

Dimension Stone Testing and Evaluation—The What, Why, When, and Where

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NATURAL STONE IS recognized and used as a construction material throughout our built world because of its visual and textural diversity, timeless beauty, sense of permanence, and association with quality. Design professionals (including architects, landscape architects, and interior designers) rely on natural stone to create the environments in which we live, work, commune, and even memorialize past events and individuals of significance from our history. The considerable demand for “new” stone, in combination with globalization, has opened opportunities for suppliers from around the world, many of whom have only recently developed their natural stone resources for commercial use. This rush to market can create healthy competition and increase the volume and diversity of stone available. However, the lack of historical experience with some stone types and inconsistent documentation of their physical properties can lead to the selection of unsuitable products and unsuccessful outcomes (see **Fig. 1** and **2**). For example, well-intentioned vendors may not realize that a stone used for interior flooring will not perform adequately in an exterior cladding application.

OVERVIEW OF NATURAL STONE CLASSIFICATIONS¹

Geologically, natural stones generally fall into three categories based on the influences of their formation: igneous, metamorphic, and sedimentary. Stone is formed through the application of heat and pressure over time on minerals within the Earth’s crust, or through deposition of degraded rock. The formation process imparts certain inherent aesthetic, structural, and performance characteristics. Because the formation process is subject to a wide range of heat, pressure, and time, all stone in a given category will not have the same characteristics and may most accurately fall between two of the three categories.

Igneous stone is formed from underground volcanic activity that produces molten material, which moves to the surface as lava under high temperature and pressure and then cools to form rock. Principal minerals are silica, mica, and feldspar.

Sedimentary rock is formed by the constant layering of marine organism fossils and weathered igneous or metamorphic rock as sediment. Over time, the pressure of the material weight and natural binders (such as iron oxide, clay, calcium, and silica) bond the materials together to form stratified stone formations or bedding planes.

Metamorphic stone forms from accumulation of sedimentary or igneous rock that continues to be exposed to extreme temperature and pressure for long periods, during which time they can be broken down and reformed or mixed with fluids or other materials.

From a mineralogy standpoint, stone can be divided into two general categories: those that contain silica (siliceous) and those containing calcium carbonate (calcareous).

ASTM International is responsible for industry-recognized standard specifications for building materials, including the most commonly used natural stone types in the building construction industry. The following are the ASTM specifications for seven commercial classifications, each of which include minimum physical properties:

- ASTM C503, *Standard Specification for Marble Dimension Stone*²
- ASTM C568, *Standard Specification for Limestone Dimension Stone*³

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FIGURE 1. Permanently stained interior flooring from moisture exposure.

- ASTM C615, *Standard Specification for Granite Dimension Stone*⁴
- ASTM C616, *Standard Specification for Quartz-Based Dimension Stone*⁵
- ASTM C629, *Standard Specification for Slate Dimension Stone*⁶
- ASTM C1526, *Standard Specification for Serpentine Dimension Stone*⁷
- ASTM C1527, *Standard Specification for Travertine Dimension Stone*⁸

Table 1 contrasts the ASTM classifications with the traditional geologic and mineralogic categories.

WHAT ARE THE CURRENT STONE TEST STANDARDS?

The standard specifications for each stone classification include minimum values for physical property testing that are directly relevant to the engineering of that stone in most building applications. Each test set includes 5 specimens that are each fully dry, saturated, cut parallel to the stone rift (the direction the stone is most easily split), and cut perpendicular to the rift, for a total of 20 specimens to bracket the likely range of values that could occur in service.

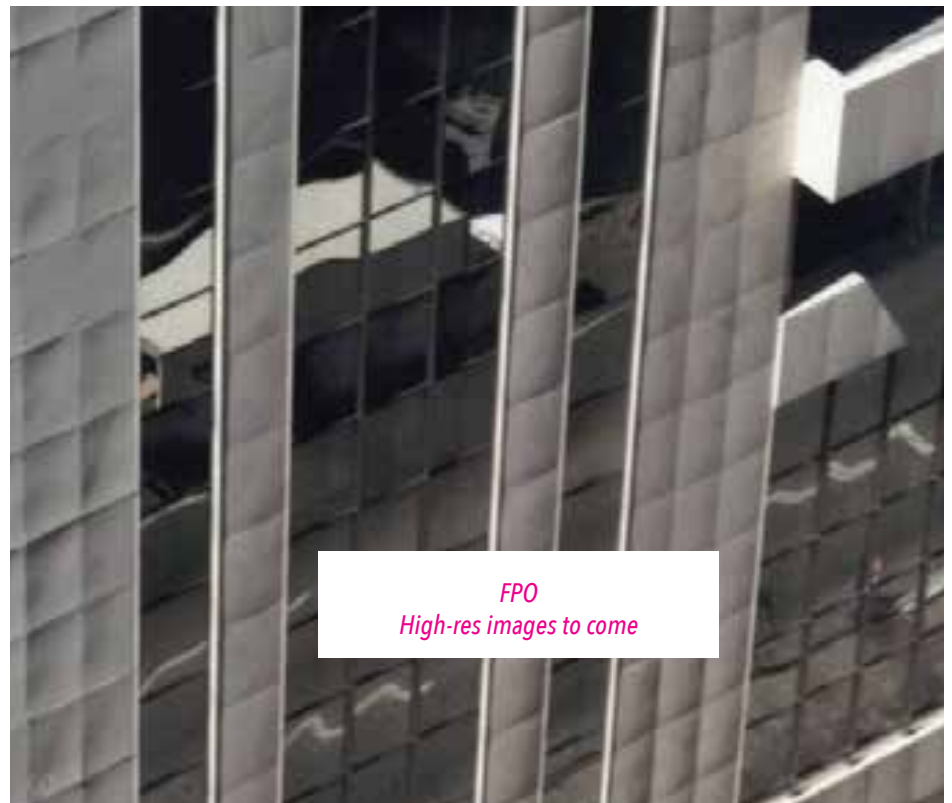


FIGURE 2. Bowing of marble cladding panels due to hysteresis.

ASTM C1799, *Standard Guide to Dimension Stone Test Specimen Sampling and Preparation*,⁹ describes the conditions under which physical testing is performed and provides guidance on the frequency of testing based on the volume of stone used for a project.

The following are tests that are directly relevant to actual stone engineering in each standard stone specification:

- ASTM C97, *Standard Test Methods for Absorption and Bulk Specific Gravity of Dimension Stone*.¹⁰ The specific gravity portion of this testing method provides a convenient and accurate means of calculating the unit weight of natural stone. Specimens are typically 2 in. (50 mm) cubes, but cylinders or prisms of specific dimensions can also be used.
- ASTM C99, *Standard Test Method for Modulus of Rupture of Dimension Stone*.¹¹ Modulus of rupture provides a value that can be used in bending calculations and anchor design in the absence of ASTM C880 testing (described below). This test method incorporates a single load application point, which is typically also the point of breaking stress. The specimens are a standard size, independent of project-specific dimensions.
- ASTM C120, *Standard Test Methods for Flexure Testing of Structural and Roofing Slate*.¹² Given the prolific use of building slate for roofing, the slate industry relies on a single test standard for shingles as well as structural slate. The specimens are a standard size, independent of project-specific dimensions. The breaking load is determined for shingles, and the modulus of rupture is the test value for structural slate.
- ASTM C170, *Standard Test Method of Compressive Strength of Dimension Stone*.¹³ Surprisingly, compressive strength is not typically considered critical in stone

engineering, except when stone elements are stacked. Stone compressive strength is typically relatively high when compared with other building materials and rarely controls a stone design. Specimens are typically 2 in. (50 mm) cubes, but cylinders of specific dimensions can also be used.

- ASTM C880, *Standard Test Method for Flexural Strength of Dimension Stone*.¹⁴ This method measures flexural strength used in bending calculations, among other design checks (Fig. 3). The testing uses specimens of project-specific stone thicknesses, with the length and width determined as a ratio of the thickness. It also incorporates two load application points, thereby exposing a wider area of the specimen to stress and providing a more accurate value of flexural strength for a specific project application. For these reasons, stone engineers typically prefer this test method over modulus of rupture for cladding and paving design. The standard specifications for limestone (ASTM C568), quartz-based stone (ASTM C616), and slate (ASTM C629) are the only standard specifications that do not include requirements for flexural strength (ASTM C880). The specifications for these three classes of materials require the use of modulus of rupture for bending calculations; however, stone engineers may require flexural strength testing for these stone classifications.
- ASTM C1354, *Standard Test Method for Strength of Individual Stone Anchorages in Dimension Stone*.¹⁵ Strength of the stone is only part of the information necessary to design a successful stone installation. The interaction between the proposed anchorage system and the stone is arguably as important. There are countless ways to secure stone cladding to a substrate, and ASTM C1242, *Standard Guide for Selection, Design, and Installation of Dimension Stone Attachment*

Systems,¹⁶ discusses many of those methods. The ASTM C1354 test method determines the capacity of the stone and anchor assembly, which is particularly important for unique anchor designs, or for highly variable stone types where standard calculation assumptions or analytical modeling may be overly conservative or insufficiently accurate.

PREDICTIVE TESTING AND EVALUATION¹⁷

In addition to physical property testing that is necessary to engineer stone for a specific application, there are several common tests for natural stone that are predictive regarding long-term performance. The following test methods can help the designer determine whether the stone will be appropriate for a given application from a serviceability standpoint, and whether it will remain structurally sound over the intended service life of the project:

- ASTM C97, *Standard Test Methods for Absorption and Bulk Specific Gravity of Dimension Stone*.¹⁰ The absorption portion of this test method is used as a predictive indicator of stain resistance and is sometimes used to predict resistance to distress from cycles of freezing and thawing. Specimens are typically 2 in. (50 mm) cubes, but cylinders or prisms of specific dimensions can also be used.
- ASTM C217, *Standard Test Methods for Weather Resistance of Slate*.¹⁸ Exclusively required for slate dimension stone and shingles, this test method assesses the softening caused by the application of mild acid, which is intended to simulate exposure to acid rain.
- ASTM C666, *Standard Test Method For Resistance of Concrete to Rapid Freezing and Thawing*.¹⁹ This standard was developed to

TABLE 1. Stone classifications by geology and mineralogy

Geologic category	Mineralogic category	ASTM classifications	Common types of building stones unclassified by ASTM
Sedimentary	Siliceous	Quartz-based (sandstone, bluestone, quartzite and similar)	
	Calcareous	Limestone, travertine	Onyx
Metamorphic	Siliceous	Slate, serpentine	Schist, gneiss, soapstone
	Calcareous	Marble	
Igneous	Siliceous	Granite	Basalt



FIGURE 3. Stone specimen tested in accordance with C880 to determine flexural strength.

evaluate concrete durability, but it is often specified for natural stone. Unfortunately, its applicability is limited; experience has shown that the method of evaluation is not appropriate for many natural stones and can mischaracterize potential in-service performance. Use of this test should be limited to comparison of possible stone selections.

- ASTM C1353, *Standard Test Method for Abrasion Resistance of Dimension Stone Subjected to Foot Traffic Using a Rotary Platform Abraser*.²⁰ Abrasion resistance based on laboratory testing is helpful in predicting the in-service behavior of natural stone in situations where it will be subject to abrasion from foot traffic or abrasion in general.
- ASTM C1721, *Standard Guide for the Petrographic Examination of Dimension Stone*.²¹ This guide is used to evaluate the physical and chemical characteristics of the stone (mineralogy, texture, composition), and other features that may have a bearing on the in-service performance of the material. Petrographic examination uses microscopy and examination under various wavelengths of light to characterize a specimen. These methods are valuable to identify and classify stone, and they also can identify characteristics that can be deleterious to the installation. Typically, the supplier selects a small specimen, perhaps less than 1 ft² (0.1 m²) in area and sends it to a petrographer for examination. However, it is best to provide a larger sample (as large as practical, such as

a full wall cladding panel or paver) and allow the petrographer to perform a macroscopic examination and then select a specimen based on that assessment for more detailed petrographic examination. This approach takes full advantage of the petrographer's experience in identifying characteristics of potential concern to examine.

- ANSI A137.1, *Standard Specifications for Ceramic Tile*.²² Although these specifications are technically for ceramic tiles, the dynamic coefficient of friction (DCOF) portion of this standard is used to determine slip resistance of natural stone in paving and flooring applications and provides a recommended value for compliance. Currently, there is no mandatory DCOF requirement, but there are industry recommendations from the Occupational Safety and Health Administration,²³ and within the Americans with Disabilities Act.²⁴
- Accelerated weathering protocol. Currently there is no formal stone industry-accepted standard for accelerated weathering to assess potential environmental effects on natural stone over time. Wiss, Janney, Elstner Associates Inc. has proposed a testing protocol to ASTM that involves cyclic temperature changes to simulate in-service temperatures and cycles of freezing and thawing, plus exposure to mildly acidic water spray to simulate acid rain. Physical property testing of the stone is performed before and after multiple temperature cycles to measure

any losses that can be associated with durability, such as strength and absorption. This testing approach is commonly used for large-scale or high-profile projects to compare proposed stone selections, but it is not accepted by ASTM as a formal test standard.

- EN 12370, *Determination of Resistance to Salt Crystallization*.²⁵ This is a European standard adopted by the European Committee for Standardization (CEN), European Committee for Electrotechnical Standardization (CENELEC), and European Telecommunications Standards Institute (ETSI). It is often used to evaluate stone that may be exposed to elevated levels of chlorides for deicing purposes, or to determine suitability of a stone for placement at grade and in contact with soil. This test evaluates the impact of salts dissolved in water and absorbed into a stone specimen, which is then dried, leaving the salts to recrystallize with the stone.
- EN 16306, *Determination of Resistance of Marble to Thermal and Moisture Cycles*.²⁶ This is another EN standard that is used in the US market; it helps to determine susceptibility of the specimen to bowing and strength loss through hysteresis (deformation and/or strength loss resulting from cyclic heating and cooling exacerbated by cyclic wetting and drying that results in the separation and dislocation of the mineral grain structure and permanent volume change), a condition associated primarily with several types of marble (both foreign and domestic) and some types of limestone.

New Work in Stone Testing Development

Stone material specification and testing standards are the responsibility of ASTM C18, Committee on Dimension Stone. In addition to maintaining and updating the existing ASTM standards, the committee considers new work items and develops new standards or guides related to the use of natural stone in building construction. Current and planned test standard work items include a stone-specific test protocol for resistance to freezing and thawing, salt crystallization resistance (similar to EN 12370), and possibly a procedure similar to EN 16306 to evaluate stone potential for strength loss and bowing.

WHY IS STONE TESTING IMPORTANT?

Stone is stone, right? Wrong. Stone is a natural material and extremely diverse in its origin, mineralogy, and physical properties.

There are several reasons why it is difficult, if not impossible, to determine the physical properties for many stone types from visual examination or by applying what is thought to be the relevant classification standard. Stone classifications are defined for construction purposes by ASTM International in the United States, and by other construction material standards organizations around the world. The classifications are generally based on common mineralogy and physical properties. However, stone properties can vary from classification to classification, within classifications, and even within the same quarry. Furthermore, the *consistency* of the physical properties of a stone can also vary. Another concern is that suppliers sometimes misclassify materials (for example, labeling marble as granite, or limestone as marble). These misclassifications can contribute to erroneous assumptions about whether a particular material is appropriate for a given application. Also, trade names for the same type of stone may vary depending on the quarry or supplier from which it originates. Quarries a few miles apart may provide essentially the same stone under differing names for marketing purposes.

For most building applications, the stone must support at least its own weight as well as some applied loads. Whether the loads are vertically or horizontally applied, stone must be engineered to support them. In conventional construction, the structural engineering of stone is typically delegated to a stone specialist who is more familiar with the variability of stone, appropriate safety factors, and the fabrication standards that will influence the design. The delegated stone design engineer can determine the demand with a high degree of certainty through application of material properties, anticipated dimensions, and relevant codes. However, they cannot estimate the capacity of the stone unless they have a resource for determining stone-specific physical properties.

The logical answer to the concerns raised herein is to improve designers' understanding of and reliance on natural stone testing to determine the physical properties necessary to implement successful designs. It is customary for a competent design professional to require physical property testing of concrete to ensure that its capacity will meet the required demand and that it will be durable in service. It would seem that a similar level of quality control should be implemented for stone when it is used in critical applications to ensure structural and serviceability expectations are met.

Stone Selection

Natural stone is selected for applications in building construction largely based on appearance, not performance. Aesthetics often drive design decisions and can lead to innovative uses of stone colors, characteristics, or textures that enhance our built environment. There is nothing wrong with this approach, provided that the physical properties of the chosen stone are understood so that its appropriateness for the application can be confirmed.

When stones from exotic classifications or unusual stone types within a classification are being considered for an atypical application, relevant physical property data may not be available or current. In the absence of adequate physical property data, one can consider using the industry-minimum properties for the particular stone classification, but that can be a problematic approach. Unfamiliar stones may be misclassified by the supplier, leading the design to erroneously make favorable assumptions that could mask a potential risk of failure. Conversely, a preferred stone selection could be eliminated from consideration because assumptions about strength or performance are overly conservative, pushing the designer to unnecessarily consider alternatives. Current stone test data can help the producer by fairly evaluating and representing their products, as well as the designer by providing reliable data about using the desired stone in the intended application.

The ASTM standard specifications provide the minimum requirements for a stone type to be categorized in one of the classifications described earlier. They are a lower-bound benchmark for preliminary stone engineering purposes. If the stone supplier certifies that the stone meets the ASTM standard, then they have the obligation to ensure through periodic testing that the stone supplied complies with the minimum physical properties for the entire period the stone is quarried, which can be decades. If the stone does not meet the standard requirements for compliance, the stone can still be considered for use; however, the designer should obtain reliable test data for a preliminary assessment to determine the material's appropriateness for the intended use.

Typical Stone Applications and the Physical Properties Needed for Design

The primary structural applications of stone in our built environment include exterior cladding, exterior paving, interior cladding, and interior flooring. Testing can be critical in such applications to determine the selected stone is appropriate for a particular use.

Of the stone applications, exterior cladding carries the greatest risk if it fails. A cladding failure can be costly and disruptive to building ownership and its tenants, and it can be a danger to the public. A stone panel falling from any height can have devastating consequences. Because exterior cladding carries such a clear structural risk, it is critical to obtain the most accurate data about the physical properties of materials selected for its design. Thin-stone-cladding design largely relies on flexural strength and anchor strength for structural adequacy. Cladding design must also consider findings from petrographic examination to determine a material's staining potential and identify stone defects that could compromise structural performance. In some environments, product data about moisture absorption and accelerated weathering are needed to determine whether strength loss or stone deterioration from environmental effects should be considered in the design.

Exterior paving is exposed to constant pedestrian traffic, precipitation, temperature extremes, and sometimes substantial vehicular loads (such as emergency vehicles). Therefore, the stones used in exterior paving applications must be very durable. To evaluate durability, petrographic examination is critical to identify deficiencies that can lead to premature deterioration or cracking. Absorption test findings are useful to assess stain resistance, and data about resistance to cycles of freezing and thawing are important since paving can remain saturated for long periods of time. Abrasion resistance data provide a measure of how quickly a stone will degrade under foot traffic. Slip resistance data can be used to assess whether additional treatments are necessary to reduce the risk of pedestrian injury. From a structural standpoint, data about the flexural strength of paving materials guides the determination of material thickness, whether the installation is supported on a setting bed, or the pavers span between supports points in a pedestal system.

The structural risks associated with interior cladding failure are similar to those associated with exterior cladding failure. However, the structural and environmental demands on interior cladding are lower than those placed on exterior cladding. Design of interior cladding relies primarily on data about flexural strength and anchor strength to resist interior pressure differentials. Compressive strength can also be a factor for some thinner stone-cladding installations that rely on stacking.

Interior flooring (in public spaces such as lobbies) can be deceptively challenging to

TABLE 2. Relevant stone testing methods by application and stone classification

Test methods	Applications			
	Exterior cladding	Exterior paving	Interior cladding	Interior flooring
Direct use*				
ASTM C97	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se
ASTM C99	Q, SI	Q, SI	Q, SI	Q, SI
ASTM C120	SI	SI	SI	SI
ASTM C170	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se
ASTM C880	M, G, T, Se	M, G, T, Se	M, G, T, Se	M, G, T, Se
ASTM C1354	M, G, L, Q, SI, T, Se		M, G, L, Q, SI, T, Se	
Predictive use†				
ASTM C97	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se
ASTM C217	SI	SI		
ASTM C666‡	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se		
ASTM C1353	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se		M, G, L, Q, SI, T, Se
ASTM C1721	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se
ANSI A137.1		M, G, L, Q, SI, T, Se		M, G, L, Q, SI, T, Se
EN 12370	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se		M, G, L, Q, SI, T, Se
EN 16306	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se		
Accelerated weathering	M, G, L, Q, SI, T, Se	M, G, L, Q, SI, T, Se		

Abbreviations: G = granite; L = limestone; M = marble; Q = quartz-based; Se = serpentine; SI = slate; T = travertine.

*Uses directly related to engineering and design of stone systems.

†Uses related to predicting in-service behavior.

‡Testing should be limited to comparative testing and may require modifications to evaluation methods for some stones.

design. Owners and designers may desire particular stone types and finishes desired for aesthetic reasons, but the materials must also stand up to constant foot traffic plus water, sand, and snow-melt chemicals tracked onto the flooring from the exterior. Interior flooring design largely relies on information about flexural strength, absorption (stain resistance), abrasion resistance, and slip resistance.

Table 2 summarizes general recommendations regarding the relevance of various direct-use and predictive stone testing procedures to the four main structural applications for stone described in this section.

WHEN IS STONE TESTING MOST CRITICAL?

Obtaining accurate and current data about a product's physical properties for use in stone design is always good practice, and such data are often readily available from suppliers that understand the need for regular testing of their products. But when reliable physical property data are not available from the supplier, stone testing is critical in certain situations to ensure a safe and reliable installation. The importance or visibility of a project is an important factor when considering stone testing. Selection of stone for a prominent monument, museum,

or institutional building with an expected service life of 100 years or more demands a comprehensive evaluation of proposed options. The decisions made regarding which stone to use can have an impact on repair and maintenance costs for generations.

Designers should also prioritize testing of stones that could be used for buildings in challenging environments. Environmental challenges can include extreme heat or cold, frequent cycles of freezing and thawing coupled with precipitation, high-wind events such as hurricanes or tornadoes, sandstorms, heavy pollution, and acid rain. Testing can provide

valuable insights into long-term performance under these adverse conditions.

A stone supplier may be able to provide examples of similar installations in similar environments with the same stone being considered. Depending on the amount of time the stone has been in service, these exemplars can be one of the best ways to predict long-term performance of a particular stone. An exemplar does not eliminate the need for physical property data to complete a design, but it can reduce the amount of predictive testing warranted based on the similarities between the exemplar and the proposed application. Conversely, the absence of exemplars heightens the need for comprehensive physical property data from stone testing, as the lack of information can be an indication that the stone is not commonly used for the intended application.

Atypical or unusual stone applications—such as sloped or inverted cladding, applications incorporating a particularly aggressive stone finishing technique (potentially causing microfractures), or applications using stones as structural members to carry more load than self-weight—require special attention. The more unique the application is, the more unpredictable the performance and outcome can be. Highly unpredictable scenarios demand a high level of engineering conservatism. Accurate physical property test data can help designers mitigate risks associated with unusual applications.

Some stone types are known to have natural characteristics that can lead to adverse outcomes when in service. For example, pyrite inclusions can cause rust-colored staining, and some types of marble are prone to strength loss through hysteresis. Stone testing establishes a benchmark for use in design, but more importantly, predictive testing can inform choices about stone selection based on how the natural characteristics of materials will likely affect in-service performance.

One of the most distinctive and attractive features of natural stones are their variability in appearance—no two pieces of the same stone will ever look the same. But that variability in appearance can also mean that physical properties are inconsistent. Stone that is highly variable in appearance should be extensively tested in an effort to benchmark the range of physical properties resulting from compositional variations such as differences in the density and directionality of veining, the presence of various metals or other substances, and the presence of voids, fissures, and seams.

Because stone is a natural material, its physical properties are often associated with

the location where it is quarried. Some quarries encompass large areas in which the geologic features can vary, leading to different physical properties from one part of the quarry to another. Designers should also be aware that the test data provided from a particular quarry may be for a stone that is several years old and may not accurately represent current production. (ASTM C17999 recommends stone test data that are less than 3 years old for this reason.) Designers should not rely on out-of-date test data, and the lack of current test data can serve as a warning that the stone has not been used in a recent application that requires engineering.

Some classifications of stone require more conservative safety factors than others. A higher safety factor is an indicator that the physical properties are less consistent historically or can vary from stone type to type within a classification. When larger safety factors are involved, accurate test data are important to obtain physical property values that are not overly conservative. Conservative values combined with large safety factors can lead to a design that is not cost effective, or simply less efficient and more expensive than necessary.

Some recent industry trends also increase the need for stone testing and accurate physical property data. For example, designers of applications such as rain screen systems in which stone is exposed to more severe environmental conditions require informative physical property data. Also, recent emphasis on sustainability has prompted scrutiny of the efficiency of all types of building products, including natural stone, which is energy intensive to produce and ship. The use of locally sourced stone materials may help meet sustainability goals and reduce costs on some projects, but designers must consider physical property test data before selecting these materials.

WHERE IS TESTING IN THE DESIGN AND CONSTRUCTION PROCESS?

Evaluation of stone testing has value at several stages of a project and can serve multiple objectives. Four major objectives to consider are feasibility, verification, material acceptance, and quality assurance.

Stone Product Feasibility

At the beginning of a project involving stone applications, designers may consider multiple stone types, with the initial evaluation of materials largely based on design intent and aesthetics. Once the options are established, physical property testing (including petrographic examination) should be solicited from the

vendors. In some cases, the testing data made available are incomplete, not current, derived from non-ASTM test standards, or written in a foreign language. If the design team encounters any of these issues, a second request for information should be made, with specific instructions to contact the quarry and improve the quality of the test data provided. The quarry may have more current test data than the vendors that market the stone. In addition to test data, designers should request information about exemplars from both the quarries and the vendors (asking both for information is prudent because their project references will be different). Of particular interest are any local applications that the design team can visit with minimal effort. Note that this process of inquiry will likely result in some relevant test data for some of the stone options, but it probably will not provide a complete set of information for any of the options.

Based on the information provided, the stone classifications should be verified. As noted earlier, the quarry or the vendor might misclassify a stone for marketing reasons or out of ignorance. Verification is critical since the purpose is to benchmark the physical test data to the appropriate ASTM standard. Once the correct classification is established, the provided test data should be interpreted as well as possible, such as by comparing EN standards to ASTM standards or by obtaining translations of non-English-language documentation.

The data about each stone under consideration can be generally compared with the other options and the minimum ASTM standards. Depending on the stone application, attention should be focused on certain tests, such as moisture absorption for flooring and flexural strength for cladding. If the most critical test data for the application are not available, that lack of information suggests that the stone may not be appropriate for the intended use. The supplier may not be willing to perform any additional testing at this stage, but they should know that the stone may not be considered further unless reliable data are provided. The design team should note any major outliers in the data (that is, values that are abnormally low or abnormally high). The test results should also be compared with publicly available published data from other suppliers (if available) to look for any major discrepancies.

Once this evaluation process is complete, the design team can loosely rank the stone options, with those that have less desirable performance or insufficient test data at the lower end. At this stage, the team may add or eliminate options

from consideration based on design intent, so the process remains fluid.

By the time stone types are being considered, the design team may have application formats and preliminary designs that indicate the parameters in which the stone will be used. Having this information as early in the process as possible helps ensure that the appropriate stone types are being considered to avoid a potential mismatch between physical properties of the stone and the demands of the application.

Verification of the Stones Selected for a Project

Once the stone types have been selected for specific applications, any gaps or concerns with the provided test data should be addressed to ensure that the selections are suitable for the applications. At this point, the quarry should be willing to supply comprehensive ASTM-specified test data that is representative of their current production, even if they must obtain additional testing. In the feasibility stage, the design team used conservative values based on the classification (either the ASTM minimums or the actual test values provided) to determine that the selected stone type can be suitable for the applications. The physical test data provided at this verification stage will be used for final stone engineering to make sure unit sizes and thicknesses will work based on the design loads anticipated.

Depending on the application and the project environment, predictive testing should be considered at this stage if relevant exemplars are unavailable. This is the last opportunity to evaluate the appropriateness of the selected stone before it is specified.

Material Acceptance


On some projects, a considerable period of time can pass between specifying a stone and the submittal process, and in that time, the stone production can change. Therefore, design teams may perform quarry visits during the material acceptance stage to verify that the selection of the stone meets the design requirements, and that quarry can achieve the production goals. Specific blocks of stone may be selected based on appearance. As part of the acceptance process, the quarry should be required to provide samples of the stone selected so that physical testing can be conducted by independent laboratory to make sure that the specimens meet the minimum design requirements and do not contain any undetected flaws or features that could compromise the installation. This process helps establish whether any culling of stone may

be needed to provide only material that meets the project requirements.

Quality Assurance during Production

To ensure the material that is being delivered throughout the installation is consistent in quality and physical properties, testing should be performed periodically on material selected at random from the delivered shipments. The scope of testing can often be scaled back to only the most critical properties for the application, and the frequency of testing may be determined by considering the uniqueness of the stone, the quantity of stone being installed, and the variability in data obtained during prior testing. As long as the test results obtained are generally consistent and in line with expectations, the material delivered should be compliant with the project requirements.

CLOSING THOUGHTS

Many stone projects can be constructed and perform well without project-specific physical property testing. In particular, project-specific testing may not be needed when projects use stone products that have a long history of success and a reputation for consistent production, and there are historical test data to demonstrate that the selected products meet industry requirements for the classification. Also, not all the physical testing methods discussed in this paper are relevant to every application. It also must be acknowledged that stone testing has a cost. Therefore, it is up to the design team and the suppliers to make good decisions about what, why, when, and where stone testing will be a benefit to a project. Ultimately, the objective of stone testing is to ensure that design requirements will be met and to reduce risk of costly failures for all the parties involved. 

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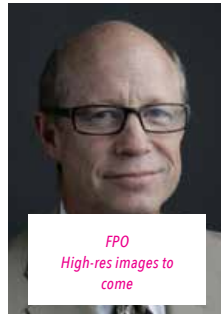
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ABOUT THE AUTHOR



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Matthew C. Farmer, PE Natural stone is recognized and used as a construction material throughout our built world because of its visual and textural diversity, timeless beauty, sense of permanence, and association with quality. Design

professionals (including architects, landscape architects, and interior designers) rely on natural stone to create the environments in which we live, work, commune, and even memorialize past events and individuals of significance from our history. The considerable demand for "new" stone, in combination with globalization, has opened opportunities for suppliers from around the world, many of whom have only recently developed their natural stone resources for commercial use. This rush to market can create healthy competition and increase the volume and diversity of stone available. However, the lack of historical experience with some stone types and inconsistent documentation of their physical properties can lead to the selection of unsuitable products and unsuccessful outcomes (see Fig. 1 and 2). For example, well-intentioned vendors may not realize that a stone used for interior flooring will not perform adequately in an exterior cladding application.

Special interest

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TO COME WORD

Special Interest

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