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Standard Test Method for Bulk Solids Characterization by Carr Indices[1]

This standard is issued under the fixed designation D 6393; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the apparatus and procedures for measuring properties of bulk solids, henceforth referred to as Carr Indices.[2]

1.2 This test method is suitable for free flowing and moderately cohesive powders and granular materials up to 2.0 mm in size. Materials must be able to pour through a 7.0 ± 1.0-mm diameter funnel outlet when in an aerated state.

1.3 This method consists of eight measurements and two calculations to provide ten tests for Carr Indices. Each individual test or a combination of several tests can be used to characterize the properties of bulk solids. These ten tests are as follows:

1.3.1 *Test A*—Measurement of Carr Angle of Repose
1.3.2 *Test B*—Measurement of Carr Angle of Fall
1.3.3 *Test C*—Calculation of Carr Angle of Difference
1.3.4 *Test D*—Measurement of Carr Loose Bulk Density
1.3.5 *Test E*—Measurement of Carr Packed Bulk Density
1.3.6 *Test F*—Calculation of Carr Compressibility
1.3.7 *Test G*—Measurement of Carr Cohesion
1.3.8 *Test H*—Measurement of Carr Uniformity
1.3.9 *Test I*—Measurement of Carr Angle of Spatula
1.3.10 *Test J*—Measurement of Carr Dispersibility

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Terminology

2.1 *Definitions of Terms Specific to This Standard:*

2.1.1 *Carr angle of difference*, *n*—the difference between the Carr angle of repose and Carr angle of fall.

2.1.2 *Carr angle of fall*, *n*—an angle of repose measured from a powder heap to which a defined vibration has been given.

2.1.3 *Carr angle of repose*, *n*—a measurement from the powder heap built up by dropping the material through a vibrating sieve and funnel above a horizontal plate.

2.1.4 *Carr angle of spatula*, *n*—a measurement by which a spatula is inserted into a powder heap parallel to the bottom and then lifting it up and out of the material.

2.1.5 *Carr cohesion*, *n*—a descriptive measure of interparticle forces based on the behavior of the material during sieving.

2.1.6 *Carr compressibility*, *n*—a calculation made by using Carr loose bulk density and Carr packed bulk density as determined in 5.8.

2.1.7 *Carr dispersibility*, *n*—a measurement by which a powder sample is dropped through a hollow cylinder above a watch glass and then the amount of powder collected by the watch glass is measured.

2.1.8 *Carr dynamic bulk density*, *n*—a calculated bulk density of a material. It is used to compute vibration time for the Carr cohesion measurement.

2.1.9 *Carr loose bulk density*, *n*—a measurement obtained by sieving the sample through a vibrating chute to fill a measuring cup.

2.1.10 *Carr packed bulk density*, *n*—a measurement obtained by dropping a measuring cup, which is filled with the sample, a specific number of times from the same height. Sometimes known as a *tapped density*.

2.1.11 *Carr uniformity*, *n*—a measurement calculated from the particle size distribution of the powder as measured by sieving.

3. Significance and Use

3.1 This test method provides measurements that can be used to describe the bulk properties of a powder or granular material.

3.2 The measurements can be combined with practical experience to provide relative rankings of various forms of bulk handling behavior of powders and granular materials for a specific application.

4. Apparatus

4.1 The main instrument includes a *timer/counter* (A), a *vibrating mechanism* (B), an *amplitude gage* (C), a *rheostat* (D), and a *tapping device* (E) (see Fig. 1).[3]

4.1.1 *Timer/Counter*—The timer is used to control the duration of vibration and the number of taps. A minimum 180-s timer for 60 Hz power supply is required. Alternatively, a

[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.24 on Characterization and Handling of Powders and Bulk Solids.

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[2] Carr, R.L., "Evaluating Flow Properties of Solids," *Chemical Engineering*, January 18, 1965, pp. 163–168.

[3] Available from Hosokawa Micron International Inc., New York, NY.

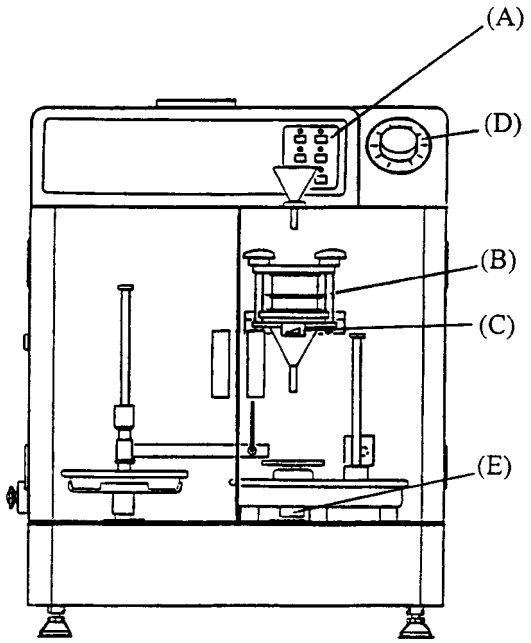

FIG. 1 Powder Characteristics Tester for Carr Indices

counter can be used to control the number of taps.

4.1.2 *Vibrating Mechanism*, to deliver vibration at 50 to 60 Hz to the vibration plate at an amplitude of 0.0 to 3.0 mm.

4.1.3 *Amplitude Gage*, mounted on the vibration plate to measure the amplitude of the vibration from 0.0 to 4.0 mm.

4.1.4 *Rheostat*—A dial used to adjust the vibration amplitude of vibration plate from 0.0 to 3.0 mm.

4.1.5 *Tapping Device*, consists of tap holder and tapping lift bar (tapping pin), which lifts and free-fall drops a measuring cup a stroke of 18.0 ± 0.1 mm and a rate of 1.0 ± 0.2 taps/s.

4.2 The spatula assembly consists of a *spatula blade* (A), a *pan base/elevator stand* (B), and a *shocker* (C) (see Fig. 2).

4.2.1 *Spatula Blade*—A chrome-plated brass plate mounted on the blade receiver to retain powder while elevator stand lowers the powder-filled pan. The dimensions of the spatula blade are 80 to 130 mm length, 22.0 ± 0.3-mm width and 3.0 ± 0.3-mm thick.

4.2.2 *Shocker*—A sliding bushing with a mass of 110.0 ± 1.0 g at a drop height of 150.0 ± 10.0 mm, measured from the lower edge of the bushing to the shocker base for the measurement of angle of spatula. The total mass of the shocker assembly including the sliding bushing, pole, spatula blade, and blade receiver is 0.65 ± 0.35 kg.

4.3 A dispersibility measuring unit consists of a *container* (A) with *shutter cover* (B), a *cylindrical glass tube* (C), and a *watch glass* (D), (see Fig. 3).

4.3.1 *Container*—A hopper unit with a shutter cover at the bottom to support a powder sample. The shutter cover opens horizontally to release the powder sample which then falls through the glass tube onto the watch glass.

4.3.2 *Cylindrical Glass Tube*, located vertically 170.0 ± 10.0 mm under the shutter cover to confine the scattering/dispersed powder. The dimension of the tube is 100.0± 5.0-mm diameter and 330.0 ± 10.0-mm length.

4.3.3 *Watch Glass*, centered 101.0 ± 1.0 mm under the cylindrical glass tube to collect undispersed powder. The dimension of watch glass is 100.0 ± 5.0-mm diameter and 2.0 ± 0.1-mm thickness with the radius of curvature of 96.3 mm, concave upwards.

4.4 *Accessories*:

4.4.1 *Spatula Pan*—A stainless steel pan with at least a 100.0-mm width, a 125.0-mm length, a 25.0 mm height, and a 1.0-mm thickness, used to retain powder for the preparation of the measurement of Carr angle of spatula.

4.4.2 *Scoop*—A stainless steel container used to transport powder.

4.4.3 *Scraper*—A chrome plated brass or stainless steel plate used to scrape off excess powder in the cup.

4.4.4 *Cup*—A 100-cm^3 stainless steel cylindrical container with the inside dimensions of 50.5 ± 0.1-mm diameter and

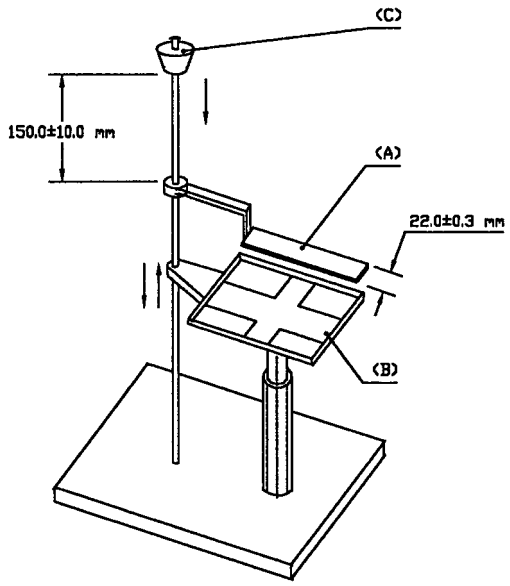

FIG. 2 Carr Spatula Assembly

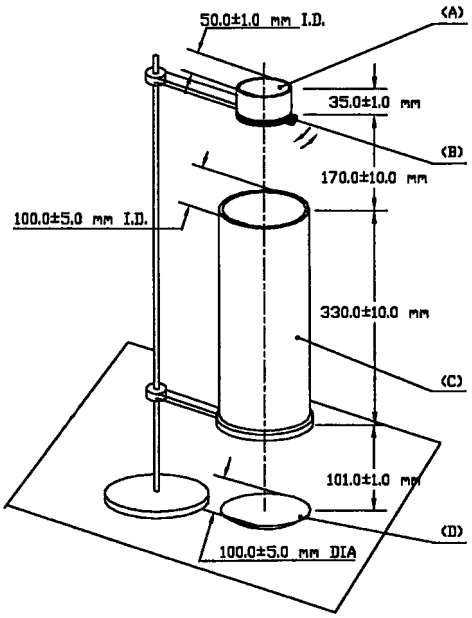

FIG. 3 Carr Dispersibility Measuring Unit

49.9 ± 0.1-mm height used for Carr bulk density measurement. The wall thickness of the cup is 1.75 ± 0.25 mm. The interior walls of the cup are sufficiently smooth that machining marks are not evident.

4.4.5 *Cup Extension*—A white Delrin™[4] extension sleeve for the 100 cm^3 measuring cup, 55.0 ± 0.1 mm in diameter by 48.0 ± 1.0 mm in height.

4.4.6 *Funnel for Angle of Repose*—A glass funnel with 55° angle bowls as measured from the horizontal, 7.0 ± 1.0-mm bottom outlet diameter and outlet stem length 33.5 mm for the measurement of Carr angle of repose.

4.4.7 *Stationary Chute*—A stainless steel conical chute with the dimensions of 75.0-mm top diameter, 55.0-mm height, and 50.0-mm bottom diameter to guide the powder flow into the measuring cup (see 4.4.4).

4.4.8 *Vibration Chute*—A stainless steel conical chute with the dimensions of 75.0-mm top diameter, 55.0-mm height, and 50.0-mm bottom diameter installed on the vibration plate to guide the powder flow to the stationary chute or cup extension.

4.4.9 *Sieves*, certified 76.0-mm diameter stainless steel sieves with the opening of 710 µm, 355 µm, 250 µm, 150 µm, 75 µm, and 45 µm.

4.4.10 *Sieve Extension*—A stainless steel extension piece used as a spacer in the vibration unit when only one sieve is used.

4.4.11 *Spacer Ring*—A white Delrin™ spacer inserted between sieve and vibration chute or glass funnel to protect them from damage.

4.4.12 *Sieve Holding Bar*—A chrome-plated brass holding bar used to hold sieve assembly on the vibration plate.

4.4.13 *Pan*, with base for tapping device, measuring cup, and shocker. A stainless steel pan, at least 210.0-mm length, 150.0-mm width, 35.0-mm height, and 1.0-mm thickness, designed to accept tapping device, measuring cup and platform, as well as provide a stand base for shocker.

4.4.14 *Platform*—A chrome-plated brass circular platform with a diameter of 80.0 ± 0.3 mm and a height of 59.0 ± 2.0 mm to be used for the measurement of Carr angle of repose.

4.4.15 *Shocker*—A sliding bushing with a mass of 110.0 ± 1.0 g at a drop height of 150.0 ± 10.0 mm, measured from the lower edge of the bushing to the shocker base for the measurement of Carr angle of fall. The total mass of the shocker, platform, and pan for the measurement of angle of fall is 1.35 ± 0.25 kg.

NOTE 1—The pan has molded-in feet so it is slightly raised from the table top. This helps make vibration more consistent.

4.4.16 *Brush*, a laboratory brush for dust removal.

4.4.17 *Cover*, for measuring dispersibility. A removable enclosure to confine the dust of sample powder when it falls onto the watch glass for the measurement of Carr dispersibility.

4.5 *Balance*, capable of measuring sample mass to an accuracy of ± 0.01 g with a max of 2.0 kg.

4.6 *Data Acquisition Equipment*—A microprocessor or computer may be used to guide the measuring operation, collect data, calculate data, and print test results.

[4] Delrin™

5. Procedure

5.1 A representative powder sample from process stream should be riffled carefully into portions for each individual measurement.

5.2 All the measurements should be performed on a strong, horizontally-leveled bench or work table. If possible, use a concrete or stone-topped table.

Test A—Measurement of Carr Angle of Repose

5.3 *Placement of Parts*:

5.3.1 Place the parts onto the vibration plate in the following order starting at the bottom:

5.3.1.1 Glass funnel;

5.3.1.2 Spacer ring;

5.3.1.3 Sieve with opening of 710 µm;

5.3.1.4 Sieve extension; and,

5.3.1.5 Sieve holding bar.

5.3.2 Fasten the vibration assembly with knob nuts located on both sides of sieve holding bar.

5.3.3 Center the platform under the glass funnel.

5.3.4 Position the stem end of the glass funnel 76.0± 1.0 mm above the platform.

5.3.5 Set desired vibration time on timer (usually 180 s on 60 Hz vibrating frequency is selected).

5.3.6 Pour 200 to 300 cm^3 of powder over the sieve using the scoop.

5.3.7 Set vibration adjustment dial (Rheostat) to 0.

5.3.8 Turn on the vibrating mechanism and timer.

5.3.9 Gradually increase the amplitude of the vibration, no more than 0.2 mm at a time, by incrementally turning the vibration adjustment dial until powder starts to flow out of the end of the glass funnel and builds up on the circular platform in a conical shape.

5.3.10 Turn off the vibration mechanism when the powder starts to fall from the edge of the platform and the powder pile is completely formed.

5.3.11 If a conical shape is not completely formed, remove the powder pile and repeat steps 5.3.6-5.3.10.

5.3.12 After the cone has been built up, calculate an average angle of the cone (from horizontal) in relation to the edge of the platform by the equation below. This average angle is called the Carr angle of repose.

$$\text{Carr Angle of Repose} = \tan^{-1}\,[H/R] \quad (1)$$

where:

H = Height of the powder pile, mm, and

R = Radius of the circular platform, mm.

5.3.13 Indicate the shape of the cone either Concave Up (A), Concave Down (B), or Straight (C) (see Fig. 4) in the report.

5.3.14 If the cone is irregular in shape, repeat the test three times and obtain an average.

5.3.15 If the powder has free-flowing characteristics or has coarse particles larger than 710 µm, the vibration and 710 µm sieve are not necessary. In this case, use the scoop to slowly pour the powder through the funnel. Adjust the pouring rate so that it takes 15 to 30 s to form the conical pile.

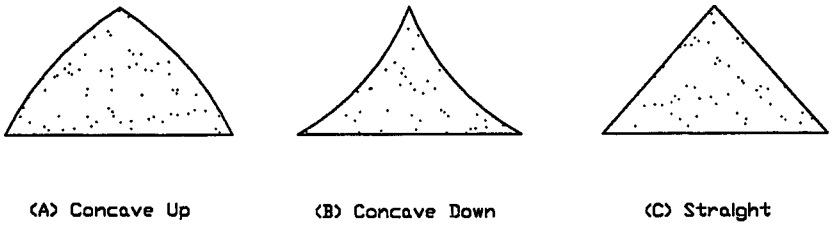

FIG. 4 The Shape of the Powder Pile

Test B—Measurement of Carr Angle of Fall

5.4 After determining the Carr Angle of Repose as in 5.3, place the shocker on the shocker base.

5.5 Then raise the sliding bushing carefully (so that the cone will not be disturbed) to the upper end of the pole (at a drop height of 150.0 ± 10.0 mm) and let it fall to give a shock to the pan. Repeat this three times. The powder layer will be collapsed and exhibit a smaller angle of repose.

5.6 Wait for 30 s after the final shock and then measure the angle as described in 5.3.12-5.3.14. This new, lower angle is called Carr angle of fall.

Test C—Calculation of Carr Angle of Difference

5.7 Subtract the Carr angle of fall from the Carr angle of repose to obtain the Carr angle of difference.

Test D—Measurement of Carr Loose Bulk Density

5.8 *Placement of Parts*:

5.8.1 Place the parts onto the vibration plate in the following order starting at the bottom:

5.8.1.1 Vibration chute;

5.8.1.2 Spacer ring;

5.8.1.3 Sieve with opening of 710 µm;

5.8.1.4 Sieve extension; and,

5.8.1.5 Sieve holding bar.

5.8.2 Fasten the vibration assembly with knob nuts located on both sides of sieve holding bar.

5.8.3 Support the stationary chute below the vibration chute.

5.8.4 Place the pan directly under the stationary chute and position the measuring cup in its base. Make sure the center of the measuring cup is in alignment below the center of the stationary chute and the distance between them is 30.0 ± 5.0 mm.

5.8.5 Use scoop to pour 200 to 300 cm^3 of the powder onto the sieve.

5.8.6 Set vibration time on timer (a normal vibration time is about 30 s).

5.8.7 Set vibration adjustment dial (rheostat) to 0.

5.8.8 Turn on the vibrating mechanism and timer.

5.8.9 Adjust the amplitude of vibration to control the powder flow rate so that the powder will fill the cup within 20 to 30 s.

5.8.10 When the cup is filled and overflowing, stop the vibration.

5.8.11 Using the scraper, lift and scrape excess material from the top of the cup as shown in Fig. 5. Remove small quantities at a time, and continue the process until the material is flush with the top of the cup. Do not exert a downward force with the scraper.

5.8.12 Weigh the cup with powder.

5.8.13 Subtract the empty cup mass from that of cup with powder. The difference divided by 100 is the Carr loose bulk density of the powder in g/cm^3.

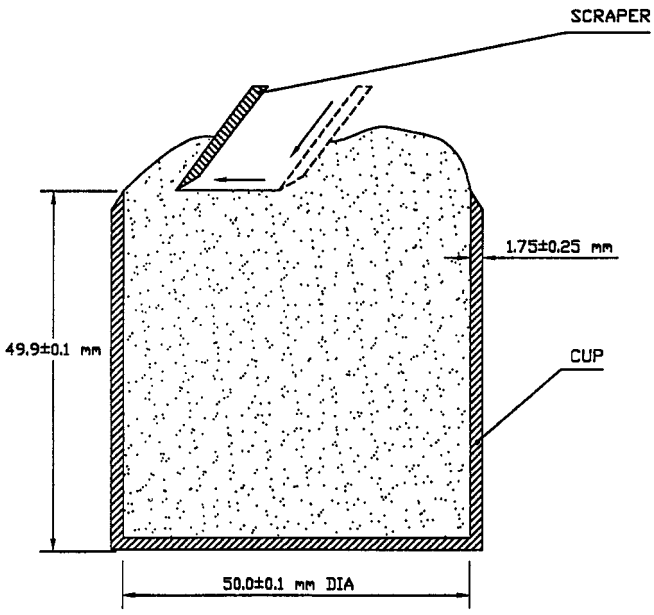

FIG. 5 Scraping Off Excess Powder

NOTE 2—The cup is exactly 100 cm^3 in volume.

5.8.14 Repeat steps 5.8.5-5.8.13 three to five times and obtain an average value.

5.8.15 When the powder is free-flowing and of fairly coarse particle size, it will not be necessary to use the vibrating sieve. The powder can be poured gently into the cup by the scoop.

Test E—Measurement of Carr Packed Bulk Density

5.9 This test is known in the field as a tapped bulk density even though the sample is dropped instead tapped.

5.9.1 Prepare the parts in the same order as with the measurement for Carr loose bulk density but without using the stationary chute.

5.9.2 Place the cup extension on the top of the measuring cup.

5.9.3 Fill the cup with sample powder to the top with the scoop and place it on the tapping device.

5.9.4 Set timer for a desired tapping duration (usually 180 s on 60 Hz power supply is selected). Alternatively, use a counter to control the number of taps.

NOTE 3—The optimal number of taps for consistent results is determined by repetitive tests in which the relationship between the tapped bulk density and number of taps is examined. The number of taps should be sufficiently large so that additional taps do not result in an increase in tapped bulk density.

5.9.5 Turn on the tapping device.

5.9.6 During the tapping period, it is necessary to observe the level of the powder and, if necessary, add powder to the cup extension so that the final powder level will not be below the rim of the measuring cup.

5.9.7 When the tapping is completed, remove the cup and its extension from the tapping device.

5.9.8 Remove the cup extension and scrape off excessive powder from the cup surface as described in 5.8.11.

5.9.9 Weigh the cup with the packed powder and subtract the empty cup mass from it. The difference divided by 100 is the Carr packed bulk density of the powder in g/cm^3. (The cup is exactly 100 cm^3 in volume).

Test F—Calculation of Carr Compressibility

5.10 Carr compressibility (C) is calculated by the following equation from the Carr loose bulk density (L), in 5.8 and the Carr packed bulk density (P) in 5.9.

$$C = 100\,(P-L)/P \tag{2}$$

Test G—Measurement of Carr Cohesion

5.11 Determine Carr loose bulk density (L), and Carr packed bulk density (P), as described in 5.8 and 5.9. Determine particle size distribution by sieving.

5.11.1 Refer to the selection guide in Fig. 6 to determine if Carr cohesion measurement is recommended. Proceed to 5.12 for Carr uniformity measurement, if Carr cohesion measurement is not recommended. If Carr cohesion measurement is recommended, select the proper sieve sizes from Fig. 6.

5.11.2 Place the parts on the vibration plate in the following order, starting at the bottom:

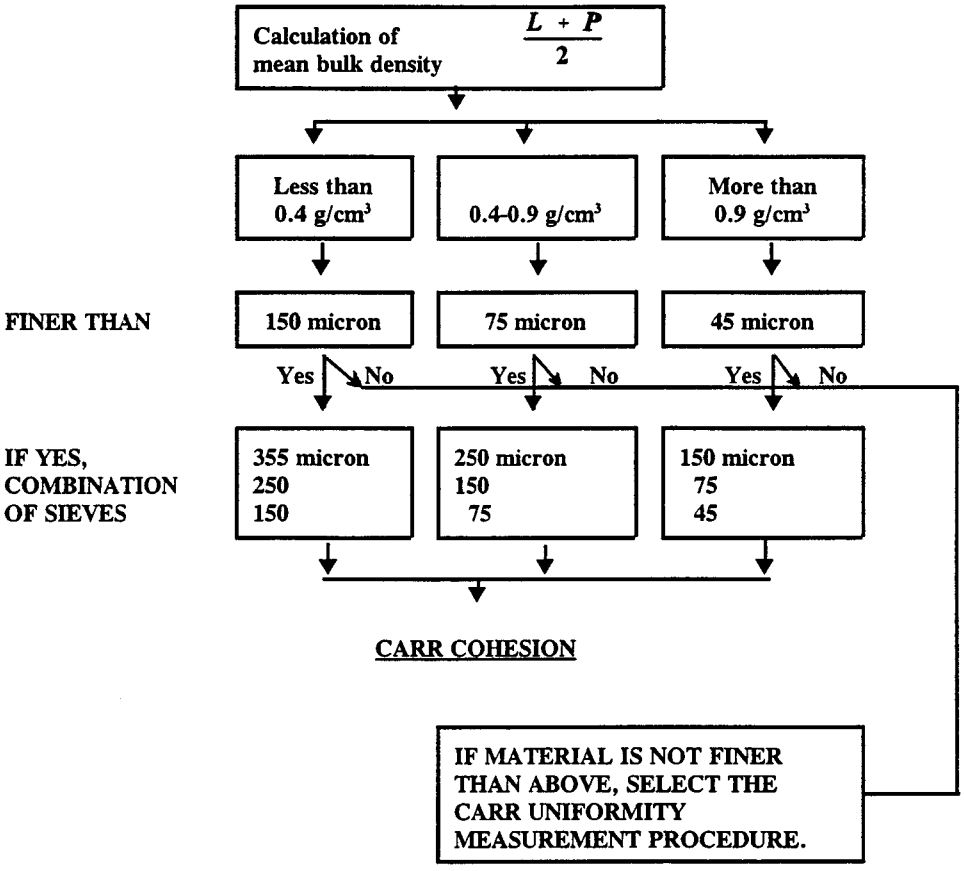

FIG. 6 Selection Guide for Carr Cohesion Measurement

5.11.2.1 Vibration chute.
5.11.2.2 Spacer ring.
5.11.2.3 Sieve 1 (smallest opening).
5.11.2.4 Sieve 2 (midsize opening).
5.11.2.5 Sieve 3 (largest opening).
5.11.2.6 Sieve holding bar.

5.11.3 Fasten the vibration assembly with knob nuts located on both sides of sieve holding bar.

5.11.4 Turn on the vibrating mechanism and adjust the amplitude of vibration to 1.0 mm with vibration adjustment dial. Wait until the vibration amplitude becomes stabilized, then turn off the vibration but keep the position of vibration adjustment dial as it was.

5.11.5 Set timer according to the vibration time calculated as follows:

$$T\,(\mathrm{s}) = 20 + [(1.6 - W)/0.016] \quad (3)$$

$$W = [(P - L)C/100] + L \quad (4)$$

where:
T = Vibration time, s,
W = Carr dynamic bulk density, g/cm^3,
C = Carr compressibility, %,
L = Carr loose bulk density, g/cm^3, and
P = Carr packed bulk density, g/cm^3.

NOTE 4—If Carr dynamic bulk density, W, is greater than 1.6 g/cm^3, vibration time, T, should be set at 20 s.

5.11.6 Weigh 2.0 ± 0.01 g of powder and place it on the top sieve.

5.11.7 Turn on the vibration mechanism.

5.11.8 When vibration stops after time T, loosen the knob nuts and remove the three sieves and weigh the amount of powder retained on each sieve. Brush off all material from the sieves.

5.11.9 Carr Cohesion is calculated as follows:

$$[(\text{Powder mass retained on the largest sieve})/2\mathrm{g}] \times 100 \quad (5)$$

$$[(\text{Powder mass retained on the midsize sieve})/2\mathrm{g}] \times 100 \times (3/5) \quad (6)$$

$$[(\text{Powder mass retained on the smallest sieve})/2\mathrm{g}] \times 100 \times (1/5) \quad (7)$$

The sum of the three calculated values (Eq 5-7) will give the Carr cohesion [%].

Test H—Measurement of Carr Uniformity

5.12 This measurement is applied instead of Carr cohesion measurement when the powder is relatively coarse and not so cohesive. See Fig. 6.

5.12.1 Obtain the particle size distribution of the sample powder by sieve analysis.

5.12.2 From the particle size distribution curve, determine a particle size of which 60 % of the powder by volume passes the sieve (d_{60}) and a particle size of which 10 % passes the sieve (d_{10}).

5.12.3 Carr uniformity is calculated below:

$$\text{Carr uniformity} = d_{60}/d_{10} \quad (8)$$

Test I—Measurement of Carr Angle of Spatula

5.13 Set the Carr spatula assembly in place as described in 4.2.

5.13.1 Put the spatula pan on the pan base.

5.13.2 Raise the pan until the pan bottom contacts the spatula.

5.13.3 Use a scoop to pour the sample powder into the pan so that the spatula is completely covered with several centimeters of powder (about 200 to 300 cm^3 on the spatula). Be consistent about the amount of powder used for each measurement, that is, same depth of powder over the spatula.

5.13.4 Slowly lower the pan away from the spatula. This will expose the spatula with a considerable amount of powder on it.

5.13.5 Calculate an average angle Θ, of the powder pile (from horizontal) in relation to the edge of spatula by the equation below and indicate the shape of the powder pile as described in 5.3.13.

$$\Theta = \tan^{-1}\,[H/X] \quad (9)$$

where:
H = height of the powder pile on the spatula, mm, and
X = half width of the spatula, mm.

5.13.6 Raise the sliding bushing to the highest point of the pole (at a drop height of 150.0 ± 10.0 mm), then drop it to give only one shock to the spatula.

5.13.7 Wait for 30 s after the shock and then calculate an average angle of the powder on the spatula again as descried in 5.13.5.

5.13.8 Average the mean angle of spatula before and after the shock to give the Carr angle of spatula.

5.13.9 If the slope of the powder pile is irregular in shape, repeat the test three times and obtain an average.

Test J—Measurement of Carr Dispersibility

5.14 The apparatus should be covered or enclosed in a box to prevent ambient air currents from disturbing the measurement and to contain the powder.

5.14.1 Set the Carr dispersibility measuring unit in place as described in 4.3.

5.14.2 Weigh the watch glass.

5.14.3 Position the watch glass concave upwards and centered under the glass tube.

5.14.4 Make sure the container is closed with the shutter cover.

5.14.5 Weigh 10.0 ± 0.01 g of powder and place it into the hopper of the container.

5.14.6 Release the shutter cover horizontally in 1 to 2 s to allow the powder to fall through the glass tube and onto the watch glass.

5.14.7 Weigh the watch glass and the powder on it.

5.14.8 Carr dispersibility is obtained by the following calculation:

$$\text{Carr dispersibility} = (10\ \mathrm{g} - \text{Mass of powder on watch glass})/10\ \mathrm{g} \times 100 \quad (10)$$

6. Report

6.1 Reports for each test should include the sample name, the sample source, the moisture content of the sample, and the temperature and relative humidity when the tests are performed. In addition, report the following information:

6.1.1 *Test A*—Carr angle of repose should be reported as

angle in degrees with an indication of the shape of the powder pile.

6.1.2 *Test B*—Carr angle of fall should be reported as angle in degrees with an indication of the shape of the powder pile.

6.1.3 *Test C*—Carr angle of difference should be reported as angle in degrees.

6.1.4 *Test D*—Carr loose bulk density should be reported in units of g/cm^3.

6.1.5 *Test E*—Carr packed bulk density should be reported in units of g/cm^3.

6.1.6 *Test F*—Carr compressibility should be reported as a % value.

6.1.7 *Test G*—Carr cohesion should be reported as a % value.

6.1.8 *Test H*—Carr uniformity should be reported as a dimensionless number.

6.1.9 *Test I*—Carr angle of spatula should be reported as angle in degrees. In addition, the average angle and the indication of the shape of the powder pile on the spatula before and after the mechanical shock should be included in the report.

6.1.10 *Test J*—Carr dispersibility should be reported as a % value.

7. Precision and Bias

7.1 *Precision*—Data are being evaluated to determine the precision of this test method.

7.2 *Bias*—No accepted reference value exists for this test method; therefore, bias cannot be determined.

8. Keywords

8.1 angle of difference; angle of fall; angle of repose; angle of spatula; Carr index; Carr indices; Carr procedures; cohesion; compressibility; dispersibility; dynamic bulk density; loose bulk density; packed bulk density; uniformity