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Standard Test Method for Grindability of Coal by the Hardgrove-Machine Method[1]

This standard is issued under the fixed designation D 409; 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.

This standard has been approved for use by agencies of the Department of Defense.

~~ε[1] NOTE—Section 10.2 was editorially corrected in October 2007.~~

INTRODUCTION

This test method is structured into the following parts:

The body of the test method discusses the scope, referenced documents, significance and use, apparatus, gross samples, preparation of test samples, procedure, calculation and report, precision and bias, and keywords.

Annex A1 through Annex A5 contain the methods used to prepare, homogenize, and assign HGI values to the international HGI reference materials (primary HGI RMs) and to calibrate an individual laboratory's HGI machine using these HGI RMs.

Annex A1 contains the method to obtain and prepare international HGI standard reference coal sample feedstock for potential use as international (primary) HGI RMs (reference materials).

Annex A2 contains the method to divide and containerize the candidate international HGI standard reference coal samples (candidate RMs) prepared from the feedstock prepared in Annex A1.

Annex A3 contains the method for homogeneity testing of the candidate international HGI standard reference coal samples (candidate RMs) containerized in Annex A2.

Annex A4 contains the method for determining the Hardgrove grindability index (HGI) to be assigned to each lot of the candidate international HGI standard reference coal samples (RMs).

Annex A5 contains the method used to calibrate the individual laboratory's Hardgrove grindability machine using the international HGI RMs.

Annex A6 through Annex A10 contain the methods used to prepare, homogenize, and assign HGI values to the national HGI reference materials (secondary HGI RMs) and to calibrate a national HGI machine using the international (primary) HGI RMs.

Annex A6 contains the method to obtain and prepare national HGI standard reference coal sample feedstock for potential use as national (secondary) HGI RMs (reference materials).

Annex A7 contains the method to divide and containerize candidate national HGI standard reference coal samples (candidate national RMs) prepared from the feedstock prepared in Annex A6.

Annex A8 contains the method for homogeneity testing of candidate national HGI standard reference coal samples (candidate national RMs) containerized in Annex A7.

Annex A9 contains the method for determining the Hardgrove grindability index to be assigned to each lot of the candidate national HGI standard reference coal samples (national RMs).

Annex A10 contains the method to calibrate a national Hardgrove machine using the international (primary) HGI RMs.

Annex A11 contains the method for determining the moisture content of the 1.18 × 0.60 mm (No. 16 × 30) test sample.

1. Scope

1.1 This test method[2] covers the determination of the relative grindability or ease of pulverization of coals in comparison with coals chosen as standards. A prepared and sized sample receives a definite amount of grinding energy in a miniature pulverizer,

[1] This test method is under the jurisdiction of ASTM Committee D05 on Coal and Coke and is the direct responsibility of D05.07 on Physical Characteristics of Coal.
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Current edition approved May 15, 2008. Published June 2008. Originally approved in 1951. Last previous edition approved in 2007 as D 409 – 02 (2007)ε1.

[2] For information concerning the experimental work on which this test method is based, see paper by Hardgrove, R. M., "Grindability of Coal," *Transactions*, American Society of Mechanical Engineers, Vol 54, F.S.P., p. 37, 1932.

and the size consist of the pulverized product is determined by sieving. The resultant size consist is used to produce an index relative to the ease of grinding (Hardgrove Grindability Index (HGI)).

1.1.1 Some coals, such as some high-volatile bituminous, subbituminous, and lignite coals, can undergo physical change as the natural or seam moisture is released during handling and preparation. This change is often sufficient to alter the grindability characteristics that will be reported when tested in the laboratory and could produce different indices dependent on the conditions of drying and the moisture level of the 1.18-mm by 600-µm (No. 16 × No. 30) (see Test Method D 4749) materials used for the test. Therefore, the repeatability and reproducibility cited in this test method may not apply for these high-volatile bituminous, subbituminous, and lignite coals.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses may be approximate.

1.3 It is recognized that the term *weight* is considered equivalent to *mass*as used in this test method.

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. Referenced Documents

2.1 *ASTM Standards:* [3]

D 2013 Practice for Preparing Coal Samples for Analysis

~~D2234/D2234MPractice for Collection of a Gross Sample of Coal~~

~~D~~ 4749 Test Method for Performing the Sieve Analysis of Coal and Designating Coal Size

D 4916 Practice for Mechanical Auger Sampling

D 6609 Guide for Part-Stream Sampling of Coal

D 6883 Practice for Manual Sampling of Stationary Coal from Railroad Cars, Barges, Trucks, or Stockpiles

D 7256/D 7256M Practice for Mechanical Collection and Within-System Preparation of a Gross Sample of Coal from Moving Streams

E 11~~Specification for Wire Cloth and Sieves for Testing Purposes~~ Specification for Wire Cloth and Sieves for Testing Purposes

E 826 Practice for Testing Homogeneity of Materials for Development of Reference Materials

NOTE 1—Part stream samples should be used for this test only if all parties find part stream sampling acceptable.

NOTE 2—If the topsize of the final sample product produced from a mechanical sampling system (whether auger, cross-stream, or cross-belt) is smaller than 4.75 mm (No. 4), the sample is unsuitable for this test procedure.

3. Significance and Use

3.1 This test method develops a measurement of grinding or pulverizing characteristics that can be used to evaluate the yield, or energy input, or both, required in a grinding or pulverizing process.

4. Apparatus

4.1 ~~*Air-Drying Oven*~~Air-Drying Oven [for air-drying the 1000 g, 4.75 mm (No. 4) sample]—A device for passing slightly heated air over the sample. The oven shall be capable of maintaining a temperature of 10 to 15°C (18 to 27°F) above room temperature with a maximum oven temperature of 40°C (104°F) unless ambient temperature is above 40°C, in which case ambient temperature shall be used. In the case of easily oxidized coals, the temperature shall not be over 10°C (18°F) above room temperature unless ambient temperature is above 37°C (100°F) in which case ambient temperature shall be used. Air changes shall be at the rate of 1 to 4 air volumes of oven capacity per minute.

4.2 ~~*Drying Pans*—Drying pans of sufficient size so that the sample may be spread to a depth of not more than 25 mm (1.0 in.) with sides not more than 38 mm (1.5 in.) high. The pans shall be nonreactive with coal and unaffected by the method of air drying selected.~~

~~4.3*Balances*—Two balances may be required: one with a sensitivity of 10 mg and a minimum capacity of 800 g and one with a sensitivity of 0.5 g in 1000 g and sufficient capacity to weigh a ≥1000-g sample along with the drying pan. A single balance meeting these specifications is permitted.~~

~~4.3.1~~*Drying Pans [for air-drying the 1000 g, 4.75 mm (No. 4) sample]*—Drying pans of sufficient size so that the sample may be spread to a depth of not more than 25 mm (1.0 in.) with sides not more than 38 mm (1.5 in.) high. The pans shall be nonreactive with coal and unaffected by the method of air drying selected.

4.3 *Balance [for weighing the 1000-g sample before and after air-drying and the sieve fractions formed during stage-crushing]*—With a sensitivity of 0.5 g in 1000 g and sufficient capacity to weigh a ≥ 1000-g sample along with the drying pan.

4.4 *Balance [for weighing the 50-g test sample and the sieve fractions formed during milling]*—With a sensitivity of 10 mg and a minimum capacity of 800 g.

D05.07.02 on Grindability is conducting ongoing investigations in regard to quality control during preparation, distribution, and use of standard reference materials and during preparation and testing of actual samples.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* ~~, Vol 05.06.~~volume information, refer to the standard's Document Summary page on the ASTM website.

NOTE 3—A single balance meeting the specifications of 4.3 and 4.4 is permitted.

4.5 *Calibration Weights*—These calibration weights shall be used to monitor the response of each balance over the range of normal use each time HGIs are determined.

~~4.4~~

4.6 *Sample Divider*~~—An enclosed riffle divider as described in Method D2013 is required and shall be used.~~

~~4.5~~— *An enclosed riffle divider with feed chute as described in Practice D 2013 is required and shall be used. Alternatively, a rotary sample divider, which has been proven to be free of significant bias, may be used.*

4.7 *Standard Sieves*—A working set of circular, standard testing sieves, which are 203 mm (8 in.) in diameter and conform to Specification E 11, are required in the following sizes, together with cover and catch pan (receiver):

TABLE 1 Standard Sieves for HGI Testing

~~Sieve Designation~~
~~Standard~~
~~Alternate~~
~~(ISO Designation)~~
~~(U.S.A. Designation)~~
~~16.0 mm~~

E 11 Specification	U.S.A. Standard Sieve Series Designation
16.0 mm	⅝ ~~in.~~
~~4.75 mm~~	~~No. 4~~
~~2.36 mm~~	~~No. 8~~
~~1.18 mm~~	~~No. 16~~
~~600 µm~~	~~No. 30~~
~~75 µm~~	~~No. 200~~in.
4.75 mm	No. 4
2.36 mm	No. 8
1.18 mm	No. 16
600 µm	No. 30
75 µm	No. 200

~~4.5.1~~4.7.1 These working sieves must be periodically inspected for wear or damage. Any excessively worn or damaged sieves (for example, sieves with holes, ~~tears cracks, and so forth,~~ tears, cracks; see Note ~~1~~4~~).~~) must be replaced immediately, and the HGI calibration procedure must be repeated after the damaged sieves are replaced (see ~~Section 8~~Annex A5). Since the HGI depends upon the sieve analysis and since the 75-µm (No. 200) sieve is fragile, it is recommended that at least one set of working sieves be obtained, identified, and used exclusively for HGI determinations and that only this exclusive set of sieves be used.

NOTE ~~1~~4—Excessive wear may be indicated by poor repeatability or by failure of quality control checks (~~8.1.1~~A5.4.1.1) to agree reasonably with the initial calibration data.

4.~~5~~7.2 Normal wear on sieves is compensated by the use of ~~proper~~ international HGI standard reference samples ~~(SRSs)~~ (HGI RMs) and proper calibration of equipment; excessive wear (such as holes or tears in the sieve cloth, and so forth) is not compensated by ~~SRSs.~~HGI RMs. Because excessive wear is unacceptable, inspect sieves carefully before each test to ensure the absence of excessive wear. For the 75- and 600-µm (No. 200 and 30) sieves, use only a soft-bristled brush (such as short-bristled camel hair) for brushing and cleaning.

NOTE~~2—It~~ 5—It is good practice to keep a separate primary 75-µm (No. 200) check sieve to be used only to check the 75-µm working sieve described in ~~4.5.1~~4.7.1 when the working sieve becomes suspect. This check is done by running a comparative HGI test between the two 75-µm sieves. Use of the working sieve for HGIs should be discontinued if HGI difference between the sieves is greater than 1 HGI unit.

~~4.6~~

4.8 *Crusher*—A laboratory plate mill capable of reducing 4.75-mm (No. 4) sieve size coal particles with the production of a minimum of minus 600-µm (minus No. 30) sieve size material (Note ~~3~~6). The crusher plates shall be serrated and about 100 mm (4 in.) in diameter (Note ~~4~~7). The distance between the plates shall be adjustable, and the relative speed of rotation of the plates shall not exceed 200 r/min.

NOTE~~3—Evidence from HGI standard reference sample user-response forms (8.4) indicates that the median value of percent recovery of the 4.75-mm (No. 4) material as 1.18-mm by 600-µm (Nos. 16 by 30) material, regardless of the HGI level, is about 55%.~~ 6—Evidence from HGI standard reference sample user-response forms (A5.4.4) indicates that the median value of % Yield (8.3) of the 4.75-mm (No. 4) material as 1.18-mm by 600-µm (Nos. 16 by 30) material, regardless of the HGI level, is about 55 %. Use this median value to gage the effectiveness/efficiency of the stage-crusher and of the stage-crushing process.

NOTE~~4—The~~ 7—The most frequently used plate mill can be equipped with "fine" or "coarse" plates. One independent study[4] has found evidence of differences in percent recovery resulting from use of different types of plate. Only the coarse plate should be used in preparation of both HGI calibration standards and unknown samples.

~~4.7~~

[4] D05.07 Minutes, J. Gardner, Georgia Power and G. Linton, October 1990.

4.9 *Mechanical Sieving Machine*—The mechanical sieving machine shall accept an assembly of vertically nested circular sieves of 203 mm (8 in.) in diameter, together with cover and receiver. The machine shall simulate the motions given testing sieves during hand sieving by imparting a horizontal oscillatory motion of approximately 28-mm (1.1-in.) amplitude at a rate of approximately 300 oscillations or cycles per minute (cpm). Simultaneously, the top of the oscillating assembly is struck at a rate of approximately 150 blows per minute by a weight of 1.9 kg (4.2 lb) moving through a vertical distance of approximately 28 mm (1.1 in.) under the influence of gravity.

~~4.8~~

4.10 *Grindability Machine*—The Hardgrove Grindability Machine such as is shown in Fig. 1 is required for this test. Essential tolerances and specifications are shown in Fig. 2. The grindability machine includes a stationary grinding bowl of polished cast iron, with a circular horizontal track that holds eight polished steel balls, each 25.40 ± 0.13 mm (1.000 ± 0.005 in.) in diameter. The balls are driven by an upper grinding ring which is rotated at 20 ± 1 r/min by means of the upper spindle and which, in turn, is driven by an electric motor through reduction gears and, in newer models, belts. Weights are added to the driving spindle so that the total vertical force on the balls as a result of the weights, shaft, top grinding ring, and gear is equal to 29.0 ± 0.2 kg (64 ± 0.5 lb). The machine is equipped with a counter and automatic device which can be properly adjusted for stopping the machine after 60 ± 0.25 revolutions.

NOTE 8—It is good laboratory practice to have the dimensions and the tolerances of the grinding balls verified by a qualified machine shop (or equivalent) on an annual basis.

~~4.8.1 The~~4.10.1 The position of the counter trip mechanism before and after the test must be used to determine the number of revolutions completed. Sometimes, it may be necessary to position strategically the counter trip mechanism at the beginning of

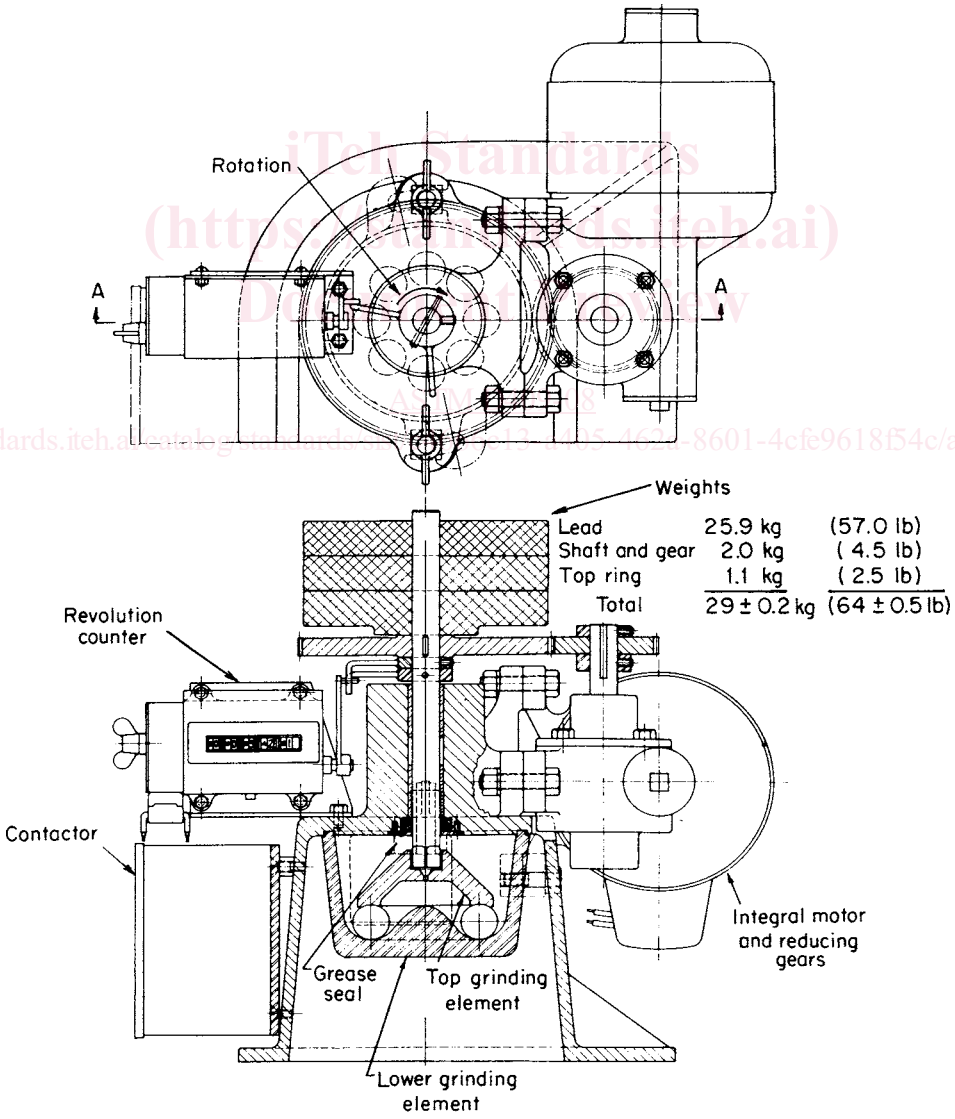

FIG. 1 Hardgrove Grindability Machine

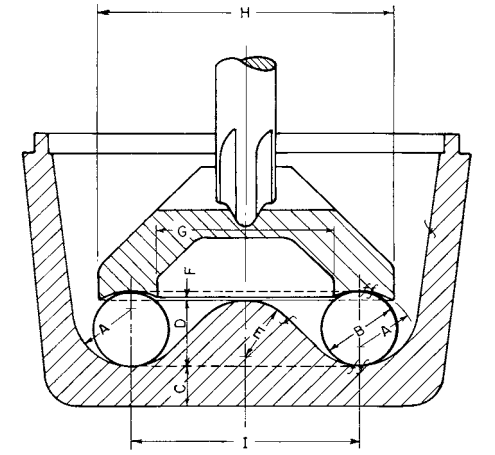

FIG. 2 Grinding Elements of Hardgrove Machine

the test to accomplish the desired number of revolutions (that is, watch where the trip mechanism is initially, count the number of revolutions from the point of origin, determine where the trip mechanism is at the end of the test, and determine if the specified 60 ± 0.25 revolutions are obtained. If not, adjust the position of the trip mechanism at the beginning of the test until the specified number of revolutions are obtained).

5. ~~Standard Reference Samples (SRSs) for Calibration~~

~~5.1Four SRSs prepared especially for this purpose (in accordance with Annex A1) and representing grindability indices of approximately 40, 60, 80, and 100 shall be used for calibration. (See Section 8.)~~

~~5.1.1Upon receipt, each of the SRSs should be examined for the following:~~

~~5.1.1.1Preparation date (no more than six months old).~~

~~5.1.1.2Oversize (material retained on a 4.75-mm (No. 4) sieve). [Less than 5%+4.75 mm and no particle on a 6.30-mm (¼-in. square-holed sieve).] (See 7.3.)~~

~~5.1.1.3Foreign, noncoal material (no wood, rock, slate, and so forth).~~

~~5.1.1.4Excessive fines (−600-µm (−No. 30) material) (less than 30%). (See 7.3.)~~

~~5.1.2When any of these parameters are unacceptable, contact the agency responsible for production of the SRSs and report the data on the response form accompanying the SRSs (see 8.4).~~

~~6.~~Gross Samples

~~6.1Collect a gross sample of coal, representative of the material from which it is taken, in accordance with Practice D2234/D2234M, and prepare the sample in accordance with Method D2013 except that the sample topsize shall not be reduced beyond the 4.75-mm (No. 4) sieve, and the sample shall weigh at least 1000 g.~~

~~7.Preparation of Test Samples~~

~~7.1Prepare a 1.18-mm×600-µm (No. 16×No. 30) test sample for establishing the HGI of SRSs, for calibration, or for routine determination of HGI.~~

~~7.2When necessary, divide the quantity of 4.75-mm (No. 4) sieve size coal to not less than 1000-g lots using an enclosed riffle, and air dry each sample in conformance with Method D2013~~

5.1 Collect a gross sample of coal, representative of the material from which it is taken, in accordance with Practice D 4916 (Note 2), D 6883, or D 7256/D 7256M (Note 2) or Guide D 6609 (Note 1), and prepare the sample in accordance with Practice D 2013 except that the sample topsize shall not be reduced beyond the 4.75-mm (No. 4) sieve and the sample shall weigh at least 1000 g.

6. Preparation of Test Samples

6.1 Prepare a 1.18-mm × 600-µm (No. 16 × No. 30) test sample for establishing the HGI of HGI RMs (Annex A4 and Annex A9), for calibration (Annex A5 and Annex A10), or for routine determination of HGI.

6.2 When necessary, divide the quantity of 4.75-mm (No. 4) sieve size coal to not less than 1000-g lots using an enclosed riffle or rotary sample divider, and air dry each sample in conformance with Practice D 2013. To calculate the % Yield (8.3), record the mass of the air-dried sample (W_1).

6.3 Sieve the entire amount (1000 g) of air-dried 4.75-mm (No. 4) sieve size sample in lots of no greater than 250 g for 2 min ± 10 s in the mechanical sieving machine. Use a set of nested sieves consisting of a 1.18-mm (No. 16) sieve on top of a 600-µm (No. 30) sieve. Weigh and record the mass of each sieve size.

NOTE 9—Include a 4.75-mm (No. 4) and a 2.36-mm (No. 8) sieve in this nest of sieves to record the particle size distribution and to verify that the topsize of the sample is appropriate for this test.

6.4 Stage crush the material retained on the 1.18-mm (No. 16) sieve with the crusher adjusted so that only the largest particles are crushed. Sieve the crushed material in portions of no greater than 250 g for 2 min ± 10 s in the mechanical sieving machine. Return the oversize to the crusher, after setting the crusher so that only the largest particles are crushed. Continue the stage crushing and sieving procedure until all the material passes the 1.18-mm sieve. Retain the 1.18-mm × 600-µm (No. 16 × No. 30) material. After all stage-crushing is completed, to calculate the % Yield (8.3), record the mass of the 1.18-mm × 600-µm (No. 16 × No. 30) fraction (W_2).

6.5 Mix well all the 1.18-mm × 600-µm (No. 16 × No. 30) material accumulated from the stage crushing and sieving and divide the quantity using an enclosed riffle or rotary sample divider to obtain approximately 120 ± 10 g.

6.6 As the final step in preparation of the test sample, dedust the 120- ± 10-g sample from 6.5 by sieving on a 600-µm (No. 30) sieve for 5 min ± 10 s using the mechanical sieving machine.

7. Procedure

7.1 Clean the grindability machine thoroughly, place the machine on a level surface, and space the balls as evenly as possible around the grinding bowl. Set the automatic stopping device so that the motion of the grindability machine will stop after 60 ± 0.25 revolutions of the upper grinding ring.

7.1.1 If the grindability machine makes a different number of revolutions other than the specified 60 ± 0.25 revolutions, the machine must be adjusted to within the tolerance specified. (This is normally done by strategically placing the counter tripper arm at the start of the test.)

7.2 Weigh 50 ± 0.01 g of the 1.18-mm × 600-µm (No. 16 × No. 30) sieve size dedusted material from 6.6 and distribute it evenly in the grinding bowl, brushing any material that falls on the elevated section of the lower grinding element into the lower grinding element, which contains the balls. Fasten the bowl in position and make sure the load is fully applied to the driving spindle.

7.3 Operate the machine for the specified 60.00 ± 0.25 revolutions.

7.4 Remove the bowl from the machine, lift out the upper grinding ring, and carefully brush adhering coal dust from the bowl and grinding ring onto a 16-mm (⅝-in.) sieve nested on a 75-µm (No. 200) sieve and a closely fitting receiving pan. Carefully empty the contents of the bowl onto the 16-mm (⅝-in.) sieve (Note 10). Brush off material adhering to the balls and remove them from the 16-mm (⅝-in.) sieve. Brush material adhering to the 16-mm (⅝-in.) sieve, including the underside of the sieve, onto the 75-µm sieve. Replace the 16-mm (⅝-in.) sieve with a close-fitting cover and shake the nested 75-µm sieve; cover and pan for 10 min ± 10 s in a mechanical sieving machine. After the 10-min ± 10-s period, carefully brush coal dust from the underside of the 75-µm sieve into the receiving pan using a soft-bristled brush to avoid damaging the sieve. Repeat the shaking of the ball-milled material and the cleaning of the underside of the 75-µm sieve for two more periods each of 5-min ± 10-s duration.

NOTE 10—Before emptying the contents of the lower grinding bowl onto the 16-mm (⅝-in.) sieve, the tops of the grinding balls may be brushed and then removed from the lower grinding bowl by use of a magnetic extraction tool. Each grinding ball is brushed off and set aside; then, the pulverized coal is emptied from the bowl onto the 16-mm (⅝-in.) sieve.

7.5 Weigh separately to the nearest 0.01 g the coal retained on the 75-µm (No. 200) sieve (W_{+200}) and the coal passing the 75-µm sieve (W_{-200}).

7.5.1 Alternatively, predetermine the tare weights of the 75-µm (No. 200) sieve ($W_{200sieve}$) and the catch pan (W_{pan}). After the sieving of 7.4, weigh the 75-µm (No. 200) sieve and its contents ($W_{200sieve+}$). Subtract the tare mass to obtain the mass of the +75-µm (+No. 200) material = $W_{+200} = W_{200sieve+} - W_{200sieve}$. Weigh the catch pan and its contents (W_{pan+}). Subtract the tare mass to obtain the mass of the –75-µm (–No. 200) material = $W_{-200} = W_{pan+} - W_{pan}$.

~~7.3Sieve the entire amount (1000 g) of air-dried 4.75-mm (No. 4) sieve size sample in lots of no greater than 250 g, for 2 min ± 10 s in the mechanical sieving machine. Use a set of nested sieves consisting of a 1.18-mm (No. 16) sieve on top of a 600-µm (No. 30) sieve. [It may be appropriate to include a 4.75-mm (No. 4) and a 2.36-mm (No. 8) sieve in this nest of sieves to record the particle size distribution and the topsize of the sample.] Weigh and record the mass of each sieve size.~~

~~7.4Stage crush the material retained on the 1.18-mm (No. 16) sieve with the crusher adjusted so that only the largest particles are crushed. Take the crushed material in lots no greater than 250 g and sieve for 2 min ± 10 s in the mechanical sieving machine. Return the oversize to the crusher, after setting the crusher so that only the largest particles are crushed. Continue the stage crushing and sieving procedure until all the material passes the 1.18-mm sieve. Retain the 1.18-mm×600-µm (No. 16×No. 30) material.~~

~~7.5Mix well all the 1.18-mm×600-µm (No. 16×No. 30) material accumulated from the stage crushing and sieving and divide the quantity using an enclosed riffle to obtain approximately 120 ± 10 g.~~

~~7.6As the final step in preparation of the test sample, dedust the 120- ± 10-g sample from 7.5 by sieving on a 600-µm (No. 30) sieve for 5 min ± 10 s using the mechanical sieving machine.~~

~~8.Calibration~~

~~8.1Calibrate each grindability machine, together with all ancillary equipment including sieves and plate mill, that will be used for this test when new, modified, repaired, suspected of being defective, or when operated by new personnel.~~

~~8.1.1SRSs shall not be used for calibration beyond 18 months from their preparation date. It is good practice to check the calibration of the HGI apparatus periodically with at least one of the SRSs (quality control check sample) even if none of the conditions in 8.1 apply. This will ensure that the system is still in control and it will allow for detection of problems previously unnoticed or not then occurring, and it will allow for use of the SRSs before their expiration date.~~

~~8.2For each calibration, process four standard reference samples with indices of approximately 40, 60, 80, and 100 separately as described above. Process the samples as outlined below (Section 9), and use the results to determine the equation of the line by use of the sum of least squares method (8.3) and, if desired, to prepare a calibration chart (8.3.1~~

7.6 If the sum of the +75-µm (W_{+200}) and the -75-µm (W_{-200}) sieve fraction masses differs by more than 0.50 g from the initial weight of 50 ± 0.01 g (W_i), reject the test and repeat. Use the calculated weight of the coal passing the 75-µm sieve (W_c), determined by subtracting the weight retained on the 75-µm sieve (W_{+200}) from the test specimen weight (W_i), in determining the sum-of-least-squares fit (A5.4.3), in preparation of the calibration chart (A5.4.3.2) or in calculation of the grindability index of the sample (8.1) $W_c = W_i - W_{+200}$.

8. Calculation and Report

8.1 Calculate the grindability index corresponding to the calculated weight of test specimen passing the 75-µm (No. 200) sieve (7.5) directly from the equation of the line prepared in A5.4.3 and report to the nearest whole number.

8.2 For ease of comparison between or among laboratories, calculate and report the percent residual moisture in the 1.18-mm by 600-µm (No. 16 by No. 30) sample (Annex A11).

~~8.3By the method of the sum of least squares, determine the equation of the line that best fits the analytical results obtained from the four HGI SRSs. An example HGI calculation from SRS data, shown in Table 1~~

8.3 Calculate the % Yield of 1.18-mm by 600-µm (No. 16 by No. 30) material generated from the initial 1000 g of 4.75-mm (No. 4) top-size sample and compare the actual value to a typical median value (4.8, Note 6) to gage the effectiveness/efficiency of the stage-crusher and of the stage-crushing process.

$$Y = \frac{W_2}{W_1} \times 100 \quad (1)$$

where:

Y = % Yield,
W_1 = mass of air dried sample (6.2), and
W_2 = mass of 1.18-mm by 600-µm (No. 16 by No. 30) material (6.4).

8.4 If other than primary HGI RMs are used for calibration of the test apparatus and method, report the source of the calibration standards used.

8.5 An example of a typical HGI preparation log sheet that has found application for record keeping during preparation of samples to be used for HGI determination is shown in Fig. 3.

9. Precision and Bias

9.1 *Precision*:

9.1.1 The precision of this test method for the determination of Hardgrove Grindability Index of Coal, whenever international (primary) HGI reference materials are used for calibration, is shown in Table 2.

9.1.2 For the HGI method, the Repeatability Limit (r) in Table 2 is the value which the absolute difference between two test results of separate and consecutive test determinations, carried out on samples in the same laboratory by the same operator using the same apparatus on samples taken at random from a single quantity of homogeneous 4.75 mm (No. 4) material, may be expected to occur with a probability of approximately 95 %.

9.1.3 For the HGI method, the Reproducibility Limit (R) in Table 2 is the value which the absolute difference between two test results, carried out in different laboratories on riffled splits of the 4.75 mm (No. 4) analysis sample, may be expected to occur with a probability of approximately 95 %.

NOTE 11—The precision of this test method for the determination of Hardgrove Grindability Index of Coal, whenever national (secondary) HGI reference materials are used for calibration, must be determined and reported by each pertinent ISO national member body (NMB) and/or their national organization responsible for obtaining and preparing national (secondary) HGI RMs. The precision limits for this test method, whenever these national (secondary) RMs are used, will be as large or larger than the precision limits stated in Table 2.

9.2 *Bias*—Since this test method (using a calibration procedure) is an empirical standard, the degree of absolute bias cannot be determined.

Sample I.D.:_____ Date:_____ Analyst:_____
Sample Description:_____

[AIR-DRYING]

Air-dry pan wt, (a)..... _____g
Initial sample and air-dry pan wt, (b). _____g
Final sample and air-dry pan wt, (c).. _____g
Air-dried sample wt, c - a, (d)..... _____g
Wt loss on drying, b - c, (e)..... _____g
Initial sample wt, b - a, (f)..... _____g
% Wt loss on drying, e/f x 100%, (g) _____%

Ambient Temp..... _____°F
Time into oven.... _____
Time out of oven. _____
Temperature..... _____°F
Heat on at..... _____
Heat off at..... _____
Fan on at..... _____
Fan off at..... _____

[INITIAL SIEVED WEIGHTS]

+No. 4, (h)..... _____g
No. 4 x No. 8, (i)..... _____g
No. 8 x No. 16, (j)..... _____g
No. 16 X No. 30, (k) _____g
-No. 30, (l)..... _____g
Topsize..... _____
Total recovered wt after sieving, (h + i + j + k + l), (m)..... _____g
Wt loss on sieving, d-m, (n)..... _____g
% Wt loss on sieving, (n/d) X 100%, (o)..... _____%

[REDUCTION OF +NO. 16]

	Weight of +No. 16		Weight of +No. 16
Initially, h + i + j, (p).....	_____g	>6th crushing of oversize, (v).....	_____g
>1st crushing of oversize, (q).....	_____g	>7th crushing of oversize, (w).....	_____g
>2nd crushing of oversize, (r).....	_____g	>8th crushing of oversize, (x).....	_____g
>3rd crushing of oversize, (s).....	_____g	>9th crushing of oversize, (y).....	_____g
>4th crushing of oversize, (t).....	_____g	>10th crushing of oversize,(z).....	_____g
>5th crushing of oversize, (u).....	_____g		

Final total wt of No. 16 x No. 30, (A)..... _____g
Final total wt of -No. 30, (B)..... _____g
Final total recovered wt, (A+B), (C)..... _____g
Loss on crushing, (m-C), (D)..... _____g
% loss on crushing, (D/d) x 100%, (E)..... _____%
% Yield of No. 16 x No. 30, A/d x 100%, (F) _____%*

[DEDUSTING 120G OF NO. 16 x NO. 30 AND MILLING]

Wt of No. 16 x No. 30 dedusted sample placed into HGI bowl, (G) _____g
No. of increments collected, (H)..... _____
Start position..... _____
Stop position..... _____
Start time..... _____
Stop time..... _____

Number of revolutions, (I)... _____
Seconds to mill, (J)..... _____sec
RPM, [I/(J/60)], (K)..... _____RPM

[SIEVING OF MILLED PRODUCT]

Tare wt of catch pan, (L)..... _____g
Tare wt of No. 200 sieve, (M)..... _____g
Wt of catch pan and -No. 200, (N)..... _____g
Wt of No. 200 sieve and +No. 200, (O)..... _____g
Calculated wt of -No. 200, (G-Q), (T)..... _____g

Wt of -No. 200, (N-L), (P)..... _____g
Wt of +No. 200, (O-M), (Q)..... _____g
Total recovery, (P+Q), (R)..... _____g
Loss (≤0.50 g), (G-R), (S)..... _____g

[ANALYTICAL RESULTS]

HGI Formula (from Least Squares Regression) _____
HGI (U) _____

Determine the percent total moisture (@ 107°C for 90 min) on 10g of No. 16 x No. 30 dedusted material not used, (V) _____%(Reference ASTM D-3302, Procedure C)

Determine the percent ash on a 1.00-gram sample of the recombined (and remixed) ±No. 200 milled product, (W) _____%

*% Yield depends upon the topsize of the original sample, whether the sample has been "dedusted" prior to preparation, etc.

FIG. 3 HGI Log Sheet is for Example Only and is Non-Mandatory

TABLE 2 Repeatability and Reproducibility for HGI of Coal

Repeatability Limit~~Reproducibility Limit~~	
r	R Reproducibility Limit
r/2	R/3

10. Keywords

10.1 grindability; Hardgrove-Grindability Index (HGI); pulverization

ANNEXES

(Mandatory Information)

A1. METHOD TO OBTAIN AND PREPARE INTERNATIONAL HGI STANDARD REFERENCE COAL SAMPLE FEEDSTOCK (HGI RM Feedstock)

A1.1 Scope

A1.1.1 This method describes the procedures used to obtain and prepare international Hardgrove Grindability Index (HGI) standard reference coal sample feedstock (*primary* HGI RM feedstock). Authority to obtain and prepare HGI RM feedstock for use as candidate primary HGI RMs is given by ASTM Committee D05 on Coal and Coke. D05 maintains oversight responsibility for these activities and for this standard method. Authority is given on the basis of the producer's capability, experience, and expertise in these activities.

A1.2 Apparatus

A1.2.1 *Sieves; 4.75 mm (No. 4) and 2.36 mm (No. 8)*—Square mesh sieves meeting the requirements of Test Method D 4749, used to verify that the candidate HGI RMs are 4.75-mm (No. 4) topsize.

A1.2.2 *Sieve Shaker*— Meeting the requirements of Test Method D 4749, used to verify that the candidate HGI RMs are 4.75-mm (No. 4) topsize.

NOTE A1.1—No specifications are given for the sieve shaker used in the processing of the feedstock; as long as the final product meets the specification of being 4.75-mm (No. 4) topsize, there is no need to specify production equipment.

A1.2.3 *Crusher*—Commensurate with the requirement to maximize the 1.18-mm by 600-µm (No. 16 by No. 30) size fraction while maintaining a 4.75-mm (No. 4) topsize.

A1.3 HGI RM Feedstock Requirements

A1.3.1 Four coals shall be collected and used as the feedstock for the HGI RMs. One feedstock shall have an HGI of approximately 40 (typically between 35 and 45); a second feedstock shall have an HGI of approximately 60 (typically between 55 and 65); a third feedstock shall have an HGI of approximately 80 (typically between 75 and 85); and a fourth feedstock shall have an HGI of approximately 100 (typically between 90 and 110).

A1.3.2 Each HGI RM feedstock shall have a minimum mass of 80 kg (175 lb). Where 80 kg (175 lb) is not adequate to produce the desired number of candidate RMs, an adequate mass to produce the desired number of candidate HGI RMs shall be obtained. Each candidate RM sample shall have a minimum mass of 1000 g.

A1.3.3 Any feedstock will be acceptable as long as the final production lot meets the homogeneity requirements found in Annex A3.

A1.3.4 To minimize the potential rejection of a production lot of HGI RMs after the lot has been processed, each feedstock coal should have the following characteristics: *(1)* be from a single seam, containing no blended materials, *(2)* be double-sieved to pass a 63-mm (2.5-in.) square-hole sieve while being retained on a 3.35-mm (⅛-in.) square-holed sieve, and *(3)* be mechanically cleaned, having been through a preparation or wash plant to remove non-coal material.

A1.3.5 Each feedstock coal shall be visually inspected upon its receipt to assure the absence of foreign material. If any foreign material (wood, rock, slate, steel, and so forth) is present, the entire shipment shall be rejected.

A1.3.6 Each feedstock coal shall be visually inspected upon its receipt to assure the absence of more than 5 % of undersized (–3.35-mm) or of oversized (+63- mm) particles. If undersized (–3.35-mm) or oversized (+63-mm) material constitutes greater than 5 % of the lot, after air-drying, the entire shipment shall be sieved to remove the undersize or oversize prior to further processing.

A1.4 Preparation of Each Candidate HGI RM

NOTE A1.2—Each feedstock is prepared according to the instructions in this section.

A1.4.1 Spread the feedstock coal (onto a smooth, flat, non-contaminating surface) to a thickness of no more than three times the particle topsize. A floor fan and periodic stirring can accelerate drying. Air dry the feedstock at room temperature for at least 12 h.

A1.4.1.1 If, after air drying, a feedstock contains >5 % undersize (–3.35-mm) or >5 % oversize (+63-mm), sieve the entire feedstock coal to remove the undersize or oversize.

A1.4.2 Reduce the air-dried feedstock to 4.75-mm (No. 4) top size. Use a crusher and a technique that will maximize the 1.18-mm by 600-μm (No. 16 by No. 30) size fraction while maintaining a 4.75-mm (No. 4) topsize.

A1.4.2.1 Verify that each reduced feedstock is a 4.75-mm (No. 4) topsize by obtaining a sample from each feedstock and conducting a size analysis [at 4.75 and 2.36 mm (No. 4 and 8)] according to the requirements of Test Method D 4749. No more than 5 % of the sample can be retained on a 4.75-mm (No. 4) sieve and no less than 5 % of the sample can be retained on a 2.36-mm (No. 8) sieve (cumulative retained basis).

A1.4.3 Dedust each feedstock by removing and discarding the –0.30-mm (–No. 50) material.

A1.4.4 If the feedstock is to be transported or held for subsequent processing, package the material in a rigid, non-contaminating container. If necessary, line the container with double plastic liners to preserve the feedstock integrity and avoid excessive handling.

A2. METHOD TO DIVIDE AND CONTAINERIZE CANDIDATE INTERNATIONAL HGI STANDARD REFERENCE COAL SAMPLES (Candidate HGI RMs)

A2.1 Scope

A2.1.1 This method describes the procedures used to divide and containerize candidate international Hardgrove Grindability Index (*primary* HGI) standard reference coal samples (candidate primary HGI RMs). Authority to divide and containerize candidate primary HGI RMs for use in determining the HGI of coal (or for calibrating national HGI machines) is given by ASTM Committee D05 on Coal and Coke. D05 maintains oversight responsibility for these activities and for this standard method. Authority is given on the basis of the producer's capability, experience, and expertise in these activities.

NOTE A2.1—Other methods for division of the candidate primary HGI RMs (e.g., riffle division or incremental division) may be envisioned, designed, and/or used. If these other methods for division are used, the resulting candidate RMs must meet the homogeneity requirements of Annex A3.

A2.2 Apparatus

A2.2.1 *Blender/Mixer*— A rotating device used to blend each feedstock before the feedstock is divided into candidate HGI RMs; typically, the blender is a double-cone- or v-type blender or designed like a cement mixer.

A2.2.2 *Hopper/Feeder*— A device that holds the blended feedstock and allows the feedstock to be feed at a uniform rate into the containers, which are along the perimeter of the rotary sample divider.

A2.2.3 *Rotary Sample Divider*—A rotating wheel upon which is fixed a level platform, which rotates at a constant speed and around which perimeter is located a series of uniformly spaced devices, which hold containers into which the candidate HGI RMs are evenly distributed.

A2.3 Blending and Division of Each Feedstock

A2.3.1 Each feedstock is blended and divided according to the instructions in this section (A2.3).

A2.3.2 Thoroughly mix the feedstock for at least 30 min in a blender with a capacity to contain the entire feedstock at once.

A2.3.3 Divide the blended feedstock coal into candidate HGI RMs.

A2.3.3.1 Feed the feedstock at a uniform rate from the stationary hopper/feeder into containers located on the perimeter of a rotary sample divider (RSD), which is rotating at a steady rate. Assign container number "1" to the container that is located at a defined position on the RSD and number all remaining containers counterclockwise in consecutive order (i.e., 1, 2, 3, …, x-1, x). Locate container "1" at such a position that, once the flow starts from the feeder into the containers, container "1" is at or near the location that receives the first increment (that is, start the RSD and, once the RSD is rotating at a steady rate, then start the feeder in such a manner that container "1" receives the first increment). Adjust the feed rate such that each container receives a maximum number of increments, but, in no case, shall less than 34 increments be collected per container.

NOTE A2.2—A stopwatch or timer should be used during the production of each feedstock lot to determine the time required to empty the hopper/feeder, which time, in conjunction with the known constant rpm of the RSD, can be used to calculate the number (and average mass of) increments going into each container.

A2.3.3.2 The number of containers shall be at least 24, but may be more, depending upon the configuration of the processing equipment.

A2.3.3.3 After all of the material has been fed into the containers, seal and label the containers according to the lot and the container number.

NOTE A2.3—Ideally, the containers will be labeled before being placed in order onto the RSD; alternatively, if assurance is such that the order of the containers remains secure after division, labels may be attached after division.