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1 July 2007

**Committee C21 on Ceramic Whitewares and Related Products  
Subcommittee C21.06 on Ceramic Tile**

**Research Report C21-1005**

**Interlaboratory Study to Establish Precision Statements for ASTM  
C1028-07, Standard Test Method for Determining the Static Coefficient  
of Friction of Ceramic Tile and Other Like Surfaces by the Horizontal  
Dynamometer Pull-Meter Method**

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**1. Introduction:**

Interlaboratory Study 107 was conducted to establish a precision statement for C1028, Determining the Static Coefficient of Friction of Ceramic Tile and Other Like Surfaces by the Horizontal Dynamometer Pull-Meter Method.

**2. Test Method:**

The Test Method used for this ILS is C1028-07. To obtain a copy of C1028, go to ASTM's website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service by phone at **610-832-9585** (8:30 a.m. - 4:30 p.m. Eastern U.S. Standard Time, Monday through Friday) or by email at [service@astm.org](mailto:service@astm.org).

**3. Participating Laboratories:**

The following laboratories participated in this interlaboratory study

1. Artfind Tile  
143 S. Market  
Wooster, Ohio 44691  
Ms. Brigid O'Connor  
330-264-7706  
[tilequeen@sssnet.com](mailto:tilequeen@sssnet.com)

5. Stonepeak Ceramics  
238 Porcelain Tile Drive  
Crossville, TN 38555  
Mr. Noah Chitty  
312-335-0321  
[nchitty@stonepeakceramics.com](mailto:nchitty@stonepeakceramics.com)

2. Crossville Inc.  
Crossville, TN 38557  
Mr. Craig Miller  
931-484-2110  
[cmiller@crossvilleinc.com](mailto:cmiller@crossvilleinc.com)

6. Summitville Labs  
81 Arborn Rd  
P.O. Box 90  
Minerva, Ohio 44657  
Mr. Joseph Dutt  
330-223-1511  
[jdutt@summitville.com](mailto:jdutt@summitville.com)

3. United States Ceramic Tile  
East Sparta, Ohio  
Mr. David Reader  
330-649-5000  
[David.Reader@Laufen.com](mailto:David.Reader@Laufen.com)

7. Tile Council of North America  
100 Clemson Research Blvd.  
Anderson, SC 29625  
Ms. Katelyn Luedeke  
864-646-8453  
[kluedeke@tileusa.com](mailto:kluedeke@tileusa.com)

4. Ironrock  
Millerton Road  
Canton, Ohio 44711  
Mr. Roy Gorton  
800-325-3945  
[rgortonjr@ironrock.com](mailto:rgortonjr@ironrock.com)

**4. Description of Samples:**

There were 5 samples of varying targeted results used for this study. Each sample was supplied, prepared and distributed by Eric Astrachan of Tile Council of North America. Below is a list of the samples with the corresponding supplier:

1. Surface A: Unglazed Porcelain

2. Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth
3. Surface C: Glazed Porcelain, lightly textured
4. Surface D: Glazed Ceramic, lightly textured
5. Surface E: Unglazed Porcelain, lightly textured

**5. Interlaboratory Study Instructions**

Laboratory participants were emailed the test program instructions. For a copy of the instructions, please see Appendix A.

**6. Description of Equipment/Apparatus<sup>1</sup>:**

For information on the equipment/apparatus used by each laboratory, please see Appendix A.

**7. Data Report Forms:**

Each laboratory was provided with a data report form for the collection of data. A copy of the data is provided in Appendix B.

Please note: The laboratories have been randomly coded and cannot be identified herein.

**8. Statistical Data Summary:**

A summary of the statistics calculated from the data returned by the participating laboratories is provided in Appendix C.

**9. Precision and Bias Statement:**

9.1 The precision of this test method is based on an interlaboratory study of C1028-06, Standard Test Method for Determining the Static Coefficient of Friction of Ceramic Tile and Other Like Surfaces by the Horizontal Dynamometer Pull-Meter Method, conducted in 2006. Each of seven laboratories tested five different materials. Every “test result” is calculated using twelve individual force readings. The laboratories obtained two replicate test results for each material, under both wet and dry conditions.<sup>1</sup>

9.1.1 *Repeatability*— Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the “*r*” value for that material; “*r*” is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

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<sup>1</sup> The equipment listed was used to develop a precision statement for C1028-07. This listing is not an endorsement or certification by ASTM International.  
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9.1.1.1 “Sr” represents the repeatability standard deviation

9.1.2 *Reproducibility*— Two test results shall be judged not equivalent if they differ by more than the “R” value for that material; “R” is the interval representing the difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

9.1.2.1 “SR” represents the reproducibility standard deviation

9.1.3 Any judgment in accordance with these two statements would have an approximate 95% probability of being correct.

Table 1. Static coefficient of friction for dry surfaces

Surface	Average	Standard Deviation	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	Sx	sr	sR	r	R
1	0.7971	0.0351	0.0242	0.0391	0.0678	0.1093
2	0.8093	0.0479	0.0183	0.0496	0.0513	0.1390
3	1.0007	0.0379	0.0228	0.0412	0.0639	0.1154
4	0.8700	0.0328	0.0173	0.0350	0.0485	0.0980
5	0.8543	0.0493	0.0093	0.0497	0.0259	0.1392

Table 2. Static coefficient of friction for wet surfaces

Surface	Average	Standard Deviation	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	Sx	sr	sR	r	R
1	0.6757	0.0113	0.0093	0.0131	0.0259	0.0367
2	0.5129	0.0269	0.0220	0.0311	0.0617	0.0871
3	0.3200	0.0338	0.0196	0.0365	0.0550	0.1023
4	0.7321	0.0269	0.0191	0.0301	0.0534	0.0843
5	0.4993	0.0137	0.0144	0.0170	0.0403	0.0477

9.2 Bias—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method, therefore no statement on bias is being made.

9.3 The precision statement was determined through statistical examination of 140 results, from seven laboratories, on five materials. Descriptions of the surfaces tested follow:

- Surface 1: unglazed porcelain
- Surface 2: glazed porcelain, lightly textured
- Surface 3: glazed ceramic, lightly textured
- Surface 4: unglazed porcelain, lightly textured
- Surface 5: proposed Standard Tile, glazed

To judge the equivalency of two test results, it is recommended to choose the surface closest in characteristics to the test surface.

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**Appendix A:**

**Procedure for ASTM C1028 ILS # 0107**

**5. Apparatus**

5.1 *Dynamometer Pull Meter*, horizontal capable of measuring 100 lbs.-force (lbf.), accurate to 0.1 lbf., and capable of holding the peak value. (see Fig.1).

5.2 *Weight*, 50-lb (22-kg) Weight shall be either cylindrical (approximately 6in. in diameter and approximately 8 in. tall) or of rectangular dimensions with the base measuring approximately 6 by 8 in. Weight must be stable, and have a uniform distribution of weight. (see Fig.2).



(a)



(b)

**FIG.1 Dynamometer Pull Meters**

5.3 *Standard Neolite Sled Assemblies*, two, one to be used for each of the wet and dry conditions.

5.3.1 Two assemblies, constructed from 8 by 8 by  $\frac{3}{4}$ -in. 6061-T6 aluminum plate or similar material, with 3 by 3 by  $\frac{1}{8}$ -in. Neolite material attached to the aluminum plate with contact adhesive.

5.3.2 Sheen must be removed from the Neolite surface prior to use. To prepare the assembly surface prior to initial use:

5.3.2.1 Place a sheet of 400 grit wet or dry silicon carbide paper (attached to a flat surface, such as a piece of float glass) on a flat and stable surface.



**FIG.2 Test Assembly**

5.3.2.2 Sand Neolite material by moving the assembly once across the sand paper towards the operator for a distance of about 4 in. (102 mm) while applying between 15-20 lbs-force to the assembly.

5.3.2.3 Remove the sled assembly and brush off any accumulated Neolite dust from the silicon carbide paper and sled assembly using a dry brush; brush to be such that it effectively removes the Neolite dust but causes no damage to the silicon carbide paper or the Neolite on the sled assembly.

5.3.2.4 Rotate the sled 90° (clockwise) and sand the Neolite again with the same procedure (one single pull towards the operator followed by removing the Neolite dust is considered one stroke).

5.3.2.5 Repeat sanding in this fashion (rotating the sled assembly by 90°, clockwise, and brushing off the Neolite dust each time between strokes) for a total of eight (8) strokes. Eight strokes equals one (1) resurfacing cycle.

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5.3.2.6 Continue sanding the Neolite until all the sheen (glossy surface produced during the manufacturing process) is removed, usually no more than 500 strokes.

5.4 *Standard Tile*. Standard tiles were manufactured under controlled conditions, assigned a unique identifying number and are available from the Tile Council of North America.

## 6. Reagents and Materials

- 6.1 *Silicon Carbide Paper*, wet or dry, 400 grit.
- 6.2 *Renovator*,
- 6.3 *Neolite*,<sup>2</sup> Standard Neolite Cement Liner (see 2.1).
- 6.4 *Rags, Sponge, or Paper Towels*.
- 6.5 *Water*, distilled.

## 7. Calibration (Dry)

- 7.1 Because many variables are associated with this test procedure, it is important that the operator calibrates the Neolite Heel Assembly surface with the Standard Tile each time the test is performed.
- 7.2 For uses other than the initial use, resurface the assembly with 400 grit wet or dry silicon carbide paper, four cycles.
- 7.3 Determine the total weight,  $W$ , of the 50-lb (22-kg) weight plus the Neolite Heel Assembly.
- 7.4 Clean the Standard Tile with a renovator.
- 7.5 Place the Neolite Heel Assembly and the 50-lb (22-kg) weight on the Standard Tile surface. Using a dynamometer, determine the force required to set the test assembly in motion.
- 7.6 Make a total of four pulls, each perpendicular to the previous pull.
- 7.7 Calculate the dry calibration factor as follows:

$$X_D = 0.86 - \frac{R_D}{NW} \quad (1)$$

where:

- $X_D$  = dry calibration factor,
- $R_D$  = sum of the four recorded dry force readings, lb (kg),
- $N$  = number of pulls (4), and
- $W$  = weight of heel assembly plus 50-lb (22-kg) weight, lb (kg).

NOTE 1— The 0.86 factor is the static coefficient of friction value as determined by the Tile Council of North America for the standard tile (see 5.4) and confirmed by an ASTM ILS in February 2007.

## 8. Test Procedure (Dry)

- 8.1 Test the following surfaces:
  - 8.1.1 The test area or separate test specimens shall not be less than 4 by 4 in. (102 by 102 mm). Bond the separate test specimens of small-sized tile, such as 1 by 1 in. (25 by 25 mm) and 2 by 2 in. (51 by 51 mm) to a suitable surface to provide the 4 by 4 in. or larger size.
  - 8.1.2 Test the surface in the as-received condition.
- 8.2 Place the 50-lb (22-kg) weight assembly with Neolite material attached on the test surface. Using a dynamometer, determine the force required to set the test assembly in motion. Record the highest reading.
- 8.3 Four pulls perpendicular to the previous pull on each of three surface areas or three test specimens constitute the twelve necessary readings to calculate the static coefficient of friction.
- 8.4 Record all readings.
- 8.5 Under no conditions should additional tiles be tested without performing a new calibration.

## 9. Calibration (Wet)

- 9.1 Immerse the Neolite portion of the sled assembly in water for a minimum of 5 minutes after resurfacing the sled per 7.2 (see 5.3)
- 9.2 It is important that the operator calibrates the assembly surface each time the test is performed. Repeat the procedure in 7.2-7.5 with one exception: Saturate the surface with distilled water and repeat the calibration with the surface wet, keeping the surface saturated.

9.3 Calculate the wet calibration factor as follows:

$$X_w = 0.51 - \frac{R_w}{NW} \quad (2)$$

where:

- $X_w$  = wet calibration factor,
- $R_w$  = sum of the four recorded wet force readings, lb (kg),
- $N$  = number of pulls (4), and
- $W$  = weight of heel assembly plus 50-lb (22-kg) weight, lb (kg).

NOTE 2— The 0.51 factor is the static coefficient of friction value as determined by the Tile Council of North America for the standard tile (see 5.4) and confirmed by an ASTM ILS in February 2007.

**10. Test Procedure (Wet)**

10.1 Repeat the procedure in 8.2-8.5 with one exception: Saturate the surface with distilled water and repeat the test with the surface wet, keeping the surface saturated.

10.2 Record all readings.

**11. Test Procedure Using Prepared Test Specimens**

11.1 Test the prepared test specimens, both wet and dry, after cleaning the test specimens with a renovator.

(For the Interlaboratory Study the samples are being provided in an already cleaned condition so this step should be omitted.)

**12. Calculation**

12.1 Calculate the static coefficient of friction as follows:

12.1.1 *Dry*:

$$F_D = (R_D/NW) + X_D \quad (3)$$

12.1.2 *Wet*:

$$F_W = (R_W/NW) + X_W \quad (4)$$

where:

- $F_D$  = static coefficient of friction for dry surface,
- $F_W$  = static coefficient of friction for wet surface,
- $R_D$  = total of the 12 dry force readings, lb (kg),
- $R_W$  = total of the 12 wet force readings, lb (kg),
- $N$  = number of pulls (12),
- $X_D$  = dry calibration factor,
- $X_W$  = wet calibration factor, and
- $W$  = total weight of the heel assembly plus 50-lb (22-kg) weight, lb (kg).

**13. Report**

13.1 Report the following information:

13.1.1 Type of tile or surface and

13.1.2 The individual and average static coefficient of friction for:

13.1.2.1 dry surfaces and

13.1.2.2 wet surfaces.

**Appendix B:****Coefficient of Friction (dimensionless)**

## Laboratory 1

Samples	Replicates	
	1	2
Surface A: Unglazed Porcelain	0.80	0.81
Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth	0.90	0.91
Surface C: Glazed Porcelain, lightly textured	0.82	0.82
Surface D: Glazed Ceramic, lightly textured	1.00	0.99
Surface E: Unglazed Porcelain, lightly textured	0.87	0.88

## Laboratory 3

Samples	Replicates	
	1	2
Surface A: Unglazed Porcelain	0.82	0.79
Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth	0.92	0.91
Surface C: Glazed Porcelain, lightly textured	0.82	0.80
Surface D: Glazed Ceramic, lightly textured	1.01	1.03
Surface E: Unglazed Porcelain, lightly textured	0.89	0.87

## Laboratory 4

Samples	Replicates	
	1	2
Surface A: Unglazed Porcelain	0.82	0.75
Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth	0.86	0.86
Surface C: Glazed Porcelain, lightly textured	0.85	0.83
Surface D: Glazed Ceramic, lightly textured	1.03	1.03
Surface E: Unglazed Porcelain, lightly textured	0.9	0.87

## Laboratory 5

Samples	Replicates	
	1	2
Surface A: Unglazed Porcelain	0.85	0.84
Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth	0.84	0.85
Surface C: Glazed Porcelain, lightly textured	0.79	0.78
Surface D: Glazed Ceramic, lightly textured	1.04	1.03
Surface E: Unglazed Porcelain, lightly textured	0.82	0.81

## Laboratory 6

Samples	Replicates	
	1	2
Surface A: Unglazed Porcelain	0.74	0.72
Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth	0.76	0.77
Surface C: Glazed Porcelain, lightly textured	0.85	0.82
Surface D: Glazed Ceramic, lightly textured	1.06	0.99
Surface E: Unglazed Porcelain, lightly textured	0.92	0.89

## Laboratory 7

Samples	Replicates	
	1	2
Surface A: Unglazed Porcelain	0.80	0.83
Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth	0.83	0.85
Surface C: Glazed Porcelain, lightly textured	0.74	0.69
Surface D: Glazed Ceramic, lightly textured	0.95	0.92
Surface E: Unglazed Porcelain, lightly textured	0.85	0.82

## Laboratory 8

Samples	Replicates	
	1	2
Surface A: Unglazed Porcelain	0.78	0.81
Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth	0.86	0.84
Surface C: Glazed Porcelain, lightly textured	0.87	0.85

RR: C21-1005

Samples	Replicates	
	1	2
Surface D: Glazed Ceramic, lightly textured	0.98	0.95
Surface E: Unglazed Porcelain, lightly textured	0.88	0.91

**Wet Coefficient of Friction**

## Laboratory 1

Samples	Replicates	
	1	2
Surface A: Unglazed Porcelain	0.67	0.67
Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth	0.52	0.53
Surface C: Glazed Porcelain, lightly textured	0.53	0.54
Surface D: Glazed Ceramic, lightly textured	0.33	0.31
Surface E: Unglazed Porcelain, lightly textured	0.75	0.72

## Laboratory 3

Samples	Replicates	
	1	2
Surface A: Unglazed Porcelain	0.69	0.68
Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth	0.47	0.52
Surface C: Glazed Porcelain, lightly textured	0.52	0.49
Surface D: Glazed Ceramic, lightly textured	0.39	0.37
Surface E: Unglazed Porcelain, lightly textured	0.71	0.72

## Laboratory 4

Samples	Replicates	
	1	2
Surface A: Unglazed Porcelain	0.65	0.67
Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth	0.50	0.49
Surface C: Glazed Porcelain, lightly textured	0.52	0.51
Surface D: Glazed Ceramic, lightly textured	0.35	0.29
Surface E: Unglazed Porcelain, lightly textured	0.70	0.72

## Laboratory 5

Samples	Replicates	
	1	2
Surface A: Unglazed Porcelain	0.66	0.67
Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth	0.49	0.49
Surface C: Glazed Porcelain, lightly textured	0.49	0.51

Samples	Replicates	
	1	2
Surface D: Glazed Ceramic, lightly textured	0.28	0.25
Surface E: Unglazed Porcelain, lightly textured	0.75	0.74

## Laboratory 6

Samples	Replicates	
	1	2
Surface A: Unglazed Porcelain	0.69	0.68
Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth	0.49	0.48
Surface C: Glazed Porcelain, lightly textured	0.50	0.44
Surface D: Glazed Ceramic, lightly textured	0.31	0.31
Surface E: Unglazed Porcelain, lightly textured	0.77	0.79

## Laboratory 7

Samples	Replicates	
	1	2
Surface A: Unglazed Porcelain	0.68	0.67
Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth	0.51	0.51
Surface C: Glazed Porcelain, lightly textured	0.53	0.49
Surface D: Glazed Ceramic, lightly textured	0.32	0.31
Surface E: Unglazed Porcelain, lightly textured	0.72	0.68

## Laboratory 8

Samples	Replicates	
	1	2
Surface A: Unglazed Porcelain	0.68	0.70
Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth	0.50	0.49
Surface C: Glazed Porcelain, lightly textured	0.56	0.55
Surface D: Glazed Ceramic, lightly textured	0.33	0.33
Surface E: Unglazed Porcelain, lightly textured	0.72	0.76

**Calibration Tile at Laboratory Conditions**

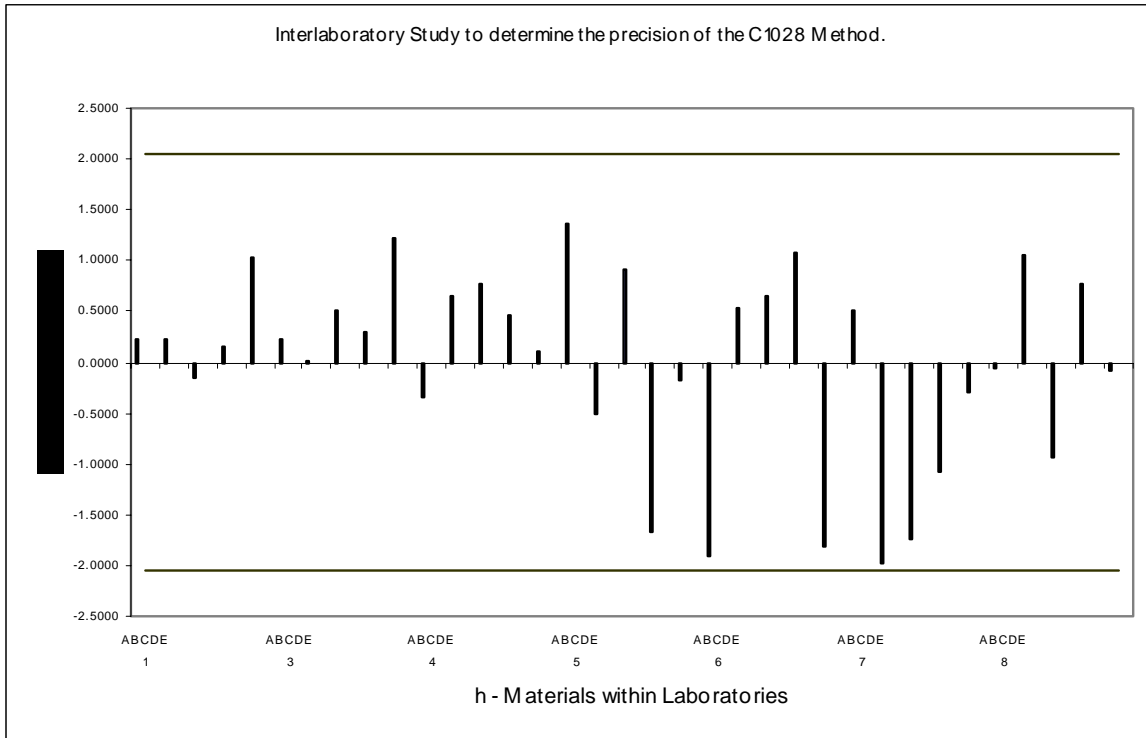
Lab #	Coefficient of Friction	Wet Coefficient of Friction
1	0.89	0.5
3	0.85	0.52
4	N/A (The laboratory could not reach laboratory conditions during dry testing)	0.51
5	0.85	N/A (The laboratory was unable to reach laboratory conditions during wet testing)
6	0.84	0.51
7	0.85	0.51
8	0.86	0.49
<b>Average:</b>	<b>0.86</b>	<b>0.51</b>

**Appendix C:**

**Coefficient of Friction (dimensionless) - h Values**

h Critical Value: 2.05

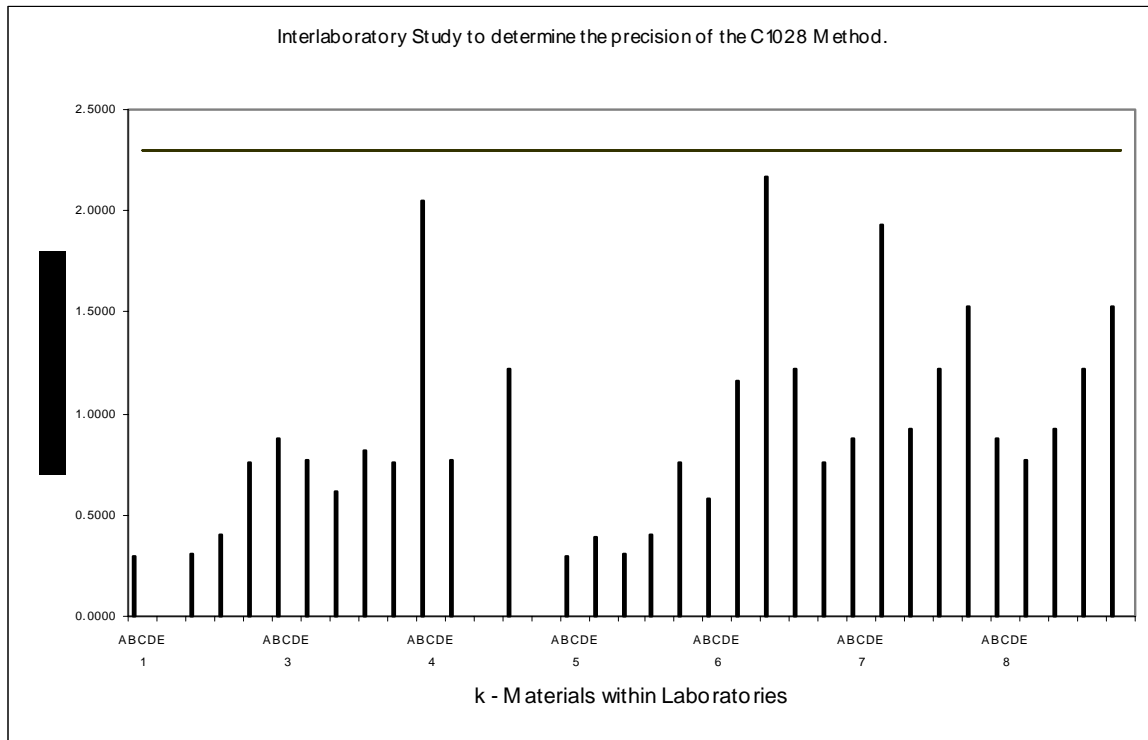
Lab	Surface A: Unglazed Porcelain	Surface C: Glazed Porcelain, lightly textured	Surface D: Glazed Ceramic, lightly textured	Surface E: Unglazed Porcelain, lightly textured	Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth
1	0.2238	0.2236	-0.1507	0.1525	1.0291
3	0.2238	0.0149	0.5088	0.3050	1.2320
4	-0.3459	0.6411	0.7726	0.4575	0.1160
5	1.3634	-0.5069	0.9045	-1.6775	-0.1884
6	-1.9128	0.5367	0.6407	1.0675	-1.8118
7	0.5087	-1.9680	-1.7336	-1.0675	-0.2899
8	-0.0610	1.0586	-0.9422	0.7625	-0.0870



**Coefficient of Friction (dimensionless) - k Values**

k Critical Value: 2.3

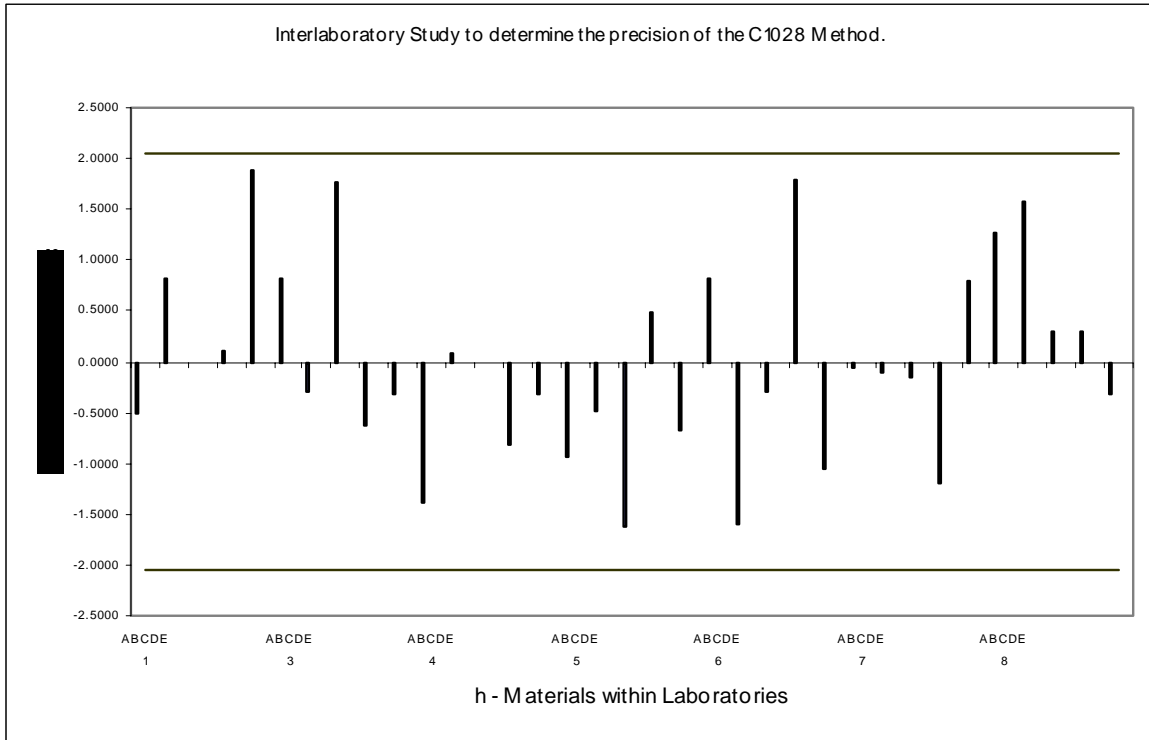
Lab	Surface A: Unglazed Porcelain	Surface C: Glazed Porcelain, lightly textured	Surface D: Glazed Ceramic, lightly textured	Surface E: Unglazed Porcelain, lightly textured	Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth
1	0.2922	0.0000	0.3097	0.4082	0.7638
3	0.8765	0.7718	0.6193	0.8165	0.7638
4	2.0452	0.7718	0.0000	1.2247	0.0000
5	0.2922	0.3859	0.3097	0.4082	0.7638
6	0.5843	1.1578	2.1676	1.2247	0.7638
7	0.8765	1.9296	0.9290	1.2247	1.5275
8	0.8765	0.7718	0.9290	1.2247	1.5275



**Wet Coefficient of Friction - h Values**

h Critical Value: 2.05

Lab	Surface A: Unglazed Porcelain	Surface C: Glazed Porcelain, lightly textured	Surface D: Glazed Ceramic, lightly textured	Surface E: Unglazed Porcelain, lightly textured	Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth
1	-0.5040	0.8230	0.0000	0.1062	1.8809
3	0.8189	-0.2920	1.7757	-0.6372	-0.3135
4	-1.3859	0.0796	0.0000	-0.8230	-0.3135
5	-0.9449	-0.4779	-1.6278	0.4779	-0.6792
6	0.8189	-1.5930	-0.2960	1.7788	-1.0449
7	-0.0630	-0.1062	-0.1480	-1.1947	0.7837
8	1.2599	1.5664	0.2960	0.2920	-0.3135



**Wet Coefficient of Friction - k Values**

k Critical Value: 2.3

Lab	Surface A: Unglazed Porcelain	Surface C: Glazed Porcelain, lightly textured	Surface D: Glazed Ceramic, lightly textured	Surface E: Unglazed Porcelain, lightly textured	Surface B: Proposed Standard Tile, Glazed Ceramic, Smooth
1	0.0000	0.3208	0.7201	1.1114	0.4913
3	0.7638	0.9625	0.7201	0.3705	2.4565
4	1.5275	0.3208	2.1602	0.7410	0.4913
5	0.7638	0.6417	1.0801	0.3705	0.0000
6	0.7638	1.9251	0.0000	0.7410	0.4913
7	0.7638	1.2834	0.3600	1.4819	0.0000
8	1.5275	0.3208	0.0000	1.4819	0.4913

