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Standard Test Method for Erosion of Solid Materials by Cavitating Liquid Jet[1]

This standard is issued under the fixed designation G134; 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.

ε^1 NOTE—Updated Section 3 to reflect Terminology G40–10b editorially in December 2010.

1. Scope

1.1 This test method covers a test that can be used to compare the cavitation erosion resistance of solid materials. A submerged cavitating jet, issuing from a nozzle, impinges on a test specimen placed in its path so that cavities collapse on it, thereby causing erosion. The test is carried out under specified conditions in a specified liquid, usually water. This test method can also be used to compare the cavitation erosion capability of various liquids.

1.2 This test method specifies the nozzle and nozzle holder shape and size, the specimen size and its method of mounting, and the minimum test chamber size. Procedures are described for selecting the standoff distance and one of several standard test conditions. Deviation from some of these conditions is permitted where appropriate and if properly documented. Guidance is given on setting up a suitable apparatus, test and reporting procedures, and the precautions to be taken. Standard reference materials are specified; these must be used to verify the operation of the facility and to define the normalized erosion resistance of other materials.

1.3 Two types of tests are encompassed, one using test liquids which can be run to waste, for example, tap water, and the other using liquids which must be recirculated, for example, reagent water or various oils. Slightly different test circuits are required for each type.

1.4 This test method provides an alternative to Test Method G32. In that method, cavitation is induced by vibrating a submerged specimen at high frequency (20 kHz) with a specified amplitude. In the present method, cavitation is generated in a flowing system so that both the jet velocity and the downstream pressure (which causes the bubble collapse) can be varied independently.

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

1.6 *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]

A276 Specification for Stainless Steel Bars and Shapes

B160 Specification for Nickel Rod and Bar

B211 Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire

D1193 Specification for Reagent Water

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

G32 Test Method for Cavitation Erosion Using Vibratory Apparatus

G40 Terminology Relating to Wear and Erosion

G73 Test Method for Liquid Impingement Erosion Using Rotating Apparatus

2.2 *ASTM Adjuncts:*

Manufacturing Drawings of the Apparatus[3]

3. Terminology

3.1 See Terminology G40 for definitions of terms relating to cavitation erosion. For convenience, definitions of some important terms used in this test method are reproduced below.

3.2 *Definitions:*

3.2.1 *cavitation*, *n*—the formation and subsequent collapse, within a liquid, of cavities or bubbles that contain vapor or a mixture of vapor and gas.

3.2.1.1 *Discussion*—Cavitation originates from a local decrease in hydrostatic pressure in the liquid, usually produced by motion of the liquid (see **flow cavitation**) or of a solid

[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 ASTM International Headquarters. Order Adjunct No. ADJG0134.

boundary (see **vibratory cavitation**). It is distinguished in this way from boiling, which originates from an increase in liquid temperature.

3.2.1.2 *Discussion*—The term cavitation, by itself, should *not* be used to denote the damage or erosion of a solid surface that can be caused by it; this effect of cavitation is termed **cavitation damage** or **cavitation erosion**. To erode a solid surface, bubbles or cavities must collapse on or near that surface. **G40**

3.2.2 *cavitation erosion*, *n*—progressive loss of original material from a solid surface due to continued exposure to cavitation. **G40**

3.2.3 *cumulative erosion*, *n—in cavitation and impingement erosion*, the total amount of material lost from a solid surface during all exposure periods since it was first exposed to cavitation or impingement as a newly-finished surface. (More specific terms that may be used are *cumulative mass loss, cumulative volume loss*, or *cumulative mean depth of erosion*. See also **cumulative erosion-time curve**.)

3.2.3.1 *Discussion*—Unless otherwise indicated by the context, it is implied that the conditions of cavitation or impingement have remained the same throughout all exposure periods, with no intermediate refinishing of the surface. **G40**

3.2.4 *cumulative erosion rate*, *n*—the cumulative erosion at a specified point in an erosion test divided by the corresponding cumulative exposure duration; that is, the slope of a line from the origin to the specified point on the cumulative erosion-time curve. (*Synonym:* **average erosion rate**) **G40**

3.2.5 *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. **G40**

3.2.6 *flow cavitation*, *n*—cavitation caused by a decrease in local pressure induced by changes in velocity of a flowing liquid. Typically, this may be caused by flow around an obstacle or through a constriction, or relative to a blade or foil. A cavitation cloud or "cavitating wake" generally trails from some point adjacent to the obstacle or constriction to some distance downstream, the bubbles being formed at one place and collapsing at another. **G40**

3.2.7 *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. Also, the exposure duration associated with this stage. (Quantitatively it is sometimes defined as the intercept on the time or exposure axis, of a straight line extension of the maximum-slope portion of the cumulative erosion-time curve.) **G40**

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

3.2.8.1 *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. **G40**

3.2.9 *normalized erosion resistance,* N_e, *n—in cavitation and liquid impingement erosion*, 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.

3.2.9.1 *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)." **G40**

3.2.10 *normalized incubation resistance,* N_o, *n*—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**.) **G40**

3.2.11 *terminal erosion rate*, *n—in cavitation or liquid impingement erosion*, the final steady-state erosion rate that is reached (or appears to be approached asymptotically) after the erosion rate has declined from its maximum value. (See also **terminal period** and **erosion rate-time pattern**.) **G40**

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *cavitating jet*, *n*—a continuous liquid jet (usually submerged) in which cavitation is induced by the nozzle design or sometimes by a center body. See also *jet cavitation*.

3.3.2 *cavitation number,* σ—a dimensionless number that measures the tendency for cavitation to occur in a flowing stream of liquid, and that, for the purpose of this test method, is defined by the following equation. All pressures are absolute.

$$\sigma = \frac{(p_d - p_v)}{\frac{1}{2}\rho V^2} \tag{1}$$

where:

p_v = vapor pressure,
p_d = static pressure in the downstream chamber,
V = jet velocity, and
ρ = liquid density.

3.3.2.1 For liquid flow through any orifice:

$$\frac{1}{2}\rho V^2 = p_u - p_d \tag{2}$$

where:

p_u = upstream pressure.

3.3.2.2 For erosion testing by this test method, the cavitating flow in the nozzle is choked, so that the downstream pressure, as seen by the flow, is equal to the vapor pressure. The cavitation number thus reduces to:

$$\sigma = \frac{p_d - p_v}{p_u - p_v} \tag{3}$$

which for many liquids and at many temperatures can be approximated by:

$$\sigma = \frac{p_d}{p_u} \tag{4}$$

since

$$p_u >> p_d >> p_v \tag{5}$$

3.3.3 *jet cavitation*, *n*—the cavitation generated in the vortices which travel in sequence singly or in clouds in the shear layer around a submerged jet. It can be amplified by the nozzle design so that vortices form in the vena contracta region inside the nozzle.

3.3.4 *stand-off distance*, *n*—in this test method, the distance between the *inlet* edge of the nozzle and the target face of the specimen. It is thus defined because the location and shape of the inlet edge determine the location of the vena contracta and the initiation of cavitation.

3.3.5 *tangent erosion rate*, *n*—the slope of a straight line drawn through the origin and tangent to the *knee* of the cumulative erosion-time curve, when the shape of that curve has the characteristic S-shape pattern that permits this. In such cases, the tangent erosion rate also represents the maximum cumulative erosion rate exhibited during the test.

3.3.6 *vena contracta*, *n*—the smallest locally occurring diameter of the main flow of a fluid after it enters into a nozzle or orifice from a larger conduit or a reservoir. At this point the main or primary flow is detached from the solid boundaries, and vortices or recirculating secondary flow patterns are formed in the intervening space.

4. Summary of Test Method

4.1 This test method produces a submerged cavitating jet which impinges upon a stationary specimen, also submerged, causing cavitation bubbles to collapse on that specimen and thereby to erode it. This test method generally utilizes a commercially available positive displacement pump fitted with a hydraulic accumulator to damp out pulsations. The pump delivers test liquid through a small sharp-entry cylindrical-bore nozzle, which discharges a jet of liquid into a chamber at a controlled pressure. Cavitation starts in the vena contracta region of the jet within the length of the nozzle; it is stabilized by the cylindrical bore and it emerges, appearing to the eye as a cloud which is visible around the submerged liquid jet. A button type specimen is placed in the path of the jet at a specified stand-off distance from the entry edge of the nozzle. Cavitation bubbles collapse on the specimen, thus causing erosion. Both the upstream and the downstream chamber pressures and the temperature of the discharging liquid must be controlled and monitored. The test specimen is weighed accurately before testing begins and again during periodic interruptions of the test, in order to obtain a history of mass loss versus time (which is not linear). Appropriate interpretation of the cumulative erosion-time curve derived from these measurements permits comparisons to be drawn between different materials, different test conditions, or between different liquids. A typical test rig can be built using a 2.5-kW pump capable of producing 21-MPa pressure. The standard nozzle bore diameter is 0.4 mm, but this may be changed if required for specialized tests.

5. Significance and Use

5.1 This test method may be used to estimate the relative resistances of materials to cavitation erosion, as may be encountered for instance in pumps, hydraulic turbines, valves, hydraulic dynamometers and couplings, bearings, diesel engine cylinder liners, ship propellers, hydrofoils, internal flow passages, and various components of fluid power systems or fuel systems of diesel engines. It can also be used to compare erosion produced by different liquids under the conditions simulated by the test. Its general applications are similar to those of Test Method G32.

5.2 In this test method cavitation is generated in a flowing system. Both the velocity of flow which causes the formation of cavities and the chamber pressure in which they collapse can be changed easily and independently, so it is possible to study the effects of various parameters separately. Cavitation conditions can be controlled easily and precisely. Furthermore, if tests are performed at constant cavitation number (σ), it is possible, by suitably altering the pressures, to accelerate or slow down the testing process (see 11.2 and Fig. A2.2).

5.3 This test method with *standard conditions* should not be used to rank materials for applications where electrochemical corrosion or solid particle impingement plays a major role. However, it could be adapted to evaluate erosion-corrosion effects if the appropriate liquid and cavitation number, for the service conditions of interest, are used (see 11.1).

5.4 For metallic materials, this test method could also be used as a screening test for applications subjected to high-speed liquid drop impingement, if the use of Practice G73 is not feasible. However, this is not recommended for elastomeric coatings, composites, or other nonmetallic aerospace materials.

5.5 The mechanisms of cavitation erosion and liquid impingement erosion are not fully understood and may vary, depending on the detailed nature, scale, and intensity of the liquid/solid interactions. Erosion resistance may, therefore, arise from a mix of properties rather than a single property, and has not yet been successfully correlated with other independently measurable material properties. For this reason, the consistency of results between different test methods (for example, vibratory, rotating disk, or cavitating jet) or under different experimental conditions is not very good. Small differences between two materials are probably not significant, and their relative ranking could well be reversed in another test.

5.6 Because of the nonlinear nature of the erosion-time curve in cavitation erosion, the shape of that curve must be considered in making comparisons and drawing conclusions. Simply comparing the cumulative mass loss at the same cumulative test time for all materials will not give a reliable comparison.

6. Apparatus

6.1 *General Arrangement*:

6.1.1 Fig. 1 shows an arrangement of the test chamber. A cavitating jet supplied from a constant pressure source (p_u) discharges, through a long-orifice nozzle (Fig. 2), into a chamber held at specified constant pressure (p_d). A flat-ended cylindrical specimen (Fig. 3) is mounted coaxially with the