



Designation: D 409 – 02 (Reapproved 2007)^{e1}

Standard Test Method for Grindability of Coal by the Hardgrove-Machine Method¹

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.

^{e1} NOTE—Section 10.2 was editorially corrected in October 2007.

1. Scope

1.1 This test method² 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, 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- μ m (No. 16 \times 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.*

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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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.

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.

2. Referenced Documents

2.1 *ASTM Standards*:³

D 2013 Practice for Preparing Coal Samples for Analysis
D 2234/D 2234M Practice for Collection of a Gross Sample of Coal

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

E 11 Specification for Wire Cloth and Sieves for Testing Purposes

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*—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

³ *Annual Book of ASTM Standards*, Vol 05.06.

weigh a ≥ 1000 -g sample along with the drying pan. A single balance meeting these specifications is permitted.

4.3.1 *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 *Sample Divider*—An enclosed riffle divider as described in Method **D 2013** is required and shall be used.

4.5 *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):

Standard (ISO Designation)	Sieve Designation	Alternate (U.S.A. Designation)
16.0 mm		$\frac{5}{8}$ 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 These working sieves must be periodically inspected for wear or damage. Any excessively worn or damaged sieves (sieves with holes, tears cracks, and so forth, see **Note 1**), must be replaced immediately, and the HGI calibration procedure must be repeated after the damaged sieves are replaced (see Section 8). 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—Excessive wear may be indicated by poor repeatability or by failure of quality control checks (**8.1.1**) to agree reasonably with the initial calibration data.

4.5.2 Normal wear on sieves is compensated by the use of proper standard reference samples (SRSs) and proper calibration of equipment; excessive wear such as holes or tears in the sieve cloth, and so forth is not compensated by SRSs. 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 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** 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 *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**). The crusher plates shall be serrated and about 100 mm (4 in.) in diameter (**Note 4**). 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 %.

NOTE 4—The most frequently used plate mill can be equipped with “fine” or “coarse” plates. One independent study⁴ 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 *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 *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.

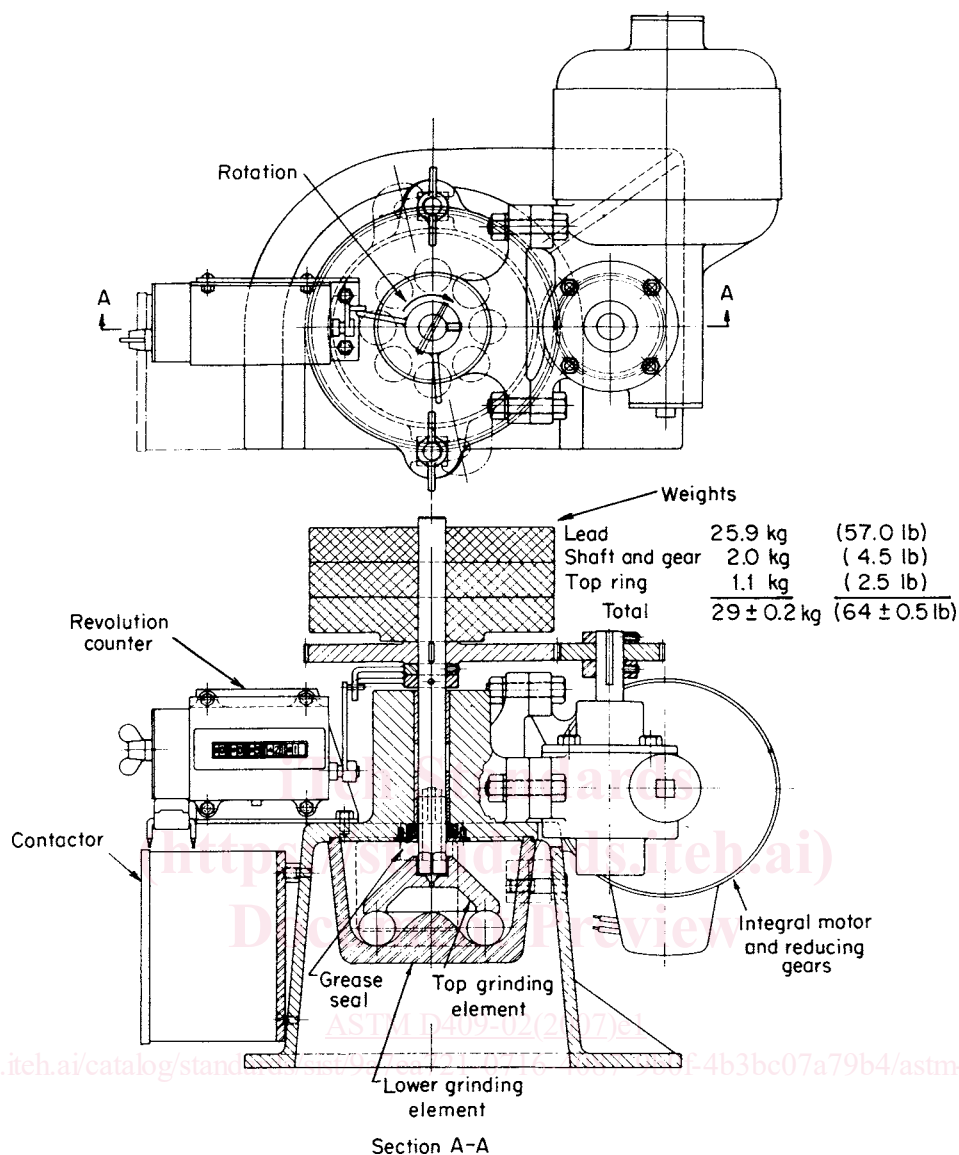
4.8.1 The position of the counter trip mechanism before and after the test must be used to determine the number of revolutions completed. Sometimes, it may be necessary to position strategically the counter trip mechanism at the beginning of the test to accomplish the desired number of revolutions (that 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 Calibration⁵

5.1 Four 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.)

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

⁵ Primary standard reference samples are available from The Pennsylvania State University, Ronald S. Wasco The Energy Institute, C-211 CUL, University Park, PA 16802, Telephone: 814-863-5384, Fax: 814-863-7432, email: rxw19@psu.edu, www.energy.psu.edu/HGI. ASTM Subcommittee D05.07 and the ASTM/DOE Liaison Task Group maintain oversight for production of only the primary standard reference samples. Secondary standard reference samples are available from other sources.



Section A-A
FIG. 1 Hardgrove Grindability Machine

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

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

5.1.1.2 Oversize (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.)

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

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

5.1.2 When 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

6.1 Collect a gross sample of coal, representative of the material from which it is taken, in accordance with Practice D 2234/D 2234M, and prepare the sample in accordance with

Method 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.

7. Preparation of Test Samples

7.1 Prepare 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.

7.2 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, and air dry each sample in conformance with Method D 2013.

7.3 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. [It may be appropriate to include a 4.75-mm (No. 4) and a 2.36-mm (No. 8) sieve in this nest of

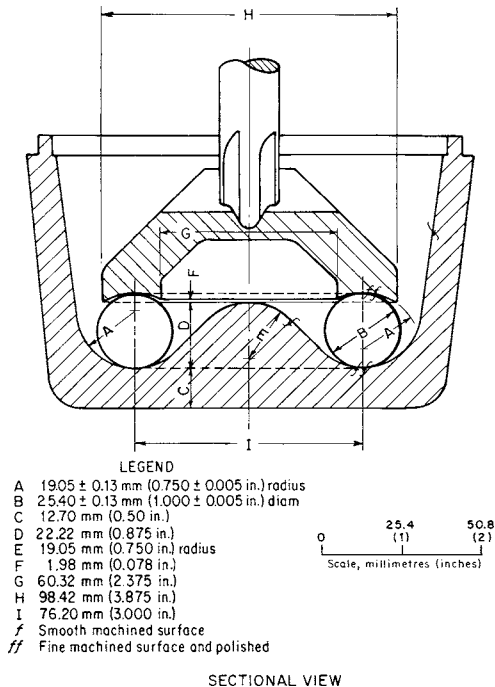


FIG. 2 Grinding Elements of Hardgrove Machine

sieves to record the particle size distribution and the topsize of the sample.] Weigh and record the mass of each sieve size.

7.4 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. 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.

7.5 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 to obtain approximately 120 ± 10 g.

7.6 As 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

8.1 Calibrate 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.

8.1.1 SRSs 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.

8.2 For 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).

8.3 By 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, illustrates this method.

8.3.1 Example—Sum of Least Squares Fit—The equation of the line for the sum of least squares takes the form of:

$$Y = a + bX \quad (1)$$

where:

Y = HGI,

a = y axis intercept,

b = slope of the regression line, and

X = calculated -75-µm (-No. 200) material.

a and b can be determined by use of the following table and equations:

Y	X	X^2	XY
40	4.35	18.92	174.00
58	7.14	50.98	414.12
83	10.44	108.99	866.52
100	13.38	179.02	1338.00
$\Sigma Y = 281$	$\Sigma X = 35.31$	$\Sigma(X^2) = 357.91$	$\Sigma(XY) = 2792.64$

$$a = \frac{\Sigma Y \Sigma X^2 - \Sigma X \Sigma XY}{n \Sigma X^2 - (\Sigma X)^2} \quad (2)$$

$$b = \frac{n \Sigma XY - \Sigma X \Sigma Y}{n \Sigma X^2 - (\Sigma X)^2} \quad (3)$$

where:

$\Sigma Y = 281,$

$\Sigma X = 35.31,$

$\Sigma(X^2) = 357.91,$

$\Sigma(XY) = 2792.64,$

$(\Sigma X)^2 = 1246.80,$ and

$n = 4.$

By doing these calculations, $a = 10.63$ and $b = 6.75$. Therefore, the equation of the line for this database is $HGI = 10.63 + 6.75$ (calculated -75-µm (-No. 200) material).

8.3.2 Use results from standard reference samples processed in accordance with Sections 7 and 9 in determining the equation of the line by the sum of least squares method and (optionally) in preparing the calibration chart (see Fig. 3).

8.4 A standard form for reporting data obtained during calibration is received with each set of HGI SRSs received

TABLE 1 Example HGI Data Calculation—Actual Weight of Materials, g

HGI ^A	Weight, i^B	+ 200	-200	Recovered	Lost	Calculated, - 200
40	50.00	45.65	4.27	49.92	0.08	4.35
58	50.00	42.86	7.11	49.97	0.03	7.14
83	50.00	39.56	10.23	49.79	0.21	10.44
100	49.99	36.61	13.25	49.86	0.13	13.38

^AValue issued with the SRSs.

^BInitial weight.