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Committee C09 on Concrete and Concrete Aggregates
Subcommittee C09.60 on Testing Fresh Concrete

Research Report C09-1022

Interlaboratory Study to Establish Precision Statements for ASTM C143/C143M, Standard Test Method for Slump of Hydraulic-Cement Concrete

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SUMMARY OF TESTING PROGRAM

The test program for determination of a precision statement for slump was forced to bring all the laboratories to the concrete because it is, of course, impossible to distribute the same fresh concrete to several different laboratories. ASTM C802-94, "Standard Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods for Construction Materials" was consulted. Paragraph 4.2 suggests at least ten laboratories be included. We used representatives from 14 laboratories representing 12 different organizations.

A series of slump tests were performed by 15 volunteer technicians on September 6, 1997. The testing which was monitored by 4 volunteer Professional Engineers took place at the University of Arkansas in Fayetteville, Arkansas. These PE's represented a private testing company, a ready mix concrete supplier, a university educator and a consulting engineer, thus providing a good industry mix.

One full load of concrete was furnished by a local ready mix concrete company. All concrete used in the testing process was discharged into a series of wheelbarrows in rapid succession at the approximate slump desired. After all wheelbarrows were loaded with a low slump concrete, water was added to the concrete remaining in the mixer drum and thoroughly mixed to provide a moderate slump concrete for the second series of tests. The same procedure was then used to obtain a high slump concrete.

Each technician performed 18 slump tests alternately using metal cones and plastic cones. A total of 6 tests were made by each technician at each of three basic slump ranges representing low, moderate and high slump concrete. The technicians represented private materials testing laboratories, ready mix concrete companies and one chemical admixture company. Those contacted and declining to participate included cement manufacturers, state government entities, and contractors.

All participants used a 16 inch by 24 inch carpenter's square as the horizontal bar needed to measure slump. Each participant was furnished a metric ruler for the actual slump measurement and all test results were recorded to the nearest millimeter (mm). All inch measurements were later converted from the mm measurements and calculations using mm. The closer than normal measurements is in accordance with the suggestions of ASTM C802, 7.2.2.1.

When time and temperature were considered in the calculation phase, it became apparent that there was no measureable difference in the test results between metal and plastic slump cones. Due to this lack of difference the precision statement developed applies to both of these slump cone materials.

The rigorous testing and statistical analysis program is believed to be consistent with ASTM C802 and C670 up to the conclusions which must be consistent with both the statistical analysis and intended use of the developed data. The data was developed from a total of 270 tests with the intent of providing two basic estimates of the precision for the slump test. These are the single-operator precision and the multilaboratory precision as described in C802. The single-operator precision provides an estimate of the difference that may be expected between duplicate measurements made on the same material in the same laboratory by the same operator using the same apparatus. The multilaboratory precision provides an estimate of the difference that may be expected between measurements made on the same material by two different laboratories.

TEMPERATURE AND TIME EFFECTS

The ambient temperature during the slump tests was in the mid to high seventy degree Fahrenheit range. Concrete temperatures started in the higher eighties and rose into the lower nineties during the test procedures. The test procedures required 1.6 hours so a 5°F rise in the concrete temperature was not unexpected.

The slump losses during the test periods averaged 13.07 mm, 21.60 mm, and 16.60 mm for the low, moderate and high range slumps. These losses, very obviously, affected the precision test statistics when a minimum of 3 replicates is required for a test series. The losses also affect the comparison of test results between metal and plastic cones.

The process used was for all 15 testing technicians to perform 6 slump tests at each of 3 slump ranges. The procedure was to use the metal cones first, third and fifth. The plastic cone was always used second, fourth and sixth.

What is really telling with regard to the affect of time after discharging the sample from the truck into the wheelbarrow are the decreases (drops) of the average slump with time. Each of the averages for a run of 15 tests are as follows, in the order performed:

TABLE 1 AVERAGE SLUMP (mm) BY TRIAL ORDER

Slump Characteristic		Low (mm)	Moderate (mm)	High (mm)
Trial	(Cone)			
1	Metal	36.00	95.60	166.33
2	Plastic	32.93	91.93	163.00
3	Metal	30.87	84.27	158.47
4	Plastic	27.20	82.80	155.13
5	Metal	24.93	79.27	152.87
6	Plastic	22.93	74.00	149.73
Avg. decrease between each trial		**2.61**	**4.32**	**3.32**

Table 1 demonstrats that, without exception, there is a decrease (drop) in the average slump measurement as time progresses. This decrease occured without regard to the slump cone material. The drop is a function of time and temperature.

The average decrease in slumps between trials are shown in Table 2, again in mm.

TABLE 2 - AVERAGE SLUMP DECREASES BETWEEN TRIALS

Trial Intervals	Low	Mod.	High	Overall Average
1 and 2	3.07	3.67	3.33	3.36
2 and 3	2.06	7.66	4.53	4.75
3 and 4	3.67	1.47	3.34	2.83
4 and 5	2.27	3.53	2.26	2.69
5 and 6	2.00	5.27	3.14	3.47
Average Drop between trials (mm)	**2.61**	**4.32**	**3.32**	**3.42**
Average Drop w/ Metal Cones (2 trial intervals)	5.53	8.17	6.73	6.81
Average Drop w/ Plastic Cones (2 trial intervals)	5.00	8.97	6.63	6.87
Average Drop w/ Metal Cones ÷ 2 (1 trial interval)	2.77	4.08	3.37	**3.41**
Average Drop w/ Plastic Cones ÷ 2 (1 trial interval)	2.50	4.48	3.32	**3.43**

The average slump decreases between trials for metal slump cones and plastic slump cones are virtually identical with the overall average drop being 3.42 mm.

TABLE 3 - LOW SLUMP RANGE ADJUSTED FOR TIME AND TEMPERATURE LOSSES

Trial	Cone Material	Measured Slump (mm)	Adjusted Slump Overall Avg. +(3.42)	Adjusted Slump Range Avg. +(2.61)
1	Metal	36.00	36.00	36.00
2	Plastic	32.93	36.35	35.54
3	Metal	30.87	37.71	36.09
4	Plastic	27.20	37.46	35.03
5	Metal	24.93	38.61	35.37
6	Plastic	22.93	40.03	35.98
LOW SLUMP RANGE (ADJUSTED AVERAGE)				
Average Metal Cone adjusted results			37.44	35.82
Average Plastic Cone adjusted results			37.95	35.52
Difference in Metal and Plastic			0.51 mm	0.30 mm

TABLE 4 - MODERATE SLUMP RANGE ADJUSTED FOR TIME AND TEMPERATURE LOSSES

Trial	Cone Material	Measured Slump (mm)	Adjusted Slump Overall Avg. +(3.42)	Adjusted Slump Range Avg. +(4.32)
1	Metal	95.60	95.60	95.60
2	Plastic	91.93	95.35	96.25
3	Metal	84.27	91.11	92.91
4	Plastic	82.80	93.06	95.76
5	Metal	79.27	92.95	96.55
6	Plastic	74.00	91.10	95.60
MODERATE SLUMP RANGE (ADJUSTED AVERAGE)				
Average Metal Cone adjusted results			93.22	95.02
Average Plastic Cone adjusted results			93.17	95.87
Difference in Metal and Plastic			0.05 mm	0.85 mm

TABLE 5 - HIGH SLUMP RANGE ADJUSTED FOR TIME AND TEMPERATURE LOSSES

Trial	Cone Material	Measured Slump (mm)	Adjusted Slump Overall Avg. +(3.42)	Adjusted Slump Range Avg. +(3.32)
1	Metal	166.33	166.33	166.33
2	Plastic	163.00	166.42	166.32
3	Metal	158.47	165.31	165.11
4	Plastic	155.13	165.39	165.09
5	Metal	152.87	166.55	166.15
6	Plastic	149.73	166.83	166.33
HIGH SLUMP RANGE (ADJUSTED AVERAGE)				
Average Metal Cone Adjusted results			166.06	165.86
Average Plastic Cone adjusted results			166.21	165.91
Differences in Metal and Plastic			0.15 mm	0.05 mm
AVERAGE DIFFERENCES FOR ALL RANGES			0.24 mm	0.40 mm

Using the overall average adjustment of 3.42 mm per time interval between tests or the range average to adjust for time and temperature changes in the recorded slumps there is no significant difference between the average measurements with metal or plastic slump cones. The average differences for 135 tests with metal slump cones and 135 tests with plastic slump cones after the time and temperature adjustments are 0.24 mm (0.01 inches) using the overall average adjustment and 0.40 mm (0.016 inches) using the individual range adjustments.

These differences are insignificant and can be disregarded in the precision test data. The use of metal or plastic slump cones is considered irrelevant and thus each set of 3 consecutive tests will be considered as the testing of a material.

The data will thus be divided into 6 groups or materials rather than 3. The material identifications for the 6 materials shall be as follows:

LOW_123
LOW_456
MOD_123
MOD_456
HIGH_123
HIGH_456

These material identifications refer to the slump range and trial numbers within each range.

References to all six (6) sets of tests as a group (one material) will be identified as follows:

LOW: 1-6
MOD: 1-6
HIGH: 1-6

TABLE 6 - TESTING TIME REQUIREMENTS

TIME IN MINUTES REQUIRED TO PERFORM
6 TESTS FROM ONE WHEELBARROW OF CONCRETE

STATION/ POSITION	LOW SLUMP MIX	MODERATE SLUMP MIX	HIGH SLUMP MIX	OVERALL AVERAGE (min.)
A 1	16	12	20	16.00
A 2	20	15	22	19.00
A 3	19	17	18	18.00
A 4	20	19	20	19.67
B 1	18	17	18	17.67
B 2	19	18	18	18.33
B 3	22	17	19	19.33
B 4	18	16	18	17.33
C 1	25	23	24	24.00
C 2	24	24	20	22.67
C 3	22	18	12	17.33
C 4	21	18	18	19.00
D 1	27	24	22	24.33
D 2	26	24	22	24.00
D 3	17	14	17	16.00
AVERAGE	20.93	18.40	19.20	**19.51 min.**

AVERAGE TIME FOR INDIVIDUAL
SLUMP TEST WAS 3.25 MINUTES (See Note A)

Note A - The 3.25 minutes includes the time between tests to clean equipment and re-mix the concrete within the wheelbarrow into a uniform mixture prior to the next test.

CONCLUSIONS EXTENDED

Due to objections to the step approach within a precision statement and objections to the use of a statistical line of best fit for the development of the steps, the original presentation method was abandoned.

The revised method of presentation is the conventional method which involves the tabular display of standard deviations at 3 different slumps and is without direction to the user for intermediate values. To avoid the use of 3 pairs of numbers the test results were recombined into 3 average slump values. Each of the averages used 6 test results per technician per slump value. The 6 tests extended over approximately 20 minutes and the average slump loss during the 20 minutes was 0.68 inches [17 mm]. Even so, a correction was not attempted in the calculations to account for the changes in material being tested.

The results of the final calculations were better than expected and give a good picture of the range of results which can be expected when 2 or more tests are made on the same material. The concrete temperature averaged approximately 90°F during the testing process, so high temperatures have already been factored into the results. The final round of the low slump tests averaged 1.0 inches [23 mm] and the initial round of the high slump tests averaged 6.5 inches [166 mm]. The test program thus covered a range from 1.0 inches to 6.5 inches with an intermediate result at 3.4 inches. This gave adequate coverage for the commonly specified slump values.

With an average standard deviation of approximately 1/2 inch and a (d2s) acceptable test value in excess of 1 inch it makes the allowable slump tolerances for producers of +/- 1 inch or +/- 1 1/2 inch, as defined in ASTM C94, begin to seem like a very small window of acceptability. The importance of good testing and the development of careful techniques becomes very clear from the results of this testing program.

All testing time, travel time, and travel costs as well as materials and the test location were donated for this project. Several people had travel times in excess of 4 hours. This project and this information could not have happened without the help of each of the participants. I cannot adequately express my gratitude to these people who were so willing to give up a Saturday of leisure to perform eighteen slump tests apiece.

Thanks also go to Nick Carino who very graciously checked the original statistical calculations and offered comments on the original draft of a proposed precision statement. The initial MCLB received a persuasive negative and several editorial comments which have resulted in a better statement of precision for the slump test.

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ASTM C09.60