MIA
Setting the Standards for Natural Stone

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Dimension Stone Test Methods, Guides, and Standards

1.0 Standards Authoring Organizations

There are numerous standards writing organizations in the world. Perhaps the two most recognized are ASTM International and CEN (European Committee for Standardization or *Comité Européen de Normalisation*). Within North America, the ASTM standards govern, and within Europe, the CEN standards, known as "EN"s, govern. Elsewhere in the world, many countries have adopted one or the other systems, or have their own testing and specification standards authored by a local organization. There are similarities between the ASTM documents and the CEN documents, to the extent that some test procedures could be considered nearly interchangeable. Conversely, some test procedures exist in both systems for which there is no equivalent counterpart in the other system. This paper is written to describe the ASTM standards and test procedures, with references to those CEN documents which are similar in scope. This paper is not intended to provide specific instructions on how the test procedures are executed, as this information should be obtained by purchasing original copies of the actual procedures.

2.0 Types of ASTM Documents

Currently, there are over twenty five documents published by ASTM International related to dimension stone. Documents pertaining to dimension stone fall into four different categories of ASTM publications:

- Standard Terminology
- Standard Guides
- Standard Material Specifications
- Standard Test Methods

A Terminology, or nomenclature, standard is a glossary of industry or material specific terms. It includes definitions of terms that are either unique to the industry/product, or are used in that industry differently than their common usage. For instance, there is no need to define a term such as *mockup* in the dimension stone terminology guide, since the common usage of the term outside the stone industry is the same as its use within the stone industry. Conversely, there is a need to define the term *anchor*, because within the stone industry, anchor does not mean "a heavy object attached to a rope to moor a vessel to the sea bottom." Terms that appear in only one ASTM document, such as a guide or test method, are sometimes defined within a terminology section of that document, rather than being included in the Terminology Standard.

Guides are simply a collection of information about a subject. They suggest no specific or prescribed course of action. They are published as an informational tool, and are oftentimes referred to in other ASTM documents, inasmuch as the reader will probably need the supplemental information provided in the guide to properly interpret the other documents.

A Specification standard merely defines the measureable requirements that a product must meet to satisfy that standard. These documents tend to be very brief, and usually include a table of physical and/or mechanical properties that should be met by the subject product of the standard, and a clarification of which test method(s) are to be used to measure that value.

A Standard Test Method, just as the name implies, is a documented protocol by which a material is to be tested to quantify a specific property. The test methods will include information on the physical test specimen size, shape, and surface treatments, as well as recommendations of sample population. The procedure will provide a detailed, step by step, description of how the test is to be performed, including all significant controls such as time, temperature, load rates, measurements, and report requirements. What it won't typically provide is the pass/fail criteria for the results. The Specification Standard is normally referenced for guidance on how to interpret the results.

The type of document published dictates not only its intended use, but also its writing style. There is a technical difference between the writing of a test method or specification, versus a guide. Test methods and specifications are normally written in what is called *mandatory* language. Verbs such as *shall, must,* and *will*

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are considered to be commands, and therefore compliance with the statement is mandatory. The use of mandatory verbiage contributes to the strict and uniform interpretation of test method and specification documents. Guides are commonly written either completely or partially with the use of "permissive" language. Verbs such as *should, may,* and *might* are considered to be recommendations, and therefore compliance with the statement is preferred, but not necessarily required. Guides are intentionally written to provide some flexibility in interpretation by using these verbs. Additionally, an ASTM Guide is generally considered to be a "description of best practice," which is intentionally above and beyond the minimum required for life safety preservation. Conversely, building codes are written to describe the minimum requirements for life safety, so guides will frequently suggest component or procedure choices that are notably superior to those required by applicable building codes. Since building codes define minimum standards, the interpretation of them is not intended to be flexible, and are therefore written in mandatory language. It is for this reason that while ASTM Test Procedures or Material Specifications are frequently referenced in building codes, ASTM Guides are rarely referenced in building codes because their permissive language would soften the mandatory compliance requirements sought by the authors of code.

3.0 Standard Terminology

There is currently one terminology standard published by ASTM that pertains to dimension stone nomenclature, and that document is *C119 Standard Terminology Relating to Dimension Stone*. It is a seven page document defining slightly more than 100 terms. The definitions range from brief, single sentence definitions to discussions of several paragraphs which may include graphics, depending on the usage of the term.

4.0 Standard Guides

There are currently seven Standard Guides published by ASTM for the dimension stone industry:

- *C1242 Standard Guide for Selection, Design, and Installation of Dimension Stone Attachment Systems* is a seventeen page document, and provides comprehensive guidance for mechanically anchoring or adhesive bonding of stone units. It includes discussion on metallurgy, common anchor devices, cutting of anchor preps, safety factors, moisture control, supervision, and inspection.
- *C1496 Standard Guide for Assessment and Maintenance of Exterior Dimension Stone Masonry Walls and Facades* is a seven page document that is intended for use by building owners and maintenance personnel to aid them in recognizing common symptoms in stone facades. It also offers guidance in determining if those symptoms are simply typical aging of the façade, or signs of distress which require remedial measures.
- *C1515 Standard Guide for Cleaning of Exterior Dimension Stone, Vertical and Horizontal Surfaces, New or Existing*, five pages in length, covers cleaning methods, cleaning chemicals, and stone type identification to prescribe cleaning and stain removal methods that are both effective and non-damaging to stone surfaces.
- *C1528 Standard Guide for Selection of Dimension Stone* is a rather extensive work designed to assist those who are relatively inexperienced in selecting and/or specifying natural stone products. It provides a background of what research, testing, and evaluations should be performed to properly assess the variety of available stone products and make an informed decision regarding selection.
- *C1721 Standard Guide for Petrographic Examination of Dimension Stone* includes the recommendations of what sampling, analytical techniques, observations, and reporting are necessary to adequately provide the mineralogical composition, textural properties, and integral structure descriptions of the stone fabric. It is intended to be used by professional petrographers and mineralogists as an aid in providing a comprehensive analysis and report.
- *C1722 Standard Guide for Repair and Restoration of Dimension Stone* pertains primarily to the structural repair and stabilization of exterior stone facades. Repair, anchor replacement, and patching of existing stone cladding units are covered in this document.

5.0 Standard Specifications

There are eight Standard Specifications for dimension stone. They are all very similar in format, in that all include some general notes about material quality, and all include a table of physical and mechanical properties against which the actual properties of the material are to be compared. The tables have been developed using values of known stones within that group that have demonstrated repeated successful performance. Therefore, they are not always considered to be absolute minimum or maximum values. Indeed, numerous materials have been successfully used that do not meet one or more of the requirements of the tables. The limestone and quartz-based specifications differ from the rest in that they contain multiple tables to cover varying density ranges (categories I, II, and III in the limestone) or stone types (sandstone, quartzitic sandstone, and quartzite in the quartz-based). There currently is no specification published for soapstone or onyx. The eight existing specifications include:

- *C406 Standard Specification for Roofing Slate*
- *C503 Standard Specification for Marble Dimension Stone*
- *C568 Standard Specification for Limestone Dimension Stone*
- *C615 Standard Specification for Granite Dimension Stone*
- *C616 Standard Specification for Quartz-Based Dimension Stone*
- *C629 Standard Specification for Slate Dimension Stone*
- *C1526 Standard Specification for Serpentine Dimension Stone*
- *C1527 Standard Specification for Travertine Dimension Stone*

6.0 Standard Test Methods

Standard Test Methods exist for determining various physical and mechanical properties of dimension stone. In some cases, two test methods are available to measure the same property, although there is usually an advantage in using one over the other. Very seldom is there a requirement to use both methods.

C97 Standard Test Methods for Absorption and Bulk Specific Gravity of Dimension Stone is the test method used to determine the absorption of water, expressed as a percent by weight, and the bulk specific gravity, which is the means by which density is determined. Water absorption by weight is a bit deceiving, in that the density of the stone influences the expression. Since stone is denser than water, it should be noted that the water absorption by volume would be greater than the water absorption by weight. Similarly, if a low density stone and a high density stone have the same water absorption as a percentage by weight, the higher density stone would have actually absorbed more water by volume. Density, or mass per unit volume, is determined by this test procedure also. What is actually measured is the bulk specific gravity, which is the ratio of the stone's unit weight to that of water. The saturated stone specimen is weighed in air, and then the same specimen is weighed while suspended in water. The comparison of the two provides the bulk specific gravity of the stone. Since we know the density of water, once we have the bulk specific gravity of the stone we can determine the stone's density by simple arithmetic conversion. An example of the typical test setup for recording the weight suspended in water is shown in **Figure 1**. This method is used because it

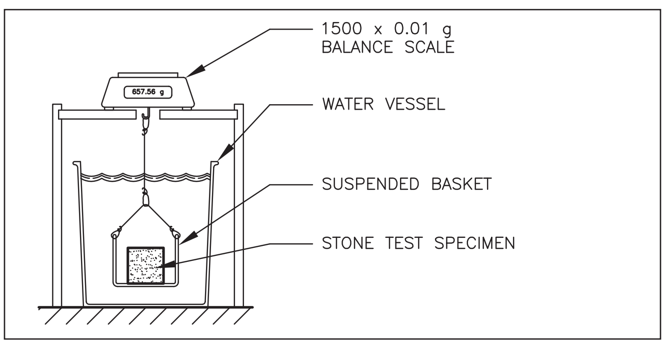

Figure 1: Typical Setup for Recording Suspended Weight in C97 Specific Gravity Test

automatically adjusts for any chips or fabrication inaccuracies in the stone specimen, and is therefore more accurate than simply measuring the specimen to determine its volume, and then dividing the mass of the specimen by that volume. All dimension stone types are tested with this method except slate which is usually tested via the C121 test method.

C120 Standard Test Methods of Flexure Testing of Slate (Breaking Load, Modulus of Rupture, Modulus of Elasticity) is used for slate because it better accommodates the thin, cleft samples for testing roofing slate. Because it uses a three-point beam loading, inter-laboratory studies are currently being conducted to evaluate the use of the C880 procedure for slate, since the C880 procedure uses a four-point beam loading fixture, which has some advantages (see discussion under C880, below).

C121 Standard Test Method for Water Absorption of Slate is used primarily for roofing slate, because it accommodates specimen sizes that can be obtained from the thin, cleft roofing slate stock.

C170 Standard Test Method for Compressive Strength of Dimension Stone is used for all dimension stone types, using a specimen that is a rectangular prism, cube, or cylinder. Specimens must be between 2" and 3" in all dimensions, and the height must be equal to or greater than the width (or diameter). The compressive strength is reported as the failure stress in either lbs/in² or MPa. A diagrammatic view of this test procedure is shown in **Figure 2**.

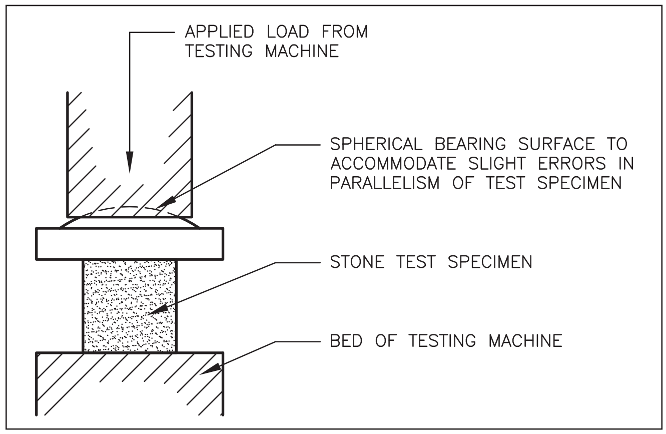

Figure 2: Test Setup for ASTM C170

C217 Standard Test Method for Weather Resistance of Slate is an acid resistance test for roofing slate. The test specimens are softened by immersion in sulfuric acid, and the degree of softening is determined by scraping of the surface.

There are two test procedures available for testing the bending strength of dimension stone. *C99 Standard Test Method for Modulus of Rupture of Dimension Stone* has been in place for 80 years, having been originally approved in 1931. While no one who was on the committee in 1931 is still alive today to verify it, it is commonly believed that the modulus of rupture test for stone was largely copied from the modulus of rupture test for brick, which predates it. (The modulus of rupture test procedure for brick is C67, and while the test procedure says it was originally approved in 1937, a version of it must have existed prior to 1931. The test designation numbers were assigned sequentially and it has a lower number than the test procedure for stone.) One of the obvious similarities of the two procedures is the test specimen size, which in C99 is specified to be 8" x 4" x 2¼", which is basically the nominal size of a standard brick. This is a very reasonable specimen size for brick testing, since bricks are manufactured to that size, but it is illogical to test this size specimen in stone when it doesn't represent any typical stone application. The C99 testing fixture **(Figure 3)**

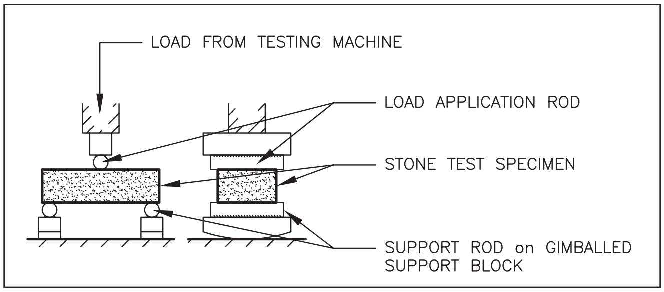

Figure 3: Example of Test Assembly for C99 Modulus of Rupture Test

holds the specimen over two supports (originally knife edges, but later revised to rods), and loaded at the center of the span with a third knife edge (also later changed to rods). For decades, the test procedure was largely untouched, since stone usage was mostly in cubic sizes which resulted in extremely low flexural stresses. Therefore the property of bending strength was commonly used merely for comparison purposes between stones, and infrequently used for structural design purposes. As stone applications, particularly cladding, utilized thinner panels, stone units would now experience significant flexural stress, and modulus of rupture data was used to determine safe loading levels. These analyses uncovered two shortcomings in the test procedure. First, the short, deep test specimen, with its high shear to moment ratio, wasn't experiencing as pure of a flexural stress as desired due to its thick beam behavior. The reported results of the test were a bit higher than realistic due to this. The second problem was the single load application line at the center of span, which concentrated the bending stresses along that line. This resulted in the reporting of higher than actual values, since the stone could have a much weaker region which would remain undetected because it wasn't at the point of the concentrated load.

In 1978, a new bending test procedure was approved and published as *C880 Standard Test Method for Flexural Strength of Dimension Stone*. This procedure addresses the two shortcomings of C99: it called for specimen depth of the actual project thickness, and a span of ten times the depth. This eliminated the thick beam behavior problem, and allowed for more representative sampling because test specimens could be cut from actual production slabs. The C880 fixture was also different, in that it loaded the test specimen along two lines, each 25% of the span from each support. **Figure 4** shows a view of a test fixture compliant with this test procedure. It should be noted that this test procedure calls for a 1" diameter loading/support rod with a smaller, unspecified diameter rod sharing the same central axis, about which the larger rod is free to rotate. Consensus does not exist as to whether the incorporation of this smaller diameter rod is actually influential to the test's results, and many laboratories' fixtures do not include this element. The quarter-point loading configuration in this fixture produces a region of constant bending moment

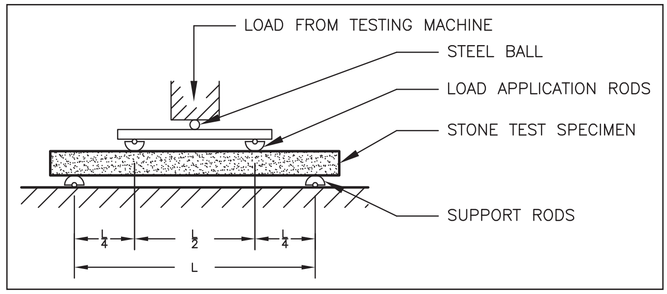

Figure 4: Example of Test Assembly for C880 Flexural Strength Test

between the load applications, which results in roughly 50% of the test specimen experiencing the maximum stress. This configuration does a much better job of seeking the weaker portion of the test specimen, which provides a much more realistic value of the actual bending strength of the material. See **Figure 5** for a comparison of the bending and shear stresses experienced by the test specimens in the two procedures.

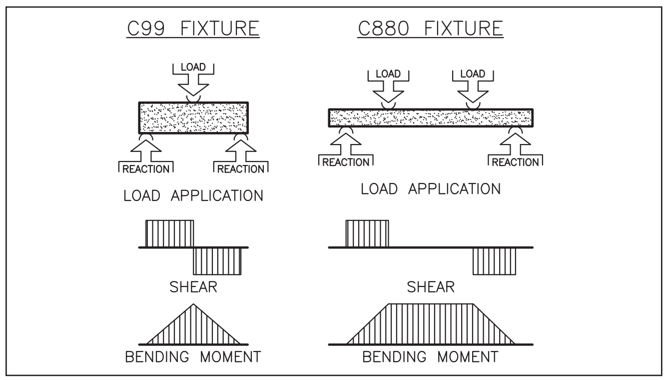

Figure 5: Comparison of Shear & Moment Distribution in C99 Modulus of Rupture & C880 Flexural Strength Test Fixtures

The C880 procedure also allows for modification to better suit the project for which the tests are being run. It calls for the actual (or proposed) project thickness to be used, allows for an actual (or proposed) project finish to be applied, and allows for the spans to be increased at the discretion of the specifier of the test. It has been suggested that in light of the advantages of the C880 procedure, the C99 procedure should be withdrawn and discontinued altogether. There have been two successful arguments against this, the first being that the C880 procedure, requiring actual thickness and spans of ten times that, uses extremely unwieldy test specimens when testing cubic stone applications of 3", 4", or greater thicknesses. Suppliers of these stone materials prefer to use the C99 procedure due to the smaller test specimen size, although they would perhaps be better served by using the C880 procedure but limiting the thickness to 2". The second argument for preserving the C99 test procedure is the ample history of data from many quarries, and the fact that since the procedure is seldom modified, it becomes a more valid tool to evaluate stone strength variation in a stone deposit over the history of that quarry.

C1201 Standard Test Method for Structural Performance of Exterior Dimension Stone Cladding Systems by Uniform Static Air Pressure Difference is designed to be a performance mockup test using full size panels with actual anchorage and either actual or simulated building frame components. In this way it differs from the C1354 procedure, which only tests an individual anchor. The use of static air pressure differences for panel loading simulates wind load on an exterior cladding panel. The significance of this test is that it includes the entire load path, starting with the stone, back to the building frame. This accounts for the influence that one component's reaction to the load has on the other components. For instance, if a component deforms significantly, allowing an anchor to rotate from its original position, the reduced capacity of the anchor would be realized in this test. Configuration of the apparatus used varies widely due to the variety of stone and anchorage configurations that could be tested with this method. A simple version of the test setup is depicted in **Figure 6.**

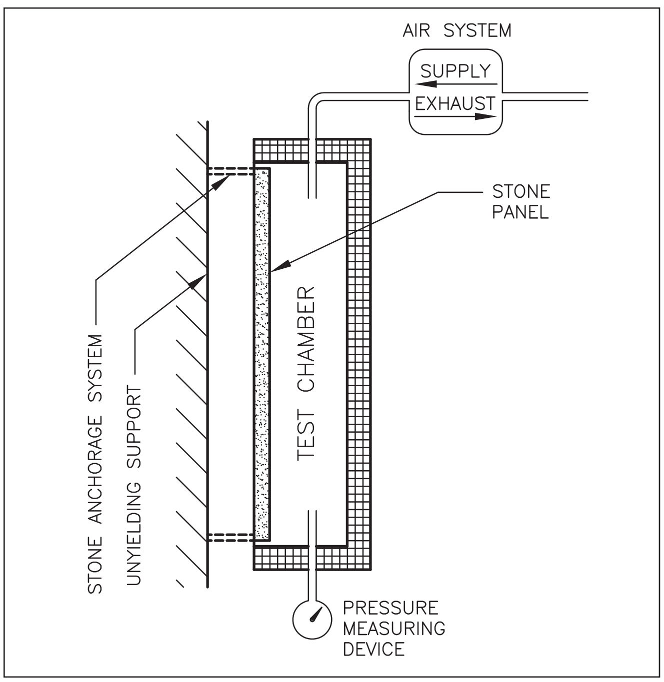

Figure 6: Typical Test Setup for ASTM C1201

C1352 Standard Test Method for Flexural Modulus of Elasticity of Dimension Stone is necessary for computer simulation of stone panel deformation and stress, more commonly known as Finite Element Analysis (FEA). Without knowing the modulus of elasticity, or resistance to bending, of the stone, the computer simulation would be invalid. The test is set up very similar to the C880 flexural strength procedure, with the inclusion of indicators to measure the deflection of the stone specimen under load.

Two test methods exist for measuring the abrasion resistance of stone intended for use as walking surfaces. The original method, *C241 Standard Test Method for Abrasion Resistance of Stone Subjected to Foot Traffic* was first approved in 1950. It used a custom designed, custom built apparatus that ground the stone specimen on a lapping wheel while an abrasive was fed to the wheel. Only three of these custom machines were built, and today, only one machine remains in the hands of a commercial testing laboratory, so the availability of vendors to provide this testing service is woefully inadequate. Further complication results from the fact that the manufacturer of the specified abrasive has changed the formulation of the abrasive, making it significantly more aggressive than the original product. This resulted in lower values for stones tested with the new abrasive. Citing the lack of equipment and the changed abrasive, a new procedure, *C1353 Standard Test Method for Abrasion Resistance of Dimension Stone Subjected to Foot Traffic Using a Rotary Platform, Double-Head Abraser* was developed and originally approved in 1996. The lengthy title of the standard is actually a generic description of the Taber Abraser, which is a commercially available laboratory instrument used for measuring abrasion properties of a variety of materials. During development of this test procedure, interlaboratory study (a.k.a. "round robin" testing) was performed by multiple laboratories on the same test specimen lots to verify reproducibility of the test method. During this phase, the test procedure was adjusted to establish a correlation with the existing C241 procedure. Establishing this correlation eliminated the need to modify all of the material specifications, since if a material had an abrasion index of 10.0 using the old method, it would still have an index of 10.0 if tested by the new method. In establishing this correlation, the study was centered about the softer stone varieties, those that had abrasion indices of 6 to 15. This was the critical range of values, since this was the range where stones were likely to either pass or fail the specified value for various applications. The hard stones, with abrasion indices of 50 to 100, were not studied, since a stone of this hardness would easily exceed any existing specification. It was ultimately determined that the Taber Abraser was not capable of actually abrading the hard stones, for instance granite, and the reported values were ridiculously high as a result. This discovery eliminated the ability to withdraw the original C241 procedure, since it was still needed to test the harder varieties of stone. Efforts are currently underway to develop drawings and specifications from the original C241 machinery from which additional machines can be built. Once available, there will be a decision made as to whether both procedures will remain with each being specific to certain varieties of stone, or if the C1353 procedure will be withdrawn and all testing standardized under one procedure.

C1354 Standard Test Method for Strength of Individual Stone Anchorages in Dimension Stone is a very simple, small scale test intended to determine the capacity of an individual anchor in stone. An actual anchor is fitted to the preparation in the stone specimen, and a load is applied and smoothly increased until failure. Fillers intended to be used in the anchor preparation may be included, although the test procedure requires that the bond between the filler be divorced at either the stone or the anchor. This rather conservative mandate stems from the fact that many stone clad buildings are built for exceptionally long service lives, and the assumption is that the bond may fail over the life of the building. Due to the huge variety of stone anchorage devices, this procedure is intentionally written to allow laboratory modifications as required to accommodate the particular device to be tested. Loads are normally applied in one direction, after which a subsequent test is performed with the load direction reversed. Simultaneous bidirectional loading is occasionally required, for instance, to model the forces upon an anchor that is responsible for both gravity (vertical) and wind (lateral) load resistance. While such bidirectional loading is referenced in the procedure, it should be noted that this is difficult to replicate in a laboratory setting, and as such, is only done when deemed absolutely necessary.

Friction Testing: Committee C18 on Dimension Stone has never authored a test procedure for testing frictional properties of natural stone walking surfaces. Committee C21, which governs standards of ceramic products, produced a test method to measure this property entitled: *ASTM C1028 Standard Test Method for Determining the Static Coefficient of Friction of Ceramic Tile and Other Like Surfaces by the Horizontal Dynamometer Pull-Meter Method*. Since, as far as frictional performance is considered, stone surfaces are "like surfaces," the stone committee had simply adopted the use of C1028 as the appropriate test method for stone surfaces as well as ceramic surfaces. The C1028 procedure used a very simple drag sled method of measuring friction, and its validity came under attack from a variety of sources for generally two reasons: One, the load application was not automated, and therefore substantial operator influence was experienced in the load application rate, directional bias, and uniformity. Second, since the test apparatus took some time to set up, it did not produce reliable data for testing in wet conditions, and could in fact produce data suggesting that frictional properties are improved by wetting of the substrate. To address these concerns, the Tile Council of North America developed an entirely new procedure which measures not static, but dynamic friction to assess walkway safety. The new procedure, first published in the ANSI A137.1-2012 document is entitled the "DCOF AcuTest[SM]" method. It uses a commercially available instrument, the BOT-3000 (Binary Output Tribometer), but with very specific protocols regarding the redressing of the test foot between tests to ensure reliability and repeatability. Substantial data collection was done with ceramic products to establish a correlation between the new method and existing methods. In February of 2014, the C21 Committee formally withdrew the C1028 test procedure, since it was no longer being used for ceramic products. This left the stone producers and users without a method to measure frictional properties of stone surfaces. Discussions have been held at the C18 Dimension Stone Committee meetings regarding the lack of a test procedure. Research of all available test methods is being conducted to determine which one would be the most appropriate to replace the now obsolete C1028 test method. Once a test procedure has been chosen, data collection and round robin testing with natural stone products will be required to establish a level of confidence for using the test method in stone products. While work has begun on this topic, consensus standards development is a time consuming process. It may be a year or more before the formal endorsement of a procedure for stone friction testing is made.

7.0 Utilizing Existing Test Data

Confusion exists within the industry as to when test data becomes too old to be a reliable indicator of the performance of a product from a given quarry. For most stones, from most quarries, the Marble Institute of America considers test data from the previous five years to be reasonably representative of the product that is currently being produced. Certain factors, such as high variability in the stone deposit, significant lateral or vertical movement of operations within the quarry deposit, uncertainty of the origin or validity of the existing test data, or a design that requires the material be taken to the limits of its performance envelope will reduce the time range over which data is considered valid. In all cases, test data should be submitted on the laboratory's stationery, clearly dated, with the stone's origin clearly identified. Data should include results from individual specimens as opposed to a summary of all tested specimens, as without these data one can not evaluate variability of the material. Summaries of material properties as are frequently seen on marketing literature are useful for preliminary comparison of materials, but such summaries are not comprehensive enough to be relied upon for final design decisions.

8.0 Required Tests

Two problems commonly exist in architectural specifications. The first is that an inadequate variety of testing is specified. The second, and actually more common problem, is that the specified testing includes test procedures which will provide no useful design or product evaluation information for the proposed application. In the case of the latter, compliance with the specification results in a waste of both time and funds. As a general rule, the table below can be referenced as a test regimen that should be considered:

■ *Indicates Required Testing*

□ *Indicates Testing to be Considered pending Historical Knowledge of the Stone Variety*

	Interior Walking Surfaces	Exterior Walking Surfaces	Interior Wall Cladding	Exterior Wall Cladding	Exterior Verhicular Traffic	Cubic Trim, Curbs, Coping, Etc.
Absorption	■	■	■	■	■	■
Density	■	■	■	■	■	■
Compressive Strength	□	□	□	□	□	□
Abrasion Resistance	■	■			■	
Flexural Strength	■	■	■	■	■	■
Friction	■	■			■	
Structural Performance				□		
Modulus of Elasticity				□	□	
Individual Anchorage			■	■		■
Petrographic Analysis	□	□	□	■	■	■

9.0 Sample versus Population Size

Generally, most ASTM procedures call for a minimum of five specimens to be tested for each subcondition of each test. Therefore, if one is testing for a given property, and wishes to include both wet and dry preconditioned samples, as well as samples cut from two different orientations with respect to rift, there would be five samples required for each of the four conditions, or a total of twenty samples required. Since most natural stone products have a rather high degree of variability, five samples actually provides a rather poor level of statistical confidence. It is not uncommon for the specifier of the test procedure to increase the number of specimens required to achieve a greater pool of data from which statistical evaluation can be more accurately accomplished. Similarly, there may not be a large degree of reliability that the supplied specimens are truly representative of the subsequent production stock. This is usually addressed by implementing an ongoing testing program throughout the supply of the project.

10.0 Preconditioning of Test Specimens

Many of the test procedures call for testing in both wet and dry conditions. The dry condition is accomplished by placing the test specimens in a ventilated oven for a period of time, usually 48 hours prior to testing. The wet condition is accomplished by submerging the specimens in room temperature water for a period of time, usually 48 hours prior to testing. In both the drying and saturating procedures, the specimens are to be weighed at the 46th, 47th, and 48th hour to verify that equilibrium has been achieved. Some stone varieties show very little difference in their values whether tested wet or dry, and those that do show a significant difference, typically show lower strength values in wet conditions. This has lead many specifiers of stone testing procedures to eliminate the requirement for dry testing. This results in either a lower cost for the testing regimen by reducing the number of specimens, or in producing data of higher statistical confidence by testing twice as many specimens in the wet condition.

11.0 Anisotropy

The root of the above word stems from the Greek word *tropos,* which means *turn,* or *direction*. The prefix *iso,* also of Greek origin, stems from the Greek word *isos,* meaning *equal*. The prefix *an* simply means *not*. So when the three syllables are combined in one word, the word *anisotropic* simply means *not equal when turned*. A material that is directionally specific, having different visual or structural properties based on direction is described as being *anisotropic.*

Dimension stone products range from those that are isotropic or mildly anisotropic, as in the case of many igneous rocks, to those that have pronounced anisotropy, as in the case of many sedimentary rocks.

Obviously, anytime a material displays a significant level of anisotropy, this must be addressed in the preparation of the test specimens. For example, in the case of a bending strength test, there are three primary directional orientations that could be tested with respect to the rift planes of the material. In **Figure 7,** the first condition has the planes of rift parallel to the planes upon which the support and load rollers will contact. This condition is generally referred to as "testing perpendicular to the rift," and is so named because the anticipated fracture surface will be roughly perpendicular to the planes of the rift. The second condition has the planes of rift parallel to the ends of the sample, and is generally referred to as "testing parallel to the rift," since the anticipated fracture surface is roughly parallel to the rift. A third orientation is possible, in which the planes of rift are parallel to the long edges of the sample. This condition is rarely tested in ASTM procedures, as its tested results should logically fall between the values

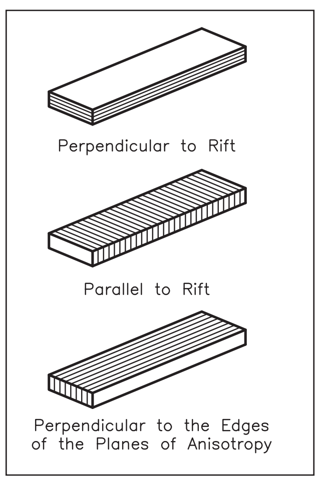

Figure 7: Rift Orientation

of the other two orientations. Common practice is to test the first and second orientation, and consider those to be the extreme high and low conditions. The EN test procedures do address this third orientation, and reference it as "load applied perpendicular to the edges of anisotropy."

Testing in a variety of rift orientations is necessary when the rift orientation of the supplied product is unknown, or if the product will be supplied in multiple, or random rift orientations. In cases where the material will be supplied in only one rift direction, and the visual properties of the material ascertain that adherence to this direction can be verified, testing in multiple directions is unwarranted. For example, there would be no influential data gained from testing a travertine in a veined direction when it is known that the entire project will be supplied as crosscut direction.

12.0 ASTM / CEN Compatibility

In general, the test procedures published by ASTM test stone to evaluate the same properties determined by the test procedures authored by CEN. Despite this, there exists no correlation between the values obtained in certain ASTM procedures and their CEN counterparts. Abrasion resistance and friction are two examples where the test methods differ so greatly that one cannot make a reasonable correlation between the results of the two procedures. Therefore, having data obtained from one system doesn't allow one to make even a rough estimate of what the results would have been if tested in the other system.

There are five properties, however, where the test methods are similar: Absorption, Density, Compressive Strength, Modulus of Rupture, and Flexural Strength.

The procedures to test absorption, ASTM C97, and its counterpart, *EN 13755 Determination of Water Absorption at Atmospheric Pressure,* use a similar sized specimen with a similar procedure. The primary difference is the mode of immersion, in which case the ASTM method immerses the test specimen completely without delay. The EN procedure immerses the specimen to only ½ of its depth for the first hour, then to ¾ of its depth for the second hour, and completely immersed for the remainder of the time. The rationale behind this protocol is that a cubic shaped stone sample, if immediately submerged, can trap the equivalent of an air bubble in its interior fabric and never achieve full saturation. By stepped immersion, this air is more efficiently evacuated from the sample. Some study of this has been done by ASTM Committee C18, and it appears that at least in some stone types this effect is noted.

Density is also tested by ASTM C97, but in EN procedures it is tested by *EN 1936 Method of Real and Apparent Density, and of Total and Open Porosity.* While the EN procedure includes additional sub procedures testing varying properties, the Apparent Density value is tested similarly to how density is determined in the ASTM system.

ASTM C170 or *EN 1926 Determination of Uniaxial Compressive Strength* are very similar procedures using similar specimen sizes for the purpose of determining compressive strength.

Modulus of Rupture per ASTM C99 can be compared to *EN 12372 Determination of Flexural Strength under Concentrated Load.* The latter includes more latitude in the finishes of the provided sample and uses a deeper and longer specimen. More significantly, the EN procedure calls for a span-to-depth ratio of 5:1, while the ratio in the ASTM procedure is slightly over 3:1. This would predictably skew the results; however the two procedures would be expected to have at least some level of correlation. It should be noted that neither procedure would be the preferred method for determining bending strength.

The ASTM C880 Flexural Strength procedure is similar to the *EN 13161 Determination of Flexural Strength under Constant Moment* procedure. The most significant difference is the span to thickness ratio, which is 10:1 in the ASTM procedure versus 5:1 in the EN method. The second significant difference is that the loading rollers are at $^1/_4$ and at $^1/_3$ of the span in the ASTM and EN methods, respectively. Both of these variations would be expected to produce slightly higher values in the EN method.

Not a test method, but rather an analysis, the ASTM C1721 and EN 12407 methods for petrographic analysis of dimension stone are similar. Either of these is likely to be significantly modified by the user to tailor them to the specific stone type.

While the above suggests that there is good correlation in these particular tests, such correlative data is likely only usable for preliminary study and evaluation. Final engineering and specification compliance will normally require data obtained from the exact, specified test procedure.

13.0 Obtaining Copies of the ASTM Documents

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