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Committee C09 on Concrete and Concrete Aggregates
Subcommittee C09.45 on Roller-Compacted Concrete

Research Report: C09-1045

Ruggedness Study for ASTM C1435/1435M - Standard Practice for Molding Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Hammer

Technical contact:
Dennis Clute,
USDA-Natural Resources Conservation Service
501 W. Felix St, Bldg. 23
Fort Worth, Texas 76115, USA
dennis.clute@ftw.usda.gov

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

1. Introduction:

Ruggedness Study 1005 was conducted to evaluate the influence of seven factors on C39/C39M compressive strength and density values for specimens made by the C1435/C1435M, Practice for Molding Roller-Compacted Concrete in Cylinder Molds Using a Vibrating Hammer. A seven factor analysis of variance was employed as described in C1067-12. The seven factors evaluated were: 1 apparatus mass, 2 number of lifts, 3 proportioning lean or rich, 4 cementitious materials, 5 coarse aggregate shape, 6 nominal maximum aggregate size, and 7 absence or presence of air entrainment. The main focus of the study was to evaluate the influence of factors 1 apparatus mass and 2 number of lifts respectively.

Compressive strength test specimens were made according to Practice Standard C1435/C1435M-08 amended to expand the range of allowable apparatus mass. C1435/C1435M is not a test standard, but it is used to make compressive strength specimens, so it is desirable to learn if compressive strength results and density values tested and obtained in accordance with C39/C39M are significantly influenced by the mass of the apparatus specified in C1435/C1435M. Thus, the study evaluates the influence of seven factors on C39/C39M compressive strength and density values for specimens made by the C1435/C1435M procedure.

A precision statement was developed to describe the precision of cylinders made according to C1435/C1435M and tested according to C39/C39M. It would be prudent to report this precision in C39/C39M or convert C1435/C1435M to a test standard to include the precision statement.

The lab program was conducted in conjunction with testing to evaluate the ruggedness of two other standards (C1170/C1170M and a draft test standard for determining air content and density) the results of which are reported in in separate research reports, respectively RR: C09-1043 and RR: C09-1045.

2. Test Method:

The methods used for this study are C1170/C1170M-08 revised to include centering spacers affixed to the surcharge mass, a draft version of practice standard C1435/C1435M-08 revised to expand the range of apparatus mass and C39/C39M-12. A copy of the revised apparatus section from both of these standards is included in Annex A. To obtain a copy of C1170/C1170M, C1435/C1435M, and C39/C39M go to ASTM's website, 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.

3. Participating Laboratory:

The following laboratory participated in this ruggedness study:

Fall Line Testing & Inspection, LLC
460 East 76th Avenue
Building 4, Unit C
Denver, Colorado 80229, USA
www.falllinetesting.com

4. **Description of Samples:**

Materials used for this study were the ingredients typically used for making RCC mixtures. Material quality was specified according to the standards shown in the Materials Quality Table below. Material data sheets for all materials (except water and cement) are included in Annex B.

Water was obtained from the city's potable water supply. No data is provided.

Cement (42 kg (92.6 lb.) sacks of Holcim Portland Type I, II was obtained from a local building supply/home improvement store.

The air-entraining agent (AEA) was specified to be "1) synthetic detergents having a chemical description of alkyl-aryl sulfonates and sulfates (e.g., sodium dodecylbenzenesulfonate) or 2) wood derived acid salts (e.g. Vinsol resin) having a chemical description of alkali or alkanolamine salt of a mixture of tricyclic acids, phenolics, and terpenes.". The AEA was specified based on discussion with Jim Hinds and Steve Tatro. Both Mr. Hinds and Mr. Tatro retired from employment with the United States Army Corps of Engineers. They stated that, while working for USACE, they were successful in entraining air with either of these types of AEA in RCC mixed in a pugmill.

MATERIALS QUALITY TABLE

Material	Type or Class	Quality Standard
Portland Cement	Type I or II	ASTM C150
Fly Ash	Class F	ASTM C618
Fine Aggregate		ASTM C33
Coarse Aggregate		ASTM C33
Water		ASTM C94
Air-Entraining Agent (AEA)		ASTM C260

5. **Interlaboratory Study Instructions**
Laboratory participants were emailed the test program instructions. For a copy of the instructions see Annex A.

6. **Description of Equipment/Apparatus[1]:**
For information on the equipment/apparatus used, please see Annexes A and B.

7. **Data Report Forms:**
A copy of the completed data report forms are provided in Annex B.

8. **Statistical Data Summary:**
A summary of the statistics calculated from the data returned by the participating laboratories is provided in Annex B and in Section 10. Analysis of Variance.

9. **Precision and Bias Statement:**

C1435/C1435M is a practice standard for molding concrete test specimens. C1435/C1435M does not require nor does it include a precision statement; however, the focus of this study is to learn if compressive strength results and density values obtained by C39/C39M are significantly influenced by the mass of the apparatus and compactive effort specified in C1435/C1435M. Thus, the study evaluates the influence of apparatus mass and the attendant compactive effort on C39/C39M compressive strength and density values for specimens made by the C1435/C1435M procedure. In that light, a temporary repeatability statement

[1] The equipment listed was used to in this study. This listing is not an endorsement or certification by ASTM International.

was developed that would be applicable to C39/C39M whenever the specimens tested in accordance with C39/C39M are made by the C1435/C1435M procedure.

The practice described in ASTM 1067-12 and employed in this research is not intended to provide information on multi-laboratory precision, but it does provide some information on single-operator precision, which has been used to develop the following temporary repeatability statement that would be applicable to C39/C39M whenever the specimens tested in accordance with C39/C39M are made by the C1435/C1435M procedure.

xx.1.2.1 Compressive Strength - The single-operator standard deviation has been found to be 0.30 MPa [43 psi][A] for mixtures with Vebe consistencies below 20s, 0.70 MPa [101 psi][A] for mixtures with Vebe consistencies over the range from 20s to 30s, and 0.45 [65 psi][A] for mixtures with Vebe consistencies above 30s. Therefore, results of two properly conducted tests by the same operator on the same material are not expected to differ from each other by more than 0.82 MPa [120 psi] for mixtures with Vebe consistencies below 20s, 1.94 MPa [281 psi] for mixtures with Vebe consistencies over the range from 20s to 30s, and 1.25 MPa [181 psi] for mixtures with Vebe consistencies above 30s.

xx.1.2.2 Density - The single-operator standard deviation has been found to be 10 kg/m^3 [0.6 lb/ft^3][A] for mixtures with Vebe consistencies below 20s, 5 kg/m^3 [0.3 lb/ft^3][A] for mixtures with Vebe consistencies over the range from 20s to 30s, and 22 kg/m^3 [1.4 lb/ft^3][A] for mixtures with Vebe consistencies above 30s. Therefore, results of two properly conducted tests by the same operator on the same material are not expected to differ from each other by more than 27 kg/m^3 [1.7 lb/ft^3] for mixtures with Vebe consistencies below 20s, 14 kg/m^3 [0.9 lb/ft^3] for mixtures with Vebe consistencies over the range from 20s to 30s, and 62 kg/m^3 [3.9 lb/ft^3] for mixtures with Vebe consistencies above 30s.

xx.2. *Bias* – The test method has no bias because the values determined can be defined only in terms of the test method.

[A] These numbers represent, respectively, the [1s] and [d2s] limits as described in ASTM Practice C670, for Preparing Precision Statements for Test Methods for Construction Materials.

10. Analysis of Variance:

The practice described in ASTM C1067-12 and employed in this research evaluates the effects of seven factors (A through G) on the results of a test. It only estimates the main effects of the factors and does not detect the effects of interactions among factors. The practice standard being evaluated is used for making specimens that are tested according to C39/C39M. C39/C39M yields two results: 1) the compressive strength and 2) the density of the concrete.

The analysis of variance results in a number for each factor evaluated. This number, termed the "F statistic", is designated F_f, for f = A through G. If F_f is greater than 5.32, the factor (A through G) has a statistically significant effect. If F_f is shown to be NS it has a value of less than or equal to 5.32 meaning that the factor (A through G) has no statistically significant effect.

The results of the ANOVA are shown in the tables and further discussed below.

Compressive Strength

Summary of F Values for All Laboratories, All Materials, and All Factors

Material	Average Compressive Strength	Apparatus Mass F_A	Number of Lifts F_B	Proportioning F_C	Cementitious Materials F_D	Coarse Aggregate Shape F_E	NMSA F_F	Air Entrainment F_G
A	2290	11.44	22.87	9103.73	16884.30	NS	107.77	2779.65
B	2540	NS	NS	1788.37	3824.38	NS	NS	388.16
C	2770	NS	NS	5336.14	9192.34	43.26	49.59	1056.29

Density

Summary of F Values for All Laboratories, All Materials, and All Factors

Material	Average Density	Apparatus Mass F_A	Number of Lifts F_B	Proportioning F_C	Cementitious Materials F_D	Coarse Aggregate Shape F_E	NMSA F_F	Air Entrainment F_G
A	146.0	NS	12.75	67.59	33.79	99.31	7.06	355.37
B	146.7	24.67	15.06	190.87	NS	329.86	65.16	571.47
C	147.5	NS	NS	7.13	NS	23.79	9.37	11.20

Although C1435/C1435M is a practice standard, the specimens made according to this standard are generally tested according to C39/C39M to determine compressive strength and density. Subcommittee C09.45 would like to change the range of mass allowed for the hammer, shaft, and tamping plate assembly currently specified in the C1435/C1435M. The current range of mass for the assembly is 23.1 to 34.1 lb. The subcommittee proposes changing this range to 24 to 44 lb in order to allow a wider range of available hammers to be used and to increase the mass of the tamping plate and shaft to allow for the construction of a stronger joint between the shaft and plate which has historically been a point of failure for some shaft/plate assemblies. Also, several years ago the number of lifts was changed from three to four. The SC wishes to study the effect of the number of lifts on the density and compressive strength to determine if it would be best to keep the current four lift requirement or require only three lifts.

F_A – Apparatus Mass

Two hammer/shaft/tamping plate assembles were used, one with a total mass of 32 lb, the other 43 lb. (Note that the dynamic compactive effort varies with hammer size, so a change in hammer mass also results in a change in the total compactive effort from dynamic components as well as static components). The apparatus mass had a slightly significant effect on the variation of compressive strength test results of Material A and the density of Material B. Otherwise the analysis showed apparatus mass to be an insignificant factor in strength and density results.

F_B – Number of Lifts

The number of lifts had a slightly significant effect on the variation of compressive strength test results of Material A and the density of Materials A & B. Otherwise the analysis showed the number of lifts to be an insignificant factor in strength and density results. More study is needed before changing the required number of lifts because there have been reports of good density with four lifts verses poor density when employing only three lifts.

F_C – Proportioning

Two basic mixes were proportioned for the study. One was a lean mix proportioned to have 300 lb. of cementitious material (CM) per cubic yard and the other a rich mix with 450 lb of CM per cubic yard. Proportioning significantly effected variation of compressive strength test results; it effected variation of density test results to a lesser degree. Because of this, it is recommended that any lab program designed to further study precision of compressive strength and density of specimens made per C1435/C1435M be designed so mix proportioning remains consistent or designed to report precision for both lean and rich mixtures.

F_D – Cementitious Material (CM)
Varying the ratio of cement to pozzolan significantly affected the variation of compressive strength test results. To a lesser degree, varying this ratio affected the variation of density test results of Material A but did not have a significant effect on the variation of density test results of Materials B and C.

It is recommended that the ratio of cement to pozzolan not change in any future lab program designed to further study precision of compressive strength of specimens made per C1435/C1435M or that the program be designed to report precision for two or more ratios of cement to pozzolan. Although not as critical as for compressive strength test results, future lab programs designed to study precision of density test results of specimens made according to C1435/C1435M would benefit from maintaining the same cement to pozzolan ratio for the entire lab program or designing the program to report precision for two or more ratios of cement to pozzolan .

F_E – Coarse Aggregate Shape
The coarse aggregate shape (rounded or angular) had no significant effect on the variation of compressive strength test results of Materials A & B, but did have a significant effect on the variation of compressive strength results of Material C. Varying coarse aggregate shape significantly affected the variation of density results of all three materials.

For future lab programs designed to study precision of compressive and density test results of specimens made according to C1435/C1435M, it would be prudent to obtain separate precision data for angular and rounded aggregate to determine if the test precision is different for angular aggregate verses that of rounded aggregate.

F_F – Nominal Maximum Size Aggregate
Changing the NMSA from ¾ inch to 1 ½ inch material effected variation in both compressive strength and density results with the exception of compressive strength results for Material B. The effect on the precision of density values for Materials A and B was slightly significant.

For future lab programs designed to study precision of compressive and density test results of specimens made according to C1435/C1435M, it would be prudent to obtain separate precision data for angular and rounded aggregate to determine if the test precision is different for angular aggregate verses that of rounded aggregate.

F_G – Air Entrainment
Air entrainment was included as a factor because it is needed in the evaluation of the proposed test standard for measuring air content and density which was also studied during this lab exercise; it was not a factor that was deemed necessary to study the precision of C39/C39M test results of specimens made according to C1435/C1435M. The presence of air entraining agent (AEA) had a significant effect on the variation in both compressive strength and density results.

It is recommended that any lab program designed to further study precision of compressive strength and density of specimens made per C1435/C1435M be designed so the mix used for the duration of the lab program is proportioned without AEA and reported as such or designed to report precision for AE mixtures separately from non-AE mixtures.

Annex A: Laboratory Instructions and Worksheets

For

ASTM Subcommittee C09.45 Ruggedness Study for Ruggedness of C1435/C1435M and Precision of C39/C39M When Used to Test Specimens Made in Accordance With C1435/C1435M

Contents of Annex A