Bureau of Materials and Physical Research
Illinois Laboratory Test Procedure
Effective Date: April 12, 2011

Standard Method of Test
for
Fine Aggregate Classification (Mortar Voids)

1. Scope

This method is intended for laboratory use in determining the angularity characteristics, and therefore, water requirements of fine aggregate. The results of this test are the basis of the water content used in the design of concrete mixtures in Illinois.

2. Apparatus

2.1 Mold

The mold is made from 2 in. (51mm) standard seamless drawn brass tubing with 3/16 in. (48 mm) wall thickness. It is provided with a securely crimped bottom of the same thickness as the wall, and has an outside height of 4 in. (102 mm) in order that the volume may be approximately 200 cc.

2.2 Scale

The scale must be accurate to the nearest gram.

2.3 Burette

The burette used for measuring water has a capacity of 250 cc and graduated in one cubic centimeter divisions.

2.4 Tamping Rod

The tamping rod is plastic, 0.75 in. (19 mm) square, approximately 8 in. (20 mm) long, and rounded at the impacting end.

2.5 Rounded End Scraper

The rounded end scraper is approximately 6.5 in. (165 mm) long with a wooden handle and a thin flat metal blade. The metal end furthest from the handle is rounded like a semi circle. The metal blade is approximately 3 in. (75mm) long and 0.75 in. (19 mm) wide.

2.6 Metal Sheet

A nonporous stainless steel sheet upon which the mortar is mixed has dimensions approximately 24 in. (610 mm) by 24 in. (610 mm).

2.7 Rubber Gloves

Rubber gloves are worn while mixing the mortar in order to reduce the moisture loss.

3. Preparation of Specimen

3.1 The test is conducted on saturated surface dry fine aggregate, all of which passes the number 4 sieve. The fine aggregate to be tested is immersed in water for a period of at least twenty-four hours to insure its maximum absorption, after which it is brought to the saturated surface dry (SSD) condition. To attain SSD condition, spread the sand on a non-absorbent surface such as plastic. Determine if the sample is at SSD condition using the Cone Test for Surface Moisture according to Illinois Modified AASHTO T 84-08. If the sample has excess moisture, dry the material using a fan. If the sample lacks moisture, use a spray bottle to add water. Repeat the Cone Test for Surface Moisture after adjustments to the amount of water. Continue this process until SSD condition is obtained.

3.2 The cement is a proportionate blend of the Department's five most used brands.

4. Proportions

4.1 The average ratio of the volume of fine aggregate to cement used in concrete construction in Illinois is about 2.44. The volume of the mold to be filled is 200 cc and, therefore, the sum of the volumes of fine aggregate and cement is arbitrarily 200 cc. Thus,

$$\begin{aligned} A / C &= 2.44 \\ A + C &= 200\ cc \\ A &= 141.9\ cc \\ C &= 58.1\ cc \end{aligned}$$

Then since the units are absolute, the weights of cement and fine aggregate are:

$$Weight\ of\ cement\ \ (grams) = G_{s\ cement} \times 58.1$$

$$Weight\ of\ fine\ aggregate\ (grams) = G_{s\ f.a.} \times 141.9$$

(Note: The specific gravity of cement is normally 3.15.)

4.2 It has been found that the actual volume of water contained in the mixture is very much affected by evaporation. To facilitate the determination of the exact water volume, even increments of water are added to the mortar and to each increment the evaporation estimate is also added.

The following table has been established (1973-74) as a good estimate of the water requirements for the test.

Actual Water Volume Added (cc)	Lost to Evaporation (Cumulative)	Actual Water in Mix (Cumulative)
40	2	38
12	4	48
11	5	58
11	6	68
11	7	78
10	7	88

This range and these increments have historically produced mortar void curves that can be accurately interpolated. These addition rates for evaporation must be checked often and changed as needed.

5. Procedure

5.1 The burette is filled with clean water, the metal mixing plate is wiped clean with a slightly damp cloth and the mold is very slightly dampened. After weighing out the correct amounts, the fine aggregate and cement are thoroughly mixed on the metal plate and the first increment of water is added. The mortar is mixed with a trowel and placed in the mold in three layers, each layer being tamped twenty-five times. After tamping each layer, uniform compaction is enhanced by soundly striking the bottom of the mold against a solid surface until water barely begins to appear on the surface of the mortar, typically three times. While striking the bottom of the mold, cover the top of the mold with your hand to keep the mortar contained in the mold. After the addition and compaction of the third layer, the surface is finished smooth with the trowel. Weigh and record the weight of the mold and contained mortar. Then record the weight of the mortar and all of the equipment that came in contact with the mortar (metal sheet, trowel, spatula, rubber gloves, plastic tamping rod, and overturned pan) to determine the amount of moisture loss.

5.2 The remaining incremental water additions and compactions are performed as above, producing a set of numbers as illustrated in Table 1. The last addition or two of water result in a more plastic material and require consolidation with a rounded end scraper instead of a plastic tamping rod because of the greater water cement ratio. The scraper is used to consolidate the material in a spading or sawing like motion. During this process, the scraper is not removed from the material.

5.3 In order to eliminate evaporation and the resulting necessary compensation for it, every precaution must be taken. This includes: maintaining a relatively close mixing pile, mixing the water into the mortar in as short a time as possible and covering the mixing pile with an overturned pan while weighing the mold.

Table 1
Mortar Voids Test Worksheet

Total Weights of Materials W_t (g)	Weight of Materials in Mold W_f (g)	Total Volume of Batch V_t (cc)	Actual Water Added (cc)	Loss (cc)	Actual Water In Batch W_n (cc)	Voids per Unit Volume V_m	Water per Unit Volume W_m
598	384	311.5	40	2	38	0.358	0.122
608	397	306.3	12	4	48	0.347	0.157
618	420	294.3	11	5	58	0.320	0.197
628	453	277.3	11	6	68	0.279	0.245
638	447	285.5	11	7	78	0.299	0.273
648	445	291.2	10	7	88	0.313	0.302
658	443	297.1	10	7	98	0.327	0.330

$G_{s\ f.a.} = 2.66$

$G_{s\ cement} = 3.15$

Weight:
Fine Aggregate 377g
Cement 183g

6. Calculation

6.1 For a derivation of the equations that are assumed in the following, see Bulletin 137 of the University of Illinois Engineering Experiment Station. The method of calculating v_m, the volume of voids per volume of mortar, and w_m the volume of water per volume of mortar for each increment is as follows:

The total weight of the batch W_t is equal to the sum of the weights of the fine aggregate, cement and water added. That is respectively

$$\mathrm{W_t} = \mathrm{W_s} + \mathrm{W_c} + \mathrm{W_w}$$

The weight of the mixture in the mold is W_f and the volume of the mold is V_f. The volume of the total batch is then

$$V_t = \frac{V_f \times W_t}{W_f}$$

Since the volume of solids in the mixture (volume of fine aggregate + cement) was 200 cc., the volume difference, $V_t - 200$ is attributed to water and trapped air. Thus the voids per unit volume of mortar is:

$$v_m = \frac{V_t - 200}{V_t}$$

The net volume of water contained is W_n and the amount of water per unit volume of mortar is:

$$w_m = \frac{W_n}{V_t}$$

The quantities v_m and w_m are calculated for all increments of water illustrated in Table 1.

6.2 From the calculated values of v_m and w_m, the mortar void curve is plotted on the Mortar Void Datasheet. (A copy of this datasheet can be obtained by contacting the Bureau of Materials and Physical Research.) The low point on this curve is the basic water content. This point must be determined very accurately since all succeeding calculations are based on these coordinates.

6.3 It has been found that concrete designed for the basic water content, although most dense, is too dry to be workable. A relative water content is thus used. A relative water content (RWC) of 1.40, for example, means that the amount of water per unit volume of mortar is 1.40 times as much as at the basic water content.

A study made by Talbot and Richart specifies that relative water contents of 1.40 through 1.55 in conjunction with cement-space ratios of 0.39 through 0.42, respectively, will produce concrete with compressive strength of 5,000 psi.

(Note: Cement-space ratio $[C'/(C' + V')]$ is the ratio of the volume of cement to the space in the concrete outside of the aggregates, water, entrapped air and cement.)

To this effect, a standard absolute volume of fine aggregate per hundredweight of cement of 1.245 ft.^{3} will be defined for this test. The fine aggregate-cement ratio (A'/C') is established at about 2.44. Knowing C' and any cement-space ratio, V' (volume of water and air) may be calculated. Knowing V', and A' and C', the volume, M', of mortar per cubic yard of concrete, may be calculated.

$$M' = A' + C' + V'$$

Then v_{mc} can be calculated as follows:

$$v_{mc} = 1 - \frac{A' + C'}{M'}$$

(v_{mc} is a theoretical v_m)

These calculations establish Table 2, which is the standard basis for all succeeding operations. The values in this table dictate the water content that is valid for 5,000 psi concrete for any given cement-space ratio, relative water content combination. Thus, if a relative water content is chosen for workability and the corresponding theoretical volume of water per volume of mortar, w_{mc}, and Table 2 value of v_{mc} do not correspond to a point on the actual graph, variation from the desired strength of concrete is indicated. For this reason, the relative water content which most closely corresponds to the actual graph, must be determined as follows:

Having w_m and v_m for the basic water content point, calculate a w_{mc} for any relative water content,

$$w_{mc} = RWC \times w_m$$

Enter the computer interpolation or plot to find the corresponding v_m. If this v_m is not within $\pm$ 0.002 of the value of v_{mc} in Table 2 for the chosen RWC, repeat the operation with another RWC. When a relative water content and w_{mc} produce a v_{mc} which corresponds to a point in the interpolation or plot, the water requirement of the particular fine aggregate is established. Read M' from Table 2 for the RWC determined above and calculate W as follows:

$$W_{\left(\frac{gallons\ of\ water}{cwt\ of\ cement}\right)} = M' \times w_{mc} \times 7.49$$

6.4 Entrained air has obviously been eliminated from the above procedure. This is due to the fact that this volume of voids is completely unpredictable when adding water in the increments described. The entrainment of air reduces the water requirements of concrete by approximately 5%, but this water reduction serves to compensate for the strength loss incurred with air entrainment.

Table 2
Theoretical Parameters for Compressive
Strength of 5000 psi

Relative Water Content	Cement-Space Ratio	V'	M'	v_{mc}
1.30	0.370	0.868	2.623	0.331
1.31	0.372	0.861	2.616	0.329
1.32	0.374	0.854	2.609	0.327
1.33	0.376	0.846	2.601	0.325
1.34	0.378	0.839	2.594	0.323
1.35	0.380	0.832	2.587	0.322
1.36	0.382	0.825	2.580	0.320
1.37	0.384	0.818	2.573	0.318
1.38	0.386	0.811	2.566	0.316
1.39	0.388	0.804	2.559	0.314
1.40	0.390	0.798	2.553	0.313
1.41	0.392	0.791	2.546	0.311
1.42	0.394	0.784	2.539	0.309
1.43	0.396	0.778	2.533	0.307
1.44	0.398	0.771	2.526	0.305
1.45	0.400	0.765	2.520	0.304
1.46	0.402	0.759	2.514	0.302
1.47	0.404	0.752	2.507	0.300
1.48	0.406	0.746	2.501	0.298
1.49	0.408	0.740	2.495	0.297
1.50	0.410	0.734	2.489	0.295
1.51	0.412	0.728	2.483	0.293
1.52	0.414	0.722	2.477	0.291
1.53	0.416	0.716	2.471	0.290
1.54	0.418	0.710	2.465	0.288
1.55	0.420	0.704	2.459	0.286

$A' / C' = 2.44$ $A' + C' = 200$ $V' = \frac{C'}{CSR} - C'$ $v_{mc} = 1 - \frac{A' + C'}{M'}$

$M' = A' + C' + V'$

7. Fine Aggregate Types

There are three general classifications of fine aggregates, those composed of completely rounded particles (Type A), completely angular particles (Type C) and a combination of rounded and angular particles (Type B). As angularity increases, the water requirement increases. The mortar voids test indicates the degree of angularity and the water requirement of the particular fine aggregate. Experience has established the fine aggregate types which correspond to the various water requirements. The generalized typing is given in Table 3 below.

Table 3
Fine Aggregate Classification

Type	W (gal/cwt)	Actually Added to Concrete (gal/cwt)
A	5.1 thru 5.29	5.1
B	5.3 thru 5.49	5.3
C	5.5 thru 5.69	5.5

After determining W as outlined in 6.3, the classification of the fine aggregate is read from Table 3. Tests resulting in W outside the 5.1 thru 5.69 range shall be retested.

8. Report

The Mortar Void Datasheet includes the fine aggregate identification, the computer interpolation and plot (mortar void curve), and the initials of the operator.