Designation: G 40 – 02

Standard Terminology Relating to Wear and Erosion[1]

This standard is issued under the fixed designation G 40; 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 The terms and their definitions given herein represent terminology relating to wear and erosion of solid bodies due to mechanical interactions such as occur with cavitation, impingement by liquid jets or drops or by solid particles, or relative motion against contacting solid surfaces or fluids. This scope interfaces with but generally excludes those processes where material loss is wholly or principally due to chemical action and other related technical fields as, for instance, lubrication.

1.2 This terminology is not exhaustive; the absence of any particular term from this collection does not necessarily imply that its use within this scope is discouraged. However, the terms given herein are the recommended terms for the concepts they represent unless otherwise noted.

1.3 Certain general terms and definitions may be restricted and interpreted, if necessary, to make them particularly applicable to the scope as defined herein.

1.4 The purpose of this terminology is to encourage uniformity and accuracy in the description of test methods and devices and in the reporting of test results in relation to wear and erosion.

NOTE 1—All terms are listed alphabetically. When a subsidiary term is defined in conjunction with the definition of a more generic term, an alphabetically-listed cross-reference is provided.

2. Referenced Documents

2.1 *ASTM Standards:*

C 242 Terminology of Ceramic Whitewares and Related Products[2]

3. Terminology

abrasive wear, *n*—wear due to hard particles or hard protuberances forced against and moving along a solid surface.

abrasion-corrosion, *n*—a synergistic process involving both abrasive wear and corrosion in which each of these processes is affected by the simultaneous action of the other and, in many cases, is thereby accelerated.

abrasivity, *n*—the ability of a material or substance to cause abrasive wear.

absolute impact velocity— See **impact velocity**.

acceleration period, *n*— *in cavitation and liquid impingement erosion*, the stage following the incubation period during which the erosion rate increases from near zero to a maximum value. (See also **erosion rate-time pattern.**)

accumulation period, *n*— *in cavitation and liquid impingement erosion*, a less-preferred term for **acceleration period**.

adhesive wear, *n*—wear due to localized bonding between contacting solid surfaces leading to material transfer between the two surfaces or loss from either surface.

angle of attack, *n*— *in impingement erosion*, the angle between the direction of motion of an impinging liquid or solid particle and the tangent to the surface at the point of impact.

angle of incidence, *n*— *in impingement erosion*, the angle between the direction of motion of an impinging liquid or solid particle and the normal to the surface at the point of impact.

apparent area of contact, *n*—*in tribology*, the area of contact between two solid surfaces defined by the boundaries of their macroscopic interface. (Contrast with **real area of contact**.)

asperity, *n*—*in tribology*, a protuberance in the small-scale topographical irregularities of a solid surface.

attenuation period, *n*— *in cavitation and liquid impingement erosion*, a less-preferred term for **deceleration period**.

average erosion rate, *n*—a less preferred term for **cumulative erosion rate.**

Beilby layer, *n*—an altered surface layer of supposedly amorphous material formed on a crystalline solid during mechanical polishing, whose existence was proposed in Sir George Beilby's writings. The existence of such a layer is not supported by recent research, and the use of this term is therefore considered archaic and is strongly discouraged.

break-in, *n*—See **run-in**.

break in, *v*—See **run in**.

brinelling, *n*—damage to a solid bearing surface characterized by one or more plastically formed indentations caused by static or impulsive overloads, especially as found in rolling contact bearings. (See also **false brinelling**.)

brittle erosion behavior, *n*—erosion behavior having characteristic properties that can be associated with brittle fracture

[1] This terminology is under the jurisdiction of ASTM Committee G02 on Wear and Erosion and is the direct responsibility of Subcommittee G02.91 on Terminology.

Current edition approved Oct. 10, 2002. Published December 2002. Originally approved in 1973. Last previous edition approved in 2001 as G 40 – 01.

[2] *Annual Book of ASTM Standards*, Vol 15.02.

of the exposed surface; that is, little or no plastic flow occurs, but cracks form that eventually intersect to create erosion fragments. (See also **ductile erosion behavior**.)

DISCUSSION—In solid impingement an easily observable aspect of erosion helps to distinguish brittle from ductile behavior. This is the manner in which volume removal varies with the angle of attack. With brittle erosion the maximum volume removal occurs at an angle near 90°, in contrast to approximately 25° for ductile erosion behavior.

carrier fluid, *n— in impingement or slurry erosion*, fluid medium that transports impinging solid or liquid particles and that gives the particles their momentum relative to the solid surface on which they are impinging.

catastrophic period, *n— in cavitation or liquid impingement erosion*, a stage during which the erosion rate increases so drastically that continued exposure threatens or causes gross disintegration of the exposed surface. This stage is not inevitable; it is observed most commonly with some brittle materials. When it does occur, it may begin during any stage of the more common erosion rate-time pattern.

catastrophic wear, *n*—rapidly occurring or accelerating surface damage, deterioration, or change of shape caused by wear to such a degree that the service life of a part is appreciably shortened or its function is destroyed.

cavitating disk device (or apparatus), *n*—a flow cavitation test device in which cavitating wakes are produced by holes in, or protuberances on, a disk rotating within a liquid-filled chamber. Erosion test specimens are attached flush with the surface of the disk, at the location where the bubbles are presumed to collapse.

cavitating jet, *n*—a continuous liquid jet (sometimes submerged) in which cavitation is induced by the nozzle design, or sometimes by an obstruction placed in the center of the flow passage.

cavitating wake, n— See **flow cavitation**.

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

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

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.

cavitation cloud, *n*—a collection of a large number of cavitation bubbles. The bubbles in a cloud are small, typically less than 1 mm (0.04 in.) in cross section. A surface that is being eroded by cavitation is usually obscured by a cavitation cloud.

cavitation damage, n— See **damage**.

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

cavitation erosion test, *n*—a procedure whereby the surface of a solid is subjected to cavitation attack under specified, or measurable, or at least repeatable conditions.

DISCUSSION—Such tests can be divided into two major classes depending on whether flow cavitation or vibratory cavitation is generated.

cavitation number, σ, *n*—a dimensionless number that measures the tendency for cavitation to occur in a flowing stream of liquid, and that is computed from the equation:

$$\sigma = \left(P_o - P_v \right) / \frac{1}{2} \rho V_o^2 \quad (1)$$

where:

P_v = vapor pressure,
P_o = static pressure in the stream in an undisturbed state,
V_o = undisturbed stream velocity, and
ρ = liquid density.

DISCUSSION—The cavitation number and the net positive suction head (NPSH) are related by the equation:

$$\text{NPSH} = (\sigma + 1) V_o^2 / 2g \quad (2)$$

where g is the acceleration due to gravity.

cavitation tunnel, *n*—a flow cavitation test facility in which liquid is pumped through a pipe or tunnel, and cavitation is induced in a test section by conducting the flow through a constriction, or around an obstacle, or a combination of these.

coefficient of friction *μ or f, n—in tribology*, the dimensionless ratio of the friction force (F) between two bodies to the normal force (N) pressing these bodies together. (See also **static coefficient of friction** and **kinetic coefficient of friction**.)

$$\mu = (F/N) \quad (3)$$

collection efficiency, *n— in impingement erosion and particulate flows*, the cross-sectional area of undisturbed fluid containing particles that will all ultimately impinge on a given solid surface, divided by the projected area of the solid surface, where these two areas are perpendicular to the direction of relative motion between the solid surface and the particles in the undisturbed fluid.

DISCUSSION—"Undisturbed fluid" means fluid that is sufficiently ahead of the solid surface to be undisturbed by the flow around the solid surface. For example, the particles could be carried in a stream of fluid moving toward a solid surface that is stationary, or the solid surface could be moving through a suspension of particles. Not all of the particles that move in the direction of the solid surface or lie in its path will impinge upon it, since some will be carried away in the fluid as it flows around the surface.

DISCUSSION—A variety of terms having the same meaning can be found in the literature. These include "collision efficiency," "capture efficiency," "catchment efficiency," "impaction ratio," and others. The term "collection efficiency," being perhaps the most widely used, is preferred.

continuous jet, n— See **liquid jet**.

corrosive wear, *n*—wear in which chemical or electrochemical reaction with the environment is significant.

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**.)

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.

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**)

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.

cutting wear, *n— in solid impingement erosion*, the erosive wear associated with the dissipation of kinetic energy of impact arising from the tangential component of the velocity of the impacting particles.

DISCUSSION—Since erosion due to oblique particle impact inevitably involves *deformation wear* as well as cutting wear, the magnitude of the cutting wear can be experimentally determined by conducting a separate test at normal impact to determine the deformation wear, and subtracting that from the total wear at any angle of impact, where both tests are conducted with the same *normal* component of impact velocity and both results are normalized to the mass of impacting particles. See also related terms **deformation wear, ductile erosion behavior**, and **brittle erosion behavior**.

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.

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.

debris, *n—in tribology*, particles that have become detached in a wear or erosion process.

deceleration period, *n— in cavitation or liquid impingement erosion*, the stage following the acceleration period or the maximum rate period (if any) during which the erosion rate has an overall decreasing trend although fluctuations may be superimposed on it. (See also **erosion rate-time pattern.**)

deformation wear, *n— in solid impingement erosion*, the erosive wear of a material associated with the dissipation of kinetic energy of impact arising from the normal component of the velocity of the impacting particles. It is therefore the sole component of wear for particles impacting at a 90° angle of attack.

DISCUSSION—This term is used for the erosion of brittle materials, even though plastic deformation is lacking. See also related terms **brittle erosion behavior, ductile erosion behavior**, and **cutting wear**.

distributed impact test, *n— in impingement erosion testing*, an apparatus or method that produces a spatial distribution of impacts by liquid or solid bodies over an exposed surface of a specimen.

DISCUSSION—Examples of such tests are those employing liquid sprays or simulated rainfields. If the impacts are distributed uniformly over the surface, the term "uniformly distributed impact test" may be used. (Contrast with **repetitive impact erosion test**.)

drop, liquid, *n*—see **liquid drop**.

drop size, *n*—the diameter of a liquid drop if it is approximately spherical; otherwise, the approximate shape and appropriate dimensions must be described.

DISCUSSION—In a spray or rainfall, there will normally be a spectrum of drop sizes, which can be presented by distribution curves or histograms, showing either number of drops or combined volume of drops as a function of drop size. A representative drop size for a distribution is afforded by the sauter mean diameter, or else by the size interval containing the largest total volume.

ductile erosion behavior, *n*—erosion behavior having characteristic properties that can be associated with ductile fracture of the exposed solid surface; that is, considerable plastic deformation precedes or accompanies material loss from the surface which can occur by gouging or tearing or by eventual embrittlement through work hardening that leads to crack formation. (See also **brittle erosion behavior**.)

DISCUSSION—In solid impingement, two easily observable aspects of erosion help to distinguish ductile erosion behavior. The first is the manner in which volume removal varies with the angle of attack. Ductile materials show maximum volume removal for angles from approximately 20 to 30°, in contrast to near 90° for brittle erosion behavior. A second indication of ductile behavior is the characteristic ripple pattern that forms on the exposed surface at low values of angle of attack.

erosion, *n—in tribology*, 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.

DISCUSSION—Because of the broad scope of this term, it is recommended that it normally be qualified to indicate the relevant mechanism or context, for example, cavitation erosion, liquid impingement erosion, solid impingement erosion, beach erosion, and so forth.

erosion-corrosion, *n*—a synergistic process involving both erosion and corrosion, in which each of these processes is affected by the simultaneous action of the other, and in many cases is thereby accelerated.

erosion rate, *n*—any determination of the rate of loss of material (erosion) with exposure duration. (See also **rationalized erosion rate**.)

DISCUSSION—Erosion rate is usually determined as a slope on the cumulative erosion-time curve. Since in cavitation or liquid impingement this curve is generally not a straight line, it is necessary to specify how any particular numerical value was determined from this curve. The following more explicit terms may be used: average erosion rate, instantaneous erosion rate, interval erosion rate, maximum erosion rate, and terminal erosion rate. See individual definitions of these terms.

erosion rate-time curve, *n*—a plot of instantaneous erosion rate versus exposure duration, usually obtained by numerical or graphical differentiation of the cumulative erosion-time curve. (See also **erosion rate-time pattern**.)

erosion rate-time pattern, *n*—any qualitative description of the shape of the erosion rate-time curve in terms of the several stages of which it may be composed.

DISCUSSION—In cavitation and liquid impingement erosion, a typical pattern may be composed of all or some of the following "periods" or "stages": **incubation period, acceleration period, maximum-rate period, deceleration period, terminal period**, and occasionally **catastrophic period**. The generic term "period" is recommended when associated with quantitative measures of its duration, and so forth; for purely qualitative descriptions the term "stage" is preferred.

exposure duration, *n*— *in erosion or wear*, exposure time, or any other appropriate measure of the accumulation of exposure to an erosion or wear environment.

DISCUSSION—For impingement erosion, some alternative duration parameters are the number of impacts that have occurred on a given point, or the mass or volume of particles that have impinged on a unit area of exposed surface. For wear, it may be the sliding distance traveled.

false brinelling, *n*—damage to a solid bearing surface characterized by indentations not caused by plastic deformation resulting from overload but thought to be due to other causes such as *fretting corrosion*. (See also **brinelling**.)

fatigue wear, *n*—wear of a solid surface caused by fracture arising from material fatigue.

flow cavitation, *n*—cavitation caused by a decrease in static 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.

fretting, *n*—*in tribology*, small amplitude oscillatory motion, usually tangential, between two solid surfaces in contact.

DISCUSSION—Here the term *fretting* refers only to the nature of the motion without reference to the wear, corrosion, or other damage that may ensue. The term *fretting* is often used to denote *fretting corrosion* and other forms of *fretting wear*. Usage in this sense is discouraged due to the ambiguity that may arise.

fretting corrosion, *n*—a form of fretting wear in which corrosion plays a significant role.

fretting wear, *n*—wear arising as a result of fretting (see **fretting**).

friction force, *n*—the resisting force tangential to the interface between two bodies when, under the action of an external force, one body moves or tends to move relative to the other. (See also **coefficient of friction**.)

galling, *n*—a form of surface damage arising between sliding solids, distinguished by macroscopic, usually localized, roughening and creation of protrusions above the original surface; it often includes plastic flow or material transfer or both.

DISCUSSION—The onset of galling usually requires that the contact pressure exceeds some threshold value. Galling can be a precursor to seizing or loss of function. The identification of galling is somewhat subjective, and complete agreement does not exist, even among experts.

hard particle erosion, *n*—deprecated term; use the preferred synonyms *solid impingement erosion* or *solid particle erosion.*

Hertzian contact area, *n*—the apparent area of contact between two nonconforming solid bodies pressed against each other, as calculated from Hertz' equations of elastic deformation.

Hertzian contact pressure, *n*—the magnitude of the pressure at any specified location in a Hertzian contact area, as calculated from Hertz' equations of elastic deformation.

impact angle, *n*— *in impingement erosion*, an angle that could be either the **angle of attack** or the **angle of incidence**, which see. Because of this ambiguity, this term should be specially defined when used or, preferably, used only in contexts where the ambiguity does not matter.

impact velocity, *n*— *in impingement erosion*, the relative velocity between the surface of a solid body and an impinging liquid or solid particle.

DISCUSSION—To describe this velocity completely, it is necessary to specify the direction of motion of the particle relative to the solid surface in addition to the magnitude of the velocity. The following related terms are also in use:

(*1*) absolute impact velocity—the magnitude of the impact velocity.

(*2*) normal impact velocity—the component of the impact velocity that is perpendicular to the surface of the test solid at the point of impact.

impact wear, *n*—wear due to collisions between two solid bodies where some component of the motion is perpendicular to the tangential plane of contact.

impingement, *n*— *in tribology*, a process resulting in a continuing succession of impacts between (liquid or solid) particles and a solid surface.

DISCUSSION—In preferred usage, "impingement" also connotes that the impacting particles are smaller than the solid surface, and that the impacts are distributed over that surface or a portion of it. If all impacts are superimposed on the same point or zone, then the term "repeated impact" is preferred.

In other contexts, the term "impingement" sometimes has different meanings, as in the steady-state impingement of a liquid stream against a solid body, or in "impingement corrosion." The definition given here applies in the context of Committee G02's scope.

impingement attack, *n*—deprecated term for **impingement corrosion**. (The latter term is preferred so as to avoid confusion with **liquid impingement erosion**.)

impingement corrosion, *n*—a form of erosion-corrosion generally associated with the impingement of a high-velocity, flowing liquid containing air bubbles against a solid surface.

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.)

instantaneous erosion rate, *n*—the slope of a tangent to the cumulative erosion-time curve at a specified point on that curve.

interval erosion rate, *n*—the slope of a line joining two specified points on the cumulative erosion-time curve.

jet, liquid, n— See **liquid jet**.

jet segment, n— See **liquid jet**.

kinetic coefficient of friction, *n*— the coefficient of friction under conditions of macroscopic relative motion between two bodies.

liquid drop, *n*—a small body of liquid held together primarily by surface tension.

liquid impingement, *n*—impingement by liquid particles.

liquid impingement damage, n—See **damage**.

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

liquid jet, *n*—a body of liquid projected into motion, usually of approximately cylindrical shape, such as could be produced by discharging the liquid through an orifice. In liquid impingement testing two kinds of liquid jet are used:

(*1*) continuous jet—a continuous flow of liquid in the form of a jet.

(*2*) slug, or jet segment—a body of liquid projected into motion, in the form approximately of a finite cylinder whose length is usually no more than several times its diameter and which moves in a direction approximately parallel to its length.

lubricant, *n*—any material interposed between two surfaces that reduces the friction or wear between them.

magnetostrictive cavitation test device, *n*—a vibratory cavitation test device driven by a magnetostrictive transducer.

mass concentration, *n— in multi-component or multi-phase mixtures*, the mass of a specified component or phase per unit mass or unit volume of the total. (See also **particle concentration**.)

DISCUSSION—Since this term has been used both in a nondimensional sense (mass per unit mass) and in a dimensional sense (mass per unit volume) it is important to make clear in which sense it is used and which units apply in the latter case.

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**.)

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.

maximum rate period, *n— in cavitation and liquid impingement erosion*, a stage following the acceleration period, during which the erosion rate remains constant (or nearly so) at its maximum value. (See also **erosion rate-time pattern**.)

mean depth of erosion, *n— in cavitation and impingement erosion*, the average thickness of material eroded from a specified surface area, usually calculated by dividing the measured mass loss by the density of the material to obtain the volume loss and dividing that by the area of the specified surface. (Also known as *mean depth of penetration* or *MDP*. Since that might be taken to denote the average value of the depths of individual pits, it is a less preferred term.)

mean depth of penetration, n—See **mean depth of erosion.**

net positive suction head, NPSH, *n*— the difference between total pressure and vapor pressure in a fluid flow, expressed in terms of equivalent height of fluid, or "head," by the equation:

$$\mathrm{NPSH} = (P_o/w) + (V^2/2g) - (P_v/w) \tag{4}$$

where:

P_o = static pressure,
P_v = vapor pressure,
V = flow velocity,
w = specific weight of fluid, and
g = gravitational acceleration.

This quantity is used in pump design as a measure of the tendency for cavitation to occur at the pump inlet. It can be related to the cavitation number.

nominal contact pressure, $[FL^{-2}]$ **,** *n—in tribology*, an average contact pressure between two conforming bodies, calculated by dividing the contact force by the **apparent area of contact**.

normal impact velocity, n—See **impact velocity**.

normalized erosion resistance, N_e**,** *n*—the volume loss rate of a test material, divided into the volume loss rate of a specified reference material similarly tested and similarly analyzed. "Similarly analyzed" means 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.

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)."

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

particle concentration, *n*—a measure of the liquid or solid particle content in a mixture of particles and fluid. The following more specific terms are in use:

(*1*) rain density—the mass of liquid per unit volume of mixture in an actual or simulated rainfield.

(*2*) solids loading ratio—the mass of solid particles per unit volume of mixture in a solid impingement environment.

(*3*) volume concentration—the volume of the liquid or solid particles per unit volume of mixture.

(*4*) quality—the mass of vapor phase per unit mass of a liquid-vapor two-phase single-component fluid.

(*5*) mass concentration—which see.

pitting, *n—in tribology*, a form of wear characterized by the presence of surface cavities the formation of which is attributed to processes such as fatigue, local adhesion, or cavitation.

plowing, *n—in tribology*, the formation of grooves by plastic deformation of the softer of two surfaces in relative motion.

pulsed cavitation test, *n*—a test using a vibratory cavitation device in which the cavitation is generated intermittently, with alternating vibratory periods and quiescent periods of controlled relative duration.

DISCUSSION—Such tests are longer than the other vibratory tests and thus approach more closely the time scale of real cavitation erosion.

Such tests are useful in investigating chemical effects in cavitation erosion, because the cavitation pulses can remove protective surface films and expose the surface to chemical attack during the quiescent periods.

PV limit, *n—in tribology*, the upper value of a load-bearing material's PV product above which a material fails to function satisfactorily. (See also **PV product**.)

DISCUSSION—PV limits are usually determined experimentally or from service experience.

PV product, *n*—**in tribology**, the product of the nominal contact pressure on a load-bearing surface and the relative surface velocity between the load-bearing material and its conterface. (See also **PV limit**.)

DISCUSSION—Several units have been used for reporting the PV product $(F \cdot L^{-2}) \cdot (L \cdot T^{-1})$. Historically, these have included psi-ft/min and MPa-m/s.

quality, *n*—See **particle concentration**.

rain density, *n*— See **particle concentration**.

rationalized erosion rate, *n—in liquid impingement erosion*, an erosion rate for impingement tests expressed in dimensionless form as follows: the volume of material lost per unit volume of (liquid or solid) particles impinging, both determined for the same area.

real area of contact, *n— in tribology*, the sum of the local areas of contact between two solid surfaces, formed by contacting asperities, that transmit the interfacial force between the two surfaces. (Contrast with **apparent area of contact**.)

repetitive impact erosion test, *n—in impingement erosion testing*, an apparatus or method that produces a controlled or countable number of impacts by liquid or solid particles of uniform size, shape, and impact velocity, all on the same location of the test specimen. One example of such a test is the "wheel-and-jet" type of liquid impact apparatus.

rolling contact fatigue, *n*—a damage process in a triboelement subjected to repeated rolling contact loads, involving the initiation and propagation of fatigue cracks in or under the contact surface, eventually culminating in surface pits or spalls.

rolling wear, *n*—wear due to the relative motion between two non-conforming solid bodies whose surface velocities in the nominal contact location are identical in magnitude, direction, and sense.

DISCUSSION—Rolling wear is not a synonym for rolling contact fatigue, although the latter can be considered one form of rolling wear.

run-in, *n—in tribology*, an initial transition process occurring in newly established wearing contacts, often accompanied by transients in coefficient of friction, or wear rate, or both, which are uncharacteristic of the given tribiological system's long term behavior. (*Synonym:* **break-in, wear-in.**)

run in, *v—in tribology*, to apply a specified set of initial operating conditions to a tribological system to improve its long term frictional or wear behavior, or both. (*Synonym:* **break in,** *v.* and **wear in,** *v*. See also **run-in,** *n:*)

sauter mean diameter, SMD [L]**,** *n*—the diameter of a drop that has the same ratio of volume to surface area as the ratio of total volume to total surface area in a distribution of drops, as computed from the equation:

$$\text{SMD} = \Sigma_i n_i d_i^{\,3} / \Sigma_i n_i d_i^{\,2} \quad (5)$$

where:

i = a sampling size interval,
d_i = drop diameter, and
n_i = number of drops in that interval.

scoring, *n—in tribology*, a severe form of wear characterized by the formation of extensive grooves and scratches in the direction of sliding.

scratching, *n—in tribology*, the mechanical removal or displacement, or both, of material from a surface by the action of abrasive particles or protuberances sliding across the surfaces. (See also **plowing**.)

scuffing—*n*, a form of wear occurring in inadequately lubricated tribosystems that is characterized by macroscopically-observable changes in surface texture, with features related to the direction of relative motion.

DISCUSSION—Features charateristic of scuffing include scratches, plastic deformation, and transferred material. (Related terms: **galling, scoring**.)

single-impact damage, *n*—See **damage**.

sliding wear, *n*—wear due to the relative motion in the tangential plane of contact between two solid bodies.

slug, *n*—See **liquid jet**.

slurry, *n*—a suspension of solid material in liquid **(C 242)**

solid impingement, *n*—impingement by solid particles.

solid impingement erosion, *n*—progressive loss of original material from a solid surface due to continued exposure to impacts by solid particles. (*Synonym:* **solid particle erosion, hard particle erosion**.)

solid particle erosion, *n*—Synonym for *solid impingement erosion.*

solids loading ratio, *n*—See **particle concentration**.

spalling, *n—in tribology*, the separation of macroscopic particles from a surface in the form of flakes or chips, usually associated with rolling element bearings and gear teeth, but also resulting from impact events.

specific energy for cutting wear [$M\ L^{-1}\ T^{-2}$], *n—in solid impingement erosion*, the kinetic energy of impinging particles associated with removal of unit volume of target material by cutting wear.

specific energy for deformation wear [$M\ L^{-1}\ T^{-2}$], *n—in solid impingement erosion*, the kinetic energy of impinging particles associated with removal of unit volume of target material by deformation wear.

specific wear rate, *n*— see **wear factor**.

static coefficient of friction, *n*— the coefficient of friction corresponding to the maximum friction force that must be overcome to initiate macroscopic motion between two bodies.

stick-slip, *n—in tribology*, a cyclic fluctuation in the magnitudes of friction force and relative velocity between two elements in sliding contact, usually associated with a relaxation oscillation dependent on elasticity in the tribosystem and on a decrease of the coefficient of friction with onset of sliding or with increase of sliding velocity.

DISCUSSION—*Classical* or true stick-slip, in which each cycle consists

of a stage of actual *stick* followed by a stage of overshoot "slip," requires that the kinetic coefficient of friction is lower than the static coefficient. A modified form of relaxation oscillation, with near-harmonic fluctuation in motion, can occur when the kinetic coefficient of friction decreases gradually with increasing velocity within a certain velocity range. A third type of stick-slip can be due to spacial periodicity of the friction coefficient along the path of contact. Random variations in friction force measurerment do not constitute stick-slip.

stiction, *n—in tribology*, a force between two solid bodies in nominal contact, acting without the need for an external normal force pressing them together, which can manifest itself by resistance to tangential motion as well as resistance to being pulled apart.

DISCUSSION—Stiction, in some cases, has been attributed to meniscous/viscous or microcapillary effects, also referred to as "liquid-mediated adhesion." Use of the term stiction is discouraged. See also **static friction**.

surface topography, *n*—the geometrical detail of a solid surface, relating particularly to microscopic variations in height.

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

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**.)

terminal period, *n— in cavitation or liquid impingement erosion*, a stage following the deceleration period, during which the erosion rate has levelled off and remains approximately constant (sometimes with superimposed fluctuations) at a value substantially lower than the maximum rate attained earlier. This occurs in some, but not all, cavitation and liquid impingement tests. (See also **erosion rate-time pattern**.)

three-body abrasive wear, *n*—a form of abrasive wear in which wear is produced by loose particles introduced or generated between the contacting surfaces.

DISCUSSION—In tribology, loose particles are considered to be a "third body."

traction, *n—in tribology*, a physical process in which a tangential force is transmitted across the interface between two bodies through dry friction or an intervening fluid film, resulting in motion, reduction in motion, or the transmission of power.

traction coefficient, *n—in tribology*, the dimensionless ratio of the traction force transmitted between two bodies to the normal force pressing them together. (See also **traction** and **traction force**.)

triboelement, *n*—one of two or more solid bodies that comprise a sliding, rolling, or abrasive contact, or a body subjected to impingement or cavitation. (Each triboelement contains one or more **tribosurfaces**.)

DISCUSSION—Contacting triboelements may be in direct contact or may be separated by an intervening lubricant, oxide, or other film that affects tribological interactions between them.

tribology, *n*—the science and technology concerned with interacting surfaces in relative motion, including friction, lubrication, wear, and erosion.

tribosurface, *n*—any surface (of a solid body) that is in moving contact with another surface or is subjected to impingement or cavitation.

tribosystem, *n*—any system that contains one or more triboelements, including all mechanical, chemical, and environmental factors relevant to tribological behavior. (See also **triboelement**.)

two-body abrasive wear, *n*—a form of abrasive wear in which the hard particles or protuberances which produce the wear of one body are fixed on the surface of the opposing body.

ultimate resilience, R_u [FL^{-2}]**,** *n*—a material parameter defined by the equation:

$$R_u = S_u^2/2E \quad (6)$$

where:

S_u = ultimate tensile strength, and
E = elastic modulus, as determined from a conventional tension test.

DISCUSSION—This parameter has been suggested as a criterion of erosion resistance. A modification of this, the true ultimate resilience, may be defined as $[S_u/(1 - R_a/100)]^2/2E$, where R_a = reduction of area, %, in the tension test.

ultrasonic cavitation test device, *n*— a vibratory cavitation test device whose driving frequency is in the ultrasonic range, about 20 kHz or greater. (For lower frequencies, the term *vibratory cavitation test device* is preferred.)

vibratory cavitation, *n*—cavitation caused by the pressure fluctuations within a liquid, induced by the vibration of a solid surface immersed in the liquid.

vibratory cavitation test device, *n*— a device used to generate cavitation in a liquid through the vibrations of a solid surface in contact with the liquid. Usually such devices are driven at a frequency roughly in the range from 10 to 30 kHz by a magnetostrictive or a piezo-electric transducer.

DISCUSSION—Vibratory cavitation erosion test devices can be divided into two classes, according to whether the specimen itself is the vibrating body and generates cavitation adjacent to its surface, or whether the specimen is held stationary and cavitation is induced by other vibrating surfaces. Unless otherwise specified, the former is generally implied.

volume concentration— See **particle concentration**.

wear, *n*—damage to a solid surface, usually involving progressive loss of material, due to relative motion between that surface and a contacting substance or substances.

wear coefficient, *n— in tribology*, a wear parameter that relates sliding wear measurements to tribosystem parameters. Most commonly, but not invariably, it is defined as the dimensionless coefficient k in the equation

$$\text{wear volume} = k\left(\frac{\text{load} \times \text{sliding distance}}{\text{hardness of the softer material}}\right) \quad (7)$$

See also **wear factor**.

DISCUSSION—

(1) The equation given above is frequently referred to in the literature as "Archard's equation" or "Archard's law."

(2) Sometimes the term *wear coefficient* has been used as a synonym for **wear factor**. While this usage is discouraged, the term should always be fully defined in context to prevent confusion.

wear factor, *n*— *in tribology*, a wear parameter that relates sliding wear measurements to operating parameters. Most commonly, but not invariably, it is defined as the total wear volume divided by the normal force or load and also divided by the sliding distance; therefore, this term should always be fully defined in context.

DISCUSSION—Another term sometimes used synonymously, especially in the United Kingdom, is **specific wear rate**.

wear in, *v*—See **run in**.

wear in, *n*—See **run in**.

wear map, *n*—a calculated or experimentally determined diagram that identifies regions within each of which the wear mechanism or wear rate remains substantially the same, the regions being separated by transition lines or bands that are functions of two or more parameters.

DISCUSSION—

(1) Wear maps may be of two types: *wear mechanism maps* or *wear rate maps*. The first identifies regions within which the wear mechanism remains the same, and the transition between regions may or may not involve a step change in wear rate. The second identifies regions of substantially constant wear rate, wherein it is to be understood that transitions should involve a change in wear rate of at least a factor of ten.

(2) Usually, in two-dimensional diagrams, the coordinate parameters are load (in terms of force or contact pressure) and sliding velocity, possibly made non-dimensional by some normalizing procedure. However, these may be replaced by other parameters, for example temperature, or (for fretting wear) amplitude.

wear mechanism map, *n*— see **wear map**.

wear rate map, *n*— see **wear map**.

wear rate, *n*—the rate of material removal or dimensional change due to wear per unit of exposure parameter, for example, quantity of material removed (mass, volume, thickness) in unit distance of sliding or unit time.

DISCUSSION—Because of the possibility of confusion, the manner of computing *wear rate* should always be carefully specified. (See also **erosion rate**.)

welding, *n*—*in tribology*, the bonding between metallic surfaces in direct contact, at any temperature.