary formation, quarry seam, or bedding plane.

43.1.15 Tooled—A finish with a linear textural pattern, with concave parallel grooves usually 6, 4, or 3 mm on center (4, 6, or 8 grooves per inch).

EVALUATION OF PROPOSED APPLICATION ENVIRONMENT

44. Introduction

44.1 The decision to use dimension stone as a component in a building mandates that the designer evaluate the latter in terms of its effects upon the dimension stone product. The design of the building structure, related elements, and the dimension stone units may need to be altered to ensure satisfactory performance throughout the anticipated service life of the building.

45. Building Movements

45.1 Dimension stone units are rigid, brittle materials. As such, they do not accommodate dimensional changes very well within the individual stone unit. Modern building frames are constantly moving in reaction to the various loads imposed upon them. To accommodate movements in the building frame, “soft” joints are required between some or all of the dimension stone units. The size and frequency of these joints should be determined by the anticipated dimensional changes in the building frame, and the compression, extension, and shear capabilities of the material filling the soft joints.

46. Thermal Expansion

46.1 Differential heating and cooling of the variety of components in the building frame and skin create dimensional variations which must be accommodated in the stone system design. These movements are typically absorbed via the use of a “soft” joint, and the size and frequency of these joints is determined by the anticipated dimensional changes in the cladding as well as the compression, extension, and shear capabilities of the material filling the soft joints.

46.2 Variations in temperature within the stone units, particularly related to partial or full direct solar exposure, can give rise to temperature induced flexural stresses within the stone unit that may equal or exceed those related to wind loading. This should be considered in design for both panel thickness and anchor capacity.

47. Construction and Fabrication Tolerances

47.1 The attachment system of the dimension stone unit is required to have sufficient adjustment capabilities to accommodate the cumulative tolerances of the fabrication, field conditions, and erection of all components. It is not uncommon for this to exceed 25 mm (1 in.). The engineering authority for the system must analyze the system’s ability to resist all anticipated loads at the extreme limits of its adjustment.

48. Wind Loading

48.1 As modern stone cladding units can be very large, wind loading is one of the principle forces to be resisted in the system design. Stresses arising from wind loading should be considered in design for both panel thickness and anchor capacity. For stone panels with complex geometry or intermediate anchors, deflections may need to be modeled to demonstrate actual loads at each anchor location during maximum wind load exposure.

48.2 Independent analysis of gravity loads and wind loads may not adequately address the effects of the two loads in combination. Due to the geometry of the anchorage assembly, wind loads can result in an increase or decrease of vertical loads on the anchor. It is usually a requirement to analyze the anchorage system with simultaneous gravity and positive/negative wind loads.

49. Seismic Loads

49.1 Seismic loads, particularly with thick stone panels, can exceed wind loads. Unlike wind loads, seismic loads can work both perpendicular to or parallel to the building face. Specialized anchors may be required to resist loads which are horizontal, but parallel to the building face, as this is a loading direction not found in non-seismic areas.

49.2 In addition to inertial loads, the inter-story drift of the building frame is a consideration in seismic design. Restraint anchors must have the capacity to adequately slip to accommodate parallelogram configurations of the building frame.

49.3 The use of “soft” joints will be required in seismic areas. Such joints must accommodate compression, extension, and shear movements within the joint filler.

50. Traffic Loads

50.1 Traffic loads, or any concentrated loads on a stone paver require extensive study. The heaviest anticipated load of each definable “footprint” must first be established. Then the effect upon the paver subjected to the load, including dynamic load, must be analyzed for every conceivable position and orientation of the load.

50.2 The most comprehensive method for this task is a computerized finite element analysis (FEA). There has been very good correlation between FEA results and destructive laboratory tests.

51. Weathering

51.1 Natural stone products, in general, exhibit remarkable resistance to weathering exposure. There are some types of dimension stones with less desirable weathering characteristics, and there are some specific climates that may attack certain stone types.

51.2 The development of a laboratory test to replicate, in an accelerated time frame, the effects of natural weathering exposure is currently a topic of study of Subcommittee C18.01 on Dimension Stone Test Methods. As this is a very complex issue, encompassing many different stone types and climatic conditions, it may be some time before a standard laboratory

test is endorsed as being reasonably correlative to natural weathering effects. Until such a test is fully developed, the designer is best advised to research the performance of the particular stone species in the same or similar climatic environment on existing structures. Most dimension stone suppliers keep databases of existing projects and are willing to share that information to anyone wishing to observe the performance of existing applications.

52. Anticipated Durability

52.1 As stone is the oldest building material known to man, most of the oldest structures in any society are built of, or clad in some type of stone product. However, modern architectural applications of stone, in which relatively thin panels rely on the flexural strength of the stone, require a much greater understanding of some stone properties than were needed for cubic, load-bearing stone structures. In addition, modern construction methods include many components and materials in conjunction with the dimension stone, some of which may have shorter service lives than the stone.

52.2 Once the desired service life of the building is established, the designer is required to ensure that all components either meet or exceed that service life, or are readily repairable/replaceable through regular maintenance activities. All concealed items, such as support and anchorage hardware, must be made from a durable, corrosive-resistant material that will meet the anticipated service life of the building.

DIMENSION STONE TESTING

53. Introduction

53.1 Currently, ASTM publishes 12 test methods applicable to dimension stone. A brief summary of each is provided as follows:

53.1.1 *Test Methods C97*—These test methods cover the determination of the water absorption and bulk specific gravity of all types of dimension stone, except slate. The test specimens may be cubes, rectangular prisms, cylinders, or any regular form with least dimension not less than 51 mm (2 in.), greatest dimension not more than 76 mm (3 in.), and surface area to volume ratio not less than 0.3 nor more than 0.5. A sawn finish or better is prescribed for all surfaces.

53.1.2 *Test Method C99*—This test method covers the determination of the modulus of rupture of all types of dimension stone, except slate. Modulus of rupture is reported as the flexural breaking stress of a 57-mm (2¼-in.) thick, 102-mm (4-in.) wide, 203-mm (8-in.) long beam, with simple supports spanning 178 mm (7 in.) and loaded at the center. A smooth ground finish is prescribed for all surfaces. Test methods are typically performed on wet and dry specimens with the supports oriented parallel and perpendicular to the stone rift or bedding plane.

53.1.3 *Test Methods C120*:

53.1.3.1 These test methods cover determination of the breaking load, modulus of rupture, and flexural modulus of elasticity of structural, electrical, and roofing slate. Structural and electrical slate tests utilize 25-mm (1-in.) thick, 32-mm (1¼-in.) wide, 305-mm (12-in.) long samples placed on simple supports spanning 254 mm (10 in.) and loaded at the center. A

Applicability of Stone Test Methods

		Test Methods									
		C 97 (C 121) Absorption/Density ⁽¹⁾	C 170 Compressive Strength ⁽²⁾	C 217 Accelerated Weathering (Slate Only) ⁽³⁾	C 241 (C 1353)Abrasion Resistance ⁽⁴⁾	C 880 Flexural Strength, C99 Modulus of Rupture C120 Flexure Testing of Slate ⁽⁵⁾	C 1201 Structural Performance of Cladding ⁽⁶⁾	C 1352 Modulus of Elasticity ⁽⁷⁾	C 1354 Individual Anchorages	C 1721 Petrographic Examination	D 2203 Staining of Joint Sealants ⁽⁸⁾
Application	Interior Walking Surface	✓	✓		✓	✓ ⁽⁹⁾				✓	✓
	Interior Countertop	✓	✓			✓ ⁽⁹⁾				✓	✓
	Interior Vertical Face	✓	✓			✓			✓	✓	✓
	Exterior Roofing	✓		✓		✓					
	Exterior Pedestrian Traffic Surface	✓	✓		✓	✓ ⁽⁹⁾				✓	✓
	Exterior Vehicular Traffic Surface	✓	✓		✓	✓		✓		✓	✓
	Exterior Cubic or Trim	✓	✓			✓ ⁽⁹⁾			✓	✓	✓
	Exterior Cladding	✓	✓			✓	✓	✓	✓	✓	✓

NOTE 1—Absorption of slates is tested per Test Method **C121**.

NOTE 2—As compressive strength is a general guide of relative performance, it is recommended to have this data available for most stone applications.

NOTE 3—At this time, there is no established ASTM test protocol for weathering tests of dimension stone types other than slate.

NOTE 4—The test apparatus for Test Method **C1353** is more commonly available than that required for the Test Method **C241** procedure, yet for harder stones such as granite, quartzite, and serpentine, the Test Method **C241** procedure may be required due to the inability of the Test Method **C1353** procedure to accurately evaluate the harder stone varieties.

NOTE 5—Test Method **C880** is the preferred method of determining bending strength for dimension stone. Modulus of Rupture and Flexural Strength of Slate is tested per Test Method **C120**. Test Method **C99**, Modulus of Rupture, may be used in testing exterior vehicular traffic surfaces, cubic and trim, and sedimentary stones of 2 in. or greater thickness.

NOTE 6—Test Method **C1201** may be required at the direction of the cladding design engineer.

NOTE 7—Modulus of Elasticity data is required for certain methods of analysis (for example, Finite Element Analyses), as well as for some very specialized industrial applications of dimension stone.

NOTE 8—Test Method **D2203** is generally only required when using silicone based joint sealer with unknown compatibility history.

NOTE 9—Flexural Strength data may not be required for the application if the anticipated flexural stresses are very low.

FIG. 1 Applicability of Stone Test Methods

smooth ground finish is prescribed for all surfaces. Test methods are typically performed on dry specimens with the supports oriented parallel and perpendicular to the stone bedding plane.

53.1.3.2 Roofing slate test methods utilize 100-mm (4-in.) by 125-mm (5-in.) rectangular samples with split faces and a minimum thickness of 5 mm ($\frac{3}{16}$ in.), placed on simple supports spanning 51 mm (2 in.) and loaded at the center. Test methods are typically performed on dry specimens with the supports oriented parallel and perpendicular to the stone bedding plane.

53.1.4 *Test Method **C121***—This test method covers the determination of the water absorption of slate. Square or rectangular test samples 5 to 8 mm ($\frac{3}{16}$ to $\frac{5}{16}$ in.) thick with split faces and measuring not less than 102 mm (4 in.) on any side are used.

53.1.5 *Test Method **C170***—This test method covers the determination of the compressive strength of all dimension stones. Compressive strength is reported as the failure stress under uniaxial compression. Test specimens may be cubes, rectangular prisms, or cylinders with a diameter or lateral dimension not less than 51 mm (2 in.), and a ratio of height to

diameter or lateral dimension not less than 1:1. Test methods are typically performed on wet and dry specimens with the compressive load applied parallel and perpendicular to the stone rift or bedding plane.

53.1.6 Test Method C217—This test method covers two procedures for determining weather resistance of slate as indicated by the depth of softening caused by submersion in a solution of 1 % sulfuric acid, as measured by a commercial scratch tester or by hand scraping. Test specimens measuring 51 mm (2 in.) by 102 mm (4 in.) with split faces are used.

53.1.7 Test Method C241—This test method covers the determination of the abrasion resistance of all types of dimension stones where the wear is caused by the abrasion of foot traffic. Test specimens 51 mm (2 in.) square by 25 mm (1 in.) thick, with sawn faces are used. Abrasion resistance is reported as a dimensionless ratio related to weight loss incurred during 225 revolutions of grinding in a custom-fabricated test machine with a prescribed abrasive grit. The prescribed abrasive is no longer available, and has been replaced with a more aggressive material, resulting in lowered test values. Test Method C1353 has been devised as a replacement for this test method.

53.1.8 Test Method C880—This test method covers the determination of the flexural strength of all dimension stones, except slate. Flexural strength for standard specimens is reported as the flexural breaking strength of a 32-mm (1¼-in.) thick, 102-mm (4-in.) wide, 381-mm (15-in.) long beam, with simple supports spanning 320 mm (12½ in.) and quarter-point loading. A smooth ground finish is prescribed for all surfaces. Test specimens with thicknesses and surface finishes specified for use on a specific construction project can also be used. Test methods are typically performed on wet and dry specimens with the supports oriented parallel and perpendicular to the stone rift or bedding plane.

53.1.9 Test Method C1201—This test method covers the determination of the structural performance of dimension stone cladding systems under positive and negative uniform static air pressure differences, using a test chamber to represent the effects of wind loads on exterior building surface elements. All parts of the test specimens are full size, using the same materials, material finishes, details and methods of anchorage used, or planned to be used, on a specific construction project. Test methods are typically performed on dry stone specimens, however wet tests can also be performed.

53.1.10 Test Method C1352—This test method covers the procedure for determining the flexural modulus of elasticity of all dimension stones, except slate. Flexural modulus of elasticity for standard specimens is reported as the slope the load/deflection curve of a 32-mm (1¼-in.) thick, 102-mm (4-in.) wide, 381-mm (15-in.) long beam, with simple supports spanning 320 mm (12½ in.) and quarter-point loading. A smooth ground finish is prescribed for all surfaces. Test specimens with thicknesses and surface finishes specified for use on a specific construction project can also be used. Test methods are typically performed on wet and dry specimens with the supports oriented parallel and perpendicular to the stone rift or bedding plane.

53.1.11 Test Method C1353—This test method covers the determination of the abrasion resistance of all types of dimension stone for floors, steps, and similar uses where the wear is caused by the abrasion of foot traffic. Abrasion resistance is reported as a dimensionless ratio related to weight loss incurred during 1000 revolutions of grinding in a commercial test machine fitted with prescribed abrasive wheels. Standard test specimens 102 mm (4 in.) square by 10 mm (¾ in.) thick, with smooth ground faces are used. Alternately, test specimens with surface finishes specified for use on a specific construction project can also be used.

53.1.12 Test Method C1354—This test method covers the determination of the ultimate strength of the stone at the anchorage points. This test method is intended to represent the interaction of the anchor with the stone panel, however it is not intended to be a test method for determining the strength of the entire mechanical anchorage assembly. Influence of the backup structure is not included in the test fixturing. Test methods are typically performed on wet stone specimens, however dry test methods can also be performed.

53.2 See Fig. 1 for Chart of Test Method Applicability.

SELECTION PROCESS

54. Outline of Process

54.1 To best match a stone to a project's architectural and durability requirements, compare the following aspects for several stones in an analysis matrix early in design development: appearance, availability, total cost, proven durability, structural properties, and fabrication limits.

55. Appearance

55.1 Identify intended appearance by referring to an existing building's material or a sample with its source. Name the color and finish texture. Many materials from the same geological source are given proprietary names by different producers, but appear alike. Several finishes created by the same fabrication process are named differently by different producers, while some finishes appear identical, but are produced differently.

55.2 Identify a range mutually agreeable between the designer and the producer by referencing published brochures, catalogues, or by observing recent buildings using the material. Because stone is a natural material, its appearance varies. Range of variation is different for each stone type and finish.

55.3 Confirm the range by selecting a group of samples produced from freshly quarried material in the project's finish, showing extremes in appearance of currently available stone. Size must be large enough to show characteristics of the extremes and their context. View samples under natural light in both wet and dry conditions. View samples from a distance and oblique angle when intended for a tall project.

55.4 Rank stones under consideration in preference order based on appearance in accordance with Section 61.

56. Availability

56.1 Verify that enough stone can be produced in the quality required within the project schedule. Many stones can be

obtained from only one quarry. Quarry size, climate, and location of quarry dictate physical availability. Whether foreign or domestic, commitments to other projects, exclusive distributor agreements, cost engineering or testing decisions control or influence availability.

56.2 Rank stones under consideration according to their availability in accordance with Section 61. Materials having the highest availability are readily available to any fabricator. Less available materials are accessible to a limited number of fabricators, and least available are single fabricators or quarries. Maximum availability minimizes direct material cost and impact on project schedule.

57. Total Cost

57.1 Approximate an installed cost by comparing the production plus installation costs for each material being considered.

57.2 For production, total cost includes influence of thickness, panel size, replicated sizes, fabricator's proximity to quarry, project's proximity to fabricator, domestic or foreign source, crating requirements, and shipment method.

57.3 For installation, total cost includes anchors and backup support which vary for different stone types depending upon their structural properties, installation method (handset on-site or off-site set onto precast, truss, or curtainwall units), and maintenance after completion.

57.4 Ask specialty contractors for an installed price in the project location giving them a representative quantity of the typical panel size, finish, and thickness for the project. Also show proportion of project that is not typical and some characterization of how different the nontypical areas are from the typical.

57.5 Rank the materials into groups based on cost or at least relative cost, since pricing during early design is speculative in accordance with Section 61.

58. Durability

58.1 Assess the durability of all dimension stones under consideration. Where possible, inspect existing applications constructed with the materials under consideration. Proven performance on buildings in exposures similar to the project is the best currently available indicator of durability.

58.2 Where exemplars are not available, or are too young to offer proof of having withstood the test of time, review test data for durability where available, and assess physical properties that could indicate durability in the project's conditions.

58.3 Inspect the quarry waste piles and ledges for staining or discoloration over time. Materials from new quarries will require more rigorous laboratory evaluation of durability because of the lack of existing buildings to prove their long-term performance.

58.4 Rank the materials into groups based on their proven durability in use in the manner proposed for the particular project in accordance with Section 61. Highest has multiple exemplars in the project's location of equal or greater age than the anticipated service life of the new project. Lowest would

have no exemplars or rigorous accelerated weathering laboratory testing directly evaluating the materials performance. Materials demonstrating unsatisfactory performance on existing applications should be excluded from the list of candidates.

59. Structural Properties

59.1 Obtain data on the structural properties of each dimension stone under consideration by studying results of ASTM standard test methods. Initial review of previous test data will indicate whether the physical properties for each material under consideration match conceptual panel size and support requirements. Consult Guide C1242 to determine the extent of further testing required prior to final selection and certainly before final engineering.

59.2 Confirm the physical properties that comply with the relevant ASTM standard specification and preliminary project requirements. More importantly, study the variability of critical stress properties that directly affect design values, safety factors, thickness, and anchor size. Do a preliminary analysis of common panels supported as conceived under loads defined for cladding, not the main structure, to confirm that the architectural concept is valid. Rank the dimension stones into the following categories in accordance with Section 61:

59.2.1 Structural properties greater than required,

59.2.2 Properties meet required criteria, and

59.2.3 Properties do not conform with requirements.

60. Fabrication Limits

60.1 All materials have some limitation on finished product size and shape due to the geological characteristics, quarry operations, physical material properties, and fabrication equipment. These limitations can include the following: block size (and hence slab dimensions), types of finishes, presence of veins or inclusions, presence of fractures, direction of rift, bedding, grain, or pattern, and consistency of color or pattern.

60.2 Understanding the limitations of the stone is important to ensure that the preferred stone can be used in the manner intended for the given project, or that the architectural design is refined to match the stone's limits.

60.3 Investigate fabrication limitations by consulting with suppliers, and if possible, by inspecting the quarry and factory. After adding production committed to other projects, check quantity output for typical work; special sizes, and irregular cross sections as they apply to the project. Pay particular attention to capabilities for drilling or cutting for anchors accurately.

60.4 Verify the facility has a dedicated project manager or expeditor who can be contacted to coordinate progress, deliveries, payments, and replacements for damaged or otherwise unacceptable work.

60.5 Check the quality control program to confirm that slabs are checked for soundness before cutting-to-size, the thicknesses and face sizes are checked before packaging, the finishes and visual characteristics are checked against approved range samples, the anchor holes and slots are inspected for accuracy, and the crating is structurally sound and adequately protects the stone from damage during shipping.

60.6 Rank the materials based on any discernible fabrication limitations in accordance with Section 61.

60.6.1 Having no fabrication limitations that influence the proposed use is the best. As limitations in capacity or capability increase, that material's desirability decreases.

61. Analysis

61.1 Compile a matrix containing the ranking of each material for the six criteria listed in 54.1. Determine if the procurement process mandates selection of only a single best option, or requires two or more comparable options to compete during bidding.

61.2 With the remaining materials, identify the most important criteria for the project, and weighting each criterion accordingly. Multiply the ranking by the weighting, sum the scores for all criteria, thereby determining the preferred material by comparing the final score.

DIMENSION STONE SPECIFICATIONS

62. Introduction

62.1 ASTM currently publishes eight specifications for various Dimension Stone varieties: **C406**, **C503**, **C568**, **C615**, **C616**, **C629**, **C1526**, **C1527**.

62.2 These specifications provide general requirements for the supply of dimension stone, including references to cracks, staining mineralogy, soundness, and other pertinent qualities of suitable dimension stone. Additionally, each specification includes a table of minimum or maximum values of physical and mechanical properties required for dimension stones to comply with the standard.

62.2.1 No historical documents are available describing what criteria were used to originally establish the table of values for many of the specifications. These tables are assumed to have been created by researching then-current material types in the marketplace with successful performance histories and using the values of those materials as a benchmark.

62.2.2 The values are then not considered to be a limiting factor in the usability of dimension stone materials, but rather a resume of properties of existing materials that have proven successful in application.

62.2.3 Due to inherent variability in natural stone, additional evaluation may be required to ensure that a material meeting or exceeding the requirements of the applicable dimension stone specification will perform in service.

62.2.4 Conversely, there are many documented cases of materials that repeatedly perform well in service, despite not meeting the values stated in the applicable specification.

62.2.5 When specifying materials that do not meet the values stated in the applicable specification, the material should be further evaluated to ascertain its worthiness of the intended application. The material should not be considered unless a competent engineering authority has evaluated relevant characteristics of the stone. This evaluation should consider both structural effects and material characteristics such as durability, permanent volume change, modulus of elasticity, thermal expansion, and the like.

63. Keywords

63.1 dimension stone; dimension stone testing; finishes; granite; limestone; marble; natural stone; natural stone finishes; quartz-based; selection; slate; stone; stone evaluation; stone selection

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