Designation: G211 – 14

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

This standard is issued under the fixed designation G211; 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 is concerned with the determination of material loss by gas-entrained solid particle impingement erosion with jet nozzle type erosion equipment. This test method can 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. Erosion service takes place under conditions where particle sizes, chemistry, microstructure, velocity, attack angles, temperature, environments, etc., vary over a wide range. 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 from multiple laboratories.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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:*[2]

B822 Test Method for Particle Size Distribution of Metal Powders and Related Compounds by Light Scattering

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

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E1601 Practice for Conducting an Interlaboratory Study to Evaluate the Performance of an Analytical Method

E1617 Practice for Reporting Particle Size Characterization Data

G40 Terminology Relating to Wear and Erosion

G76 Test Method for Conducting Erosion Tests by Solid Particle Impingement Using Gas Jets

2.2 *American National Standard:*[3]

ANSI B74.10 Grading of Abrasive Microgrits

2.3 *Japanese Industrial Standard:*[4]

JIS 6001 Bonded Abrasive Grain Sizes

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.

3.1.3 *interlaboratory study (ILS)*—study undertaken to ascertain if a test method is suitable for its intended use. The ILS includes preparation, testing, and evaluation phases.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *mass loss erosion rate*—the mass loss of specimen material divided by the total mass of erodent particles that impacted the specimen (milligrams of specimen material loss / gram of erodent impacting the specimen).

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

[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.

Current edition approved July 15, 2014. Published August 2014. DOI: 10.1520/G0211-14.

[2] 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.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] Available from Japanese Standards Organization (JSA), 4-1-24 Akasaka Minato-Ku, Tokyo 107-8440, Japan, http://www.jsa.or.jp.

containing erodent particles which impacts the surface of a test specimen at elevated temperatures. 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 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.

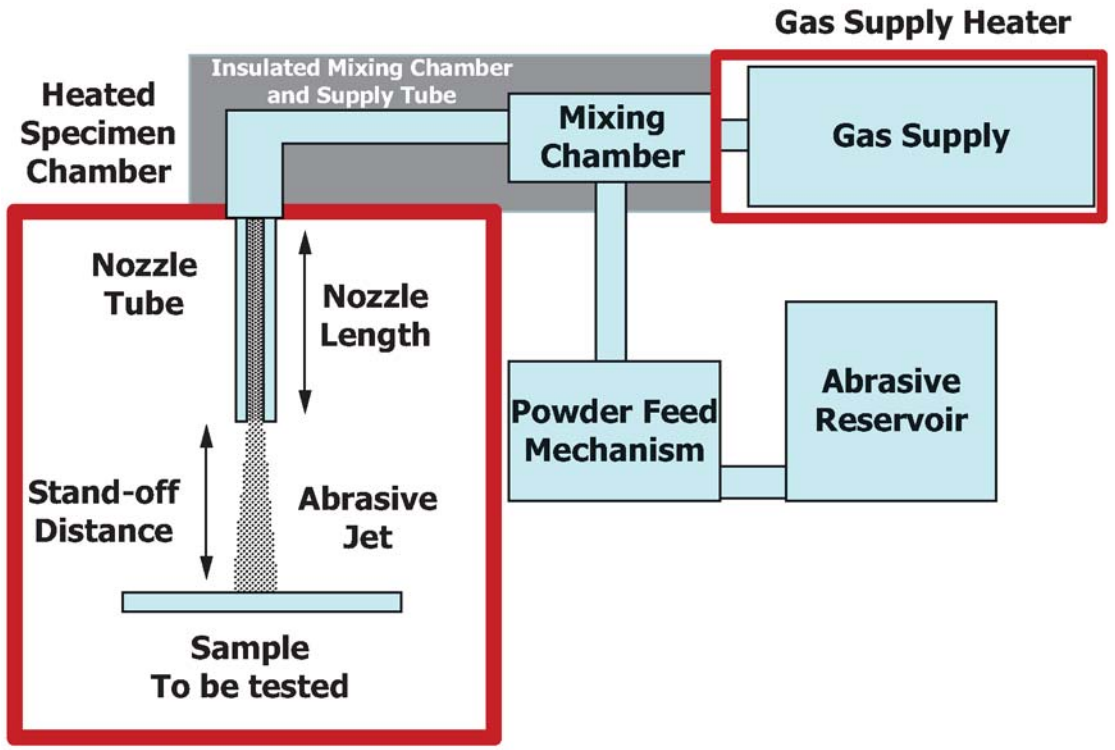
6. Apparatus

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. 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.

6.2 Necessary features of the apparatus shall include a means of controlling, measuring, and adjusting the (*a*) particle impact velocity, (*b*) particle feed rate, (*c*) the specimen standoff distance, (*d*) angular orientation of sample relative to the impinging stream, and (*e*) gas stream and test specimen temperature.

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. The total amount of erodent impinging the specimen is to be recorded. Depending on the feed system, the feeding rate may be determined by different methods. If a tank reservoir is used, the tank weight may be measured by weighting both before and after the single test or a given time duration. Also, the applied dose may be calculated by measuring the time duration. Verification and qualification of constant feed rate should be established by initial trials.

6.4 A method to measure the particle velocity shall be available for use with the erosion equipment. The mass erosion rate is highly dependent on particle velocity as shown in the power law equation (Eq 1).



NOTE 1—The erosion rig orientation may vary and does not affect the test results.

FIG. 1 Schematic Drawing of Solid Particle Erosion Test System

6.4.1 The relationship of erosion rate (E) and impact velocity (v) can often be described by an equation of the form:

$$E = kv^m \quad (1)$$

where k is a constant and m is the velocity exponent which is approximately equal to two (parabolic behavior). If E is measured from experiments, v may be calculated from equations provided in Figs. X3.1-X3.3 to cross-check the measured velocities in the experiments.

6.5 Examples of accepted methods to measure the particle velocity are high-speed photography, double rotating disk (DRD), laser Doppler velocimetry (LDV), and particle image velocimetry (PIV). Particle velocity shall be measured at the location to be occupied by the specimen and under the conditions of the test. Examples of the double rotating disc are described in Appendix X1.

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 25 by 75 by 3 mm thick. Larger specimens and other shapes can be used where necessary, but must be documented. It is critical that all of the particles impinge the test specimen. Overspray outside of the test specimens is not permitted.

7.2 For the reference tests Type 410 stainless steel as described in 8.2.4 shall be used with the alumina erodent specified. Other erodent materials, if used after the reference testing is complete, shall be uniform in essential characteristics such as particle size, moisture, chemical composition, hardness, the friability of the erodent, reactivity with carrier gas and test material, modulus of the erodent at temperature of test, etc. Erodent particle size distribution (PSD) and particle morphology shall be documented for each new powder lot used. Light scattering powder size determination methods have been demonstrated to be an effective way to document the PSD of each erodent batch. Reporting the PSD as D10, D50, and D90 diameters has been found useful. Practices B822 and E1617 should be consulted.

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. Test Condition and Test Procedure

8.1 *Test Conditions:*

8.1.1 The following conditions summarized in Table 1 are recommended which were used during the ILS study. Note that each high-temperature erosion rig used in this study is unique in design and operational variables. Each one of the employed different nozzle diameters, sample stand-off distance, particle feed mechanism, velocity measurement method, etc.

8.2 *Test Procedure:*

8.2.1 The inside diameter of the erodent delivery nozzle shall be a minimum of 4 mm. Measure the nozzle inside diameter at or within 1 mm from the exit end to an accuracy of 0.05 mm before the start of the tests and record the measurements. Measure and record the diameter after completing tests on a single specimen, that is, after five runs on the same test coupon. Calibrated pins, optical methods, or direct measurements using precision calipers may be employed for such measurements.

8.2.2 The test gas shall be nominally dry air with a dew point of -50°C or lower. Record the amount of water present in the test gas in the test report.

8.2.3 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. Clean the specimen surface carefully with a non-corrosive cleaning agent such as ethanol, acetone, etc., and air dry. Important considerations in cleaning include surface oils or greases, surface rust or corrosion, adhering abrasive particles, etc. A surface roughness of <0.2 µm Ra or better is recommended. Weigh on an analytical balance to an accuracy of ±0.1 mg (±0.0001 g).

8.2.4 For the reference tests, use Type 410 Stainless Steel conforming to the characteristics shown in Tables 2 and 3 and Fig. 2. The specimen dimensions are 75 by 25 by 4.5 mm. Other dimensions may be used; record dimensions to an accuracy of ±0.5 mm. The thickness of the specimen should be large enough that bending of the specimen should not occur due to residual stress effects, after the erosion tests.

8.2.5 The erodent particles used shall be nominal 50-µm angular Al_2O_3, conforming to the JIS 6001 320 microgrit standard and equivalent to those used in the interlaboratory test series (see Figs. 3 and 4). Record the particle size distribution as shown in the note below (Note 1). The erodent shall be used only once.

NOTE 1—Typical size distribution D10 – 34 µm, D50 – 50 µm, D90 – 75 µm (see Fig. 4).

8.2.6 Fix the angle between the nozzle axis and the specimen surface at 90 ± 2° and 30 ± 2°. Other angles may be used if needed with the same set-up accuracy.

8.2.7 The particle feed rate shall be 2.0 ± 0.5 g·min^{-1}. Adjust the controls to deliver this feed rate (Note 2).

NOTE 2—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.

8.2.8 For the room temperature (RT) tests the normal ambient value (typically between 18 to 28°C) and for the high-temperature (HT) tests it shall be 600 ± 5°C. For the initial calibration of the apparatus, measure the test specimen temperature using a thermocouple in contact with the specimen. Adjust the heating controls to achieve the desired temperature. Perform this temperature calibration before and after a series of tests. Record the temperatures on the test data record sheet. Note any deviations during the test in the temperature of the carrier gas if heated gas is used or the temperature of the specimen chamber if a heating enclosure is used.

8.2.9 The erodent particle velocity shall be 200 ± 10 m·s^{-1}. measure the velocity at the specimen location. Report the velocity measurement method used and the accuracy (scatter band) of the measurements (Note 3).

NOTE 3—The ILS study was conducted at 200 m/s. However, this test

TABLE 1 Round-Robin Erosion Testing Requirements for the ILS Study

Erosion Test Key Variables	Room Temperature (RT)	Elevated Temperature (600°C)
Nozzle ID	System dependent; record nozzle diameter	System dependent; record nozzle diameter
Test Gas	Dry air –50°C dew point or lower	Dry air –50°C dew point or lower
Erodent Particles	50 micrometer angular Alumina; JIS R6001 320 microgrit	50 micrometer angular Alumina; JIS R6001 320 microgrit
Particle Velocity	200 ± 10 m/s; Report measurement method and estimate of accuracy	200 ± 10 m/s; Report measurement method and estimate of accuracy
Test Coupon Dimensions	2.5 cm × 7.5 cm × 4.5 mm	2.5 cm × 7.5 cm × 4.5 mm
Reference Material	410 Stainless Steel	410 Stainless Steel
Gas Flow	System dependent – record and report	System dependent – record and report
System Pressure	System dependent – record and report	System dependent – record and report
Particle Feedrate	2.0 ± 0.5 g/min; Document powder feed rate reproducibility	2.0 ± 0.5 g/min; Document powder feed rate reproducibility
Particle Dose	5 intervals of 20 grams each for a total of 100 grams exposure	5 intervals of 20 grams each for a total of 100 grams exposure
Particle Flux	System dependent	System dependent
Test Time	5 – ten minute exposure increments; sample weight recorded at each interval	5 – ten minute exposure increments; sample weight recorded at each interval
Time Measurement Accuracy	within 5 seconds	within 5 seconds
Test Angle(s)	30 and 90 ± 2°	30 and 90 ± 2°
Test Temperature	18 to 28°C	600 ± 5°C (on test specimen)
Nozzle to Specimen Distance	Adjust to achieve erosion scar of ~1.4 cm diameter at 90° impingement; No overspray >2 cm dia. All particles to impinge sample surface; Report standoff distance	Adjust to achieve erosion scar of ~1.4 cm diameter at 90° impingement; No overspray >2 cm dia. All particles to impinge sample surface; Report standoff distance
Sample Weight Loss	Record ±0.1 mg	Record ±0.1 mg
Normalized Erosion Rate	mg/g of erodent	mg/g of erodent
Erosion Scar Depth	Measure and report max. depth with pointed tip micrometer	Measure and report max. depth with pointed tip micrometer
Erosion Scar Geometry	Record diameter and depth for 90°; major and minor axes plus depth for 30°; Document with digital photograph	Record diameter and depth for 90°; major and minor axes plus depth for 30°; Document with digital photograph
Material Hardness	HRB = 74	HRB = 74
Test Coupon Surface Roughness	<0.2 micrometer R_a	<0.2 micrometer R_a

procedure is applicable to other particle velocities. Plots shown in Figs. X3.1-X3.3 may be used to calibrate the test system.

TABLE 2 Characteristics of Type 410 Stainless Steel Reference Material Used in the ILS

Solution Annealed Condition
-Tensile strength (UTS) as annealed min. 65 000 psi (445 MPa),
-Yield strength (YS) minimum 30 000 psi (207 MPa), and elongation in 2 in. (51 mm) at 20 %
-For solution annealing, slow controlled cooling from 1500/1600°F (815/871°C) to room temperature
ILS Study Coupon Lot Properties:
UTS: 64.5 ksi (444 MPa)
YS: 42.5 ksi (293 MPa)
Hardness: 74 to 76 R_b

8.2.10 Adjust the distance from specimen surface to the nozzle tip to achieve an erosion scar diameter of approximately 14 mm at 90° and the minor axis of the ellipse at 30°. As shown in Fig. 5 schematic and on tested specimens. Figs. X2.4 and X2.5 in Appendix X2 illustrate how to determine the boundary of the erosion scar.

8.2.11 Conduct the erosion tests as a series of five 10 min test interval exposures on the same specimen at the same spot. Take the specimen out of the test chamber, clean the specimens by blowing compressed air and weigh the specimens at the start and end of each test interval. Repeat these steps after each 10 min or 20 g dose for a total exposure of 100 g of the erodent. Determine the total erodent dose to an accuracy of ±1 g and record. Report the dose of the erodent for each interval and the final total dose for each specimen.

8.2.12 Reposition the test specimen after each intermittent weight measurement, accurately at the same spot. If you use specially designed fixtures to hold the test specimens in the test chamber, maintain an accuracy of position of the central point of the wear scar within ±0.1 mm (0.004 in.).

9. Report

9.1 The test report shall include the following information:

9.1.1 *Material Identification*—Type, chemical specification, heat and processing treatment, hardness, and density.

9.1.2 *Specimens*—Method of preparing and cleansing specimens, initial surface roughness, and number tested.

9.1.3 *Eroding Particle Identification*—Size distribution, shape, composition, purity, source, and manufacturing method. Provide photomicrograph of typical collection of particles.

9.1.4 *Test Conditions*—Nozzle diameter and stand-off distance; particle velocity (average) and method of determination; specimen orientation relative to the impinging stream; particle flow and total mass of erodent; mass loss on the specimen; eroded area (size, shape); temperature of the specimen, particles, and carrier gas; test duration; carrier gas composition, including water content pressure, and measurement method; and method of determining the mass of erodent used.

9.1.5 Description of the test equipment.

9.1.6 Tabulation of erosion rate and standard deviation for each specimen reported as a unit mass loss of material on the sample per unit mass of erodent (mg/g).

9.1.7 Plot of each erosion series at 20 g intervals versus erosion rate for each specimen tested. Other incremental weight intervals more frequent than this may be used based on the substrate, coating, etc., properties to obtain reliable data. In some cases with highly erosion resistant coatings, the incremental mass of erodent may be much greater than 20 g.

9.2 Each test program shall include among the materials tested a reference material tested under the same conditions to permit calculation and report of the mass loss erosion rate.

9.3 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.

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

10. Precision and Bias (Provisional)

10.1 The precision of this test method is based on an interlaboratory study of WK31526, New Standard Test Method for Elevated Temperature Solid Particle Erosion conducted in 2012. A total of six laboratories participated in this study in an effort to determine the intralaboratory and interlaboratory precision of the test method at both room temperature and 600°C. Laboratories were asked to report 25 replicate test results, each result being an individual determination. Practice E691 was followed for the design and analysis of the data; the details are given in ASTM Research Report No. RR:G02-1014.[5]

10.1.1 *Repeatability (r)*—The difference between repetitive results obtained by the same operator in a given laboratory applying the same test method with the same apparatus under constant operating conditions on identical test material within short intervals of time would in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in 20.

10.1.1.1 Repeatability can be interpreted as the maximum difference between two results, obtained under repeatability conditions, that is accepted as plausible due to random causes under normal and correct operation of the test method.

10.1.1.2 Repeatability limits are listed in Tables 4-7 below.

10.1.2 *Reproducibility (R)*—The difference between two single and independent results obtained by different operators applying the same test method in different laboratories using different apparatus on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in 20.

10.1.2.1 Reproducibility can be interpreted as the maximum difference between two results, obtained under reproducibility conditions, which are accepted as plausible due to random causes under normal and correct operation of the test method.

10.1.2.2 Reproducibility limits are listed in Tables 4-7 below.

10.1.3 The above terms (repeatability and reproducibility) are used as specified in Practice E177.

10.1.4 Any judgment in accordance with statements 10.1.1 and 10.1.2 would normally have an approximate 95 % probability of being correct; however, the precision statistics

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:G02-1014. Contact ASTM Customer Service at service@astm.org.

TABLE 3 Composition of Type 410 Stainless Steel and Chemical Analysis of the ILS Coupon Lot

Grade 410 SS	Fe	Cr	Ni	Mn	Si	Ti	C	P	S	N
Min.	Balance	11.5	—	—	—	—	—	—	—	—
ILS Coupon Lot	Balance	12.1	0.13	0.31	0.49	0.13	0.014	0.021	0.002	0.0074
Max.	Balance	13.5	0.75	1	1	—	0.15	0.04	0.03	—

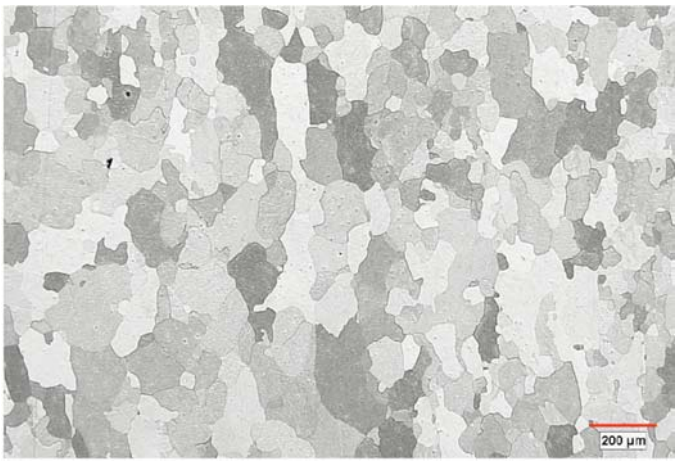


FIG. 2 Microstructure of 410 Stainless Steel Reference Material

obtained in this ILS must not be treated as exact mathematical quantities which are applicable to all circumstances and uses. The limited number of laboratories reporting results guarantees that there will be times when differences greater than predicted by the ILS results will arise, sometimes with considerably greater or smaller frequency than the 95 % probability limit would imply. Consider the repeatability limit and the reproducibility limit as general guides, and the associated probability of 95 % as only a rough indicator of what can be expected.

10.2 *Bias*—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method; therefore, no statement on bias can be made.

10.3 The precision statement was determined through statistical examination of all reported results, from a total of five laboratories, on a single material type.

11. Keywords

11.1 erosion; gas jet; mass loss erosion rate; metal erosion; solid particles; velocity measurements

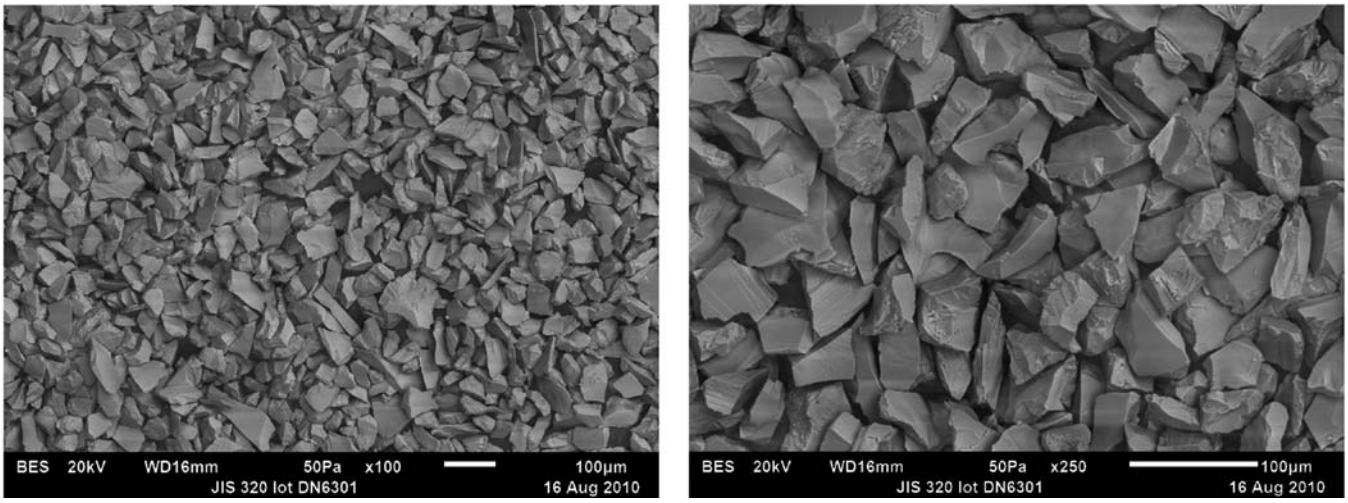


FIG. 3 Photomicrograph of Nanko 320 microgrit Al_2O_3 Particles Used in Interlaboratory Testing (JIS R6001 – 320 microgrit)

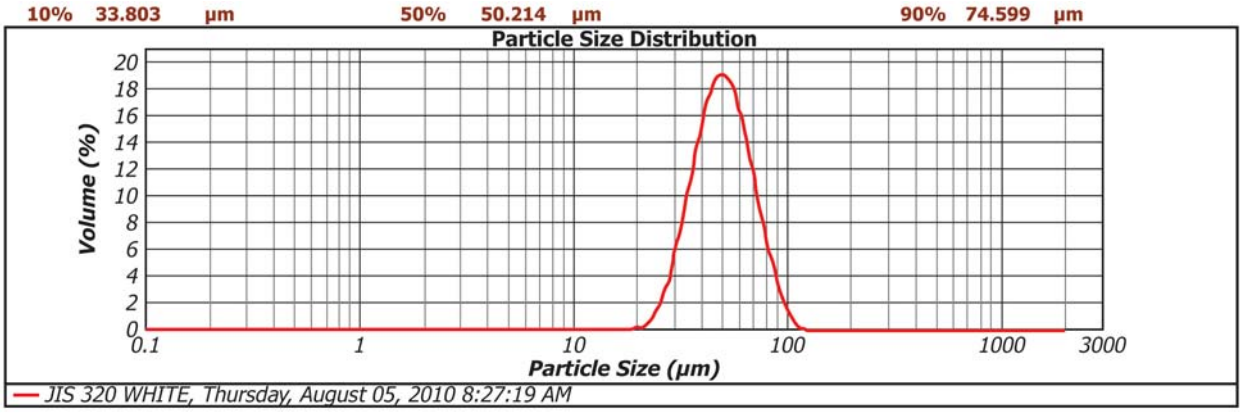


FIG. 4 Malvern Powder Size Distribution for Nanko 320 microgrit Lot DN6301 Used in the ILS Study

NOTE 1—Darker color represents the main scar and the lighter color the overspray region.

FIG. 5 Erosion Scar Size Recommended by Adjusting Nozzle to Coupon Standoff Distance with 25 by 75 mm Type 410 Stainless Steel Test Specimens

TABLE 4 Room Temperature 30° Test Mass Loss Erosion Rate (mg/g) – 5 Labs (n = 123 readings)

Material	Average Erosion Rate	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	E	s_r	S_R	r	R
Coupon ID 1	2.61	0.34	0.41	0.95	1.14

TABLE 5 Room Temperature 90° Test Mass Loss Erosion Rate (mg/g) – 5 Labs (n = 125 readings)

Material	Average Erosion Rate	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	E	s_r	s_R	r	R
Coupon ID 1	1.50	0.11	0.20	0.30	0.55

TABLE 6 600°C 30° Test Mass Loss Erosion Rate (mg/g) – 4 Labs (n = 100 readings)

Material	Average Erosion Rate	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	E	s_r	s_R	r	R
Coupon ID 1	3.32	0.34	0.86	0.96	2.41

TABLE 7 600°C 90° Test Mass Loss Erosion Rate (mg/g) – 4 Labs (n = 100 readings)

Material	Average Erosion Rate	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	E	s_r	s_R	r	R
Coupon ID 1	1.57	0.12	0.19	0.34	0.53

APPENDIXES

(Nonmandatory Information)

X1. DOUBLE ROTATING DISK EROSIVE PARTICLE VELOCITY MEASUREMENT SYSTEM

X1.1 The Double Rotating Disk (DRD) method has been found effective for accurately and cost effectively measuring the velocity of the erosive particles and has been found to be satisfactory for these tests. RSE, Sp.A has provided the following design information for use in this test method (see Figs. X1.1 and X1.2) and has demonstrated particle velocity measurement capability up to 200 m/s. At higher particle velocities, laser Doppler velocimeter (LDV) and particle imaging velocimeter (PIV) optical methods are preferred methods for accurately determining particle velocity.

X1.2 The upper disc has one or more open slits allowing the powder to impinge the lower disc surface. The distance, *L*, between the two discs should be known. This distance between the two discs must be the same as that from the nozzle exit and the specimen. For this reason the distance between the two discs may be suitably modified according to test conditions. If the discs rotate at a suitable rate, it is possible to measure the particle velocity, *v*, of the erosive particles by measuring the length, *S*, of the arc not eroded by the erosive stream on the lower disk as follows:

$$v = \frac{2\pi n}{60 \cdot S} R \cdot L \qquad \text{(X1.1)}$$

where *n* is the rotating rate (in revolutions per minute, RPM); *R* is the distance of the slit from the disk center. Parameters that have been found to be acceptable for measuring particle velocities at up to 200 m/s are:

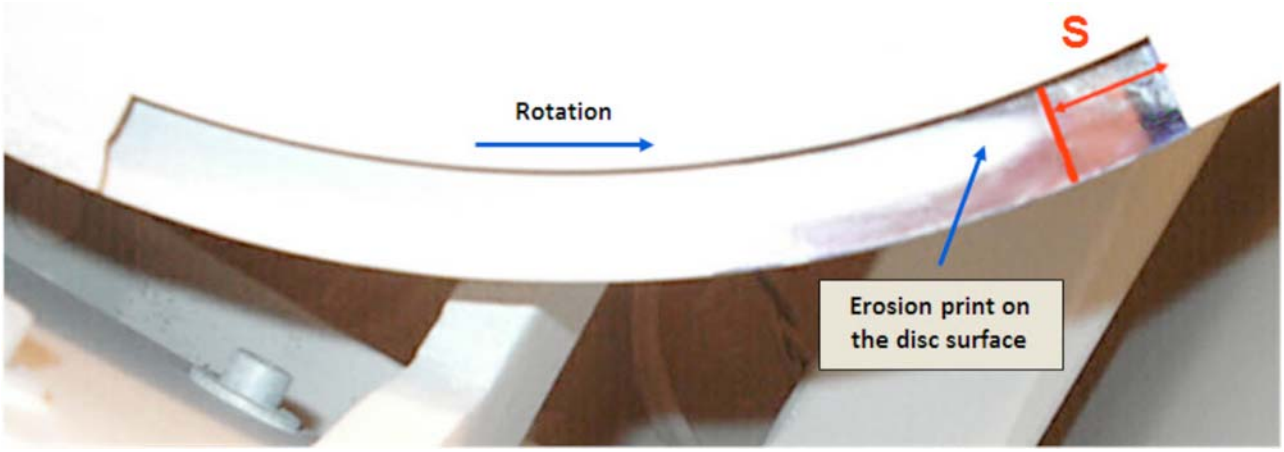
n = 4000 rpm (revolutions per minute) accuracy and constancy ±2 %,
R = 186 mm, and
L = 16 mm.

However, the geometry of the double disc may need to be altered to suit the particular laboratory's system.

X1.3 Other geometries for a DRD apparatus with elliptical holes at the top disc are also in use at various laboratories. The geometries of the elliptical holes, the diameter of the discs, and the rotation rates (RPM) vary among the labs.

NOTE 1—Courtesy: RSE, SpA)

FIG. X1.1 (a) Double Rotating Disc (DRD) for Particle Velocity Measurements, and (b) Close Up View of the Nozzle



NOTE 1—Length, *S*, will yield the maximum velocity at the center of the particle beam using Eq X1.1. (Courtesy: RSE, Sp.A)

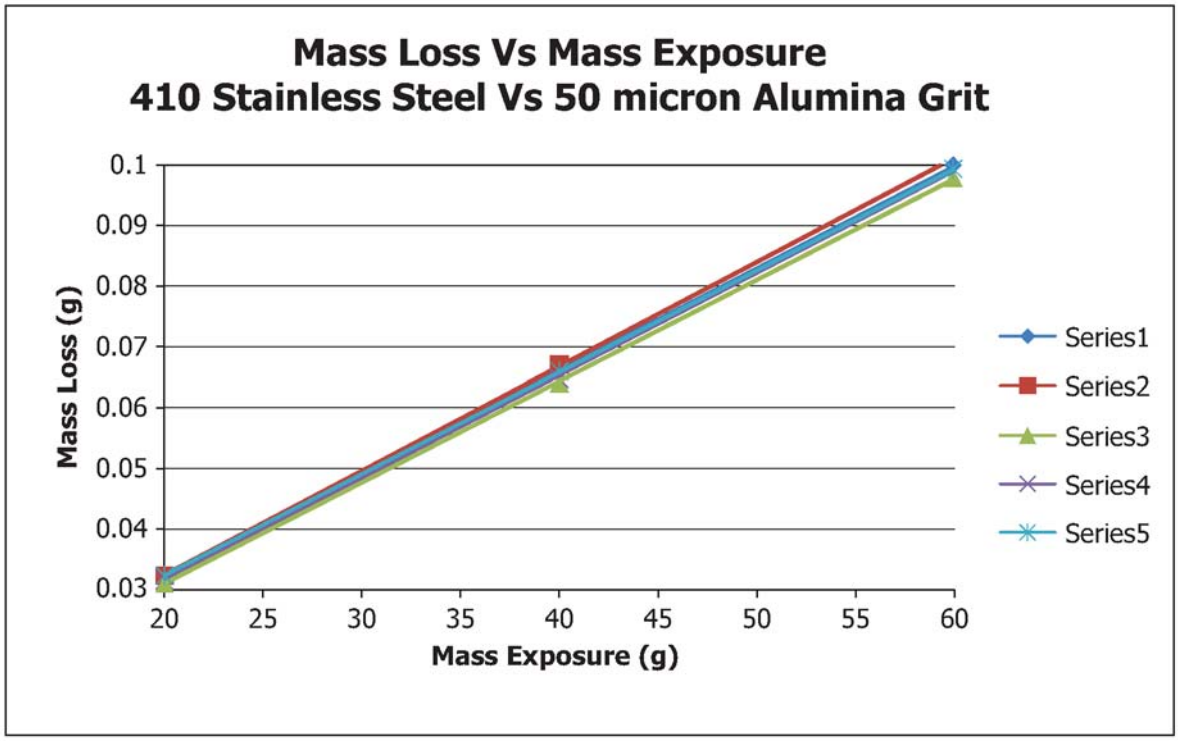
FIG. X1.2 Erosion Print on the Two Disc Assembly with a Slot for Particle Velocity Measurement

NOTE 1—Courtesy: DUCOM

FIG. X1.3 Example of a DRD with Holes in the Top Disc

X2. SUPPLEMENTARY TEST DATA – INTERLABORATORY STUDY

X2.1 See Figs. X2.1-X2.5.



NOTE 1—Type 410 stainless steel at room temperature (24°C), 200 m/s at 90° with 50 micrometer alumina at 2 g/min feed rate (Nanko JIS 6001 320 grit).

FIG. X2.1 Data ILS Qualification Test Data Graphed Showing the Tight Clustering of Mass Loss Numbers for Five Different Test Coupons

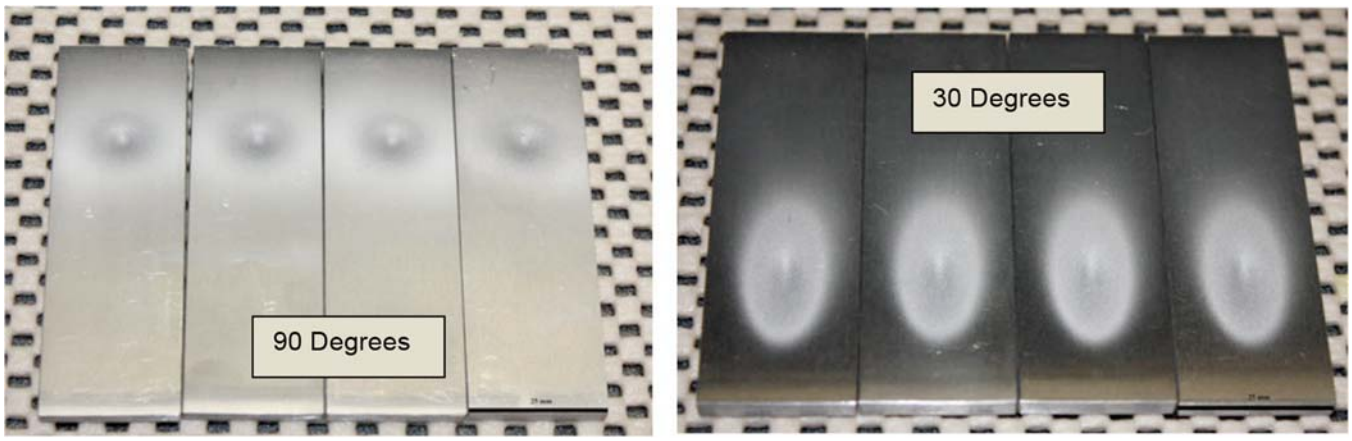
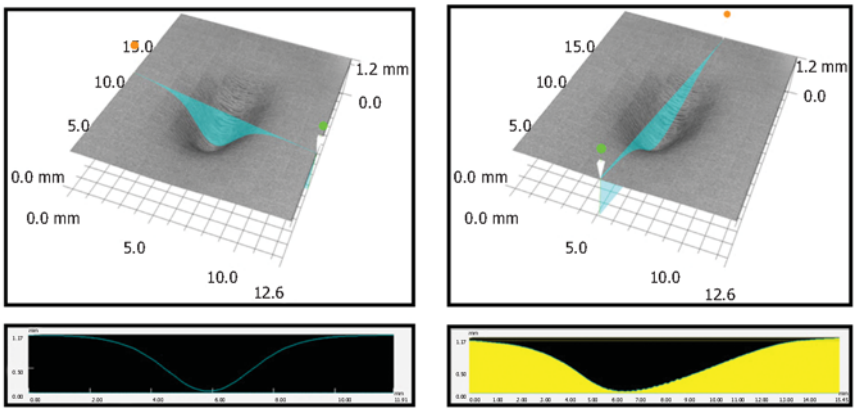
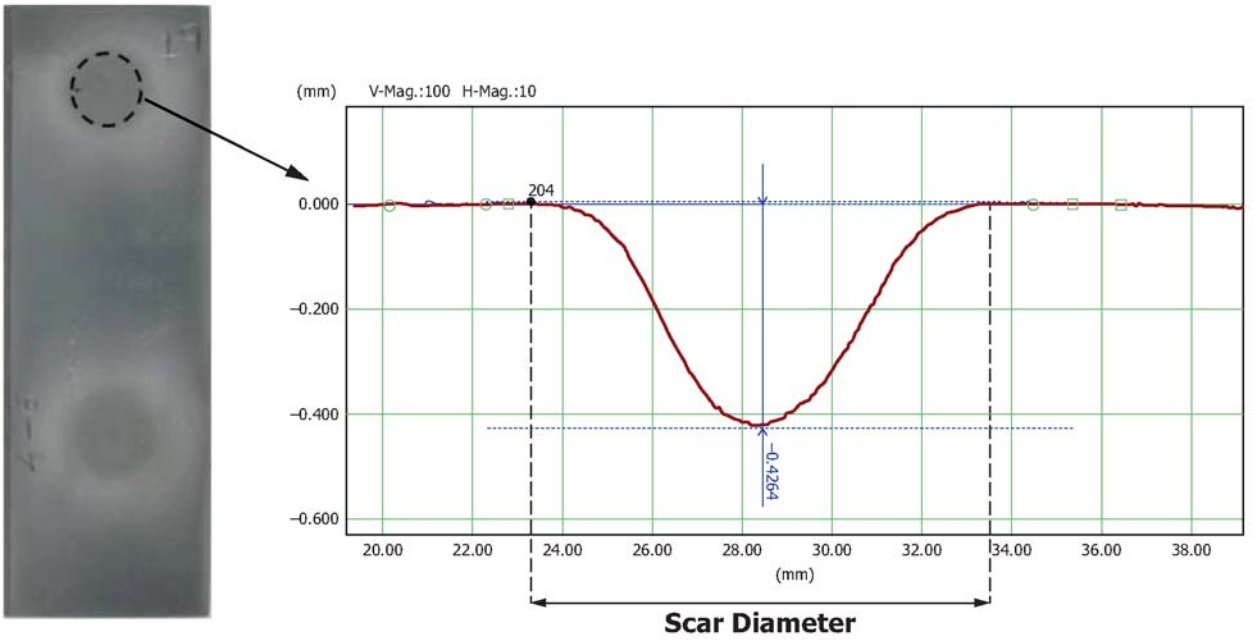


FIG. X2.2 Erosion Scars on Five Test Specimens Eroded in 50 micrometer Alumina (Nanko JIS 6001 320 grit) at Room Temperature, 90 and 30°, 200 m/s, for a Total of 60 g Alumina Exposure



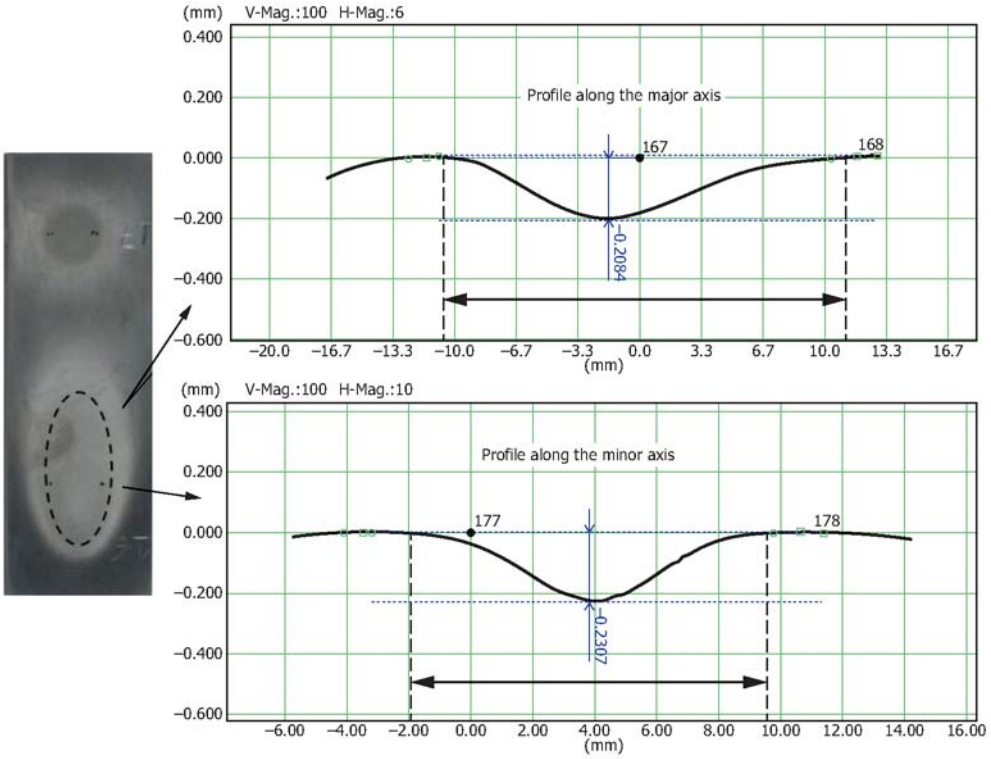
NOTE 1—Erosion scar is ~9.5 × 15.5 mm with a depth of 1.13 mm.

FIG. X2.3 Example of Optical Profilometry of Erosion Scar on Test Specimens Eroded at 30° with 50 micrometer Alumina (Nanko JIS 6001 320 grit) at Room Temeprature, 200 m/s, for a Total of 100 g Alumina Exposure



NOTE 1—Five millimetre nozzle diameter; 14 mm stand-off distance; 25 g dose; Scar diameter = 10 mm; maximum depth = 0.42 mm.

FIG. X2.4 Contact Profilometry of RT Test Scar at 90° Impingement



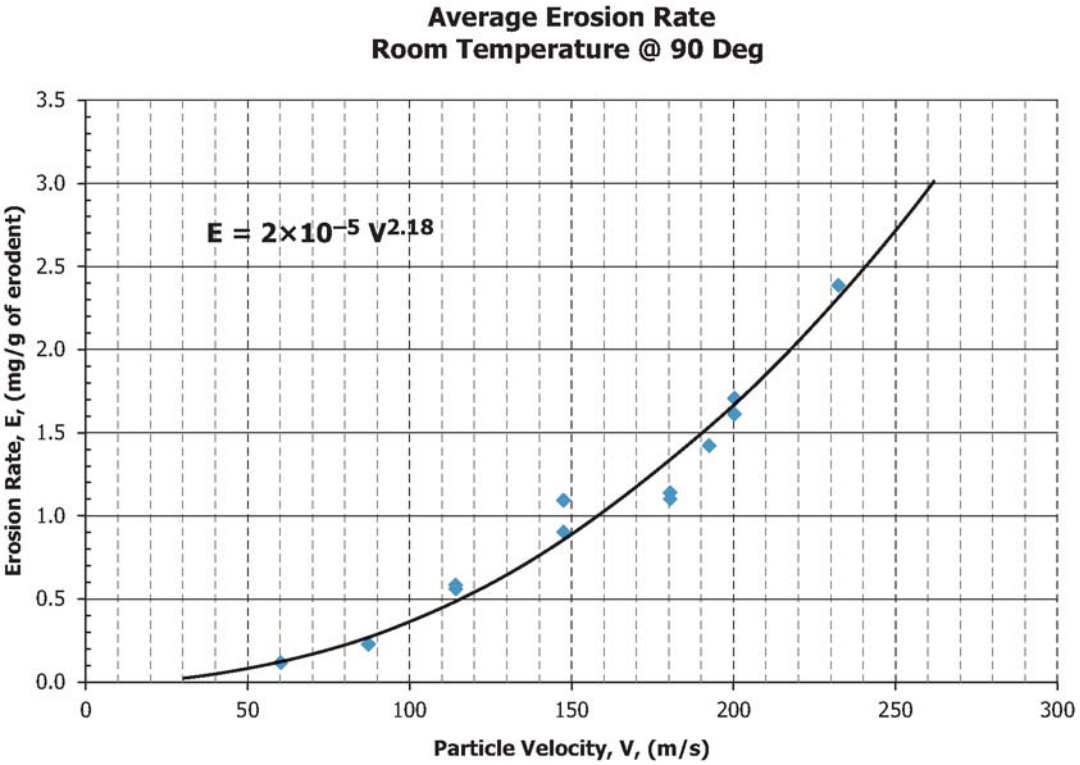
NOTE 1—Five millimetre nozzle diameter; 18 mm SOD; 50 g dose; The major and minor axes are show by arrows. Major axis = 21 mm; Minor axis = 11.5 mm; Maximum scar depth = 0.23 mm.

NOTE 2—Differences in the scales on X-axes.

FIG. X2.5 Contact Profilometry of RT Test Scar at 30°

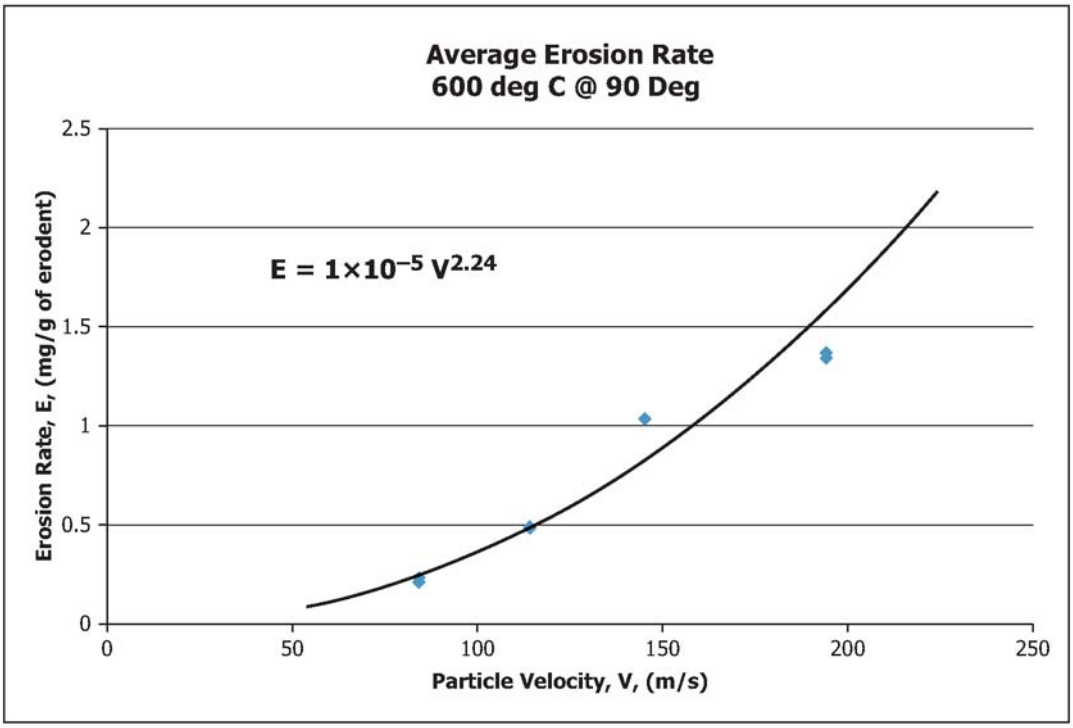
X3. ERODENT PARTICLE VELOCITY CALIBRATION CHECK OF APPARATUS

X3.1 Specimens fabricated from Type 410 stainless steel equivalent to that used in the interlaboratory test series may be periodically tested using the specified 50 µm Al_2O_3 particles (JIS 6001 – 320 standard) at 90° impingement at room temperature to verify the satisfactory performance of the apparatus and as a velocity calibration check. By calculating the erosion rate using the power law equation (Eq 1) and the graph shown in Fig. X3.1, the actual mean particle velocity can be established. Figs. X3.2 and X3.3 are similar plots of data obtained at 600°C at two impingement angles from a single laboratory provided here for information only.



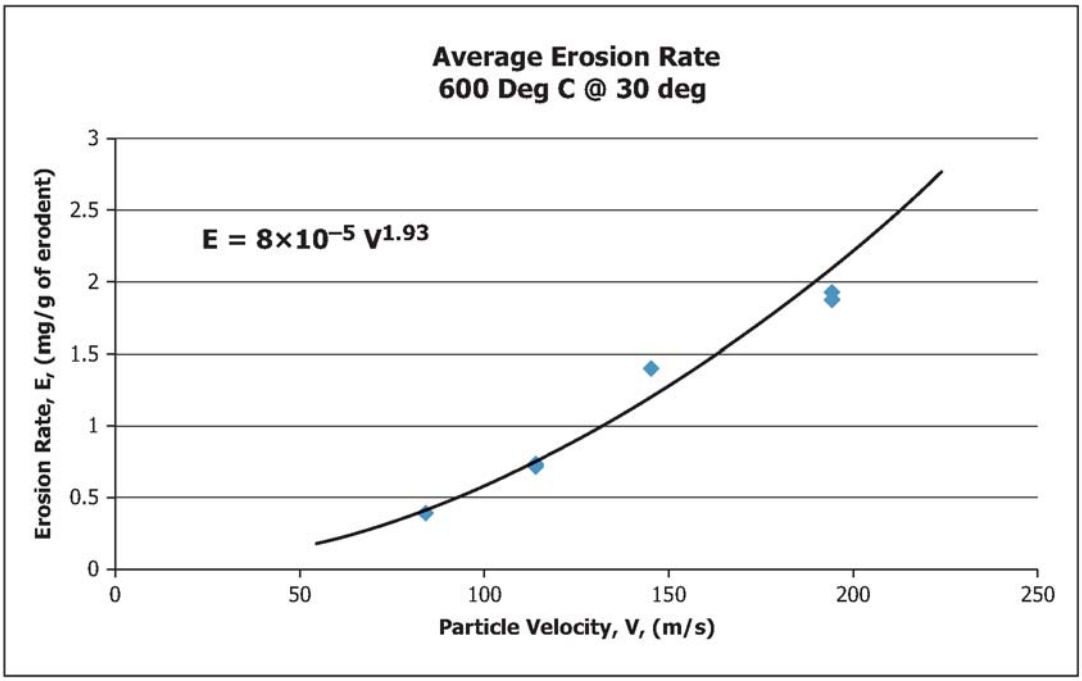
NOTE 1—Correlation coefficient for curve fit (R^2) = 0.98.

FIG. X3.1 Power Law Data Fit for Erosion Rate as a Function of Particle Velocity at Room Temperature and 90° Impingement Angle



NOTE 1—Correlation coefficient for curve fit (R^2) = 0.96.

FIG. X3.2 Power Law Data Fit for Erosion Rate as a Function of Particle Velocity at 600°C and 90° Impingement Angle



NOTE 1—Correlation coefficient for curve fit (R^2) = 0.97.

FIG. X3.3 Power Law Data Fit for Erosion Rate as a Function of Particle Velocity at 600°C and 30° Impingement Angle

X4. ADDITIONAL INFORMATION

X4.1 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.

X4.2 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.

X4.3 Normally, this test is conducted on numerous separate coated 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 coated specimen by carefully repositioning the specimen after eroding it, removing it for cleaning, and weighing it. In such a case, the coated specimen must occupy the identical position for each test in the series; otherwise, the accumulated erosion effect will not be correct. If the specimen size permits, multiple tests on a single specimen could be conducted at different spots as illustrated in Figs. X2.4 and X2.5.

BIBLIOGRAPHY

(1) Cernuschi, F., Guardamagna, C., and Lorenzoni, L. "Solid Particle Erosion Characterization of Materials for Power Generation," Presentation, *Proc. Intl. Conf. on Solid Particle and Liquid Droplet Erosion: Testing Modeling and Applications*, Milan, Italy, June 18–19, 2012, EPRI and RSE. S.p.A.

(2) Dube, N. M., "Gas Jet Erosion Testers: Design Challenges" Presentation, *Proc. Intl. Conf. on Solid Particle and Liquid Droplet Erosion: Testing Modeling and Applications*, Milan, Italy, June 18–19, 2012, EPRI and RSE. S.p.A.

(3) Ruff and Ives, L. "Measurement of Solid Particle Velocity in Erosive Wear," *Wear*, Vol 35, 1975, pp. 195–199.

(4) Smith, J., Swaminathan, V. P., Gandy, D., "Development of an Elevated Temperature Solid Particle Erosion Test Standard," Presentation, *Proc. of the Intl. Conf. on Solid Particle and Liquid Droplet Erosion: Testing Modeling and Applications*, Milan, Italy, June 18–19, 2012, EPRI and RSE. S.p.A.

(5) Swaminathan, V. P., Smith, J., and Gandy, D., "High-Temperature Erosion Testing Standard Development and Round Robin Testing," *Proc. of the Sixth International Conference on Advances in Materials Technology for Fossil Power Plants*, Santa Fe, Aug. 31–Sept. 03, 2010, Electric Power Research Institute, Sept. 2000.

(6) Tilly, G. P., and Sage, W. "The Interaction of Particle and Material Behavior in Erosion Processes," *Wear*, Vol 16, 1970, pp. 447–465.

(7) Weissman, C., "High Accuracy Particle Velocity and Size Measurement Using Optical Methods," Presentation, *Proc. Intl. Conf. on Solid Particle and Liquid Droplet Erosion: Testing Modeling and Applications*, Milan, Italy, June 18–19, 2012, EPRI and RSE. S.p.A.