Designation: G76 – 13

Standard Test Method for Conducting Erosion Tests by Solid Particle Impingement Using Gas Jets[1]

This standard is issued under the fixed designation G76; 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 determination of material loss by gas-entrained solid particle impingement erosion with jetnozzle type erosion equipment. This test method may be used in the laboratory to measure the solid particle erosion of different materials and has been used as a screening test for ranking solid particle erosion rates of materials in simulated service environments (**1, 2**).[2] Actual erosion service involves particle sizes, velocities, attack angles, environments, and so forth, that will vary over a wide range (**3-5**). Hence, any single laboratory test may not be sufficient to evaluate expected service performance. This test method describes one well characterized procedure for solid particle impingement erosion measurement for which interlaboratory test results are available.

1.2 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard (exceptions below).

1.2.1 *Exceptions:* Table 1 uses HRB hardness. Footnote 7 and 11.2 use abrasive grit designations.

1.3 *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]

E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process

G40 Terminology Relating to Wear and Erosion

2.2 *American National Standard:*

ANSI B74.10 Grading of Abrasive Microgrits[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *erosion*—progressive loss of original material from a solid surface due to mechanical interaction between that surface and a fluid, a multicomponent fluid, or impinging liquid or solid particles.

3.1.2 *impingement*—a process resulting in a continuing succession of impacts between (liquid or solid) particles and a solid surface.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *erosion value*—the volume loss of specimen material divided by the total mass of abrasive particles that impacted the specimen ($mm^3 \cdot g^{-1}$).

3.2.2 *Normalized Erosion Rate*—erosion value ($mm^3 \cdot g^{-1}$) of specimen material divided by erosion value ($mm^3 \cdot g^{-1}$) of reference material.

4. Summary of Test Method

4.1 This test method utilizes a repeated impact erosion approach involving a small nozzle delivering a stream of gas containing abrasive particles which impacts the surface of a test specimen. A standard set of test conditions is described. However, deviations from some of the standard conditions are permitted if described thoroughly. This allows for laboratory scale erosion measurements under a range of conditions. Test methods are described for preparing the specimens, conducting the erosion exposure, and reporting the results.

5. Significance and Use

5.1 The significance of this test method in any overall measurements program to assess the erosion behavior of materials will depend on many factors concerning the conditions of service applications. The users of this test method should determine the degree of correlation of the results

[1] This test method is under the jurisdiction of ASTM Committee G02 on Wear and Erosion and is the direct responsibility of Subcommittee G02.10 on Erosion by Solids and Liquids.

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[2] The boldface numbers in parentheses refer to a list of references at the end of this standard.

[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* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

TABLE 1 Characteristics of Type 1020 Steel Reference Material

Annealed 900 s at 760°C, air cooled.
Hardness: HRB = 70 ± 2.
Chemical Composition:
C = 0.20 ± 0.01 wt %
Mn = 0.45 ± 0.10
S = 0.03 ± 0.01
Si = 0.1± 0.05
P = 0.01 ± 0.01

obtained with those from field performance or results using other test systems and methods. This test method may be used to rank the erosion resistance of materials under the specified conditions of testing.

6. Apparatus

6.1 The apparatus is capable of eroding material from a test specimen under well controlled exposure conditions. A schematic drawing of the exit nozzle and the particle-gas supply system is shown in Fig. 1. Deviations from this design are permitted; however, adequate system characterization and control of critical parameters are required. Deviations in nozzle design and dimensions must be documented. Nozzle length to diameter ratio should be 25:1 or greater in order to achieve an acceptable particle velocity distribution in the stream. The recommended nozzle[5] consists of a tube about 1.5 mm inner diameter, 50 mm long, manufactured from an erosion resistant material such as WC, $A1_2O_3$, and so forth. Erosion of the nozzle during service shall be monitored and shall not exceed 10 % increase in the initial diameter.

6.2 Necessary features of the apparatus shall include a means of controlling and adjusting the particle impact velocity, particle flux, and the specimen location and orientation relative to the impinging stream.

6.3 Various means can be provided for introducing particles into the gas stream, including a vibrator-controlled hopper or a screw-feed system. It is required that the system provide a uniform particle feed and that it be adjustable to accommodate desired particle flow values.

6.4 A method to measure the particle velocity shall be available for use with the erosion equipment (**6-9**). Examples of accepted methods are high-speed photography (**7**), rotating double-disk (**6**), (**8**), and laser velocimeter (**9**). Particle velocity shall be measured at the location to be occupied by the specimen and under the conditions of the test.

7. Test Materials and Sampling

7.1 This test method can be used over a range of specimen sizes and configurations. One convenient specimen configuration is a rectangular strip approximately 10 by 30 by 2 mm thick. Larger specimens and other shapes can be used where necessary, but must be documented.

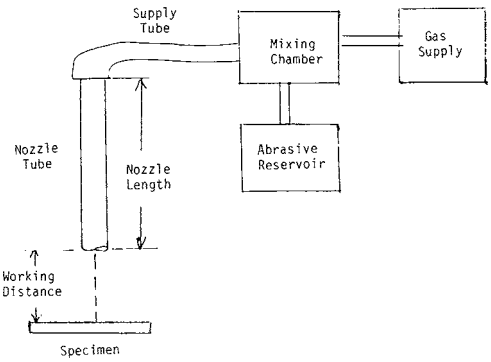

FIG. 1 Schematic Drawing of Solid Particle Erosion Equipment

7.2 The abrasive material to be used shall be uniform in essential characteristics such as particle size, moisture, chemical composition, and so forth.

7.3 Sampling of material for the purpose of obtaining representative test specimens shall be done in accordance with acceptable statistical practice. Practice E122 shall be consulted.

8. Calibration of Apparatus

8.1 Specimens fabricated from Type 1020 steel (see Table 1 and Fig. 2) equivalent to that used in the interlaboratory test series[6] shall be tested periodically using specified (see Section 9) 50 µm $A1_2O_3$ particles to verify the satisfactory performance of the apparatus. It is recommended that performance be verified using this reference material every 50 tests during a measurement series, and also at the beginning of each new test series whenever the apparatus has been idle for some time. The recommended composition, heat treatment, and hardness range for this steel are listed in Table 1. The use of a steel of different composition may lead to different erosion results. A photomicrograph of the specified $A1_2O_3$ particles is shown in Fig. 3. The range of erosion results to be expected for this steel under the standard test conditions specified in Section 9 is shown in Table 2 and is based on interlaboratory test results.[6]

8.2 Calibration at standard test conditions is recommended even if the apparatus is operated at other test conditions.

8.3 In any test program the particle velocity and particle feed rate shall be measured at frequent intervals, typically every ten tests, to ensure constancy of conditions.

9. Standard Test Conditions

9.1 This test method defines the following standard conditions.

9.1.1 The nozzle tube shall be 1.5 mm ± 0.075 mm inner diameter at least 50 mm long.

9.1.2 The test gas shall be nominally dry air. The test report shall indicate the amount of water present in the test gas, at what pressure, and how the measurement was conducted.

NOTE 1—In the interlaboratory testing, one laboratory utilized cylinder-type compressed air having a water content amount described as "-50°C dew point" by the manufacturer. Whatever gas source is used in testing, a

[5] The sole source of supply of the recommended nozzle (tungsten carbide) known to the committee at this time is Kennametal Inc., 1600 Technology Way, PO Box 231, Latrobe, PA 15650-0231. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[6] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:G02-1003.

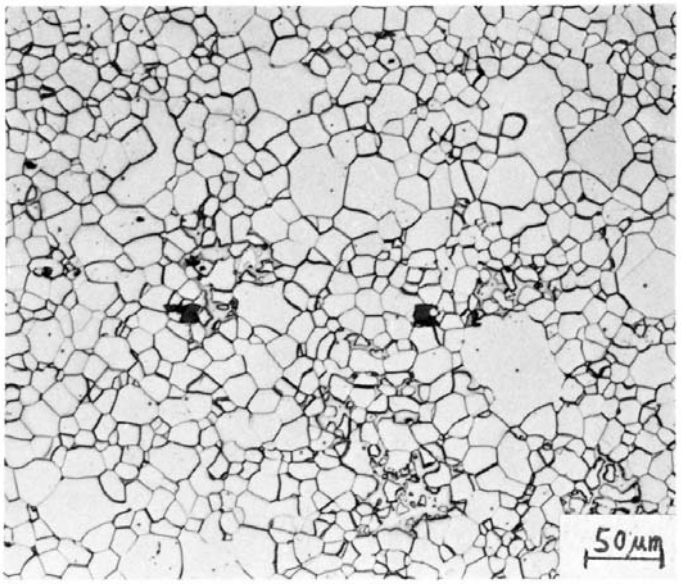

FIG. 2 Microstructure of 1020 Steel Reference Material ASTM Grain Size 9

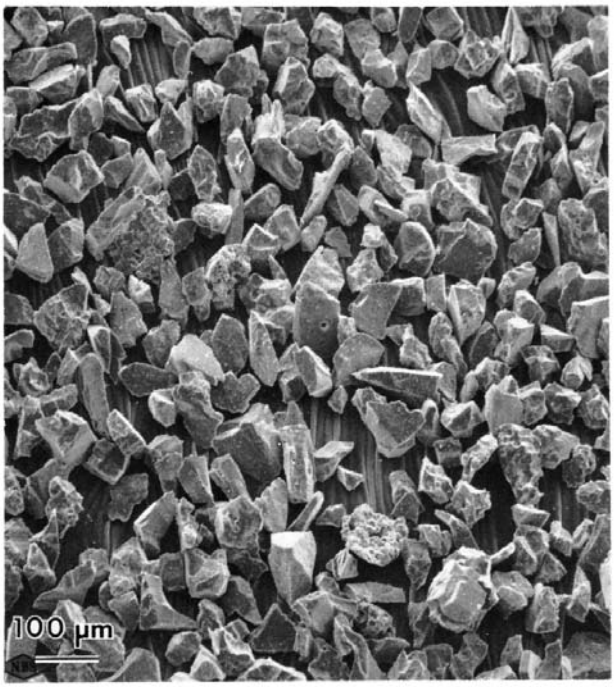

FIG. 3 Photomicrograph of 50 µm $A1_2O_3$ Particles Used in Interlaboratory Testing

comparable level of dryness to that is recommended.

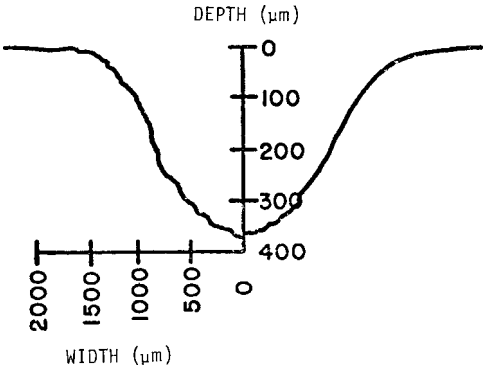

FIG. 4 Example of Erosion Crater Profile for 1020 Steel Eroded at 70 m/s Particle Velocity Using Standard Conditions Otherwise

9.1.3 The abrasive particles shall be nominal 50-µm angular $A1_2O_3$,[7] equivalent to those used in the interlaboratory test series (see Fig. 3). Abrasive shall be used only once.

NOTE 2—Typical size distribution (determined by sedimentation): 100 % between 20 to 83 µm, 50 % between 42 to 57 µm, 50 % coarser than 48 µm.

9.1.4 The abrasive particle velocity shall be 30 ± 2 $m{\cdot}s^{-1}$, measured at the specimen location. At this velocity the gas flow rate will be approximately 0.13 L/s and the system pressure will be approximately 140 kPa although the pressure will depend on the specific system design.

9.1.5 The test time shall be 600 s to achieve steady state conditions. Longer times are permissible so long as the final erosion crater is no deeper than 1 mm.

9.1.6 The angle between the nozzle axis and the specimen surface shall be 90 ± 2°.

9.1.7 The test temperature shall be the normal ambient value (typically between 18°C to 28°C).

9.1.8 The particle feed rate shall be 0.033 ± 0.008 g/s. This corresponds to a particle flux at the specimen surface of about 2 $mg{\cdot}mm^{-2}{\cdot}s^{-1}$ under standard conditions. Particle flux determination requires measurement of the eroded area on the specimen and is subject to considerable error. A measured width and depth profile of an erosion crater produced using stated conditions is shown in Fig. 4 and indicates a typical eroded width/depth relation.

9.1.9 The distance from specimen surface to nozzle end shall be 10 ± 1 mm.

10. Optional Test Conditions

10.1 When test conditions or materials other than those given in Section 9 are used, reference to this test method shall

[7] The sole source of supply of the aluminum oxide particles—obtained as grade 240-grit alundum powder— known to the committee at this time is Norton Co., 1 New Bond St, Worcester, MA 01606. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

clearly specify all test conditions and materials. It should be noted that other conditions, for example, larger particle velocities, may adversely affect measurement precision.

11. Test Procedure

11.1 Establish and measure the particle velocity and particle flow specified. Adjust equipment controls to obtain proper velocity and flow conditions before inserting test specimens. Particle flow rate values are determined by collecting (see Note 3) and subsequently weighing the abrasive exiting from the nozzle for a measured time period.

NOTE 3—Particles may be collected by directing the flow from the nozzle into a large vented container. Care must be taken to avoid causing any significant back pressure on the nozzle as this will disturb the system flow conditions.

11.2 Prepare the specimen surface if required to achieve uniformity and adequate finish. Grinding through a series of abrasive papers to 400 grit is usually adequate so long as all surface scale is removed. A surface roughness of 1 µm (40 µin.) rms or smaller is recommended. Clean the specimen surface carefully (see Note 4). Weigh on an analytical balance to ±0.01 mg (see Note 5).

NOTE 4—Important considerations in cleaning include surface oils or greases, surface rust or corrosion, adhering abrasive particles, etc.

NOTE 5—Erosion weight loss determinations to ±0.1 mg may be sufficient for particle velocities above 70 $m \cdot s^{-1}$ or sufficiently long exposure times which lead to weight losses greater than 10 mg.

11.3 Mount the specimen in proper location and orientation in the apparatus. Subject the specimen to particle impingement for a selected time interval, measured to an accuracy of 5 s. Remove the specimen, clean carefully (see Note 4), reweigh and calculate the mass loss.

11.4 Repeat this process utilizing a new specimen each time to determine at least four points for a total time of at least 600 s and plot those values as mass loss versus elapsed time. Suitable times would be 120, 240, 480, and 960 s for a material such as Type 1020 steel. Steady state erosion should result after 60 to 120 s, depending on the material. Two examples of measured erosion versus time curves are shown in Fig. 5.

11.5 The steady state erosion rate (see Terminology G40) is determined from the slope of the mass loss versus time plot. The average erosion value is calculated by dividing erosion rate (mg/s) by the abrasive flow rate (g/s) and then dividing by the specimen density ($g \cdot cm^{-3}$). Report the average erosion value as ($mm^3 \cdot g^{-1}$).

11.6 Repeat 11.1 at the end of a series of tests (typically every 10 tests) and more frequently if necessary.

12. Report

12.1 The test report shall include the following information:

12.1.1 Material identification: type, chemical specification, heat and processing treatment, hardness, and density. Processing conditions shall include method of casting (such as chill or sand); method of forming (such as forging or pressing and sintering); and the percent of ideal density (important for ceramics and powder metallurgy alloys).

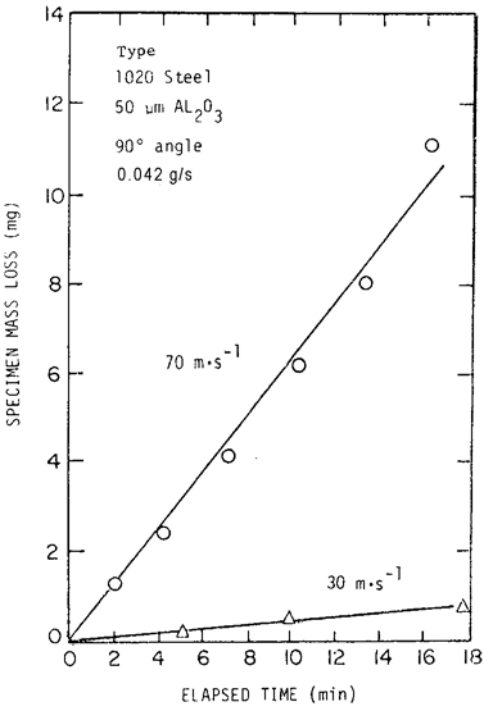

FIG. 5 Two Examples of Erosion versus Time for Type 1020 Steel at 30 $m \cdot s^{-1}$ and 70 $m \cdot s^{-1}$

12.1.2 Specimens: method of preparing and cleaning specimens, initial surface roughness, and number tested.

12.1.3 Eroding particle identification: size distribution, shape, composition, purity, source, and manufacturing method. Provide photograph of typical collection of particles. Reference **(10)** can be consulted for information on methods of characterization.

12.1.4 Test conditions: particle velocity (average) and method of determination; specimen orientation relative to the impinging stream; particle flow; particle flux; eroded area (size, shape); temperature of the specimen and particles and carrier gas; test duration; method of determining steady-state erosion conditions; carrier gas composition, including water content, pressure, and measurement method; and method of determining the mass of abrasive used.

12.1.5 Description of the test equipment.

12.1.6 Tabulation of erosion value and standard deviation for each specimen reported as a volume loss of material per unit mass of abrasive ($mm^3 \cdot g^{-1}$).

12.2 Each test program shall include among the materials tested a reference material tested under the same conditions to permit calculation and report of the normalized erosion rate. A suitable reference material would be Type 1020 steel (see Table 1).

12.3 The report shall state clearly whether testing was done at standard conditions, shall itemize any deviations from those conditions, and shall indicate the frequency of calibration using reference materials.

12.4 Any special occurrences or observations during testing should be noted.

TABLE 2 Interlaboratory Test Results (Provisional)

Test Conditions	Laboratory Number	Number of Replicates	Average (.001 mm^3/g)	Standard Deviation (.001 mm^3/g)	Deviation from Average (.001 mm^3/g)
Condition A:	1	9	2.240	0.420	–0.494
1020 steel,	2	9	3.130	0.130	0.396
50 µm Al_2O_3,	3	10	2.130	0.068	–0.604
30 m/s, 90°	4	10	3.720	0.680	0.986
0.033 g/s	5	10	2.450	0.660	–0.284
	5	9.600	2.734	0.468	0.807
	Number	Average	Average	Within-Laboratory Standard Deviation	Between-Laboratory Standard Deviation (Provisional)
			Coefficient of Variation (%) =	17.1	29.5
			95 % Limits =	1.31	2.26
				Within-Laboratory	Between-Laboratory
Condition B:	1	8	31.500	1.100	3.340
1020 steel,	2	8	23.200	0.040	–4.960
50 µm Al_2O_3,	3	8	22.900	0.900	–5.260
70 m/s, 90°	4	4	32.400	0.650	4.240
0.033 g/s	5	8	30.800	1.500	2.640
	5	7.200	28.160	0.969	4.786
	Number	Average	Average	Within-Laboratory Standard Deviation	Between-Laboratory Standard Deviation (Provisional)
			Coefficient of Variation (%) =	3.4	17.0
			95 % Limits =	2.71	13.40
				Within-Laboratory	Between-Laboratory
Condition C:	1	8	40.000	1.300	7.640
304 stainless steel,	2	8	25.400	0.120	–6.960
50 µm Al_2O_3,	3	8	26.300	0.780	–6.060
70 m/s, 90°	4	4	38.000	1.200	5.640
0.033 g/s	5	8	32.100	3.000	–0.260
	5	7.200	32.360	1.597	6.786
	Number	Average	Average	Within-Laboratory Standard Deviation	Between-Laboratory Standard Deviation (Provisional)
			Coefficient of Variation (%) =	4.9	21.0
			95 % Limits =	4.47	19.00
				Within-Laboratory	Between-Laboratory

13. Precision and Bias

13.1 Absolute values of erosion rates of materials are generally not available because of the wide range of possible exposure conditions. The erosion measurement conditions established by this practice are designed to facilitate obtaining precise, reproducible data applicable to the test conditions employed. Interlaboratory test results utilizing this practice on well-characterized metal are given in Table 2. Examples of 95 % confidence limits for three erosion test conditions are shown in Table 2. For Condition A, a statement of precision would be: average erosion was 2.73×10^{-3} mm^3/g; 95 % repeatability limit was 1.31×10^{-3} mm^3/g; 95 % reproducibility limit was 2.26×10^{-3} mm^3/g.

13.2 No bias can be assigned to this test method since there is no absolute accepted value for erosion rate.

13.3 *General Considerations*—Participants in the interlaboratory testing that led to the statements of precision and bias given above involve five laboratories, two different materials, two test conditions, and five replicate measurements each. Subsequent to this testing, described in Research Report RR:G02-1003,[6] data were received from another laboratory that utilized a commercial test machine. Those data were found consistent with the results of the interlaboratory study and will be included in the research report.

14. Keywords

14.1 erosion; erosion rate; gas jet; metal erosion; solid particle

APPENDIX

(Nonmandatory Information)

X1. ADDITIONAL INFORMATION

X1.1 This erosion test is usually applied to bulk materials. It may also be applied to coatings upon bulk substrates, if care is taken not to penetrate the coating during the test. The test results from coated test specimens should apply to the material comprising the coating, and thus to the coated system, as long as the coating is not altered, fragmented, or dislodged during the test.

X1.2 In the case where this test is applied to coatings on bulk substrates, some of the test steps may need to be modified. For example, surface preparation of the coating, like mechanical polishing, before testing may not be appropriate. Cleaning of the surface may be constrained by the nature of the coating. In such cases, the user shall ensure that the preparation steps used for this test do not alter the characteristics of the coating being tested. The procedures that are used shall be adequately described in the test report.

X1.3 Normally, this test is conducted on numerous separate specimens, each eroded for a given time and condition. While not recommended, it is possible to conduct repeated erosion tests (under the same conditions) on the same individual specimen by carefully repositioning the specimen after eroding it, removing it for cleaning, and weighing it. In such a case, the specimen must occupy the identical position for each test in the series; otherwise the accumulated erosion effect will not be correct.

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