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INTERNATIONAL

Designation: G73 – 10 (Reapproved 2021)

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 cavitating liquid environment. The test method is *not* intended nor applicable for evaluating or predicting the resistance of materials against erosion due to solid particle impingement, due to "impingement corrosion" in bubbly flows, due to liquids or slurries "washing" over a surface, or due to continuous high-velocity liquid jets aimed at a surface. For background on various forms of erosion and erosion tests, see Refs (**1**) through (**2**).[4] Ref (**3**) is an excellent comprehensive treatise.

5.2 *Discussion of Erosion Resistance*—Liquid impingement erosion and cavitation erosion are, broadly speaking, similar processes and the relative resistance of materials to them is similar. In both, the damage is associated with repeated, small-scale, high-intensity pressure pulses acting on the solid surface. The precise failure mechanisms in the solid have been shown to differ depending on the material, and on the detailed nature, scale, and intensity of the fluid-solid interactions (Note 1). Thus, "erosion resistance" should not be regarded as one precisely-definable property of a material, but rather as a complex of properties whose relative importance may differ depending on the variables just mentioned. (It has not yet been possible to successfully correlate erosion resistance with any independently measurable material property.) For these reasons, the consistency between relative erosion resistance as measured in different facilities or under different conditions is not very good. Differences between two materials of say 20 % or less are probably not significant: another test might well show them ranked in reverse order. For bulk materials such as metals and structural plastics, the range of erosion resistances is much greater than that of typical strength properties: On a normalized scale on which Type 316 stainless steel is given a value of unity, the most resistant materials (some Stellites and tool steels) may have values greater than 10, and the least resistant (soft aluminum, some plastics) values less than 0.1 (see Refs (**2**) and (**4**)).

NOTE 1—On failure mechanisms in particular, see in Ref (**3**) under "The Mechanics of Liquid Impact" by W. F. Adler, "Erosion of Solid Surfaces by the Impact of Liquid Drops" by J. H. Brunton and M. C. Rochester, and "Cavitation Erosion" by C. M. Preece.

5.3 *Significance of the Variation of Erosion Rate with Time:*

5.3.1 The rate of erosion due to liquid impact or cavitation is not constant with time, but exhibits one of several "erosion rate-time patterns" discussed more fully in 10.3.3. The most common pattern consists of an "incubation period" during which material loss is slight or absent, followed by an acceleration of erosion rate to a maximum value, in turn followed by a declining erosion rate which may or may not tend to a "terminal" steady-state rate. The significance of the various stages in this history can differ according to the intended service applications of the materials being tested. In almost no case, however, are significant results obtained by simply testing all materials for the same length of time and comparing their cumulative mass loss.

5.3.2 The "incubation period" may be the most significant test result for window materials, coatings, and other applications for which the useful service life is terminated by initial surface damage even though mass loss is slight.

5.3.3 For bulk materials, this test method provides for determination of the "nominal incubation period" as well as the "maximum erosion rate," and material ratings based on each. Empirical relationships are given in Annex A2 by which the nominal incubation period and the maximum erosion rate can then be estimated for any liquid impingement conditions in which the principal impingement variables are known. It must be emphasized, however, that because of the previously described variation of erosion rate with exposure time, the above-mentioned parameters do not suffice to predict erosion for long exposure durations. Extrapolation based on the maximum erosion rate could overestimate the absolute magnitude of long-term cumulative erosion by a factor exceeding an order of magnitude. In addition, it could incorrectly predict the relative difference between long-term results for different materials.

5.3.4 Because of these considerations, some experimenters concerned with long-life components may wish to base material ratings not on the maximum erosion rate, but on the lower "terminal erosion rate" if such is exhibited in the tests. This can be done while still following this test method in many respects, but it should be recognized that the terminal erosion rate is probably more strongly affected by secondary variables such as test specimen shape, "repetitive" versus "distributed" impact conditions, drop size distributions, and so forth, than is the maximum erosion rate. Thus, between-laboratories variability may be even poorer for results based on terminal erosion rate, and the test time required will be much greater.

5.4 This test method is applicable for impact velocities ranging roughly from 60 m/s to 600 m/s; it should not be assumed that results obtained in that range are valid at much higher or lower velocities. At very low impact velocities, corrosion effects become increasingly important. At very high velocities the material removal processes can change markedly, and specimen temperature may also become a significant factor; testing should then be done at the velocities corresponding to the service environment.

5.5 *Related Test Methods*—Since the resistances of materials to liquid impingement erosion and to cavitation erosion have been considered related properties, cavitation erosion Test Methods G32 and G134 may be considered as alternative tests to this test method for some applications. For metals, the relative results from Test Method G32 or G134 should be similar but not necessarily identical to those from a liquid impact test (see 5.2). Either Test Method G32 or G134 may be less expensive than an impingement test, and provides for standardized specimens and test conditions, but may not match the characteristics of the impingement environment to be simulated. The advantages of a liquid impingement test are that droplet or jet sizes and impact velocities can be selected and it can simulate more closely a specific liquid impingement environment. A well-designed liquid impingement test is to be preferred for elastomers, coatings, and brittle materials, for which size effects may be quite important.

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

6. Apparatus

6.1 This test method is applicable principally to those erosion test devices in which one or more specimens are attached to the periphery of a rotating disk or arm, and their circular path passes through one or more liquid jets or sprays, causing discrete impacts between the specimen and the droplets or the cylindrical surface of the jets (Note 2). Fig. 1 and Fig. 2 show two representative devices of very different size and speed that participated in the interlaboratory study referred to in Section 13, though the device shown in Fig. 2 is no longer in service. Considerations relating to the specimens and their attachment are covered in Section 7.

NOTE 2—Some representative rotating apparatus are described in Ref (**5**) by Ripken (pp. 3–21) and Hoff et al (pp. 42–69); in Ref. (**6**) by Elliott et al (pp. 127–161) and Thiruvengadam (pp. 249–287); and by A. A. Fyall in "Radome Engineering Handbook," J. D. Walton, editor, Marcel Dekker, Inc., New York, NY, 1970, pp. 461–572.

6.2 A distinction is made between "distributed impact tests" and "repetitive impact tests." Devices using sprays or simulated rainfields fall into the first category, and most using jets into the second.

NOTE 3—Repetitive impact tests, as compared to distributed impact tests, generally provide much higher specific impact frequencies and have higher severity factors (see 6.5), thus producing erosion more rapidly at equal impact velocities. However, because the damage is localized at a line or point on the specimen, the topography and progress of damage differs somewhat from that in distributed impact tests or under most typical service conditions.

6.3 Test devices of the types described above have been built for peripheral velocities (and hence impact velocities) from about 50 m/s to as high as 1000 m/s. The higher velocities pose considerable difficulties relating to power requirements, aerodynamic heating and noise, and balancing. Partial evacuation of the test chamber may be required. At the intended operating speeds it should be possible to maintain the speed steady within 0.5 %, and to measure it within 0.1 %.

6.4 Droplet or jet diameters have ranged from around 0.1 mm to about 5 mm. Droplets may be generated by spray nozzles, vibrating hollow needles, or rotating disks with water fed onto their surface. The typical droplet or jet diameter, and the volume of liquid actually impacting the specimen per unit time, should be determined within 10 %. For jets, the diameter can usually be assumed to equal the nozzle diameter. However, photographic verification is desirable since jets may exhibit instabilities under some conditions. With drops, there will usually be a size distribution, and in most cases it will be necessary to determine that distribution by photography and analysis of the photographs. Some drop-generating techniques, such as vibrating needles, provide more uniform drop sizes than sprays. For a single-number characterization, the volume mean diameter should be used, so as to obtain the correct relationship between total volume and total number of drops. Ideally, the apparatus should be characterized by the drop population per unit volume in the path traversed by the specimen, and the repeatability thereof, as a function of test settings. From this, the impingement rate and specific impact frequency, needed for Section 11, can then be readily determined.

6.5 Even when erosion test results are "rationalized" (see Section 11) by taking into account the amount of liquid impacting the specimen, there will still be systematic differences from one apparatus to another. These are represented by the "apparatus severity factors," which can be calculated from test results by equations given in 11.5, and can be estimated in the design stage as shown in Annex A2. This can help in

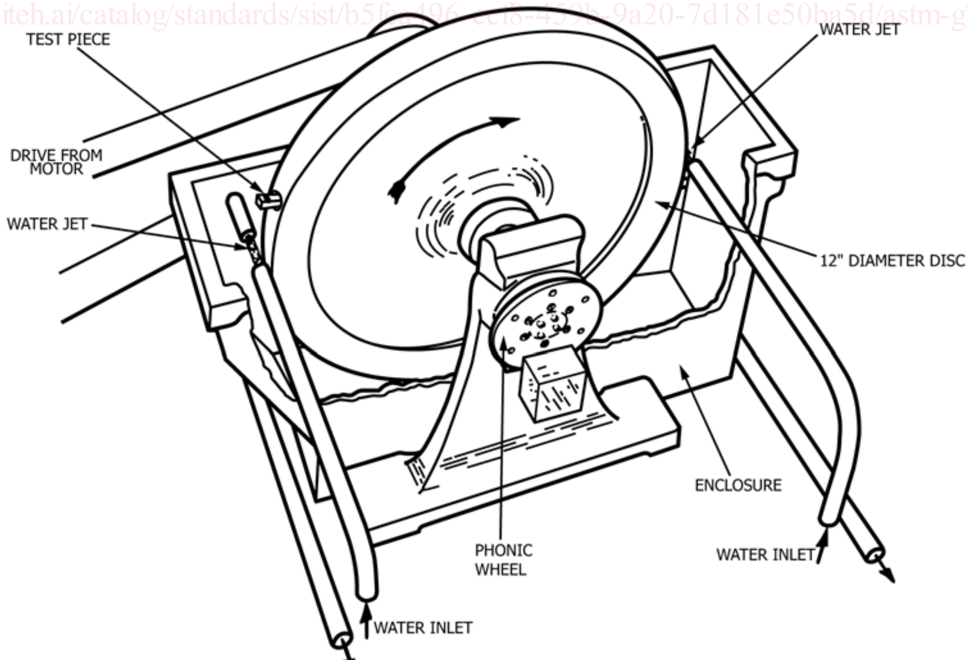
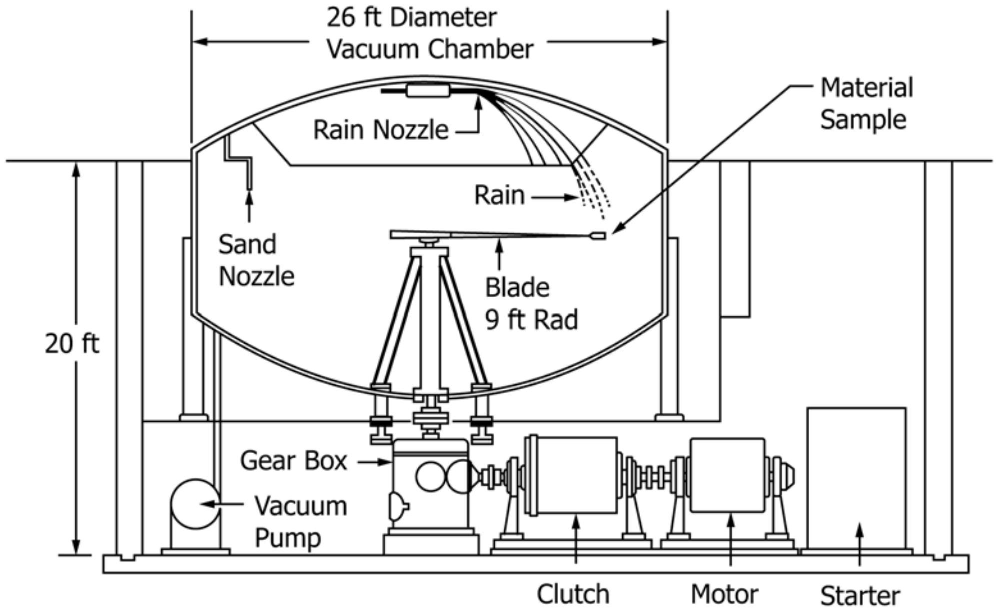


FIG. 1 Example of a Small, Relatively Low-Speed, Rotating Disk-and-Jet Repetitive Impact Apparatus (Courtesy of National Engineering Laboratory, East Kilbride, Scotland, UK)



NOTE 1—This specific apparatus is no longer in service.

FIG. 2 Example of a Large, High-Speed, Rotating Arm-and-Spray Distributed Impact Apparatus (Courtesy of Bell Aerospace TEXTRON, Buffalo, NY)

planning an apparatus suitable for the type of materials to be tested and in predicting the required test times.

6.6 For repetitive impact tests using jets and plane specimens, care should be taken to ensure that the erosion track is of uniform width and depth, and that undue erosion is not occurring at a specimen edge. This may require appropriate angular alignment of the specimen.

6.7 For both repetitive and distributed impact tests, care should be taken to ensure that the jet or spray can reconstitute itself between successive passages of a specimen. Otherwise the actual amount and shape of liquid impinging may be considerably different from that assumed.

6.8 There are other types of liquid impact erosion-test devices besides those described above. Some research investigations have been made with "liquid gun" devices, in which a short discrete slug of liquid is projected out of a nozzle against a target specimen. Both single-shot and repetitive-shot versions of this type exist. For tests at very high impact velocities, specimen-carrying rocket sleds passing through an artificial rain field have been used (Note 4). On the laboratory scale, there are linear test devices in which a specimen carrier is projected against a stationary suspended droplet or other liquid body. Some of the provisions of this test method may be applied to these tests and their reports also.

NOTE 4—Typical "liquid gun" apparatus are described in Ref (**1**) by deCorso and Kothmann (pp. 32–45) and Brunton (pp. 83–98); in Ref (**7**) by Rochester and Brunton (pp. 128–151); and in Ref (**8**) by Field et al (pp. 298–319). Rocket sled tests are described by Schmitt in Ref (**6**) (pp. 323–352) and in Ref (**8**) (pp. 376–405).

NOTE 5—It is *not* feasible to accelerate droplets to adequately high velocities by entrainment in a fast-moving stream of gas or vapor, because the droplets are likely to be broken up into such smaller sizes that their damage potential is slight.

7. Test Specimens

7.1 Specimens may present a curved (airfoil or cylindrical) or a flat surface to the impinging liquid. The shape chosen may depend on the test objectives, such as whether a particular prototype geometry is to be simulated. It should be recognized, however, that a curved profile will result in a variation of the normal component of impact velocities, impact angles, and impingement rates over the exposed surface, and a variation in the extent of damaged area as the test proceeds.

7.2 Specimens may be machined from solid bar, cut from sheet, or consist of a coating applied to a standardized substrate, any of which may be attached over a supporting structure. Specimens and their attachment provisions should be designed to facilitate the repeated removal, cleaning, and weighing of the specimens. The specimen should fit only one way and be located by positive stops, or other provisions for repeatable alignment shall be used. (**Warning—**Specimen holders or attachment methods should be designed to minimize localized stressing of the specimen due to centrifugal or clamping forces, especially when weak or brittle materials are to be tested.)

7.3 If specimens are machined from bulk or bar material, the final cuts should be light to avoid work-hardening of the surface, which may have a significant effect on the incubation period. Surface roughness should be in the range from 0.4 µm to 1.6 µm (16 µin. to 63 µin.) rms, as obtained by fine machining or medium grinding, unless there is a specific reason for choosing another value. In that case, it should be reported.

7.4 If the specimen is formed from sheet material, or is a coating, it should be recognized that wave reflection from the interface with the backup or base material may affect results.

Care should be taken that sheet materials are properly supported. Deposited coatings should have the thickness to be used in service, or the thickness must be considered a test variable.

7.5 The performance of elastomeric coatings will depend on the application technique and on the substrate. Unless the effect of technique is being investigated, each coating should be applied using its manufacturer's recommended technique, including whatever surface preparation, curing method, and post-application conditioning are specified. Two types of substrates are recommended: (*1*) a substrate identical in construction to that of the end use item on which the coating is to be used (this type of specimen will enable investigation of coating/substrate interactions under liquid impact), and (*2*) a standardized substrate (such as a glass-epoxy laminate, a graphite-epoxy composite, or an aluminum alloy) so that relative ranking and resistance of the coating may be determined.

8. Reference Materials; Apparatus Calibration

8.1 In any test whose objective is the determination of the erosion resistance properties of test materials, at least *two* of the reference materials listed in 8.3 shall be included in the test program. This serves the dual purpose of providing a reference for calculating relative or normalized resistance values of the test materials, and for calculating the "severity factors" of the facility. For the second purpose, metallic reference materials are always used. Annex A1 gives some of the properties of the metallic reference materials and their nominal "reference erosion resistance" values to be used in these calculations. The data analysis procedures for determining normalized erosion resistance are specified in Section 10. Optional procedures for determining "Apparatus Severity Factors" are given in Section 11.

8.2 The choice of the reference materials should be based on the expected erosion resistance of the materials to be evaluated. The greater the difference between test material and reference material, the poorer is the consistency of the normalized results among different laboratories.

8.3 *Reference Materials:*

8.3.1 *For Metals and Other High-Resistance Materials:*

8.3.1.1 Aluminum 1100-0.

8.3.1.2 Aluminum 6061-T6.

8.3.1.3 Nickel, 99.98 % pure, annealed.[5]

8.3.1.4 Stainless Steel Type AISI 316, of hardness 155-170 HV.

8.3.1.5 (See Annex A1 for properties from interlaboratory test.)

8.3.2 *For Plastics, Ceramics, and Window Materials*—One of the metals specified, plus:

8.3.2.1 Poly (methyl methacrylate)—(*PMMA*), conforming to MIL-P-8184, Type II, Class 2 (as cast).[6]

8.3.3 *For Reinforced Plastic and Composite Materials*—One of the metals specified, plus one of the following:

8.3.3.1 Glass-Epoxy Laminate (E-Glass, Style 181 fabric Epon 828 epoxy resin), without gel coating.

8.3.3.2 Poly (methyl methacrylate) (*PMMA*), conforming to MIL-P-8184,[6] as cast.

8.3.4 *For Elastomers* (*as coatings*)—One of the metals specified, plus:

8.3.4.1 Polyurethane, sprayed, in accordance with MIL-C-83231.

8.3.4.2 Uncoated Substrate (glass-epoxy laminate, aluminum, or other materials as above).

9. Test Procedures

9.1 *Introduction:*

9.1.1 Since the test procedures for different types of material differ to some extent, separate sections are provided below for structural materials and coatings (9.2), elastomeric coatings (9.3), window materials (9.4), and transparent thin-film coatings on window materials (9.5). A generalized cleaning and drying procedure is given in 9.6 for eroded specimens where retained moisture may be a problem.

9.1.2 Unless otherwise specified, at least three specimens shall be tested for each test variation (that is, for a given material at a given test condition).

9.1.3 A common requirement in most of these test procedures is that the test must be interrupted periodically for the specimen to be removed for cleaning, drying, and weighing or other damage evaluation. In those cases where the time required for these steps is much greater than the time of actual testing (as may be true for elastomeric coatings and other nonmetallic specimens), an acceptable alternative procedure is to test a series of identical specimens, each for a different length of uninterrupted exposure, to obtain one synthesized test record. This option is to be taken as implied in the subsequent sections.

9.1.4 When damage is determined by mass loss measurements, repeat the cleaning, drying, and weighing operations until two successive weighings yield identical (or acceptably similar) readings, unless prior qualification of the cleaning procedure has proved such repetition unnecessary.

9.2 *Test Procedure for Structural Bulk Materials and Coatings:*

9.2.1 This section applies to specimens representative of structural materials and systems for which the loss of material and consequent change of shape and size is of primary concern. This includes metals, structural plastics, structural composites, metals with metallic or ceramic coatings, and so forth. The applicable portions of this section may be followed for the other classes of materials if mass loss is also of interest.

9.2.2 The primary test result to be obtained for each specimen is a cumulative erosion-versus-time curve, generated

[5] Nickel 270 was used in the interlaboratory test for this test method, as well as for the first (1967–68) interlaboratory test for Test Method G32, but it may no longer be available. Nickel 200 (containing 99 % Ni) was substituted for the second (1990–91) interlaboratory test for Test Method G32. It proved to have an erosion resistance about 40 % higher, and incubation resistance about 65 % higher, than Ni 270.

[6] Plexiglas 55, conforming to MIL-P-8184, obtained from Rohm and Haas Co., was used widely as a reference material at the time this test method was first developed, but it may no longer be available and is not on the Qualified Product List for MIL-P-8184.