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Standard Test Method for Liquid Impingement Erosion Using Rotating Apparatus[1]

This standard is issued under the fixed designation G73; 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 tests in which solid specimens are eroded or otherwise damaged by repeated discrete impacts of liquid drops or jets. Among the collateral forms of damage considered are degradation of optical properties of window materials, and penetration, separation, or destruction of coatings. The objective of the tests may be to determine the resistance to erosion or other damage of the materials or coatings under test, or to investigate the damage mechanisms and the effect of test variables. Because of the specialized nature of these tests and the desire in many cases to simulate to some degree the expected service environment, the specification of a standard apparatus is not deemed practicable. This test method gives guidance in setting up a test, and specifies test and analysis procedures and reporting requirements that can be followed even with quite widely differing materials, test facilities, and test conditions. It also provides a standardized scale of erosion resistance numbers applicable to metals and other structural materials. It serves, to some degree, as a tutorial on liquid impingement erosion.

1.2 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1003 Test Method for Haze and Luminous Transmittance of Transparent Plastics

E92 Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials

E140 Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness

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

E179 Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials

G1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens

G32 Test Method for Cavitation Erosion Using Vibratory Apparatus

G40 Terminology Relating to Wear and Erosion

G134 Test Method for Erosion of Solid Materials by Cavitating Liquid Jet

2.2 *Military Standards:*[3]

MIL-C-83231 Coatings, Polyurethane, Rain Erosion Resistance for Exterior Aircraft and Missile Plastic Parts

MIL-P-8184 Plastic Sheet, Acrylic, Modified

3. Terminology

3.1 See Terminology G40 for definitions of terms that are not defined below in either 3.2 or 3.3. Definitions appear in 3.2 that are taken from Terminology G40 for important terms related to the title, Scope, or Summary of this test method. Definitions of Terms Specific to this Test Method are given in 3.3 that are not in Terminology G40.

[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] 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 DLA Document Services, Building 4/D, 700 Robbins Ave., Philadelphia, PA 19111-5094, http://quicksearch.dla.mil.

3.2 *Definitions:*

3.2.1 All definitions listed below are quoted from Terminology G40–05 (some modified).

3.2.2 *cumulative erosion-time curve, n—in cavitation and impingement erosion*, a plot of cumulative erosion versus cumulative exposure duration, usually determined by periodic interruption of the test and weighing of the specimen. This is the primary record of an erosion test. Most other characteristics, such as the incubation period, maximum erosion rate, terminal erosion rate, and erosion rate-time curve, are derived from it.

3.2.3 *damage, n—in cavitation or impingement*, any effect on a solid body resulting from its exposure to these phenomena. This may include loss of material, surface deformation, or any other changes in microstructure, properties, or appearance.

3.2.3.1 *Discussion*—This term as here defined should normally be used with the appropriate modifier, for example, "cavitation damage," "liquid impingement damage," "single-impact damage," and so forth.

3.2.4 *incubation period, n—in cavitation and impingement erosion*, the initial stage of the erosion rate-time pattern during which the erosion rate is zero or negligible compared to later stages.

3.2.4.1 *Discussion*—The incubation period is usually thought to represent the accumulation of plastic deformation and internal stresses under the surface that precedes significant material loss. There is no exact measure of the duration of the incubation period. See related term, *nominal incubation period* in 3.3.9.

3.2.5 *liquid impingement erosion, n*—progressive loss of original material from a solid surface due to continued exposure to impacts by liquid drops or jets.

3.2.6 *maximum erosion rate, n—in cavitation and liquid impingement*, the maximum instantaneous erosion rate in a test that exhibits such a maximum followed by decreasing erosion rates. (See also *erosion rate–time pattern*.)

3.2.6.1 *Discussion*—Occurrence of such a maximum is typical of many cavitation and liquid impingement tests. In some instances it occurs as an instantaneous maximum, in others as a steady-state maximum which persists for some time.

3.2.7 *normalized erosion resistance, N_e, n*—a measure of the erosion resistance of a test material relative to that of a specified reference material, calculated by dividing the volume loss rate of the reference material by that of the test material when both are similarly tested and similarly analyzed. By "similarly analyzed," it is meant that the two erosion rates must be determined for corresponding portions of the erosion rate-time pattern; for instance, the maximum erosion rate or the terminal erosion rate.

3.2.7.1 *Discussion*—A recommended complete wording has the form, "The normalized erosion resistance of (test material) relative to (reference material) based on (criterion of data analysis) is (numerical value)."

3.2.8 *normalized incubation resistance, N_0, n—in cavitation and liquid impingement erosion*, the nominal incubation period of a test material, divided by the nominal incubation period of a specified reference material similarly tested and similarly analyzed. (See also *normalized erosion resistance*.)

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *apparatus severity factor, F*—an empirical factor that accounts for the systematic differences between rationalized erosion rates (or rationalized incubation periods) as determined for the same material and impact velocity in different facilities. It reflects variations in test conditions not accounted for by the data reduction procedures of this test method.

3.3.2 *erosion resistance number,* NER—the normalized erosion resistance of a test material relative to a standardized scale, calculated from test results with one or more designated reference materials as described in this test method. See also *reference erosion resistance* (3.3.12).

3.3.3 *exposed surface (or area)*—that surface (or area) on the specimen nominally subjected to liquid impingement.

(1) For "distributed impact tests," it is generally to be taken as the projected area of the exposed surface of the specimen on a plane perpendicular to the direction of impingement. However, if a plane specimen surface is deliberately oriented so as to obtain impingement at an oblique angle, then the actual plane area is used.

(2) For "repetitive impact tests," it is to be taken as the projected area of the impinging liquid bodies on the specimen, the projection being taken in the direction of relative motion.

3.3.3.1 *Discussion*—In practice, it is usually found that the damaged area in repetitive impact tests is greater than the exposed area as defined above, but the above definition is adopted not only for simplicity but also for consistency between some of the other calculations for distributed and repetitive tests.

3.3.4 *impingement rate, U_i* [LT^{-1}]—the volume of liquid impinging per unit time on a unit area of exposed surface; for a plane target surface it is given by $\psi\ V \cos\theta$.

3.3.5 *incubation impingement, H_0* [L]—the mean cumulative impingement corresponding to the nominal incubation period; hence, impingement rate times nominal incubation time.

3.3.6 *incubation resistance number,* NOR—the normalized incubation resistance of a test material relative to a standardized scale, calculated from test results with one or more designated reference materials as described in this test method. See also reference incubation resistance (3.3.13).

3.3.7 *incubation specific impacts, N_0*—same as rationalized incubation period.

3.3.8 *mean cumulative impingement, H* [L]—the cumulative volume of liquid impinged per unit area of exposed surface; impingement rate times exposure time.

3.3.9 *nominal incubation period, t_0*—the intercept on the time or exposure axis of the straight-line extension of the maximum-slope portion of the cumulative erosion-time curve; while this is not a true measure of the incubation stage, it serves to locate the maximum erosion rate line on the cumulative erosion versus exposure coordinates.

3.3.10 *rationalized erosion rate,* R_e—volume of material lost per unit volume of liquid impinged, both calculated for the same area.

3.3.11 *rationalized incubation period,* N_0—the duration of the nominal incubation period expressed in dimensionless terms as the number of specific impacts; hence, the specific impact frequency times nominal incubation time. (Also referred to as *incubation specific impacts*.)

3.3.12 *reference erosion resistance,* S_{er}—a normalized erosion resistance, based on interlaboratory test results, assigned to a specified reference material in this test method so as to constitute a benchmark in the "erosion resistance number" scale. The value of unity is assigned to 316 stainless steel of hardness 155 to 170 HV.

3.3.13 *reference incubation resistance,* S_{or}—a normalized incubation resistance, based on interlaboratory test results, assigned to a specific reference material in this test method so as to constitute a benchmark in the "incubation resistance number" scale. The value of unity is assigned to 316 stainless steel of hardness 155 to 170 HV.

3.3.14 *specific impacts, N*—the number of impact stress cycles of damaging magnitude experienced by a typical point on the exposed surface, or an approximation thereof as estimated on the basis of simplified assumptions as described in this test method. (This concept has sometimes been termed "impacts per site.")

3.3.15 *specific impact frequency,* f_i [T^{-1}]—the number of specific impacts experienced per unit time, given by $(a/b)\ U_i$.

3.3.16 *volume concentration,* ψ—the ratio of the volume of liquid to the total volume in the path traversed or swept out by the exposed area of the specimen.

3.3.17 *volume mean diameter* [L]—in a population of drops of different sizes, the diameter of a sphere whose volume equals the total volume of all drops divided by the total number of drops.

3.4 *Symbols:*

A = exposed area of specimen, m^2,
a = projected area of impinging drop or jet, m^2,
b = volume of impinging drop or jet, m^3,
d = diameter of impinging drop or jet, m,
F_0 = apparatus severity factor for incubation,
F_e = apparatus severity factor for erosion rate,
f_i = specific impact frequency, s^{-1},
H = mean cumulative impingement, m,
H_0 = incubation impingement, m,
N_0 = number of specific impacts for incubation, or "rationalized incubation period," dimensionless,
NER = erosion resistance number,
NOR = incubation resistance number,
n = number of jets or drops impacting on exposed surface of specimen in one revolution,
Q_e = volumetric erosion rate, m^3/s,
R_e = "rationalized erosion rate," (dY/dH), dimensionless,
S_e = normalized erosion resistance (relative to a specified reference material),
S_{er} = reference erosion resistance,
S_0 = normalized incubation resistance (relative to a specified reference material),
S_{or} = reference incubation resistance,
t = exposure time, s,
t_0 = nominal incubation time, s,
U_e = linear erosion rate (dY/dt), m/s = Q_e/A,
U_i = impingement rate (dH/dt), m/s,
U_r = rainfall rate, m/s,
U_t = terminal velocity of drops in falling rainfield, m/s,
V = impact velocity of drop or jet relative to specimen, m/s,
V_n = component of impact velocity normal to specimen surface, m/s,
Y = mean depth of erosion, m,
θ = angle of incidence—the angle between the direction of impacting drops and the normal to the solid surface at point of impact,
ψ = volume concentration of liquid in rainfield or in space swept through by specimen, and
Ω = rotational speed of specimens, rev/s.

3.5 Except in equations where different units are expressly specified, the use of SI units listed in 3.4, or any other *coherent* system of units, will make equations correct without the need of additional numerical factors. When referring to quantities in text, tables, or figures, suitable multiples or submultiples of these units may, of course, be used.

4. Summary of Test Method

4.1 Liquid impingement tests are usually, but not always, conducted by attaching specimens to a rotating disk or arm, such that in their circular path they repeatedly pass through and impact against liquid sprays or jets (Sections 6 and 7). Standard reference materials (Section 8) should be used to calibrate the apparatus and included in all test programs.

4.2 Data analysis begins by establishing a cumulative erosion-time curve from measurements of mass loss (or other damage manifestation) periodically during the tests (Section 9). These curves are then characterized by specified attributes such as the nominal incubation time and the maximum erosion rate (Section 10).

4.3 For comparative materials evaluations, the results are normalized (Section 10) with respect to the standard reference materials included in the test program. A standardized scale of "erosion resistance numbers" is provided for structural bulk materials and coatings (10.4.3). For more in-depth analysis of the results, the incubation times or erosion rates are expressed in dimensionless "rationalized" forms that are based on more physically meaningful exposure duration variables than clock time as such (Section 11).

4.4 The information to be given in the report depends on the objectives of the test (Section 12).

5. Significance and Use

5.1 *Erosion Environments*—This test method may be used for evaluating the erosion resistance of materials for service environments where solid surfaces are subjected to repeated impacts by liquid drops or jets. Occasionally, liquid impact tests have also been used to evaluate materials exposed to a