NATURAL STONE INSTITUTE

Technical Bulletin

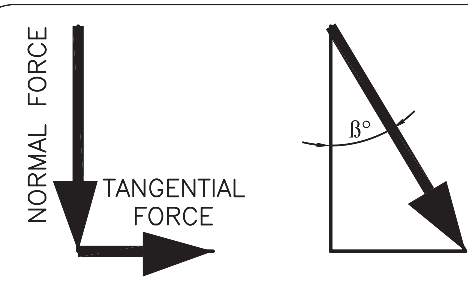
# Testing Frictional Properties of Natural Stone Walking Surfaces

**1. Friction Testing of Natural Stone Products:** The dictionary defines the word friction as a noun which means "The resistance that one surface or object encounters when moving over another." In a flooring application, one of those surfaces is the flooring finish material, and the other surface is the sole of the pedestrian's shoe. Some amount of friction is required to facilitate human ambulation. The amount required, however, will vary based on many factors. When the required friction is greater than the available friction, slips and falls are inevitable. Yet, somewhat illogical, some slippage is necessary for safe walking. So, based on the individual, there is actually a point where increased friction would making walking more difficult.

**1.1. Required Friction:** Required Friction, or "Utilized Friction" will vary based on several factors about the individual, including body dimensions, mass, stride length, and speed. Various studies have been conducted, including one by Burnfield and Powers reported in their paper titled *Influence of Age and Gender on Utilized Coefficient of Friction during Walking at Different Speeds*, published in ASTM International's STP 1424 in 2003. In this study, they found that the average utilized coefficient of friction for slow, medium, and fast gates, was 0.22, 0.24, and 0.26 respectively. These values were the averages of all test subjects, however, while the range of recorded values was rather extreme, spanning from a low of 0.13 to a high of 0.44.

**1.2. Available Friction:** The available friction can be determined by testing the floor surface with a simulated test foot, however a test of this nature has an extreme limitation in that the actual surface of the shoe's sole cannot be determined. A gymnasium sneaker, for example, will provide far greater friction on a given flooring surface than would a dress shoe. Testing a flooring material for friction then requires that a standardized test foot be used, which would represent neither the highest nor the lowest friction producing footwear available.

**1.3. Defining Coefficient of Friction:** A coefficient is merely a ratio, and a coefficient of friction is then the ratio of the tangential force to the normal force. If the tangential force is that force which is recorded when the movement is initiated, it is termed "Static Coefficient of Friction," and if the tangential force is recorded as movement is sustained, it is termed "Dynamic Coefficient of Friction."




The Coefficient of Friction would be the ratio of the Tangential Force to the Normal Force, or simply the Tangent of the Angle ß.

**2. History of Friction Testing for Stone:** A brief history of testing protocol for friction of natural stone walking surfaces is below:

**2.1. 1984:** ASTM Committee C21 (Ceramics) authored and published a very simple test method for determining the static coefficient of Friction of hard flooring surfaces 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 C18 stone committee 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 had come under attack from a variety of sources for two reasons: One, the load application is not automated, and therefore substantial operator influence is experienced in the load application rate, directional bias, and uniformity. Second, since the test apparatus takes some time to set up, wet condition tests can produce a suction, referred to by many as "sticktion," preventing it from providing reliable data on smooth and especially polished surfaces in wet conditions. It can in fact produce data suggesting that frictional properties are improved by the wetting of the substrate.

**2.2. 1990's:** ASTM Committee C18 starts a draft of its own friction test, but abandons the project since the early drafts appeared to be very similar, nearly duplicates, of the existing C1028 procedure. It was decided by the committee that it was simpler for the stone industry to endorse the use of the existing C1028 procedure for stone flooring products.

**2.3. 1990's:** ASTM recognizes that numerous materials committees have friction test procedures. A process was implemented to consolidate most of the walkway safety standards into one committee, F13 (Pedestrian/Walkway Safety and Footwear). The C1028 test procedure, however, was not included in this consolidation of test methods under the jurisdiction of committee F13, but rather remained within Committee C21.

**2.4. 2012:** To address the concerns about shortcomings of the C1028 test, the ANSI accredited standards committee A108, of which the Tile Council of North America (TCNA) is the secretariat, 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 was 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. Building on a large collection of data previously obtained by German researchers, substantial additional data was collected to develop the new more reliable and repeatable method of COF measurement.


*BOT-3000*

**2.5. 2014:** Committee C21 formally withdraws the C1028 Test Method from ASTM's active standards. Since the ANSI DCOF AcuTest$^{SM}$ method was already in use, withdrawal of the C1028 procedure would eliminate the confusion of having two test methods for the same property, as well as save the costs of redundant testing when both test methods were specified.

**2.6. 2015 through 2017:** The MIA + BSI (now known as The Natural Stone Institute) researches the use of the ANSI DCOF AcuTest$^{SM}$ test method on natural stone flooring surfaces.

**2.7. Other Friction Testing Standards:** Numerous ASTM Standards and Test Methods regarding friction have been published by various committees. A brief summary of these standards and their current status is provided in Table 1.

**3. Description of the ANSI DCOF Test Procedure:** The test procedure, which was originally part of ANSI 137.1, is now published as a standalone document entitled ANSI A326.3 *Standard Test Method for Measuring Dynamic Coefficient of Friction of Hard Surface Flooring Materials*. This document was released in April, 2017, and the primary improvement of it versus the previous version is that the procedure now specifically addresses in situ testing in addition to laboratory testing.

**3.1. Test Instrument:** The test procedure uses the BOT (Binary Output Tribometer) 3000E, manufactured by Regan Scientific Instruments in Southlake, Texas.

**3.1.1.** The test foot is an SBR Rubber sensor of specified density and hardness, also available from Regan Scientific.

| Standard | Author | Status | Title |
|---|---|---|---|
| D6205 | D21.06 | Active | Standard Practice for Calibration of the James Static Coefficient of Friction Machine |
| C2047 | D21.06 | Active | Standard Test Method for Static Coefficient of Friction of Polish-Coated Flooring Surfaces as Measured by the James Machine |
| D4103 | D21.06 | Active | Standard Practice for Preparation of Substrate Surfaces for Coefficient of Friction Testing |
| F2913 | F13.03 | Active | Standard Test Method for Measuring the Coefficient of Friction for Evaluation of Slip Performance of Footwear and Test Surfaces/Flooring Using a Whole Shoe Tester |
| D5859-96e1 | F13.10 | Withdrawn | Standard Test Method for Determining the Traction of Footwear on Painted Surfaces Using the Variable Incidence Tester (Withdrawn 2005) |
| F489 | F13.10 | Withdrawn | Standard Test Method for Using a James Machine (Withdrawn 2005) |
| F1677 | F13.10 | Withdrawn | Standard Test Method for Using a Portable Inclineable Articulated Strut Slip Tester (PIAST) (Withdrawn 2006) |
| F1678 | F13.10 | Withdrawn | Standard Test Method for Using a Portable Articulated Strut Slip Tester (PAST) (Withdrawn 2005) |
| F1679 | F13.10 | Withdrawn | Standard Test Method for Using a Variable Incidence Tribometer (VIT) (Withdrawn 2006) |
| F609 | F13.10 | Active | Standard Test Method for Using a Horizontal Pull Slipmeter (HPS) |
| F2048 | F13.10 | Active | Standard Practice for Reporting Slip Resistance Test Results |
| F2508 | F13.10 | Active | Standard Practice for Validation, Calibration, and Certification of Walkway Tribometers Using Reference Surfaces |
| F1637 | F13.50 | Active | Standard Practice for Safe Walking Surfaces |
| C1028 | C21.06 | Withdrawn | Standard Test Method for Determining the Static Coefficient of Friction of Ceramic Tile and Other Like Surfaces by the Horizontal Dynamometer Pull-Meter Method (Withdrawn 2014) |

**Table 1: Summary of ASTM Standards Regarding Friction and Their Current Status**

**3.1.2.** A re-dressing fixture is provided to redress the test foot to keep test results within a valid range.

**3.1.3.** Reference surface tiles are required to validate all equipment prior to performing tests.

**3.1.4.** Annual recalibration by Regan Scientific Instruments is required.

**3.2. Surfactant:** A 0.05% solution of Sodium-Lauryl Sulfate is applied to the tested surface prior to the test. This is a very slightly "soapy" solution, and is intended to replicate the lubrication that would occur on an interior floor when wetted, due to residual janitorial detergents on the flooring surface.

**3.3. Test Specimens:** For laboratory testing, three test specimens of a minimum of 10" x 10" (250 x 250 mm) are required, although 12" x 12" (300 x 300 mm) are preferred.

**3.4. Running the Test:** Each specimen is tested in 4 orthogonal directions, creating 12 measurements total.

**3.5. Pass Fail Criteria:** ANSI 326.3 states that hard flooring surfaces in level, interior spaces that are expected to be walked on when wet, shall have a DCOF of 0.42 or greater.

**3.5.1.** ANSI 326.3 makes no specification for exterior or ramped surfaces.

**4. The Natural Stone Institute Study:** For the purposes of this study, 51 different stone materials were measured, each of them in 6 different finishes:

**4.1. Stone Materials:** The 51 different stone materials were collected from a variety of sources, both domestic and international. Stone types were grouped into families based on working properties, which meant that some materials are included in a stone family which would not necessarily match their scientific, geological classification:

**4.1.1. Granite:** This group included true granites and "granite-like" materials, such as gabbro and gneiss. Forty-eight tests were performed in this category.

**4.1.2. Limestone:** This group included both calcium carbonate and calcium-magnesium carbonate (dolomite) limestones. Forty-two tests were performed in this category.

**4.1.3. Limestone-marble:** This group include high-density, compact limestones that are capable of achieving a high-gloss polish, yet are not fully metamorphosed, true marbles. Commercially, most of these stones are marketed as marble, yet are not geologically true marble. This was the largest group of test specimens, with 114 tests performed in this category.

**4.1.4. Marble:** This group contained true marbles. Seventy-two tests were performed in this category.

**4.1.5. Quartzite:** This was an extremely limited group, in which only 16 tests were performed.

**4.1.6. Travertine:** This was also an extremely limited group, in which only 16 tests were performed.

**4.2. Finishes:** Textured finishes such as sanded or flamed were not included in this study as these surfaces would knowingly test well in excess of the pass/fail benchmark, so no useful data would be generated. The test focused mainly on a spectrum of coarse to fine honed finishes, in an attempt to determine at which grit size a honed surface would meet the 0.42 standard. Honed finishes of 50, 100, 200, 400, and 800 grit were tested, plus polished finish. Grit sizes of 60, 120, and 240 were included in the same data group as grit sizes of 50, 100, and 200 respectively. The finishing application on the surfaces was limited to three fabricators in an effort to reduce fabricator-specific variability in finish profilometry.

**4.3. Sealers:** Sealers were intentionally eliminated from this research. There are a myriad of sealers on the market, some of which are specifically designed to increase friction. Attempting to include sealers in this study would have introduced many variables, including the degradation of the sealer between reapplication intervals.

**4.4. In situ Wear:** All stones were tested in a fresh, as received condition. It is anticipated that friction measurements would change, particularly in the softer stone varieties, after time in service in heavy traffic areas.

**4.5. Testing Venue:** All tests were performed by the same Natural Stone Institute technician in the association's internal testing laboratory. The same BOT 3000 machine was used for all tests, with appropriate redressing and calibration verifications completed at recommended intervals.

**5. Test Data:** A summary of the test data is included on page 7, showing the average for each stone family group, and also the highest and lowest values to indicate range. Page 6 shows a comparison of the various surface finishes and a comparison of the stone family groups.

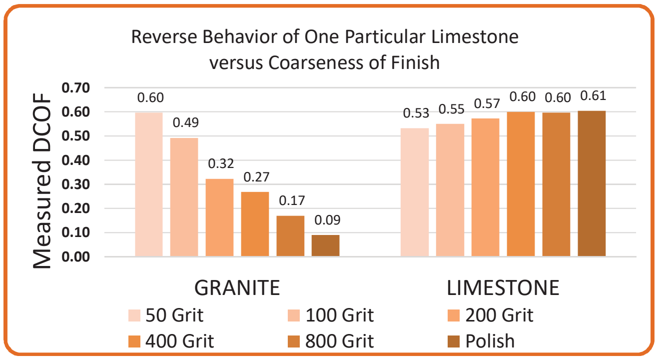
**5.1.** Repeatability was generally very good. Several specimens were tested twice for the purpose of evaluating repeatability, and the re-tests generally varied from the original value by ≤5%. The average Coefficient of Variation (ratio of standard deviation to arithmetic mean) for all specimens was approximately 6%. Part of this is attributable to orthogonal anisotropy of some stone varieties.

**5.2.** Quartzite was expected to perform similar to granite, and travertine was expected to perform similar to limestone, so a limited number of specimens was tested in each group, which confirmed the expectations of performance comparable to stones of similar density.

**5.3.** The test results indicate that harder, higher density materials consistently test lower than softer, lower density materials in the same finish.

**5.4.** In two cases of limestone, there was a very apparent reverse trend in the measured friction values, in that the finer finishes actually produced higher friction than the coarser. Data from one of these stones is shown in the accompanying graph, with data from one granite for comparison. The granite shows a nearly perfect linear trend downward as the finish gets progressively finer, while the limestone shows a nearly perfect linear trend upward across the same finishes.




**5.5.** Application of the surfactant to very soft, high porosity stones, such as extremely low density limestones, is difficult because the stone specimen can absorb the surfactant before the test can be completed.

**5.6.** As expected, polished finishes do not meet the 0.42 benchmark in any stone type as an average, although several individual specimens did. Those that did meet it were all in the softer stone categories of travertine, limestone, and limestone-marble.

**5.7.** As evident in the accompanying graphs, there is considerable range in all varieties, so testing of specimens that are representative of the actual supply and finished on the same equipment as the actual supply is required.

**5.8.** Tradenames of the stones included in this study are intentionally omitted from this Technical Bulletin to prevent users from applying these data for actual projects.

## 6. Advantages and Disadvantages:

**6.1.** Advantages of the ANSI 326.3 Dynamic Coefficient of Friction Test:

**6.1.1.** The test is relatively easy to run and produces repeatable results. This is particularly noteworthy for a friction test, since friction testing is often associated with noisy data.

**6.1.2.** The BOT3000E produces an automated printout of the data, which can be retained by the technician as proof that the test values were not altered in the reporting.

**6.1.3.** The test is already a standard for ceramic products. Many companies in the stone industry also offer ceramic products, so simplicity is gained by using the same test procedure for both products.

**6.1.4.** The test procedure comes with a documented pass/fail specification, which significantly reduces liability for both specifiers and suppliers by providing a safety benchmark established by a committee consensus process.

**6.1.5.** The test can be run either in situ or in laboratory settings.

**6.2.** Disadvantages of the ASNI 326.3 Dynamic Coefficient of Friction Test:

**6.2.1.** The stone industry typically uses test protocols published by ASTM. This test procedure is not likely to ever be endorsed by an ASTM Committee or rewritten as an ASTM procedure. The primary reason for this is that it requires a proprietary piece of equipment (BOT 3000E), and mandating the use of proprietary equipment is generally not allowed in ASTM procedures.

**6.2.2.** The test procedure requires the purchase of a rather expensive piece of equipment, the BOT 3000E. While a laboratory or consulting service that specializes in friction testing can easily amortize the cost of the equipment over many tests, a laboratory that performs the test infrequently will be unable to justify the investment.

**6.2.3.** There is no specification for exterior or ramped surfaces. In the stone industry, exterior surfaces are nearly always supplied in textured finishes, which will logically test much higher than the 0.42 specification. Yet the burden of establishing a minimum value for an exterior or ramped surface rests on the specifier.

## 7. The Natural Stone Institute Recommendation:

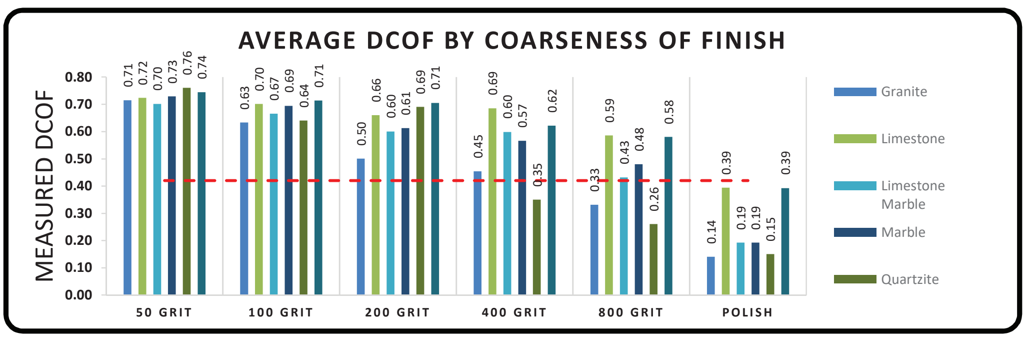
**7.1.** Because of the huge liability that slip/fall accidents create for specifiers and suppliers alike, a standardized test protocol and a minimum performance specification are necessary to protect them from that liability. No perfect test for evaluating traction of flooring surfaces exists, nor will one ever exist due to the countless number of variables involved. It is analogous to the speed limits on highways. Complying with the posted speed limit does not guarantee safe arrival at your destination, nor does exceeding the speed limit assure disaster. The posted speed limit simply represents a reasonable level of risk, and provides a measureable, enforceable value. The same can be said of a flooring friction specification.

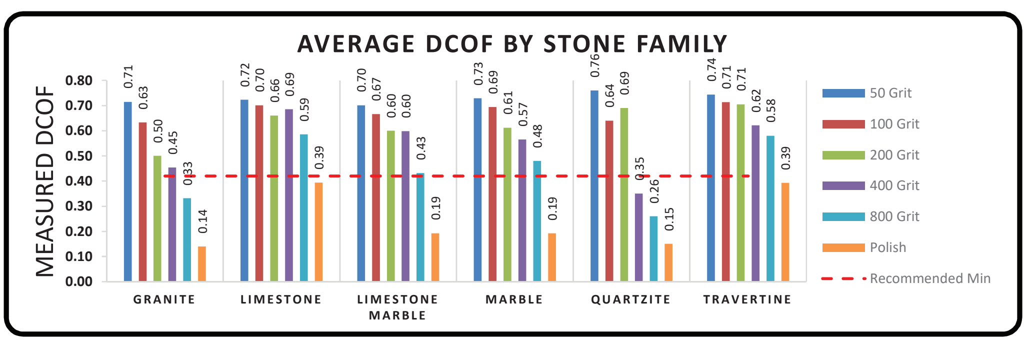
**7.2.** Friction is currently a topic of study of numerous committees, associations, and companies, both in the United States and elsewhere. A test method and evaluation method may evolve in the future that proves to be superior to ANSI 326.3, but currently, the ANSI 326.3 procedure provides a very practical method of friction measurement and evaluation.

**7.3.** While use of this test procedure for natural stones is not as common as it is for ceramic products, the title of the procedure is *"Standard Test Method for Measuring Dynamic Coefficient of Friction of Hard Surface Flooring Materials,"* which suggests that the intent of the authors of the test procedure was for it to be applicable to stone products, since stone is without question a *"hard surface flooring material."* The intended use of the test procedure for natural stone is further clarified by the scope of the ANSI A108 committee, which states, *"The Committee works to develop standards which define the installation of ceramic, glass, and stone tiles and panels as well as the test methods, physical properties, and sustainability of ceramic, glass, stone, and other hard surface tile and panels, and installation materials."*

**7.4.** For the reasons outlined above, it is the recommendation of The Natural Stone Institute that the industry adopt the ANSI 326.3 Dynamic Coefficient of Friction test method for use with Natural Stone Walking Surfaces.

**8. Acknowledgments:** The Natural Stone Institute would like to thank Miller Druck Specialty Contractors, Artistic Tile, Coldspring, Tennessee Marble Company, and TexaStone Quarries for their assistance in procurement of test specimens.




## Average DCOF of All Specimens

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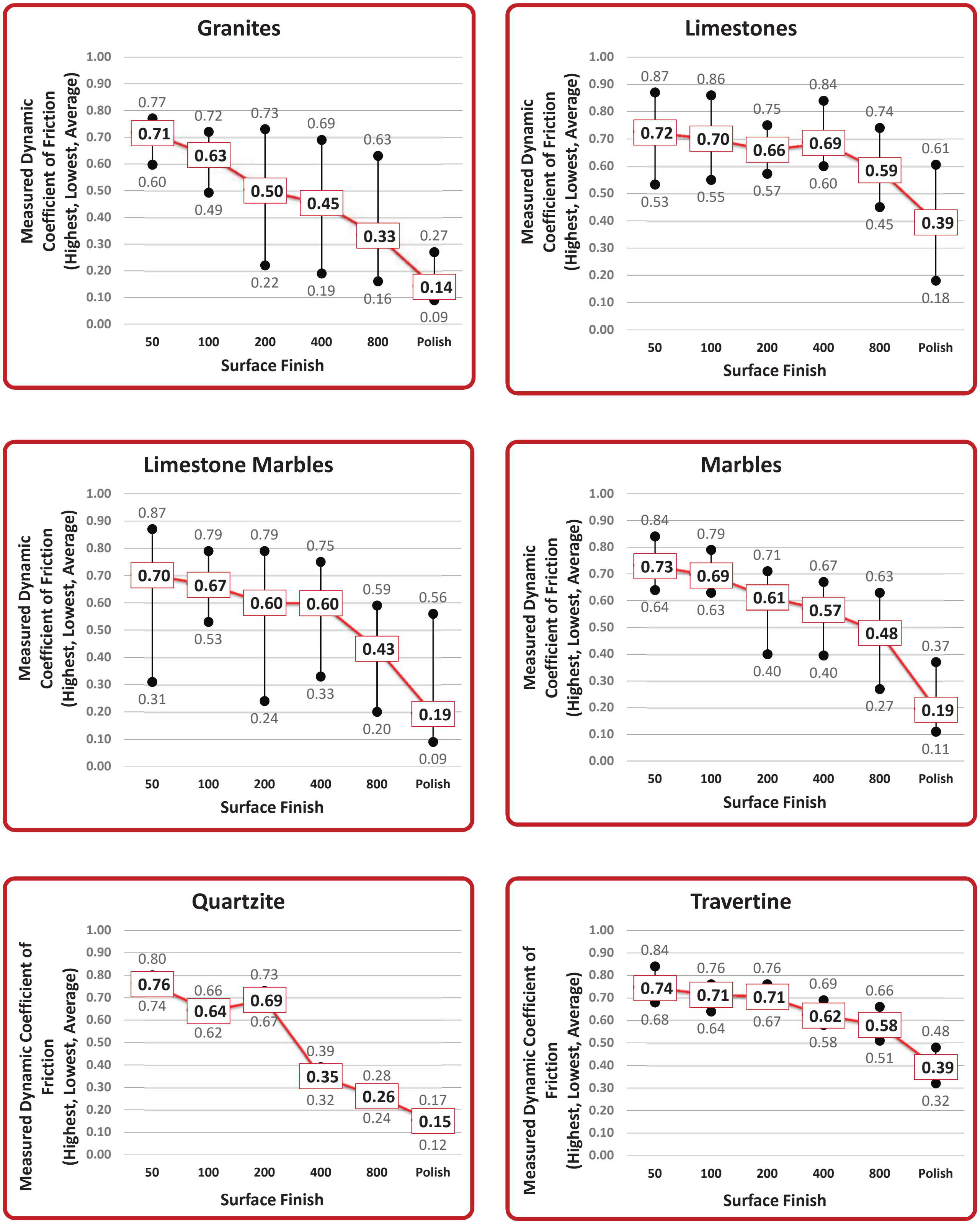
*__Disclaimer:__ The contents of this Technical Bulletin are being offered as general guidance only. Each individual or business entity whom reviews the contents of the Technical Bulletin must still use its own independent judgment and discretion when determining whether or not to utilize the ANSI test procedure to assess the safety of its particular flooring material. A testing procedure and program should be reviewed on a case-by-case basis depending upon the individual management structure, product lines, location and other factors which may be unique to the individual flooring material, contractor and end-user and the application for which the flooring material is being utilized. The general guidelines in this Technical Bulletin are not intended to create new legal liabilities or expand existing rights or obligations of The Natural Stone Institute, nor otherwise affect the legal position of any member company.*




## MEASURED DYNAMIC COEFFICIENT of FRICTION

**(Highest, Lowest, and Average, by Stone Family)**

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