15 July 2014

Committee G02 on Wear and Erosion
Subcommittee G02.10 on Erosion by Solids and Liquids

Research Report: G02-1014

Interlaboratory Study to Establish Precision Statements for ASTM G211-14, Standard Test Method for Conducting Elevated Temperature Erosion Tests by Solid Particle Impingement Using Gas Jets

Technical contact:
Jeff Smith,
Materials Process Tech LLC
1965 Forest Park Rd
NORTON SHORES, MI 49441
US
jeffsmith@mpt-llc.com

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

1. Introduction:

Interlaboratory Study 678 was conducted to establish a precision statement for G211-14, **Standard Test Method for Conducting Elevated Temperature Erosion Tests by Solid Particle Impingement Using Gas Jets**

2. Test Method:

The Test Method used for this ILS is G211-14. To obtain a copy of G211, go to ASTM's website, www.astm.org, or contact ASTM Customer Service by phone at 610-832-9585 (8:30 a.m. - 4:30 p.m. Eastern U.S. Standard Time, Monday through Friday) or by email at service@astm.org.

3. Participating Laboratories:

The following laboratories participated in this interlaboratory study:

Cranfield University
Cranfield, UK
Prof. John Nichols
+44 1234 754039
j.r.nicholls@cranfield.ac.uk

ERSE S.p.A.
Milan, Italy
Dr. Federico Cernuschi
+39 02 3992 4577
Federico.Cernuschi@rse-web.it

Institute of Turbomachinery
Xian, China
Prof. Jing-Ru Mao or
Dr. Shun-sen Wang
+86-29-82667808
jrmao@mail.xjtu.edu.cn

GE Global Research
Bangalore, India
Dr. Prajina Bhattacharya
+91 80 4012 0584 or
Tamara Muth (GE-PS, USA)
+1 518 385-9755
Prajina.Bhattacharya@ge.com
tamara.muth@ge.com

Ducom Instruments Pvt. Ltd
Bangalore, India
Dr. Narendra Dube
+91 80 4080 5555
nmdube@ducom.com

WPAFML (UDRI)
Dayton, Ohio, USA
Dr. Andrew Phelps
+1 937 229-2793
andrew.phelps@udri.udayton.edu

4. Description of Samples:

Test samples were machined from heat treated Type 410 stainless steel. Material properties are included in Annex A. Each test sample was prepared and distributed by Swami Swaminathan of TurboMet International. The 50 micrometer alumina erodent was also procured from a single batch, tested and supplied to the test laboratories. Distributor for the Type 410 stainless steel samples and the alumina erodent:

Dr. Swami Swaminathan,
TurboMet International
Phone: +1 210 520-9030
swami@turbo-met.com
www.turbo-met.com

5. **Interlaboratory Study Instructions**
Laboratory participants were emailed the test program instructions. For a copy of the instructions, please see Annex A

6. **Description of Equipment/Apparatus[1]:**
For information on the equipment/apparatus used by each laboratory, please see Annex B

7. **Data Report Forms:**
Each laboratory was provided with a data report form for the collection of data. A copy of the data is provided in Annex C.

Please note: The laboratories have been randomly coded and cannot be identified herein.

8. **Statistical Data Summary:**
A summary of the statistics calculated from the data returned by the participating laboratories is provided in Annex D.

9. **Precision and Bias Statement:**

9.1 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. G02-1014. [i]

9.1.1 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.

9.1.1.1 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.

9.1.1.2 Repeatability limits are listed in Tables 1 – 4 below.

9.1.2 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

[1] The equipment listed was used to develop a precision statement for G211-14. This listing is not an endorsement or certification by ASTM International.

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.

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

9.1.2.2 Reproducibility limits are listed in Tables 1 - 4 below.

9.1.3 The above terms (repeatability limit and reproducibility limit) are used as specified in Practice E 177.

9.1.4 Any judgment in accordance with statements 9.1.1 and 9.1.2 would normally have an approximate 95% probability of being correct, however the precision statistics 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.

Table 1. 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
410 Stainless Steel	2.61	0.34	0.41	0.95	1.14

Table 2. 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
410 Stainless Steel	1.50	0.11	0.20	0.30	0.55

Table 3. 600 degree 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
410 Stainless Steel	3.32	0.34	0.86	0.96	2.41

Table 4. 600 degree 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
410 Stainless Steel	1.57	0.12	0.19	0.34	0.53

9.2 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.

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

Annex A:

Table A1. Round Robin erosion testing requirements for this 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 X 7.5 cm X 4.5 mm	2.5 cm X 7.5 cm X 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 & 90 +/- 2 degrees	30 & 90 +/- 2 degrees
Test Temperature	18-28°C	600°C +/- 5 degrees (on test specimen)
Nozzle to specimen Distance	Adjust to achieve erosion scar of ~1.4 cm diameter at 90 degree 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 degree 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
Mass loss 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

A.1 Test Procedure

A.1.1 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, i.e., after 5 runs on the same test coupon. Calibrated pins, optical methods or direct measurements using precision calipers may be employed for such measurements.

A.1.2 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.

A.1.3 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 ± 0.01 mg. (± 0.0001 g).

A.1.4 For the reference tests, use Type 410 Stainless Steel conforming to the characteristics shown in Tables A2 & A3 and Figure A2. The specimen dimensions are 75 mm x 15 mm x 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.

A.1.5 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 Fig. A3 & A4). 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 um, D50 – 50um, D90 – 75 um (see Figure 4).

A.1.6 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.

A.1.7 The particle feed rate shall be 2.0 ± 0.5 $g \cdot min^{-1}$. 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.

A.1.8 For the room temperature (RT) tests the normal ambient value (typically between 18°C 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.

A.1.9 The erodent particle velocity shall be 200 ± 10 $m \cdot s^{-1}$. Measure the velocity at the specimen location. Report the velocity measurement method used and the accuracy (scatter band) of the measurements.

A.1.10 Adjust the distance from specimen surface to the nozzle tip to achieve an erosion scar diameter of approximately 14 mm at 90 degrees and the minor axis of the ellipse at 30 degrees. As shown in Figure 5 schematic and on tested specimens.

A.1.11 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 gram dose for a total exposure of 100 grams of the erodent. Determine the total erodent dose to an accuracy of +/- 1 gram and record. Report the dose of the erodent for each interval and the final total dose for each specimen.

A.1.12 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.)