Abrasive Wear: The removal of material from a surface when hard particles slide or roll across the surface under pressure. The particles may be loose or may be part of another surface in contact with the surface being abraded. Compare with *adhesive wear.*

Accelerated Corrosion Test: Method designed to approximate, in a short time, the deteriorating effect under normal long-term service conditions.

Accelerated Testing: A test performed on material assemblies that are meant to produce failures caused by the same failure mechanism as expected in field operation but in significantly shorter time. The failure mechanism is accelerated by changing one or more of the controlling test parameters.

Acicular Ferrite: A highly sub structured none-quiaxed ferrite formed upon continuous cooling by a mixed diffusion and shear mode of transformation that begins at a temperature slightly higher than the transformation temperature range for upper bainite. It is distinguished from bainite in that it has a limited amount of carbon available; thus, there is only a small amount of carbide present.

Acoustic Emission: A measure of integrity of a material, as determined by sound emission when a material is stressed. Ideally, emissions can be correlated with defects and/or incipient failure.

Active: The negative direction of electrode potential; also used to describe corrosion and its associated potential range when an electrode potential is more negative than an adjacent depressed corrosion rate (passive) range.

Adhesive Wear: (1) Wear by transference of material from one surface to another during relative motion due to a process of solid-phase welding. Particles that are removed from one surface are either permanently or temporarily attached to the other surface. (2) Wear due to localized bonding between contacting solid surfaces leading to material transfer between the two surfaces or loss from either surface. Compare with *abrasive wear.*

Age Hardening: Hardening by aging (heat treatment) usually after rapid cooling or cold working.

Aging (Heat Treatment): A change in the properties of certain metals and alloys that occurs at ambient or moderately elevated temperatures after hot working or a heat treatment (quench aging in ferrous alloys, natural or artificial aging in ferrous and nonferrous alloys) or after a cold-working operation (strain aging). The change in properties is often, but not always, due to a phase change (precipitation), but never involves a change in chemical composition of the metal or alloy.

Air-Hardening Steel: A steel containing sufficient carbon and other alloying elements to harden fully during cooling in air or other gaseous media from a temperature above its transformation range. The term should be restricted to steels that are capable of being hardened by cooling in air in fairly large sections, about 50 mm (2 in.) or more in diameter, the same as self-hardening steel.

Alclad: Composite wrought product comprised of an aluminum alloy core having one or both surfaces a metallurgically bonded aluminum or aluminum alloy coating that protects the core against corrosion.

Allotropy: (1) A near synonym for polymorphism. Allotropy is generally restricted to describing polymorphic behavior in elements, terminal phases, and alloys whose behavior closely parallels that of the predominant constituent element. (2) The existence of a substance, especially an element, in two or more physical states (for example, crystals).

Alloy: (1) A substance having metallic properties and being composed of two or more chemical elements of which at least one is a metal. (2) To make & melt an alloy.

Alloy Cast Iron: Highly alloyed cast irons containing more than 3% alloy content. Alloy cast irons may be of a type of white iron, gray iron, or ductile iron.

Alloying Element: An element added to and remaining in a metal that changes structure and properties.

Alloy Steel: Steel containing specified quantities of alloying elements (other than carbon and the commonly accepted amounts of manganese, copper, silicon, sulfur, and phosphorus) within the limits recognized for constructional alloy steels, added to effect changes in mechanical or physical properties.

Alpha Brass: A solid-solution phase of one or more alloying elements in copper having the same crystal lattice as copper.

Alpha Iron: The body-centered cubic form of pure iron, stable below 910 °C (1670 °F).

Amorphous: Not having a crystal structure; noncrystalline.

Amorphous Solid: A rigid material whose structure lacks crystalline periodicity; that is, the pattern of its constituent atoms or molecules does not repeat periodically in three dimensions. See also *metallic glass.*

Angstrom (unit): A unit of linear measure equal to $1*10^{-10}$m, or 0.1 nm (nanometer), sometimes used to express small distances such as inter-atomic distances and some wavelengths.

Anisotropy: The characteristic of exhibiting different values of a property in different directions with respect to a fixed reference system in the material.

Annealing: A generic term denoting a treatment consisting of heating to and holding at a suitable temperature followed by cooling at a suitable rate, used primarily to soften metallic materials, but also to simultaneously produce desired changes in other properties or in microstructure. The purpose of such changes may be, but is not confined to: improvement of machinability, facilitation of cold work, improvement of mechanical or electrical properties, and/or increase in stability of dimensions. When the term is used unqualifiedly, full annealing is implied. When applied only for the relief of stress, the process is properly called stress relieving or stress-relief annealing. In ferrous alloys, annealing usually is done above the upper critical temperature, but the time-temperature cycles vary widely both in maximum temperature attained and in cooling rate employed, depending on composition, material condition, and results desired. When applicable, the following commercial process names should be used: black annealing, blue annealing, box annealing, bright annealing, cycle annealing, flame annealing, full annealing, graphitizing, in-process annealing, isothermal annealing, malleabilizing, orientation

annealing, process annealing, quench annealing, spheroidizing, subcritical annealing. In nonferrous alloys, annealing cycles are designed to: (a) remove part or all of the effects of cold working (recrystallization may or may not be involved); (b) cause substantially complete coalescence of precipitates from solid solution in relatively coarse form; or (c) both, depending on composition and material condition. Specific process names in commercial use are final annealing, full annealing, intermediate annealing, partial annealing, recrystallization annealing, stress-relief annealing, anneal to temper.

Anode: (1) The electrode of an electrolyte cell at which oxidation occurs. Electrons flow away from the anode in the external circuit. It is usually at the electrode that corrosion occurs and metal ions enter solution. (2) The positive (electron-deficient) electrode in an electrochemical circuit. Contrast with *cathode.*

Anodizing: Forming a conversion coating on a metal surface by anodic oxidation; most frequently applied to aluminum.

Apparent Density: (1) The weight per unit volume of a powder, in contrast to the weight per unit volume of the individual particles. (2) The weight per unit volume of a porous solid, where the unit volume is determined from external dimensions of the mass. Apparent density is always less than the true density of the material itself.

Ar_{cm}, Ar_1, Ar_3, Ar_4 , Ar', Ar": Defined under *transformation temperature.*

Arc Strike: A discontinuity consisting of any localized remelted metal, heat-affected metal, or change in the surface profile of any part of a weld or base metal resulting from an arc.

Arc Welding: A group of welding processes that produce coalescence of metals by heating them with an arc, with or without the application of pressure, and with or without the use of filler metal.

Argon Oxygen Decarburization (AOD): A secondary refining process for the controlled oxidation of carbon in a steel melt. In the AOD process, oxygen, argon, and nitrogen are injected into a molten metal bath through submerged, side-mounted tuyeres.

Artifact: A feature of artificial character, such as a scratch or a piece of dust on a metallographic specimen that can be erroneously interpreted as a real feature.

Artificial Aging: Aging above room temperature. See *aging (heat treatment).* Compare with *natural aging.*

As-Cast Condition: Castings as removed from the mold without subsequent heat treatment.

Atmospheric Corrosion: The gradual degradation or alteration of a material by contact, with substances present in the atmosphere, such as oxygen, carbon dioxide, water vapor, and sulfur and chlorine compounds.

Austempered Ductile Iron: A moderately alloyed ductile iron that is austempered for high strength with appreciable ductility. See also *austempering.*

Austempering: A heat treatment for ferrous alloys in which a part is quenched from the austenitizing temperature at a rate fast enough to avoid formation of ferrite or pearlite and then held at a temperature just above M, until transformation to bainite is complete. Although designated as bainite in both austempered steel and austempered ductile iron (ADI), austempered steel consists of two phase mixtures containing ferrite and carbide, while austempered ductile iron consists of two phase mixtures containing ferrite and austenite.

Austenite: A solid solution of one or more elements in face-centered cubic iron (gamma iron). Unless otherwise designated (such as nickel austenite), the solute is generally assumed to be carbon.

Austenitic Grain Size: The size attained by the grains in steel when heated to the austenitic region. This may be revealed by appropriate etching of cross sections after cooling to room temperature.

A**ustenitic Manganese Steel:** A wear-resistant material containing about 1.2% C and 12% Mn. Used primarily in the fields of earthmoving, mining, quarrying, railroading, ore processing, lumbering, and in the manufacture of cement and clay products. Also known as Hadfield steel.

Austenitic Stainless steel: Stainless steel whose structure is normally austenitic at room temperature. The most common grade is the 1818 or 304 grade which contains 18% chromium and 8% nickel

Austenitizing: Forming austenite by heating a ferrous alloy into the transformation range (partial austenitizing) or above the transformation range (complete austenitizing). When used without qualification, the term implies complete austenitizing

A**utogenous weld**: A fusion weld made without the addition of filler metal.

Babbitt metal: A nonferrous bearing alloy originated by Isaac Babbitt in 1839. Currently, the term includes several tin-base alloys consisting mainly of various amounts of copper, antimony, tin, and lead. Lead base Babbitt metals are also used.

Back gouging: The removal of weld metal and base metal from the other side of a partially welded joint to facilitate complete fusion and complete joint penetration upon subsequent welding from that side.

Bainite: A metastable aggregate of ferrite and cementite resulting from the transformation of austenite at temperatures below the pearlite range but above M e the martensite start temperature. Upper bainite is an aggregate that contains parallel lath-shape units of ferrite, produces the so-called "feathery" appearance in optical microscopy, and is formed above approximately350 °C (660 °F). Lower bainite, which has an acicular appearance similar to tempered martensite, is formed below approximately 350 °C (660 °F).

Banding: Inhomogeneous distribution of alloying elements or phases aligned in filaments or plates parallel to the direction of working.

Bar: (1) A section hot rolled from a billet to a form, such as round, hexagonal, octagonal, square, or rectangular, with sharp or rounded corners or edges and a cross-sectional area of less than 105 cm^2 (16 in^2). (2) A solid section that is long in relationship to its cross-sectional dimensions.

B**arstock**: Same as *bar.*

Basic refractories: Refractories whose major constituent is lime, magnesia, or both, and which may react chemically with acid refractories, acid slags, or acid fluxes at high temperatures. Basic refractories are used for furnace linings. Compare with *acid refractory.*

Beach marks: Macroscopic progression marks on a fatigue fracture or stress-corrosion cracking surface that indicate successive positions of the advancing crack front. The classic appearance is of irregular elliptical or semielliptical rings, radiating outward from one or more origins. Beach marks (also known as clamshell marks or arrest marks) are typically found on service fractures where the part is loaded randomly, intermittently, or with periodic variations in mean stress or alternating stress. See also *striation.*

Bend test: A test for determining relative ductility of metal that is to be formed (usually sheet, strip, plate, or wire) and for determining soundness and toughness of metal (after welding, for example). The specimen is usually bent over a specified diameter through a specified angle for a specified number of cycle.

Billet: (1) A semifinished section that is hot rolled from a metal ingot, with a rectangular cross section usually ranging from 105 to 230 cm2 (16 to 36 in. 2), the width being less than twice the thickness. Where the cross section exceeds 230 cm2 (36 in. 2), the term bloom is properly but not universally used. Sizes smaller than 105 cm2 (16 in. 2) are usually termed bars. (2) A solid semifinished round or square product that has been hot worked by forging, rolling, or extrusion. See also *bar.*

Binder: (1) In foundry terminology, a material, other than water, added to foundry sand to bind the particles together, sometimes with the use of heat. (2) In powder technology, a cementing medium: either a material added to the powder to increase the green strength of the compact, which is expelled during sintering; or a material (usually of relatively low melting point) added to a powder mixture for the specific purpose of cementing together powder particles that alone would not sinter into a strong body.

Black oxide: A black finish on a metal produced by immersing it in hot oxidizing salts or salt solutions.

Blank: (1) In forming, a piece of sheet metal, produced in cutting dies, that is usually subjected to further press operations. (2) A pressed, presintered, or fully sintered powder metallurgy compact, usually in the unfinished condition and requiring cutting, machining, or some other operation to produce the final shape. (3) A piece of stock from which a forging is made, often called a *slug* or *multiple.*

Blast furnace: A shaft furnace in which solid fuel is burned (usually coke) with an air blast to smelt ore in a continuous operation. Where the temperature must be high, as in the production of pig iron, the air is preheated.

Blasting or blast cleaning: A process for cleaning or finishing metal objects with an air blast or centrifugal wheel that throws abrasive particles against the surface of the workpiece. Small, irregular particles of metal are used as the abrasive in gritblasting; sand, in sandblasting; and steel, in shotblasting.

Blind riser: A riser that does not extend through the top of the mold.

Bloom: (1) A semifinished hot-rolled product, rectangular in cross section, produced on a blooming mill. See also *billet.* For steel, the width of a bloom is not more than twice the thickness, and the cross-sectional area is usually not less than about 230 cm 2 (36 in. 2). Steel blooms are sometimes made by forging. (2) A visible exudation or efflorescence on the surface of an electroplating bath. (3) A bluish

fluorescent cast to a painted surface caused by deposition of a thin film of smoke, dust, or oil. (4) A loose, flowerlike corrosion product that forms when certain metals are exposed to a moist environment.

Blowhole: A hole in a casting or a weld caused by gas entrapped during solidification. See also *porosity.*

Blue brittleness: Brittleness exhibited by some steels after being heated to some temperature within the range of about 205 to 370 °C (400 to 700 °F), particularly if the steel is worked at the elevated temperature. Killed steels are virtually free of this kind of brittleness.

Boss: A relatively short protrusion or projection from the surface of a forging or casting, often cylindrical in shape; usually intended for drilling and tapping for attaching parts.

Bowing: Deviation from flatness.

Brale indenter: Diamond indenter with a conical tip (a 0.2 mm tip radius is typical) used in certain types of Rockwell and scratch hardness tests.

Brass: A copper-zinc alloy containing up to 40% Zn, to which smaller amounts of other elements may be added.

Braze: A weld produced by heating an assembly to suitable temperatures and by using a filler metal having a liquids above 450 °C (840 °F) and below the solidus of the base metal. The filler metal is distributed between the closely fitted faying surfaces of the joint by capillary action.

Brazeability: The capacity of a metal to be brazed under the fabrication conditions imposed into a specific suitably designed structure and to perform satisfactorily in the intended service.

Brinell hardness test: A test for determining the hardness of a material by forcing a hard steel or carbide ball of specified diameter (typically, 10 mm) into it under a specified load. The result is expressed as the Brinell hardness number.

Brittle fracture: Separation of a solid accompanied by little or no macroscopic plastic deformation. Typically, brittle fracture occurs by rapid crack propagation with less expenditure of energy than for ductile fracture. Brittle tensile fractures have a bright, granular appearance and exhibit little or no necking. A chevron pattern may be present on the fracture surface, pointing toward the origin of the crack, especially in brittle fractures in flat platelike components. Examples of brittle fracture include transgranular cracking (cleavage and quasi-cleavage fracture) and intergranular cracking (decohesive rupture).

Brittleness: The tendency of a material to fracture without first undergoing significant plastic deformation. Contrast with *ductility.*

Bronze: A copper-rich copper-tin alloy with or without small proportions of other elements such as zinc and phosphorus. By extension, certain copper-base alloys containing considerably less tin than other alloying elements, such as manganese bronze (copper-zinc plus manganese, tin, and iron) and leaded tin bronze (copper-lead plus tin and sometimes zinc). Also, certain other essentially binary copper-base alloys containing no tin, such as aluminum bronze (copper-aluminum), silicon bronze (copper-silicon), and beryllium bronze (copper-beryllium). Also, trade designations for certain specific copper-base alloys that are actually brasses, such as architectural bronzes (57 Cu, 40 Zn, 3 Pb) and commercial bronze (90 Cu, 10 Zn).

Buckling: (1) A mode of failure generally characterized by an unstable lateral material deflection due to compressive action on the structural element involved. (2) In metal forming, a bulge, bend, kink, or other wavy condition of the workpiece caused by compressive stresses. See also *compressive stress.*

Buildup: (1) A weld surfacing variation in which surfacing metal is deposited to achieve the required dimensions. See also *buttering.* (2) Excessive electrodeposition that occurs on high-current-density areas, such as corners or edges.

Buttering: A form of surfacing in which one or more layers of weld metal are deposited on the groove face of one member (for example, a high-alloy weld deposit on steel base metal that is to be welded to a dissimilar base metal). The buttering provides a suitable transition weld deposit for subsequent completion of the butt weld (joint).

Camber: (1) Deviation from edge straightness, usually referring to the greatest deviation of side edge from a straight line. (2) The tendency of material being sheared from sheet to bend away from the sheet in the same plane. (3) Sometimes used to denote crown in rolls where the center diameter has been increased to compensate for deflection caused by the rolling pressure. (4) The planar deflection of a flat cable or flexible laminate from a straight line of specified length. A flat cable or flexible laminate with camber is similar to the curve of an unbanked race track.

Capillary action: (1) The phenomenon of intrusion of a liquid into interconnected small voids, pores, and channels in a solid, resulting from surface tension. (2) The force by which liquid, in contact with a solid, is distributed between closely fitted faying surfaces of the joint to be brazed or soldered.

Carbide: A compound of carbon with one or more metallic elements.

Carbide tools: Cutting or forming tools, usually made from tungsten, titanium, tantalum, or niobium carbides, or a combination of them, in a matrix of cobalt, nickel, or other metals. Carbide tools are characterized by high hardnesses and compressive strengths and may be coated to improve wear resistance. See also *cemented carbide.*

Carbon equivalent: (1) For cast iron, an empirical relationship of the total carbon, silicon, and phosphorus contents expressed by the formula:

$$CE = \%C + 0.3(\%Si) + 0.33(\%P) - 0.027(\%Mn) + 0.4(\%S)$$

(2) For rating of weldability:

$$CE = C + Mn/6 + Ni/15 + Cu/15 + Cr/5 + Mo/5 + V/5$$

Carbonitriding: A case-hardening process in which a suitable ferrous material is heated above the lower transformation temperature in a gaseous atmosphere of such composition as to cause simultaneous absorption of carbon and nitrogen by the surface and, by diffusion, create a concentration gradient. The heat-treating process is completed by cooling at a rate that produces the desired properties in the work piece.

Carbon potential: A measure of the ability of an environment containing active carbon to alter or maintain, under prescribed conditions, the carbon level of a steel. In any particular environment, the carbon level attained will depend on such factors as temperature, time, and steel composition.

Carbon steel: Steel having no specified minimum quantity for any alloying element—other than the commonly accepted maximum amounts of manganese (1.65%), silicon (0.60%), and copper (0.60%)—and containing only an incidental amount of any element other than carbon, silicon, manganese, copper, sulfur, and phosphorus. Low-carbon steels contain up to 0.30% C, medium-carbon steels contain from 0.30 to 0.60% C, and high-carbon steels contain from 0.60 to 1.00% C.

Carburizing: Absorption and diffusion of carbon into solid ferrous alloys by heating, to a temperature usually above Ac3, in contact with a suitable carbonaceous material. A form of case hardening that produces a carbon gradient extending inward from the surface, enabling the surface layer to be hardened either by quenching directly from the carburizing temperature or by cooling to room temperature, then reaustenitizing and quenching.

Case: In heat treating, that portion of a ferrous alloy, extending inward from the surface, whose composition has been altered during case hardening. Typically considered to be the portion of an alloy (a) whose composition has been measurably altered from the original composition, (b) that appears light when etched, or (c) that has a higher hardness value than the core. Contrast with *core.*

Case hardening: A generic term covering several processes applicable to steel that change the chemical composition of the surface layer by absorption of carbon, nitrogen, or a mixture of the two and, by diffusion, create a concentration gradient. The processes commonly used are carburizing and quench hardening; cyaniding; nitriding; and carbonitriding. The use of the applicable specific process name is preferred.

Castability: (1) A complex combination of liquid-metal properties and solidification characteristics that promotes accurate and sound final castings. (2) The relative ease with which a molten metal flows through a mold or casting die.

Casting: (1) Metal object cast to the required shape by pouring or injecting liquid metal into a mold, as distinct from one shaped by a mechanical process. (2) Pouring molten metal into a mold to produce an object of desired shape.

Casting defect: Any imperfection in a casting that does not satisfy one or more of the required design or quality specifications. This term is often used in a limited sense for those flaws formed by improper casting solidification.

Cast iron: A generic term for a large family of cast ferrous alloys in which the carbon content exceeds the solubility of carbon in austenite at the eutectic temperature. Most cast irons contain at least 2% carbon, plus silicon and sulfur, and may or may not contain other alloying elements. See also *compacted graphite iron, ductile iron, gray iron, malleable iron,* and *white iron.*

Cast structure: The metallographic structure of a casting evidenced by shape and orientation of grains and by segregation of impurities.

Catastrophic failure: Sudden failure of a component or assembly that frequently results in extensive secondary damage to adjacent components or assemblies.

Cathode: The negative electrode of an electrolytic cell at which reduction is the principal reaction. (Electrons flow toward the cathode in the external circuit.) Typical cathodic processes are cations taking up electrons and being discharged, oxygen being reduced, and the reduction of an element or group of elements from a higher to a lower valence state. Contrast with *anode.*

Cathodic protection: (1) Reduction of corrosion rate by shifting the corrosion potential of the electrode toward a less oxidizing potential by applying an external electromotive force. (2) Partial or complete protection of a metal from corrosion by making it a cathode, using either a galvanic or an impressed current. Contrast with *anodic protection.*

Cavitation: The formation and collapse, within a liquid, of cavities or bubbles that contain vapor or gas or both. In general, cavitation originates from a decrease in the static pressure in the liquid. It is distinguished in this way from boiling, which originates from an increase in the liquid temperature. There are certain situations where it may be difficult to make a clear distinction between cavitation and boiling, and the more general definition that is given here is therefore- to be preferred. In order to erode a solid surface by cavitation, it is necessary for the cavitation bubbles to collapse on or close to that surface.

Cavitation corrosion: A process involving conjoint corrosion and cavitation.

Cemented carbide: A solid and coherent mass made by pressing and sintering a mixture of powders of one or more metallic carbides, such as tungsten carbide, and a much smaller amount of a metal, such as cobalt, to serve as a binder.

Center drilling: Drilling a short, conical hole in the end of a workpiece—a hole to be used to center the workpiece for turning on a lathe.

Centrifugal casting: The process of filling molds by (1) pouring metal into a sand or permanent mold that is revolving about either its horizontal or its vertical axis or (2) pouring metal into a mold that is subsequently revolved before solidification of the metal is complete. See also centrifuge casting.

Centrifuge casting: A casting technique in which mold cavities are spaced symmetrically about a vertical axial common downgate. The entire assembly is rotated about that axis during pouring and solidification.

CG iron: Same as *compacted graphite cast iron.*

Chamfer: (1) A beveled surface to eliminate an otherwise sharp corner. (2) A relieved angular cutting edge at a tooth corner.

Chaplet: Metal support that holds a core in place within a casting mold; molten metal solidifies around a chaplet and fuses it into the finished casting.

Charge: (1) The materials fed into a furnace. (2) Weights of various liquid and solid materials put into a furnace during one feeding cycle.

Charpy test: An impact test in which a V-notched, keyhole-notched, or U-notched specimen, supported at both ends, is struck behind the notch by a striker mounted at the lower end of a bar that can swing as a pendulum. The energy that is absorbed in fracture is calculated from the height to which the striker would have risen had there been no specimen and the height to which it actually rises after fracture of the specimen. Contrast with *Izod test.*

Checks: (1) Numerous, very fine cracks in a coating or at the surface of a metal part. Checks may appear during processing or during service and are most often associated with thermal treatment or thermal cycling. Also called check marks, or *heat checks.* (2) Minute cracks in the surface of a casting caused by unequal expansion or contraction during cooling. (3) Cracks in a die impression corner, generally due to

forging strains or pressure, localized at some relatively sharp corner. Die blocks too hard for the depth of the die impression have a tendency to check or develop cracks in impression corners. (4) A series of small cracks resulting from thermal fatigue of hot forging dies.

Chemical conversion coating: A protective or decorative nonmetallic coating produced in situ by chemical reaction of a metal with a chosen environment. It is often used to prepare the surface prior to the application of an organic coating.

Chemical polishing: A process that produces a polished surface by the action of a chemical etching solution. The etching solution is compounded so that peaks in the topography of the surface are dissolved preferentially.

Chemical vapor deposition (CVD): A coating process, similar to gas carburizing and carbonitriding, whereby a reactant atmosphere gas is fed into a processing chamber where it decomposes at the surface of the workpiece, liberating one material for either absorption by, or accumulation on, the workpiece. A second material is liberated in gas form and is removed from the processing chamber, along with excess atmosphere gas.

Chevron pattern: A fractographic pattern of radial marks (shear ledges) that look like nested letters "V"; sometimes called a herringbone pattern. Chevron patterns are typically found on brittle fracture surfaces in parts whose widths are considerably greater than their thicknesses. The points of the chevrons can be traced back to the fracture origin.

Chill: (1) A metal or graphite insert embedded in the surface of a casting sand mold or core or placed in a mold cavity to increase the cooling rate at that point. (2) White iron occurring on a gray or ductile iron casting, such as the chill in the wedge test. See also *chilled iron.* Compare with *inverse chill.*

Chilled iron: Cast iron that is poured into a metal mold or against a mold insert so as to cause the rapid solidification that often tends to produce a white iron structure in the casting.

CIP: The acronym for *cold isostatic pressing.*

Cladding: (1) A layer of material, usually metallic, that is mechanically or metallurgically bonded to a substrate. Cladding may be bonded to the substrate by any of several processes, such as roll-cladding and explosive forming. (2) A relatively thick layer (1 mm, or 0.04 in.) of material applied by surfacing for the purpose of improved corrosion resistance or other properties. See also *coating, surfacing,* and *hardfacing.*

Clad metal: A composite metal containing two or more layers that have been bonded together. The bonding may have been accomplished by co-rolling, co-extrusion, welding, diffusion bonding, casting, heavy chemical deposition, or heavy electroplating.

Cleavage: (1) Fracture of a crystal by crack propagation across a crystallographic plane of low index. (2) The tendency to cleave or split along definite crystallographic planes.

Cleavage fracture: A fracture, usually of a polycrystalline metal, in which most of the grains have failed by cleavage, resulting in bright reflecting facets. It is one type of crystalline fracture and is associated with low-energy brittle fracture. Contrast with *shear fracture.*

Closed-die forging: The *shaping* of hot metal completely within the walls or cavities of two dies that come together to enclose the workpiece on all sides. The impression for the forging can be entirely

either di e or divided between the top and bottom dies. Impression-die forging, often used interchangeably with the term closed-die forging, refers to a closeddie operation in which the dies contain a provision

Coalescence: (1) The union of particles of a dispersed phase into larger units, usually effected at temperatures below the fusion point. (2) The growing together or growth into one body of the materials being welded. (3) Growth of grains at the expense of the remainder by absorption or the growth of a phase or particle at the expense of the remainder by absorption or reprecipitation.

Coarsening: An increase in grain size, usually, but not necessarily, by grain growth.

Coating: A relatively thin layer (<1 mm, or 0.04 in.) of material applied by surfacing for the purpose of corrosion prevention, resistance to high-temperature scaling, wear resistance, lubrication, or other purposes.

Cohesive strength: (1) The hypothetical stress causing tensile fracture without plastic deformation. (2) The stress corresponding to the forces between atoms.

Coke: A porous, gray, infusible product resulting from the dry distillation of bituminous coal, petroleum, or coal tar pitch that drives off most of the volatile matter. Used as a fuel in cupola melting.

Cold cracking: (1) Cracks in cold or nearly cold cast metal due to excessive internal stress caused by contraction. Often brought about when the mold is too hard or the casting is of unsuitable design. (2) A type of weld cracking that usually occurs below 205 °C (400 °F). Cracking may occur during or after cooling to room temperature, sometimes with a considerable time delay. Three factors combine to produce cold cracks; stress (for example, from thermal expansion and contraction), hydrogen (from hydrogen-containing welding consumables), and a susceptible microstructure (plate martensite is most susceptible to cracking, ferritic and bainitic structures are least susceptible). See also *hot cracking, lamellar tearing,* and *stress-relief cracking.*

Cold heading: Working metal at room temperature such that the cross-sectional area of a portion or all of the stock is increased. See also *heading* and *upsetting.*

Cold lap: (1) Wrinkled markings on the surface of an ingot or casting from incipient freezing of the surface and too low a casting temperature. (2) A flaw that results when a workpiece fails to fill the die cavity during the first forging. A seam is formed as subsequent dies force metal over this gap to leave a seam on the workpiece surface. See also *cold shut.*

Cold shot: (1) A portion of the surface of an ingot or casting showing premature solidification; caused by splashing of molten metal onto a cold mold wall during pouring. (2) Small globule of metal embedded in, but not entirely fused with, the casting.

Cold shut: (1) A discontinuity that appears on the surface of cast metal as a result of two streams of liquid meeting and failing to unite. (2) A lap on the surface of a forging or billet that was closed without fusion during deformation. (3) Freezing of the top surface of an ingot before the mold is full.

Cold treatment: Exposing steel to suitable subzero temperatures (-85 °C, or —120 °F) for the purpose of obtaining desired conditions or properties such as dimensional or microstructural stability. When the treatment involves the transformation of retained austenite, it is usually followed by tempering.

Cold welding: A solid-state welding process if which pressure is used at room temperature to produce coalescence of metals with substantial deformation at the weld. Compare with *hot pressure welding, diffusion welding,* and *forge welding.*

Cold working: Deforming metal plastically under conditions of temperature and strain rate that induce strain hardening. Usually, but not necessarily, conducted at room temperature. Contrast with *hot working.*

Columnar structure: A coarse structure of parallel elongated grains formed by unidirectional growth, most often observed in castings, but sometimes seen in structures resulting from diffusional growth accompanied by a solid-state transformation.

Compact: (1) The object produced by the compression of metal powder, generally while confined in a die. (2) The operation or process of producing a compact; sometimes called pressing.

Compacted graphite iron: Cast iron, having a graphite shape intermediate between the flake form typical of gray cast iron and the spherical form of fully spherulitic ductile cast iron. An acceptable compacted graphite iron structure is one that contains no flake graphite, <20% spheroidal graphite, and 80% compacted graphite (ASTM A 247, type IV). Also known as CG iron or vermicular iron, compacted graphite cast iron is produced in a manner similar to that for ductile cast iron, but using a technique that inhibits the formation of fully spherulitic graphite nodules.

C**omposite electrode**: A welding electrode made from two or more distinct components, at least one of which is filler metal. A composite electrode may exist in any of various physical forms, such as stranded wires, filled tubes, or covered wire.

Composite material: A combination of two or more materials (reinforcing elements, fillers, and composite matrix binder), differing in form or composition on a macroscale. The constituents retain their identities, that is, they do not dissolve or merge completely into one another although they act in concert. Normally, the components can be physically identified and exhibit an interface between one another. Examples are fiberglass and metal-matrix composites.

Composite structure: A structural member (such as a panel, plate, pipe, or other shape) that is built up by bonding together two or more distinct components, each of which may be made of a metal, alloy, nonmetal, or composite material. Examples of composite structures include: honeycomb panels, clad plate, electrical contacts, sleeve bearings, carbide-tipped drills or lathe tools, and weldments constructed of two or more different alloys.

Compressive strength: The maximum compressive stress that a material is capable of developing, based on original area of cross section. If a material fails in compression by a shattering fracture, the compressive strength has a very definite value. If a material does not fail in compression by a shattering fracture, the value obtained for compressive strength is an arbitrary value depending on the degree of distortion that is regarded as indicating complete failure of the material.

Conditioning heat treatment: A preliminary heat treatment used to prepare a material for a desired reaction to a subsequent heat treatment. For the term to be meaningful, the exact heat treatment must be specified.

Consumable electrode: A general term for any arc welding electrode made chiefly of filler metal. Use of specific names such as *covered electrode, bare electrode, flux-cored electrode,* and *lightly coated electrode* is preferred.

Contact corrosion: A term primarily used in Europe to describe galvanic corrosion between dissimilar metals.

Contaminant: An impurity or foreign substance present in a material or environment that affects one or more properties of the material.

Continuous casting: A casting technique in which a cast shape is continuously withdrawn through the bottom of the mold as it solidifies, so that its length is not determined by mold dimensions used primarily to produce semi finished mill products such as billets, blooms, ingots, slabs, strip, and tubes. See also *strand casting.*

Continuous phase: In an alloy or portion of an alloy containing more than one phase, the phase that forms the matrix in which the other phase or phases are dispersed.

Continuous-type furnace: A furnace used for heat treating materials that progress continuously through the furnace, entering one door and being discharged from another.

Cooling curve: A graph showing the relationship between time and temperature during the cooling of a material. It is used to find the temperatures at which phase changes occur. A property or function other than time may occasionally be used—for example, thermal expansion.

Cope: In casting, the upper or topmost section of a flask, mold, or pattern.

Copper-accelerated salt-spray (CASS) test: An accelerated corrosion test for some electrodeposits and for anodic coatings on aluminum.

Copper brazing: A term improperly used to denote brazing with a copper filler metal.

Core: (1) A specially formed material inserted in a mold to shape the interior or other part of a casting that cannot be shaped *as* easily by the pattern. (2) In a ferrous alloy prepared for case hardening, that portion of the alloy that is not part of the case. Typically considered to be the portion that (a) appears dark (with certain etchants) on an etched cross section, (b) has an essentially unaltered chemical composition, or (c) has a hardness, after hardening, less than a specified value.

Core binder: In casting, any material used to hold the grains of core sand together.

Coring: (1) A condition of variable composition between the center and surface of a unit of microstructure (such as a dendrite, grain, carbide particle); results from nonequilibrium solidification, which occurs over a range of temperature. (2) A central cavity at the butt end of a rod extrusion, sometimes called *extrusion pipe.*

Corrosion: The chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties.

Corrosion embrittlement: The severe loss of ductility of a metal resulting from corrosive attack, usually intergranular and often not visually apparent.

Corrosion potential: The potential of a corroding surface in an electrolyte, relative to a reference electrode; also called rest potential, open-circuit potential, or freely corroding potential.

Corrosion product: Substance formed as a result of corrosion.

Corrosion rate: Corrosion effect on a metal per unit of time. The type of corrosion rate used depends on the technical system and on the type of corrosion effect. Thus, corrosion rate may be expressed as an increase in corrosion depth per unit of time (penetration rate, for example, mils/yr) or the mass of metal turned into corrosion products per unit area of surface per unit of time (weight loss, for example, $g/m^2/yr$). The corrosion effect may vary with time and may not be the same at all points of the corroding surface. Therefore, reports of corrosion rates should be accompanied by information on the type, time dependency, and location of the corrosion effect.

Corrosion resistance: The ability of a material to withstand contact with ambient natural factors or those of a particular, artificially created atmosphere, without degradation or change in properties. For metals, this could be pitting or rusting; for organic materials, it could be crazing.

Covered electrode: A composite filler metal electrode consisting of a core of a bare electrode or metal cored electrode to which a covering sufficient to provide a slag layer on the weld metal has been applied. The covering may contain materials providing such functions as shielding from the atmosphere, deoxidation, and arc stabilization and can serve as a source of metallic additions to the weld. Compare with *lightly coated electrode.*

Crack: (1) A fracture type discontinuity characterized by a sharp tip and high ratio of length and width to opening displacement. (2) A line of fracture without complete separation.

Crater: In arc welding, a depression at the termination of a weld bead or in the molten weld pool.

Crater crack: A crack in the crater of a weld bead.

Craze cracking: Irregular surface cracking of a metal associated with thermal cycling. This term is used more in the United Kingdom than in the United States, where the term checking is used instead. See also *checks.*

Creep: Time-dependent strain occurring under stress. The creep strain occurring at a diminishing rate is called primary creep; that occurring at a minimum and almost constant rate, secondary creep; and that occurring at an accelerating rate, tertiary creep. Creep generally increases as temperature increases.

Creep rate: The slope of the creep-time curve at a given time. Deflection with time under a given static load.

Creep-rupture test: A test in which progressive specimen deformation and the time for rupture are both measured. In general, deformation is much greater than that developed during a creep test; also known as stress-rupture test.

Creep test: A method of determining the extension of metals under a given load at a given temperature. The determination usually involves the plotting of time elongation curves under constant load; a single test may extend over many months. The results are often expressed as the elongation (in millimeters or inches) per hour on a given gage length (e.g., 25 mm, or I in.).

Crevice corrosion: Localized corrosion of a metal surface at, or immediately adjacent to, an area that is shielded from full exposure to the environment because of close proximity between the metal and the surface of another material.

Critical flaw size: The size of a flaw (defect) in a structure that will cause failure at a particular stress level.

Cryogenic treatment: See *cold treatment.*

Crystalline: That form of a substance that comprises predominantly (one or more) crystals, as opposed to glassy or amorphous.

Cup-and-cone-fracture: A mixed-mode fracture, often seen in tensile-test specimens of a ductile material, where the central portion undergoes plane-strain fracture and the surrounding region undergoes plane stress fracture. It is called a cup fracture (or cup-andcone fracture) because one of the mating fracture surfaces looks like a miniature cup—that is, it has a central depressed flat-face region surrounded by a shear lip; the other fracture surface looks like a miniature truncated cone.

Cut-off (casting): Removing a casting from the sprue by refractory wheel or saw, arc-air torch, or gas torch.

Cycle (N): In fatigue, one complete sequence of values of applied load that is repeated periodically. See also *S-N curve.*

Cyclic load: (1) Repetitive loading, as with regularly recurring stresses on a part, that sometimes leads to fatigue fracture. (2) Loads that change value by following a regular repeating sequence of change.

Decarburization: Loss of carbon from the surface layer of a carbon-containing alloy due to reaction with one or more chemical substances in a medium that contacts the surface.

Deep etching: In metallography, macroetching, especially for steels, to determine the overall character of the material, that is, the presence of imperfections, such as seams, forging bursts, shrinkage-void remnants, cracks, and coring.

Defect: (1) A discontinuity whose size, shape, orientation, or location makes it detrimental to the useful service of the part in which it occurs. (2) A discontinuity/discontinuities which by nature or accumulated effect (for example, total crack length) render a part or product unable to meet minimum applicable acceptance standards or specifications. This term designates rejectability. See also *discontinuity* and *flaw.*

Defective: A quality control term, describing a unit of product or service containing at least one *defect,* or having several lesser imperfections that, in combination, cause the unit not to fulfill its anticipated function.

Deformation: A change in the form of a body due to stress, thermal change, change in moisture, or other causes. Measured in units of length.

Delta ferrite: See *ferrite.*

Dendrite: A crystal that has a treelike branching pattern, being most evident in cast metals slowly cooled through the solidification range.

Deoxidation products: Those nonmetallic inclusions that form as a result of adding deoxidizing agents to molten metal.

Deoxidizing: (1) The removal of oxygen from molten metals through the use of a suitable deoxidizer. (2) Sometimes refers to the removal of undesirable elements other than oxygen through the introduction of elements or compounds that readily react with them. (3) In metal finishing, the removal of oxide films from metal surfaces by chemical or electrochemical reaction.

Deposit corrosion: Corrosion occurring under or around a discontinuous deposit on a metallic surface. Also called poultice corrosion.

Descaling: (1) Removing the thick layer of oxides formed on some metals at elevated temperatures. (2) A chemical or mechanical process for removing scale or investment material from castings.

Dewaxing: In casting, the process of removing the expendable wax pattern from an investment mold or shell mold; usually accomplished by melting out the application of heat or dissolving the wax with an appropriate solvent.

Diamond pyramid hardness test: See *Vickers hardness test.*

Die: A tool, usually containing a cavity, that imparts shape to solid, molten, or powdered metal primarily because of the shape of the tool itself. Used in many press operations (including blanking, drawing, forging, and forming), in die casting, and in forming green powder metallurgy compacts. Die-casting and powder metallurgy dies are sometimes referred to Ar *molds.* See also *forging dies.*

Die casting: (1) A casting made in a die. (2) A casting process in which molten metal is forced under high pressure into the cavity of a metal mold. See also *cold chamber machine* and *hot chamber machine.*

Die cavity: The machined recess that gives a forging or stamping its shape.

Diffusion: (1) Spreading of a constituent in a gas, liquid, or solid, tending to make the composition of all parts uniform. (2) The spontaneous movement of atoms or molecules to new sites within a material.

Dilatometer: An instrument for measuring the linear expansion or contraction in a metal resulting from changes in such factors as temperature and allotropy

Direct chill casting: A continuous method of making ingots for rolling or extrusion by pouring the metal into a short mold. The base of the mold is a platform that is gradually lowered while the metal solidifies, the frozen shell of metal acting as a retainer for the liquid metal below the wall of the mold. The ingot is usually cooled by the impingement of water directly on the mold or on the walls of the solid metal as it is lowered. The length of the ingot is limited by the depth to which the platform can be lowered; therefore, it is often called semicontinuous casting.

Discontinuity: (1) Any interruption in the normal physical structure or configuration of a part, such as cracks, laps, seams, inclusions, or porosity. A discontinuity may or may not affect the utility of the part. (2) An interruption of the typical structure of a weldment, such as a lack of homogeneity in the mechanical, metallurgical, or physical characteristics of the material or weldment. A discontinuity is not necessarily a defect. See also *defect* and *flaw.*

Distortion: Any deviation from an original size, shape, or contour that occurs because of the application of stress or the release of residual stress.

Disturbed metal: The cold-worked metal layer formed at a polished surface during the process of mechanical grinding and polishing.

Double tempering: A treatment in which a quenchhardened ferrous metal is subjected to two complete tempering cycles, usually at substantially the same temperature, for the purpose of ensuring completion of the tempering reaction and promoting stability of the resulting microstructure.

Draft: (1) An angle or taper on the surface of a pattern, core box, punch, or die (or of the parts made with them) that facilitates removal of the parts from a mold or die cavity, or a core from a casting. (2) The change in cross section that occurs during rolling or cold drawing.

Drag: The bottom section of *a. flask, mold,* or *pattern.*

Drawing: A term used for a variety of forming operations, such as deep drawing a sheet metal blank; redrawing a tubular part; and drawing rod, wire, and tube. The usual drawing process with regard to sheet metal working in a press is a method for producing a cuplike form from a sheet metal disk by holding it firmly between blankholding surfaces to prevent the formation of wrinkles while the punch travel produces the required shape.

Dross: (1) The scum that forms on the surface of molten metal largely because of oxidation but sometimes because of the rising of impurities to the surface. (2) Oxide and other contaminants that form on the surface of molten solder.

Dual-phase steels: A class of high-strength low-alloy steels characterized by a tensile strength value of approximately 550 MPa (80 ksi) and by a microstructure consisting of about 20% hard martensite particles dispersed in a soft ductile fenite matrix. The term dual phase refers to the predominance in the microstructure of two phases, ferrite and martensite. However, small amounts of other phases, such as bainite, pearlite, or retained austenite, may also be present.

Ductile fracture: Fracture characterized by tearing of metal accompanied by appreciable gross plastic deformation and expenditure of considerable energy. Contrast with *brittle fracture.*

Ductile iron: A cast iron that has been treated while molten with an element such as magnesium or cerium to induce the formation of free graphite as nodules or spherulites, which imparts a measurable degree of ductility to the cast metal. Also known as nodular cast iron, spherulitic graphite cast iron, and spheroidal graphite (SG) iron. Ductile iron has replaced malleable iron in many applications because it does not require a lengthy heat treatment.

Ductility: The ability of a material to deform plastically without fracturing.

Duplex grain size: The simultaneous presence of two grain sizes in substantial amounts, with one grain size appreciably larger than the others. Also termed mixed grain size.

Duplex microstructure: A two-phase structure.

Duplex stainless steels: Stainless steels having a fine grained mixed microstructure of ferrite and austenite with a composition centered around 26Cr-6.5Ni.

Eddy-current testing: An electromagnetic nondestructive testing method in which eddy-current flow is induced in the test object. Changes in flow caused by variations in the object are reflected into a nearby coil or coils where they are detected and measured by suitable instrumentation.

EDM: Abbreviation for *electrical discharge machining.*

Elastic deformation: A change in dimensions directly proportional to and in phase with an increase or decrease in applied force.

Elastic limit: The maximum stress that a material is capable of sustaining without any permanent strain (deformation) remaining upon complete release of the stress. A material is said to have passed its elastic limit when the load is sufficient to initiate plastic, or nonrecoverable, deformation. See also *proportional limit.*

Elastic modulus: Same as *modulus of elasticity*

Electrical discharge machining (EDM): Metal removed by a rapid spark discharge between different polarity electrodes, one on the work piece and the other the tool separated by a gap distance of 0.013 to 0.9 mm (0.0005 to 0.035 in.). The gap is filled with dielectric fluid and metal particles that are melted, in part vaporized, and expelled from the gap.

Electrode: Compressed graphite or carbon cylinder or rod used to conduct electric current in electric arc furnaces, arc lamps, and so forth.

Electrolyte: (1) A chemical substance or mixture, usually liquid, containing ions that migrate in an electric field. (2) A chemical compound or mixture of compounds which when molten or in solution will conduct an electric current.

Electrolytic polishing: An electrochemical polishing process in which the metal to be polished is made the anode in an electrolytic cell where preferential dissolution at high points in the surface topography produces a specularly reflective surface. Also referred to as *electropolishing.*

Electromagnetic radiation: Energy propagated at the speed of light by an electromagnetic field.

Elongation, **percent**: The extension of a uniform section of a specimen expressed as a percentage of the original gage length:

Embrittlement: The severe loss of ductility or toughness or both, of a material, usually a metal or alloy. Many forms of embrittlement can lead to brittle fracture. Many forms can occur during thermal treatment or elevated-temperature service (thermally induced embrittlement). Some of these forms of embrittlement, which affect steels, include blue brittleness, 885 °F (475 °C) embrittlement, quench-age embrittlement, sigma-phase embrittlement, strain-age embrittlement, temper embrittlement, tempered martensite embrittlement, and thermal embrittlement. In addition, steels and other metals and alloys can be embrittled by environmental conditions (environmentally assisted embrittlement). The forms of environmental embfittlement include acid embrittlement, caustic embrittlement, corrosion embrittlement, creep-rupture embrittlement, hydrogen embrittlement, liquid metal embrittlement, neutron embrittlement, solder embrittlement, solid metal embrittlement, and stress-corrosion cracking.

End-quench hardenability test: A laboratory procedure for determining the hardenability of a steel or other ferrous alloy; widely referred to as the Jominy test. Hardenability is determined by heating a standard specimen above the upper critical temperature, placing the hot specimen in a fixture so that a stream of cold water impinges on one end, and, after cooling to room temperature is completed, measuring the hardness near the surface of the specimen at regularly spaced intervals along its length. The data are normally plotted as hardness versus distance from the quenched end.

Endurance limit: The maximum stress that a material can withstand for an infinitely large number of fatigue cycles. See also *fatigue limit* and *fatigue strength.*

Equiaxed grain structure: A structure in which the grains have approximately the same dimensions in all directions.

Equilibrium diagram: A graph of the temperature, pressure, and composition limits of phase fields in an alloy system as they exist under conditions of thermodynamical equilibrium. In metal systems, pressure is usually considered constant. Compare with *phase diagram.*

Erosion-corrosion: A conjoint action involving corrosion and erosion in the presence of a moving corrosive fluid, leading to the accelerated loss of material.

Etchant: A chemical solution used to etch a metal to reveal structural details. See also *etching.*

Etching: (1) Subjecting the surface of a metal to preferential chemical or electrolytic attack in order to reveal structural details for metallographic examination. (2) Chemically or electrochemically removing tenacious films from a metal surface to condition the surface for a subsequent treatment, such as painting or electroplating.

Eutectic: (1) An isothermal reversible reaction in which a liquid solution is converted into two or more intimately mixed solids on cooling, the number of solids formed being the same as the number of components in the system. (2) An alloy having the composition indicated by the eutectic point on a phase diagram. (3) An alloy structure of intermixed solid constituents formed by a eutectic reaction often in the form of regular arrays of lamellas or rods.

Eutectoid: (1) An isothermal reversible reaction in which a solid solution is converted into two or more intimately mixed solids on cooling, the number of solids formed being the same as the number of components in the system. (2) An alloy having the composition indicated by the eutectoid point on a phase diagram. (3) An alloy structure of intermixed solid constituents formed by a eutectoid reaction.

Extensometer: An instrument for measuring changes in length over a given gage length caused by application or removal of a force. Commonly used in tension testing.

Extrusion: The conversion of an ingot or billet into lengths of uniform cross section by forcing metal to flow plastically through a die orifice. In forward (direct) extrusion, the die and ram are at opposite ends of the extrusion stock, and the product and ram travel in the same direction. Also, there is relative motion between the extrusion stock and the die. In backward (indirect) extrusion, the die is at the ram end of the stock and the product travels in the direction opposite that of the ram, either around the ram *(as* in the impact extrusion of cylinders such as cases for dry cell batteries) or up through the center of a hollow ram. See also *hydrostatic extrusion* and *impact extrusion.*

Failure: A general term used to imply that a part in service (a) has become completely inoperable, (b) is still operable but incapable of satisfactorily performing its intended function, or (c) has deteriorated seriously, to the point that it has become unreliable or unsafe for continued use.

Fatigue: The phenomenon leading to fracture under repeated or fluctuating stresses having a maximum value less than the ultimate tensile strength of the material. Fatigue failure generally occurs at loads that applied statically would produce little perceptible effect. Fatigue fractures are progressive, beginning as minute cracks that grow under the action of the fluctuating stress.

Fatigue strength: The maximum cyclical stress a material can withstand for a given number of cycles before failure occurs.

Fatigue test: A method for determining the range of alternating (fluctuating) stresses a material can withstand without failing.

Ferrite: (1) A solid solution of one or more elements in body-centered cubic iron. Unless otherwise designated (for instance, as chromium ferrite), the solute is generally assumed to be carbon. On some equilibrium diagrams, there are two ferrite regions separated by an austenite area. The lower area is a ferrite; the upper, 8 ferrite. If there is no designation, a ferrite is assumed. (2) An essentially carbon-free solid solution in which a iron is the solvent and which is characterized by a body-centered cubic crystal structure. Fully ferritic steels are only obtained when the carbon content is quite low. The most obvious microstructural features in such metals are the ferrite grain boundaries.

Ferrite number: An arbitrary, standardized value designating the ferrite content of an austenitic stainless steel weld metal. This value 'directly replaces percent ferrite or volume percent ferrite and is determined by the magnetic test described in AWS A4.2

Ferroalloy: An alloy of iron that contains a sufficient amount of one or more other chemical elements to be useful as an agent for introducing these elements into molten metal, especially into steel or cast iron.

File hardness: Hardness as determined by the use of a steel file of standardized hardness on the assumption that a material that cannot be cut with the file is as hard as, or harder than, the file. Files covering a range of hardnesses may be employed; the most common are files heat treated to approximately 67-68 HRC.

Filler metal: Metal added in making a brazed, soldered, or welded joint. See also *brazing filler metal, electrode (welding), solden welding rod,* and *welding wire.*

Fillet: (1) Concave corner piece usually used at the intersection of casting sections. Also the radius of metal at such junctions as opposed to an abrupt angular junction. (2) A radius (curvature) imparted to inside meeting surfaces.

Fine silver: Silver with a fineness of three nines (999); equivalent to a minimum content of 99.9% Ag with the remaining content unrestricted.

Flake graphite: Graphitic carbon, in the form of platelets, occurring in the microstructure of gray iron.

Flame cutting: See preferred term *oxygen cutting.*

Flame hardening: A process for hardening the surfaces of hardenable ferrous alloys in which an intense flame is used to heat the surface layers above the upper transformation temperature, where upon the work piece is immediately quenched.

Flame spraying: A thermal spraying process in which an oxyfuel gas flame is the source of heat for melting the surfacing material. Compressed gas may or may not be used for atomizing and propelling the surfacing material to the substrate.

Flash: (1) In forging, metal in excess of that required to fill the blocking or finishing forging impression of a set of dies completely. Flash extends out from the body of the forging as a thin plate at the line where the dies meet and is subsequently removed by trimming. Because it cools faster than the body of the

component during forging, flash can serve to restrict metal flow at the line where dies meet, thus ensuring complete filling of the impression. See also closed die forging. (2) In casting, a fin of metal that results from leakage between mating mold surfaces. (3) In welding, the material that is expelled or squeezed out of a weld joint and that forms around the weld.

F**law**: A nonspecific term often used to imply a crack like discontinuity. See preferred terms *discontinuity* and *defect.*

Fluorescent magnetic-**particle inspection**: Inspection with either dry magnetic particles or those in a liquid suspension, the particles being coated with a fluorescent substance to increase the visibility of the indications.

Fluorescent penetrant inspection: Inspection using a fluorescent liquid that will penetrate any surface opening; after the surface has been wiped clean, the location of any surface flaws may be detected by the fluorescence, under ultraviolet light, of back-seepage of the fluid.

Flux: (1) In metal refining, a material added to a melt to remove undesirable substances, like sand, ash, or dirt. Fluxing of the melt facilitates the agglomeration and separation of such undesirable constituents from the melt. It is also used as a protective covering for certain molten metal baths. Lime or limestone is generally used to remove sand, as in iron smelting; sand, to remove iron oxide in copper refining. (2) In brazing, cutting, soldering, or welding, material used to prevent the formation of: or to dissolve and facilitate removal of, oxides and other undesirable substances.

Flux cored arc welding (**FCAW**): An arc welding process that joins metal by heating them with an arc between a continuous tubular filler-metal electrode and the work. Shielding is provided by a flux contained within the consumable tubular electrode. Additional shielding may or may not be obtained from an externally supplied gas or gas mixture. See also *flux cored elctrode.*

Fold: (1) A defect in metal, usually on or near the surface, caused by continued fabrication of overlapping surfaces. (2) A forging defect caused by folding metal back onto its own surface during its flow in the die cavity. See also *lap.*

Forging: The process of working metal to a desired shape by impact or pressure in hammers, forging machines (up setters), presses, rolls, and related forming equipment Forging hammers, counterblow equipment, and high-energy-rate forging machines apply impact to the workpiece, while most other types of forging equipment apply squeeze pressure in shaping the stock. Some metals can be forged at room temperature, but most are made more plastic for forging by heating. Specific forging processes defined in this glossary include *closed-die forging, high-energy-rate forging, hot upset forging, isothermal forging, open-die forging, powder forging, precision forging, radial forging, ring rolling, oll forging, rotary forging, and rotary swaging.*

Formability: The ease with which a metal can be shaped through plastic deformation. Evaluation of the formability of a metal involves measurement of strength, ductility, and the amount of deformation required to cause fracture. The term workability is used interchangeably with formability; however, formability refers to the shaping of sheet metal, while workability refers to shaping materials by bulk forming. See also *forgeability.*

Foundry: A commercial establishment or building where metal castings are produced.

Fractography: Descriptive treatment of fracture of materials, with specific reference to photographs of the fracture surface. Macrofractography involves photographs at low magnification (<25x); microfractography, photographs at high magnification (>25x).

Fracture: The irregular surface produced when a piece of metal is broken. See also *brittle fracture, cleavage fracture, crystalline fracture, decohesive rupture, dimple rupture, ductile fracture, fibrous fracture, granular fracture, intergranular fracture, silky fracture,* and *transgranular fracture.*

Fracture test: Test in which a specimen is broken and its fracture surface is examined with the unaided eye or with a low-power microscope to determine such factors as composition, grain size, case depth, or discontinuities.

Fracture toughness: A generic term for measures of resistance to extension of a crack. The term is sometimes restricted to results of fracture mechanics tests, which are directly applicable in fracture control. However, the term commonly includes results from simple tests of notched or pre-cracked specimens not based on fracture mechanics analysis. Results from tests of the latter type are often useful for fracture control, based on either service experience or empirical correlations with fracture mechanics tests. See also *stress-intensity factor.*

Free carbon: The part of the total carbon in steel or cast iron that is present in elemental form as graphite or temper carbon. Contrast with *combined carbon.*

Free machining: Pertains to the machining characteristics of an alloy to which one or more ingredients have been introduced to produce small broken chips, lower power consumption, better surface finish, and longer tool life; among such additions are sulfur or lead to steel, lead to brass, lead and bismuth to aluminum, and sulfur or selenium to stainless steel.

Fretting: A type of wear that occurs between tight-fitting surfaces subjected to cyclic relative motion of extremely small amplitude. Usually, fretting is accompanied by corrosion, especially of the very fine wear debris. Also referred to *as fretting corrosion* and *false brinelling* (in rolling-element bearings).

Fretting corrosion: (1) The accelerated deterioration at the interface between contacting surfaces as the result of corrosion and slight oscillatory movement between the two surfaces. (2) A form of fretting in which chemical reaction predominates. Fretting corrosion is often characterized by the removal of particles and subsequent formation of oxides, which are often abrasive and so increase the wear. Fretting corrosion can involve other chemical reaction products, which may not be abrasive.

Friction welding (FRW): A solid-state welding process that produces coalescence of materials under compressive force contact of work pieces rotating or moving relative to one another to produce heat and plastically displace material from the faying surfaces.

Full annealing: An imprecise term that denotes an annealing cycle to produce minimum strength and hardness. For the term to be meaningful, the composition and starting condition of the material and the time-temperature cycle used must be stated.

Full hard: A temper of nonferrous alloys and some ferrous alloys corresponding approximately to a cold-worked state beyond which the material can no longer be formed by bending. In specifications, a full hard temper is commonly defined in terms of minimum hardness or minimum tensile strength (or, alternatively, a range of hardness or strength) corresponding to a specific percentage of cold reduction

following a full anneal. For aluminum, a full hard temper is equivalent to a reduction of 75% from *dead soft;* for austenitic stainless steels, a reduction of about 50 to 55%.

Fusion: The melting together of filler metal and base metal (substrate), or of base metal only, which results in coalescence. See also *depth of fusion.*

Fusion welding: Any welding process that uses fusion of the base metal to make the weld.

Gage length: The original length of that portion of the specimen over which strain, change of length and other characteristics are measured.

Galling: (1) A condition whereby excessive friction between high spots results in localized welding with subsequent *spalling* and a further roughening of the rubbing surfaces of one or both of two mating parts. (2) A severe form of scuffmg associated with gross damage to the surfaces or failure. Galling has been used in many ways in tribology; therefore, each time it is encountered its meaning must be ascertained from the specific context of the usage. See also *scoring* and *scuffing.*

Galvanic corrosion: Corrosion associated with the current of a galvanic cell consisting of two dissimilar conductors in an electrolyte or two similar conductors in dissimilar electrolytes. Where the two dissimilar metals are in contact, the resulting reaction is referred to as couple action.

Galvanize: To coat a metal surface with zinc using any of various processes.

Galvanneal: To produce a zinc-iron alloy coating on ,iron or steel by keeping the coating molten after hot dip galvanizing until the zinc alloys completely with the basis metal.

Gamma iron: The face-centered cubic form of pure iron, stable from 910 to 1400 °C (1670 to 2550 °F).

Gas holes: Holes in castings or welds that are formed by gas escaping from molten metal as it solidifies. Gas holes may occur individually, in clusters, or throughout the solidified metal.

Gas metal arc welding (**GMAW**): An arc welding process that produces coalescence of metals by heating them with an arc between a continuous filler metal electrode and the workpieces. Shielding is obtained entirely from an externally supplied gas.

Gas pocket: A cavity caused by entrapped gas.

Gas porosity: Fine holes or pores within a metal that are caused by entrapped gas or by the evolution of dissolved gas during solidification.

Gas shielded arc welding: A general term used to describe gas metal arc welding, gas tungsten arc welding, and flux cored arc welding (when gas shielding is employed).

Gas tungsten arc cutting: An arc-cutting process in which metals are severed by melting them with an arc between a single tungsten (nonconsumable) *electrode* and the workpiece. Shielding is obtained from a gas or gas mixture.

General corrosion: (1) A form of deterioration that is distributed more or less uniformly over a surface. (2) Corrosion dominated by uniform thinning that proceeds without appreciable localized attack. See also *uniform corrosion.*

Globular transfer: In consumable-electrode arc welding, a type of metal transfer in which molten filler metal passes across the arc as large droplets. Compare with *short-circuiting transfer* and *spray transfer.*

Grain: An individual crystal in a polycrystalline material; it may or may not contain twinned regions and subgrains.

Grain boundary: A narrow zone in a metal or ceramic corresponding to the transition from one crystallographic orientation to another, thus separating one grain from another; the atoms in each grain are arranged in an orderly pattern.

Grain-boundary corrosion: Same as *intergranular corrosion.* See also *interdendritic corrosion.*

Grain growth: (1) An increase in the average size of the grains in polycrystalline material, usually as a result of heating at elevated temperature. (2) In polycrystalline materials, a phenomenon occurring fairly close below the melting point in which the larger grains grow still larger while the smallest ones gradually diminish and disappear. See also *recrystallization.*

Grain size: (1) For metals, a measure of the areas or volumes of grains in a polycrystalline material, usually expressed as an average when the individual sizes are fairly uniform. In metals containing two or more phases, grain size refers to that of the matrix unless otherwise specified. Grain size is reported in terms of number of grains per unit area or volume, in terms of average diameter, or as a grain-size number derived from area measurements. (2) For grinding wheels, see preferred term *grit size.*

Gray iron: A cast iron characterized by a gray fracture surface due to the presence of flake graphite.

Green compact: An unsintered powder metallurgy or ceramic compact.

Grinding cracks: Shallow cracks formed in the surfaces of relatively hard materials because of excessive grinding heat or the high sensitivity of the material. See also *grinding sensitivity.*

Guided bend test: A test in which the specimen is bent to a definite shape by means of a punch (mandrel) and a bottom block.

Hadfield steel: See *austenitic manganese steel.*

Hardenability: The relative ability of a ferrous alloy to form martensite when quenched from a temperature above the upper critical temperature. Hardenability is commonly measured as the distance below a quenched surface at which the metal exhibits a specific hardness (50 HRC, for example) or a specific percentage of martensite in the microstructure.

Hardening: Increasing hardness of metals by suitable treatment, usually involving heating and cooling. When applicable, the following, more specific terms should be used: *age hardening, case hardening, flame hardening, induction hardening, laser hardening, precipitation hardening,* and *quench hardening.*

Hardfacing: The application of a hard, wear-resistant material to the surface of a component by welding, spraying, or allied welding processes to reduce wear or loss of material by abrasion, impact, erosion, galling, and cavitation. See also *surfacing.*

Hardness: A measure of the resistance of a material to surface indentation or abrasion; may be thought of as a function of the stress required to produce some specified type of surface deformation. There is no absolute scale for hardness; therefore, to express hardness quantitatively, each type of test has its

own scale of arbitrarily defined hardness. Indentation hardness can be measured by Brinell, Rockwell, Vickers and Knoop.

Heat: A batch of metal obtained from a period of continuous melting in a cupola or furnace.

Heat-affected zone (HAZ): That portion of the base metal that was not melted during brazing, cutting, or welding, but whose microstructure and mechanical properties were altered by the heat.

Heat check: A pattern of parallel surface cracks that are formed by alternate rapid heating and cooling of the extreme surface metal, sometimes found on forging dies and piercing punches. There may be two sets of parallel cracks, one set perpendicular to the other.

Heat-resistant alloy: An alloy developed for very-high-temperature service where relatively high stresses (tensile, thermal, vibratory, or shock) are encountered and where oxidation resistance is frequently required.

Heat treatment: Heating and cooling a solid metal or alloy in such a way as to obtain desired conditions or properties. Heating for the sole purpose of hot working is excluded from the meaning of this definition.

High-strength low-alloy (HSLA) steels: Steels designed to provide better mechanical properties and/or greater resistance to atmospheric corrosion than conventional carbon steels. They are not considered to be alloy steels in the normal sense because they are designed to meet specific mechanical properties rather than a chemical composition (HSLA steels have yield strengths greater than 275 MPa, or 40 ksi). The chemical composition of a specific HSLA steel may vary for different product thicknesses to meet mechanical property requirements. The HSLA steels have low carbon contents (0.05 to 0.25% C) in order to produce adequate formability and weldability, and they have manganese contents up to 2.0%. Small quantities of chromium, nickel, molybdenum, copper, nitrogen, vanadium, niobium, titanium, and zirconium are used in various combinations.

Hot corrosion. An accelerated corrosion of metal surfaces that results from the combined effect of oxidation and reactions with sulfur compounds and other contaminants, such as chlorides, to form a molten salt on a metal surface that fluxes, destroys, or disrupts the normal protective oxide. See also *gaseous corrosion.*

Hot crack: A crack that develops in a weldment or casting during solidification.

Hot isostatic pressing: (1) A process for simultaneously heating and forming a compact in which the powder is contained in a sealed flexible sheet metal or glass enclosure and the so-contained powder is subjected to equal pressure from all directions at a temperature high enough to permit plastic deformation and sintering to take place. (2) A process that subjects a component (casting, powder forgings, etc.) to both elevated temperature and isostatic gas pressure in an autoclave. The most widely used pressurizing gas is argon. When castings are hot isostatically pressed, the simultaneous application of heat and pressure virtually eliminates internal voids and microporosity through a combination of plastic deformation, creep, and diffusion.

Hot shortness: A tendency for some alloys to separate along grain boundaries when stressed or deformed at temperatures near the melting point. Hot shortness is caused by a low-melting constituent, often present only in minute amounts, that is segregated at grain boundaries.

Hot tear: A fracture formed in a metal during solidification because of *hindered contraction.*

Hot top: (1) A reservoir thermally insulated or heated, that holds molten metal on top of a mold for feeding of the ingot or casting as it contracts on solidifying, thus preventing formation of pipe or voids. (2) A refractory-lined steel or iron casting that is inserted into the tip of the mold and is supported at various heights to feed the ingot as it solidifies.

Hot working: (1) The plastic deformation of metal at such a temperature and strain rate that recrystallization takes place simultaneously with the deformation, thus avoiding any strain hardening, also referred to as hot forging and hot forming. (2) Controlled mechanical operations for shaping a product at temperatures above the recrystallization temperature. Contrast with *cold working.*

Hydrogen damage: A general term for the embrittlement, cracking, blistering, and hydride formation that can occur when hydrogen is present in some metals.

Hydrogen embrittlement: A process resulting in a decrease of the toughness or ductility of a metal due to the presence of atomic hydrogen. Hydrogen embrittlement has been recognized classically as being of two types. The first, known as internal hydrogen embrittlement, occurs when the hydrogen enters molten metal which becomes supersaturated with hydrogen immediately after solidification. The second type, environmental hydrogen embrittlement, results from hydrogen being absorbed by solid metals. This can occur during elevated-temperature thermal treatments and in service during electroplating, contact with maintenance chemicals, corrosion reactions, cathodic protection, and operating in high pressure hydrogen. In the absence of residual stress or external loading, environmental hydrogen embrittlement is manifested in various forms, such as blistering, internal cracking, hydride formation, and reduced ductility. With a tensile stress or stress-intensity factor exceeding a specific threshold, the atomic hydrogen interacts with the metal to induce subcritical crack growth leading to fracture. In the absence of a corrosion reaction (polarized cathodically), the usual term used is hydrogen-assisted cracking (HAC) or hydrogen stress cracking (HSC). In the presence of active corrosion, usually as pits or crevices (polarized anodically), the cracking is generally called stress-corrosion cracking (SCC), but should more properly be called hydrogen-assisted sfress-corrosion cracking (HSCC). Thus, HSC and electrochemically anodic SCC can operate separately or in combination (HSCC). In some metals, such as high-strength steels, the mechanism is believed to be all, or nearly all, HSC. The participating mechanism of HSC is not always recognized and may be evaluated under the generic heading of SCC.

Hydrogen-induced cracking (HIC): Same as *hydrogen embrittlement.*

Hydrogen stress cracking (HSC): See *hydrogen embrittlement.*

IACS: International annealed copper standard; a standard reference used in reporting electrical conductivity. The conductivity of the annealed copper is defined to be 100% IACS.

Impact energy: The amount of energy, usually given in joules or foot-pound force, required to fracture a material, usually measured by means of an Izod test or Charpy test. The type of specimen and test conditions affects the values and therefore should be specified.

Impact strength: A measure of the resiliency or toughness of a solid. The maximum force or energy of a blow (given by a fixed procedure) that can be withstood without fracture, as opposed to fracture strength under a steady applied force.

Impact test: A test for determining the energy absorbed in fracturing a test piece at high velocity, as distinct from static test. The test may be carried out in tension, bending, or torsion, and the test bar may be notched or unnotched. See also *Charpy test, impact energy,* and *Izod test.*

Impingement corrosion: A form of *erosion-corrosion* generally associated with the local impingement of a high-velocity, flowing fluid against a solid surface.

Impregnation: (1) Treatment of porous castings with a sealing medium to stop pressure leaks. (2) The process of filling the pores of a sintered compact, usually with a liquid such as a lubricant. (3) The process of mixing particles of a nonmetallic substance in a cemented carbide matrix, as in diamond-impregnated tools.

Impurities: (1) Elements or compounds whose presence in a material is undesirable. (2) In a chemical or material, minor constituent(s) or component(s) not included deliberately; usually to some degree or above some level, undesirable.

Inclusion: (I) A physical and mechanical discontinuity occurring within a material or part, usually consisting of solid, encapsulated foreign material. Inclusions are often capable of transmitting some structural stresses and energy fields, but to a noticeably different degree than from the parent material. (2) Particles of foreign material in a metallic matrix. The particles are usually compounds, such as oxides, sulfides, or silicates, but may be of any substance that is foreign to (and essentially insoluble in) the matrix. See also *exogenous inclusion, indigenous inclusion,* and *stringer.*

Incomplete fusion: In welding, fusion that is less than complete.

Induction hardening: A surface-hardening process in which only the surface layer of a suitable ferrous work piece is heated by electromagnetic induction to above the upper critical temperature and immediately quenched.

Induction welding: A welding process that produces coalescence of metals by the heat obtained from the resistance of the work pieces to the flow of induced high-frequency welding current with or without the application of pressure. The effect of the high-frequency welding current is to concentrate the welding heat at the desired location.

Inert gas: (1) A gas, such as helium, argon, or nitrogen, that is stable, does not support combustion, and does not form reaction products with other materials. (2) In welding, a gas that does not normally combine chemically with the base metal or filler metal. See also *protective atmosphere.*

Infiltration: The process of filling the pores of a sintered or unsintered compact with a metal or alloy of lower melting temperature.

Infrared spectroscopy: The study of the interaction of material systems with electromagnetic radiation in the infrared region of the spectrum. The technique is useful for determining the molecular structure of organic and inorganic compounds by identifying the rotational and vibration energy levels associated with the various molecules. See also *electromagnetic radiation.*

Intercrystalline: Between the crystals, or grains, of a polycrystalline material.

Interdendritic corrosion: Corrosive attack that progresses preferentially along interdendritic paths. This type of attack results from local differences in composition, such as coring commonly encountered in alloy castings.

Intergranular cracking: Cracking or fracturing that occurs between the grains or crystals in a polycrystalline aggregate, also called intercrystalline cracking. Contrast with *transgranular cracking.*

Intergranular stress-corrosion cracking (IGSCC): Stress-corrosion cracking in which the cracking occurs along grain boundaries.

Internal shrinkage: A void or network of voids within a casting caused by inadequate feeding of that section during solidification.

Investing: In investment casting, the process of pouring the investment slurry into a flask surrounding the pattern to form the mold.

Investment casting: (1) Casting metal into a mold produced by surrounding, or investing, an expendable pattern with a refractory slurry coating that sets at room temperature, after which the wax or plastic pattern is removed through the use of heat prior to filling the mold with liquid metal Also called *precision casting* or *lost wax process.* (2) A part made by the investment casting process.

Ion nitriding: A method of surface hardening in which nitrogen ions are diffused into a work piece in a vacuum through the use of high-voltage electrical energy. Synonymous with plasma nitriding or glowdischarge nitriding.

Isocorrosion diagram: A graph or chart that shows constant corrosion behavior with changing solution (environment) composition and temperature.

Izod test: A type of impact test in which a V-notched specimen, mounted vertically, is subjected to a sudden blow delivered by the weight at the end of a pendulum arm. The energy required to break off the free end is a measure of the impact strength or toughness of the material. Contrast with *Charpy test.*

Karat: A unit for designating the fineness of gold in an alloy. In this system, 24 karat (24 k) is 1000 fine or pure gold. The most popular jewelry golds are:

Karat Designation	Gold Content
24k	100% Au (99.5% min)
18k	18/24ths, or 75% Au
14k	14/24ths or 58.33% Au
10k	10/24ths, or 41.67% Au

Keel block: A standard test casting, for steel and other high-shrinkage alloys, consisting of a rectangular bar that resembles the keel of a boat, attached to the bottom of a large riser, or shrinkhead. Keel blocks that have only one bar are often called Y-blocks; keel blocks having two bars, double keel blocks. Test specimens are machined from the rectangular bar, and the shrinkhead is discarded.

Knoop hardness number (HK): A number related to the applied load and to the projected area of the permanent impression made by a rhombic-based pyramidal diamond indenter having included edge angles of 172° 30' and 130° 0' computed from the equation:

$HK = P/0.07028\ d^2$

where *P* is applied load, kgf; and *d* is the length of the long diagonal of the impression, mm. In reporting Knoop hardness numbers, the test load is stated.

Lack of fusion (LOF): A condition in a welded joint in which fusion is less than complete.

Lack of penetration (LOP): A condition in a welded joint in which joint penetration is less than that specified.

Lamellar tearing: Occurs in the base metal adjacent to weldments due to high through-thickness strains introduced by weld metal shrinkage in highly restrained joints. Tearing occurs by decohesion and linking along the working direction of the base metal; cracks usually run roughly parallel to the fusion line and are step like in appearance.

Lamination: (1) A type of discontinuity with separation or weakness generally aligned parallel to the worked surface of a metal. May be the result of pipe, blisters, seams, inclusions, or segregation elongated and made directional by working. Laminations may also occur in powder metallurgy compacts. (2) In electrical products such as motors, a blanked piece of electrical sheet that is stacked up with several other identical pieces to make a stator or rotor.

Laser beam welding (LBW): A welding process that produces coalescence of materials with the heat obtained from the application of a concentrated coherent light beam impinging upon the joint.

Ledeburite: The eutectic of the iron-carbon system, the constituents of which are austenite and cementite. The austenite decomposes into ferrite and cementite on cooling below Ar. the temperature at which transformation of austenite to ferrite or ferrite plus cementite is completed during cooling.

Leidenfrost phenomenon. Slow cooling rates associated with a hot vapor blanket that surrounds a part being quenched in a liquid medium such as water. The gaseous vapor envelope acts as an insulator, thus slowing the cooling rate.

Liquid carburizing: Surface hardening of steel by immersion into a molten bath consisting of cyanides and other salts.

Liquid metal embrittlement (**LME**): Catastrophic brittle failure of a normally ductile metal when in contact with a liquid metal and subsequently stressed in tension. See also *solid metal embrittlement.*

Liquid Nitriding: A method of surface hardening in which molten nitrogen-bearing, fused-salt baths containing both cyanides and cyanates are exposed to parts at subcritical temperatures.

Liquid penetrant inspection: A type of nondestructive inspection that locates discontinuities that are open to the surface of a metal by first allowing a penetrating dye or fluorescent liquid to infiltrate the discontinuity, removing the excess penetrant, and then applying a developing agent that causes the penetrant to seep back out of the discontinuity and register as an indication. Liquid penetrant inspection is suitable for both ferrous and nonferrous materials, but is limited to the detection of open surface discontinuities in nonporous solids.

Liquidus: (1) The lowest temperature at which a metal or an alloy is completely liquid. (2) In a phase diagram, the locus of points representing the temperatures at which the various compositions in the system begin to freeze on cooling or finish melting on heating. See also *solidus.*

Longitudinal direction: That direction parallel to the direction of maximum elongation in a worked material. See also *normal direction* and *transverse direction.*

Lost foam casting: An expendable pattern process in which an expandable polystyrene pattern surrounded by the unbounded sand, is vaporized during pouring of the molten metal.

Lost wax process: An investment casting process in which a wax pattern is used.

Lot: (1) A specific amount of material produced at one time using one process and constant conditions of manufacture, and offered for sale as a unit quantity. (2) A quantity of material that is thought to be uniform in one or more stated properties such as isotopic, chemical, or physical characteristics. (3) A quantity of bulk material of similar composition whose properties are under study. Compare with *batch.*

Low-alloy steels: A category of ferrous materials that exhibit mechanical properties superior to plain carbon steels as the result of additions of such alloying elements as nickel, chromium, and molybdenum. Total alloy content can range from 2.07% up to levels just below that of stainless steels, which contain a minimum of 10% Cr.

Macrograph: A graphic representation of the surface of a prepared specimen at a magnification not exceeding 25x. When photographed, the reproduction is known as a photomacrograph.

Macroshrinkage: Isolated, clustered, or interconnected voids in a casting that are detectable macroscopically. Such voids are usually associated with abrupt changes in section size and are caused by feeding that is insufficient to compensate for solidification shrinkage.

Macrostructure: The structure of metals as revealed by macroscopic examination of the etched surface of a polished specimen

Magnetic-particle inspection: A nondestructive method of inspection for determining the existence and extent of surface cracks and similar imperfections in ferromagnetic materials. Finely divided magnetic particles, applied to the magnetized part, are attracted to and outline the pattern of any magnetic leakage fields created by discontinuities.

Malleable iron: A cast iron made by prolonged annealing of white iron in which decarburization, graphitization, or both take place to eliminate some or all of the cementite. The graphite is in the form of temper carbon. If decarburization is the predominant reaction, the product will exhibit a light fracture surface; hence whiteheart malleable. Otherwise, the fracture surface will be dark; hence blackheart malleable. Only the blackheart malleable is produced in the United States. Ferritic malleable has a predominantly ferritic matrix; pearlitic malleable may contain pearlite, spheroidite, or tempered martensite, depending on heat treatment and desired hardness.

Maraging: A precipitation-hardening treatment applied to a special group of high-nickel iron-base alloys (maraging steels) to precipitate one or more intermetallic compounds in a matrix of essentially carbonfree martensite.

Martempering: (1) A hardening procedure in which an austenitized ferrous material is quenched into an appropriate medium at a temperature just above the martensite start temperature of the material, held in the medium until the temperature is uniform throughout, although not long enough for bainite to form, then cooled in air. The treatment is frequently followed by tempering. (2) When the process is applied to carburized material, the controlling martensite start temperature is that of the case. This variation of the process is frequently called marquenching.

Martensite: A generic term for microstructures formed by diffusionless phase transformation in which the parent and product phases have a specific crystallographic relationship. Martensite is characterized by an acicular pattern in the microstructure in both ferrous and nonferrous alloys. In alloys where the solute atoms occupy interstitial positions in the martensitic lattice (such as carbon in iron), the structure is hard and highly strained; but where the solute atoms occupy substitutional positions (such as nickel in iron), the martensite is soft and ductile. The amount of high-temperature phase that transforms to martensite on cooling depends to a large extent on the lowest temperature attained, there being a rather distinct beginning temperature (Ms) and a temperature at which the transformation is essentially complete (Mf. See also *lath martensite, plate martensite,* and *tempered martensite.*

Matrix: The continuous or principal phase in which another constituent is dispersed.

McQuaid-Ehn grain size: The austenitic grain size developed in steels by carburizing at 927 °C (1700 °F) followed by slow cooling. Eight standard McQuaid-Ehn grain sizes rate the structure, from No. 8, the finest, to No. 1, the coarsest. The use of standardized ASTM methods for determining grain size is recommended.

Mechanical properties: The properties of a material that reveal its elastic and inelastic behavior when force is applied, thereby indicating its suitability for mechanical applications; for example, modulus of elasticity, tensile strength, elongation, hardness, and fatigue limit. Compare with *physical properties.*

Mechanical testing: The methods by which the mechanical properties of a metal are determined.

Metal: (1) An opaque lustrous elemental chemical substance that is a good conductor of heat and electricity and, when polished, a good reflector of light. Most elemental metals are malleable and ductile and are, in general, denser than the other elemental substances. (2) As to structure, metals may be distinguished from nonmetals by their atomic binding and electron availability. Metallic atoms tend to lose electrons from the outer shells, the positive ions thus formed being held together by the electron gas produced by the separation. The ability of these "free electrons" to carry an electric current, and the fact that this ability decreases as temperature increases, establish the prime distinctions of a metallic solid. (3) From a chemical viewpoint, an elemental substance whose hydroxide is alkaline. (4) An alloy.

Metallography: The study of the structure of metals and alloys by various methods, especially by optical and electron microscopy.

Metallurgy: The science and technology of metals and alloys. Process metallurgy is concerned with the extraction of metals from their ores and with refining of metals; physical metallurgy, with the physical and mechanical properties of metals as affected by composition, processing, and environmental conditions; and mechanical metallurgy, with the response of metals to applied forces.

Metal-matrix composite: A material that consists of a nonmetallic reinforcement, such as ceramic fibers or filaments, incorporated into a metallic matrix.

Metal spraying: Coating metal objects by spraying molten metal against their surfacas. See also *thermal spraying.*

Microhardness: The hardness of a material as determined by forcing an indenter such as a Vickers or Knoop indenter into the surface of a material under very light load; usually, the indentations are so small that they must be measured with a microscope. Capable of determining hardnesses of different

microconstituents within a structure, or of measuring steep hardness gradients such as those encountered in case hardening. See also *microhardness test.*

Microhardness test: A microindentation hardness test using a calibrated machine to force a diamond indenter of specific geometry, under a test load of 1 to 1000 gram-force, into the surface of the test material and to measure the diagonal or diagonals optically. See also *Knoop hardness test* and *Vickers hardness test.*

Microsegregation: Segregation within a grain, crystal, or small particle. See also *coring.*

Microshrinkage: A casting imperfection, not detectable microscopically, consisting of interdendritic voids. Microshrinkage results from contraction during solidification where the opportunity to supply filler material is inadequate to compensate for shrinkage. Alloys with wide ranges in solidification temperature are particularly susceptible.

Microstructure: The structure of an object, organism, or material as revealed by a microscope at magnifications greater than 25x.

MIG welding: Metal inert-gas welding; see preferred term *gas metal arc welding.*

Mild steel: Carbon steel with a maximum of about 0.25% C and containing 0.4 to 0.7% Mn, 0.1 to 0.5% Si, and some residuals of sulfur, phosphorus, and/or other elements.

Misrun: Denotes an irregularity on a cast metal surface caused by incomplete filling of the mold due to low pouring temperatures, gas back pressure from inadequate venting of the mold, and inadequate gating.

Modulus of elasticity (E): (1) The measure of rigidity or stiffness of a material; the ratio of stress, below the proportional limit, to the corresponding strain. If a tensile stress of 13.8 MPa (2.0 ksi) results in *an* elongation of 1.0%, the modulus of elasticity is 13.8 MPa (2.0 ksi) divided by 0.01, or 1380 MPa (200 ksi). (2) In terms of the stress-strain curve, the modulus of elasticity is the slope of the stressstrain curve in the range of linear proportionality of stress to strain. Also known as *Young's modulus.*

Mohs hardness: The hardness of a body according to a scale proposed by Mohs, based on ten minerals, each of which would scratch the one below it. These minerals, in decreasing order of hardness, are:

Diamond	10
Corundum	9
Topaz	8
Quartz	7
Othoclase (feldspar)	6
Apatite	5
Fluorite	4
Calcite	3
Gypsum	2
Talc	1

Mottled cast iron: Iron that consists of a mixture of variable proportions of gray cast iron and white cast iron; such a material has a mottled fracture appearance.

Multiple-pass weld: A weld made by depositing filler metal with two or more successive passes.

NDT: See *nondestructive testing*

Necking: (1) The reduction of the cross-sectional area of a material in a localized area by uniaxial tension or by stretching. (2) The reduction of the diameter of a portion of the length of a cylindrical shell or tube.

Nitriding: Introducing nitrogen into the surface layer of a solid ferrous alloy by holding at a suitable temperature (below Ac 1 for ferritic steels) in contact with a nitrogenous material, usually ammonia or molten cyanide of appropriate composition. Quenching is not required to produce a hard case. See also *bright nitriding* and *liquid nitriding.*

Noble metal: (1) A metal whose potential is highly positive relative to the hydrogen electrode. (2) A metal with marked resistance to chemical reaction, particularly to oxidation and to solution by inorganic acids. The term as often used is synonymous with precious metal.

Nodular graphite: Graphite in nodular (rounded) form as opposed to flake form (see *flake graphite).* See also *ductile iron* and *spheroidal graphite.*

Nodular iron: See preferred term ductile iron.

Nondestructive evaluation (NDE): Broadly considered synonymous with *nondestructive inspection (NDI).* More specifically; the quantitative analysis of NDI findings to determine whether the material will be acceptable for its function, despite the presence of discontinuities. With NDE, a discontinuity can be classified by its size, shape, type, and location, allowing the investigator to determine whether or not the flaw(s) is acceptable. Damage tolerant design approaches are based on the philosophy of ensuring safe operation in the presence of flaws.

Nondestructive inspection (NDI): A process or procedure, such *as* ultrasonic or radiographic inspection, for determining the quality or characteristics of a material, part, or assembly, without permanently altering the subject or its properties. Used to find internal anomalies in a structure without degrading its properties or impairing its serviceability.

Nondestructive testing (NDT): Broadly considered synonymous with *nondestructive inspection (NDI).*

nonmetallic inclusions: See *inclusions.*

Normalizing: Heating a ferrous alloy to a suitable temperature above the transformation range and then cooling in air to a temperature substantially below the transformation range.

Notched specimen: A test specimen that has been deliberately cut or notched, usually in a V-shape, to induce and locate point of failure.

Notch sensitivity: The extent to which the sensitivity of a material to fracture is increased by the presence of a stress concentration, such as a notch, a sudden change in cross section, a crack, or a scratch. Low notch sensitivity is usually associated with ductile materials, and high notch sensitivity is usually associated with brittle materials.

Nuclear grade: Material of a quality adequate for use in nuclear application.

Nucleation: The initiation of a phase transformation at discrete sites, with the new phase growing on the nuclei. See also *nucleus (2).*

Nucleus: (1) The heavy central core of an atom, in which most of the mass and the total positive electric charge are concentrated. (2) The first structurally stable particle capable of initiating recrystallization of a phase or the growth of a new phase and possessing an interface with the parent metallic matrix. The term is also applied to a foreign particle that initiates such action.

Offset yield strength: The stress at which the strain exceeds by a specific amount (the offset) an extension of the initial, approximately linear, proportional portion of the stress-strain curve. It is expressed in force per unit area. (0.2% offset yield strength is common with metallic alloys)

Optical emission spectroscopy (OES): Pertaining to emission spectroscopy in the near-ultraviolet, visible, or near infrared wavelength regions of the electromagnetic spectrum. See also *electromagnetic radiation.*

Orange peel: A surface roughening in the form of a pebble-grained pattern that occurs when a metal of unusually coarse grain size is stressed beyond its elastic limit, also called pebbles and alligator skin.

Oxidation: (1) A reaction in which there is an increase in valence resulting from a loss of electrons. Contrast with *reduction.* (2) A corrosion reaction in which the corroded metal forms an oxide; usually applied to reaction with a gas containing elemental oxygen, such as air. Elevated temperatures increase the rate of oxidation. (3) A chemical reaction in which one substance is changed to another by oxygen combining with the substance. Much of the dross from holding and melting furnaces is the result of oxidation of the alloy held in the furnace.

Pack carburizing: A method of surface hardening of steel in which parts are packed in a steel box with a carburizing compound and heated to elevated temperatures. This process has been largely supplanted by gas and liquid carburizing processes.

Partial annealing: An imprecise term used to denote a treatment given cold-worked metallic material to reduce its strength to a controlled level or to effect stress relief. To be meaningful, the type of material, the degree of cold work, and the time-temperature schedule must be stated.

Passivation: (1) A reduction of the anodic reaction rate of an electrode involved in corrosion. (2) The process in metal corrosion by which metals become passive. (3) The changing of a chemically active surface of a metal to a much less reactive state. Contrast with *activation.*

Passivity: A condition in which a piece of metal, because of an impervious covering of oxide or other compound, has a potential much more positive than that of the metal in the active state.

Pearlite: A metastable lamellar aggregate of ferrite and cementite resulting from the transformation of austenite at temperatures above the bainite range.

Peel test: A destructive method of inspection that mechanically separates a lap joint by peeling.

Peening: Mechanical working of metal by hammer blows or shot impingement.

Permanent mold: A metal, graphite, or ceramic mold (other than an ingot mold) of two or more parts that is used repeatedly for the production of many castings of the same form. Liquid metal is usually poured in by gravity.

Permeability: (1) The passage or diffusion (or rate of passage) of a gas, vapor, liquid, or solid through a material (often porous) without physically or chemically affecting it; the measure of fluid flow (gas or

liquid) through a material. (2) A general term used to express various relationships between magnetic induction and magnetizing force.

Phase: A physically homogeneous and distinct portion of a material system

Phase change: The transition from one physical state to another, such as gas to liquid, liquid to solid, gas to solid, or vice versa.

Phase diagram: A graphical representation of the temperature and composition limits of phase fields in an alloy or ceramic system as they actually exist under the specific conditions of heating or cooling. A phase diagram may be an equilibrium diagram, an approximation to an equilibrium diagram, or a representation of metastable conditions or phases. Synonymous with constitution diagram. Compare with *equilibrium diagram.*

Phosphating: Forming an adherent phosphate coating on a metal by immersion in a suitable aqueous phosphate solution. Also called phosphatizing. See also *conversion coating.*

Pickling: The chemical removal of surface oxides (scale) and other contaminants such as dirt from iron and steel by immersion in an aqueous acid solution. The most common pickling solutions are sulfuric and hydrochloric acids.

Pitting: (1) Forming small sharp cavities in a surface by corrosion, wear, or other mechanically assisted degradation. (2) Localized corrosion of a metal surface, confined to a point or small area, that takes the form of cavities.

Plasma arc welding (**PAW**): An arc welding process that produces coalescence of metals by heating them with a constricted arc between an electrode and the workpiece (transferred arc) or the electrode and the constricting nozzle (nontransferred arc). Shielding is obtained from hot, ionized gas issuing from an orifice surrounding the electrode and may be supplemented by an auxiliary source of shielding gas, which may be an inert gas or a mixture of gases. Pressure may or may not be used, and fdler metal may or may not be supplied.

Plasticity: The property of a material that allows it to be repeatedly deformed without rupture when acted upon by a force sufficient to cause deformation and that allows it to retain its shape after the applied force has been removed.

P/M: The acronym for *powder metallurgy.*

Poisson's ratio (v): The absolute value of the ratio of transverse (lateral) strain to the corresponding axial strain resulting from uniformly distributed axial stress below the proportional limit of the material.

Polishing: (1) Smoothing metal surfaces, often to a high luster, by rubbing the surface with a fine abrasive, usually contained in a cloth or other soft lap. Results in microscopic flow of some surface metal together with actual removal of a small amount of surface metal. (2) Removal of material by the action of abrasive grains carried to the work by a flexible support, generally either a wheel or a coated abrasive belt. (3) A mechanical, chemical, or electrolytic process or combination thereof used to prepare a smooth, reflective surface suitable for microstructural examination that is free of artifacts or damage introduced during prior sectioning or grinding. See also *electrolytic polishing* and *electropolishing.*

Porosity: (1) Fine holes or pores within a solid; the amount of these pores is expressed as a percentage of the total volume of the solid. (2) Cavity-type discontinuities in weldments formed by gas entrapment

during solidification. (3) A characteristic of being porous, with voids or pores resulting from trapped air or shrinkage in a casting. See also *gas porosity* and *pinhole porosity.*

Postweld heat treatment: Any heat treatment that follows the welding operation.

Poultice corrosion: A term used in the automotive industry to describe the corrosion of vehicle body parts due to the collection of road salts and debris on ledges, and in pockets that are kept moist by weather and washing. Also called *deposit corrosion* or attack.

Powder metallurgy (P/M): The technology and art of producing metal powders and utilizing metal powders for production of massive materials and shaped objects.

Precious metals: Relatively scarce, highly corrosion resistant, valuable metals found in periods 5 and 6 (groups VIII and lb) of the periodic table. They include ruthenium, rhodium, palladium, silver, osmium, iridium, platinum, and gold. See also *noble metal.*

Precipitation hardening: Hardening in metals caused by the precipitation of a constituent from a supersaturated solid solution. See also *age hardening* and *aging.*

Preheating: (1) Heating before some further thermal or mechanical treatment. For tool steel, heating to an intermediate temperature immediately before final austenitizing. For some nonferrous alloys, heating to a high temperature for a long time, in order to homogenize the structure before working. (2) In welding and related processes, heating to an intermediate temperature for a short time immediately before welding, brazing, soldering, cutting, or thermal spraying. (3) In powder metallurgy, an early stage in the sintering procedure when, in a continuous furnace, lubricant or binder burnoff occurs without atmosphere protection prior to actual sintering in the protective atmosphere of the high heat chamber.

Process annealing: A heat treatment used to soften metal for further cold working. In ferrous sheet and wire industries, heating to a temperature close to but below the lower limit of the transformation range and subsequently cooling for working. In the nonferrous industries, heating above the recrystallization temperatures at a time and temperature sufficient to permit the desired subsequent cold working.

Proof: (1) To test a component or system at its peak operating load or pressure. (2) Any reproduction of a die impression in any material; often a lead or plaster cast. See also *die proof.*

Quality: (1) The totality of features and characteristics of a product or service that bear on its ability to satisfy a given need (fitness-for-use concept of quality), (2) Degree of excellence of a product or service (comparative concept) often determined subjectively by comparison against an ideal standard or against similar products or services available from other sources. (3) A quantitative evaluation of the features and characteristics of a product or service (quantitative concept).

Quantitative metallography: Determination of specific characteristics of a microstructure by quantitative measurements on micrographs or metallographic images. Quantities so measured include volume concentration of phases, grain size, particle size, mean free path between like particles or secondary phases, and surface-area-to-volume ratio of microconstituents, particles, or grains.

Quench cracking: Fracture of a metal during quenching from elevated temperature. Most frequently observed in hardened carbon steel, alloy steel, or tool steel parts of high hardness and low toughness. Cracks often emanate from fillets, holes, corners, or other stress raisers and result from high stresses due to the volume changes accompanying transformation to martensite.

Quench hardening: In ferrous alloys, hardening by austmitizing and then cooling at a rate such that a substantial amount of austenite transforms to martensite.

Quenching crack: A crack formed in a metal as a result of thermal stresses produced by rapid cooling from a high temperature.

Radiograph: A photographic shadow image resulting from uneven absorption of penetrating radiation in a test object. See also *radiography.*

Radiography: A method of nondestructive inspection in which a test object is exposed to a beam of x-rays or gamma rays and the resulting shadow image of the object is recorded on photographic film placed behind the object, or displayed on a viewing screen. Internal discontinuities are detected by observing and interpreting variations in the image caused by differences in thickness, density, or absorption within the test object. See also *real-time radiography.*

Radius of bend: The radius of the cylindrical surface of the pin or mandrel that comes in contact with the inside surface of the bend during bending. In the case of free or semiguided bends to 180° in which a shim or block is used, the radius of bend is one-half the thickness of the shim or block.

Recarburize: To carburize a metal part to return surface carbon lost in processing; also known as carbon restoration.

Recrystallization: (1) The formation of a new, strainfree grain structure from that existing in cold-worked metal, usually accomplished by heating. (2) The change from one crystal structure to another, as occurs on heating or cooling through a critical temperature. (3) A process, usually physical, by which one crystal species is grown at the expense of another or at the expense of others of the same substance but smaller in size. See also *crystallization.*

Recrystallization Temperature: The approximate minimum temperature at which complete recrystallization of a cold-worked metal occurs within a specified time.

Red mud: A residue, containing a high percentage of iron oxide, obtained in purifying bauxite in the production of alumina in the Bayer process.

Reduction in area (**RA**): The difference between the original cross-sectional area of a tensile specimen and the smallest area at or after fracture as specified for the material undergoing testing, also known as reduction of area.

Reference material: In materials characterization, a material of definite composition that closely resembles in chemical and physical nature the material with which an analyst expects to deal; used for calibration or standardization See also *standard reference material.*

Refractory: (1) A material (usually an inorganic, nonmetallic, ceramic material) of very high melting point with properties that make it suitable for such uses *as* furnace linings and kiln construction. (2) The quality of resisting heat.

Refractory alloy: (1) A heat-resistant alloy. (2) An alloy having an extremely high melting point. See also *refractory metal.* (3) An alloy difficult to work at elevated temperatures.

Residual elements: Small quantities of elements unintentionally present in an alloy.

Residual stress: (1) The stress existing in a body at rest, in equilibrium, at uniform temperature, and not subjected to external forces often caused by the forming or thermal processing. (2) An internal stress not depending on external forces resulting from such factors as cold working, phase changes, or temperature gradients. (3) Stress remaining in a structure or member as a result of thermal or mechanical treatment or both. Stress arises in fusion welding primarily because the weld metal contracts on cooling from the solidus to room temperature.

Resistance spot welding: A resistance welding process that produces coalescence at the faying surfaces of a joint by the heat obtained from resistance to the flow of welding current through the workpieces from electrodes that serve to concentrate the welding current and pressure at the weld areas.

Resistance welding: A group of welding processes that produce coalescence of metals with resistance heating and pressure. See *also flash welding, projection welding, resistance seam welding,* and *resistance spot welding.*

Restraint: Any external mechanical force that prevents a part from moving to accommodate changes in dimension due to thermal expansion or contraction. Often applied to weldments made while clamped in a fixture. Compare with *constraint.*

Ring rolling: The process of shaping weldless rings from pierced disks or shaping thick-wall ring-shaped blanks between rolls that control wall thickness, ring diameter, height, and contour.

Riser: A reservoir of molten metal connected to a casting to provide additional metal to the casting, required as the result of shrinkage before and during solidification.

Rock candy fracture: A fracture that exhibits separated- grain facets; most often used to describe an inter-granular fracture in a large-grained metal.

Rockwell hardness number: A number derived from the net increase in the depth of impression as the load on an indenter is increased from a fixed minor load to a major load and then returned to the minor load. Various scales of Rockwell hardness numbers have been developed based on the hardness of the materials to be evaluated. The scales are designated by alphabetic suffixes to the hardness designation. For example, 64 HRC represents the Rockwell hardness number of 64 on the Rockwell C scale. See also *Rockwell superficial hardness number.*

Rockwell superficial hardness test: The same test as used to determine the Rockwell hardness number except that smaller minor and major loads are used. In Rockwell testing, the minor load is 10 kgf, and the major load is 60, 100, or 150 kgf. In superficial Rockwell testing, the minor load is 3 kgf, and major loads are 15, 30, or 45 kgf. In both tests, the indenter may be either a diamond cone or a steel ball, depending principally on the characteristics of the material being tested.

Root crack: A crack in either the weld or heat-affected zone at the root of a weld.

Rough machining: Machining without regard to finish, usually to be followed by a subsequent operation.

Rust: A visible corrosion product consisting of hydrated oxides of iron. Applied only to ferrous alloys. See also *white rust.*

Sacrificial protection: Reduction of corrosion of a metal in an electrolyte by galvanically coupling it to a more anodic metal; a form of cathodic protection.

Salt fog test: An accelerated corrosion test in which specimens are exposed to a fine mist of a solution usually containing sodium chloride, but sometimes modified with other chemicals, also known as salt spray test.

Sand casting: Metal castings produced in sand molds.

Scale: Surface oxidation, consisting of partially adherent layers of corrosion products, left on metals by heating or casting in air or in other oxidizing atmospheres.

Scleroscope hardness test: A dynamic indentation hardness test using a calibrated instrument that drops a diamond-tipped hammer from a fixed height onto the surface of the material being tested. The height of rebound of the hammer is a measure of the hardness of the material. (The Leeb hardness test (Equotip) is a modern version of this test)

Scrap: (1) Products that are discarded because they are defective or otherwise unsuitable for sale. (2) Discarded metallic material, from whatever source, that may be reclaimed through melting and refining.

Scratch hardness: The hardness of a metal determined by the width of a scratch made by drawing a cutting point across the surface under a given pressure.

Seam: (1) On a metal surface, an unwelded fold or lap that appears as a crack, usually resulting from a discontinuity. (2) A surface defect on a casting related to but of lesser degree than *a cold shut.* (3) A ridge on the surface of a casting caused by a crack in the mold face.

Seam weld: A continuous weld made between or upon overlapping members, in which coalescence may start and occur on the faying surfaces, or may have proceeded from the outer surface of one member. The continuous weld may consist of a single weld bead or a series of overlapping spot welds.

Segregation: (1) Nonuniform distribution of alloying elements, impurities, or microphases in metals and alloys. (2) A casting defect involving a concentration of alloying elements at specific regions, usually as a result of the primary crystallization of one phase with the subsequent concentration of other elements in the remaining liquid. Microsegregation refers to normal segregation on a microscopic scale in which material richer in an alloying element freezes in successive layers on the dendrites (coring) and in constituent network. Macrosegregation refers to gross differences in concentration (for example, from one area of a casting to another). See also *inverse segregation* and *normal segregation.*

Segregation banding: Inhomogeneous distribution of alloying elements aligned in filaments or plates parallel to the direction of working.

Seizing: The stopping of a moving part by a mating surface as a result of excessive friction.

Sensitization: In austenitic stainless steels, the precipitation of chromium carbides, usually at grain boundaries, on exposure to temperatures of about 540 to 845 °C (about 1000 to 1550 °F), leaving the grain boundaries depleted of chromium and therefore susceptible to preferential attack by a corroding medium. Welding is the most common cause of sensitization. Weld decay (sensitization) caused by carbide precipitation in the weld heat-affected zone leads to intergranular corrosion.

Severity of quench: Ability of quenching medium to extract heat from a hot steel workpiece; expressed in terms of the *Grossmann number (H).*

Shape memory alloys: A group of metallic materials that demonstrate the ability to return to some previously defined shape or size when subjected to the appropriate thermal procedure.

Shear: (1) The type of force that causes or tends to cause two contiguous parts of the same body to slide relative to each other in a direction parallel to their plane of contact. (2) A machine or tool for cutting metal and other material by the closing motion of two sharp, closely adjoining edges; for example, squaring shear and circular shear. (3) An inclination between two cutting edges, such as between two straight knife blades or between the punch cutting edge and the die cutting edge, so that a reduced area will be cut each time. This lessens the necessary force, but increases the required length of the working stroke. This method is referred to as angular shear. (4) The act of cutting by shearing dies or blades, as in shearing lines.

Shear modulus (**G**): The ratio of shear stress to the corresponding shear strain for shear stresses below the proportional limit of the material. Values of shear modulus are usually determined by torsion testing, also known *as* modulus of rigidity.

Shielded metal arc welding (**SMAW**): An arc welding process that produces coalescence of metals by heating them with an arc between a covered metal electrode and the workpieces. Shielding is obtained from decomposition of the electrode covering. Pressure is not used, and filler metal is obtained from the electrode, also commonly referred to as stick welding.

Shielding gas: (1) Protective gas used to prevent atmospheric contamination during welding. (2) A stream of inert gas directed at the substrate during thermal spraying so as to envelop the plasma flame and substrate; intended to provide a barrier to the atmosphere in order to minimize oxidation.

Shock load: The sudden application of an external force that results in a very rapid buildup of stress—for example, piston loading in internal combustion engines.

Shotblasting: Blasting with metal shot; usually used to remove deposits or mill scale more rapidly or more effectively than can be done by sandblasting

S**hot peening**: A method of cold working metals in which compressive stresses are induced in the exposed surface layers of parts by the impingement of a stream of shot, directed at the metal surface at high velocity under controlled conditions.

Shrinkage: (1) The contraction of metal during cooling after hot forging. Die impressions are made oversize according to precise shrinkage scales to allow the forgings to shrink to design dimensions and tolerances. (2) See *casting shrinkage.*

Sigma phase: A hard, brittle, nonmagnetic, intermediate phase occurring in many binary and ternary alloys of the transition elements. The composition of this phase in the various systems is not the same, and the phase usually exhibits a wide range in homogeneity. Sigma phase is frequently encountered in stainless steel.

Sintered density: The quotient of the mass (weight) over the volume of the sintered body expressed in grams per cubic centimeter.

Sintering: The bonding of adjacent surfaces of particles in a mass of powder or a compact by heating. Sintering strengthens a powder mass and normally produces densification and, in powdered metals, recrystallization. See also *liquid phase sintering* and *solid-state sintering.*

Size effect: Effect of the dimensions of a piece of metal on its mechanical and other properties and on manufacturing variables such as forging reduction and heat treatment. In general, the mechanical properties are lower for a larger size.

Slag: A nonmetallic product resulting from the mutual dissolution of flux and nonmetallic impurities in smelting, refining, and certain welding operations (see, for example, *electroslag welding).* In steelmaking operations, the slag serves to protect the molten metal from the air and to extract certain impurities.

Slag inclusion: (1) Slag or dross entrapped in a metal. (2) Nonmetallic solid material entrapped in weld metal or between weld metal and base metal.

Slip band: A group of parallel slip lines so closely spaced as to appear as a single line when observed under an optical microscope. See also *slip line.*

Slip line: Visible traces of slip planes on metal surfaces; the traces are (usually) observable only if the surface has been polished before deformation. The usual observation on metal crystals (under a light microscope) is of a cluster of slip lines known as a *slip band.*

***S-N* curve**: A plot of stress (*S*) against the number of cycles to failure (*N*). The stress can be the maximum stress (S_{max}) or the alternating stress amplitude (S_a). For *N* a log scale is almost always used. For *S* a linear scale is used most often, but a log scale is sometimes used, also known as *S-N* diagram.

Solidification: The change in state from liquid to solid upon cooling through the melting temperature or melting range.

Solid-state welding: A group of welding processes that join metals at temperatures essentially below the melting points of the base materials, without the addition of a brazing filler metal. Pressure may or may not be applied to the joint. Examples include *cold welding, diffusion welding, forge welding, friction stir welding, hot pressure welding, roll welding, and ultrasonic welding.*

Solidus: (1) The highest temperature at which a metal or alloy is completely solid. (2) In a phase diagram, the curved line representing the temperatures at which various compositions stop freezing upon cooling or begin to melt upon heating. See also *liquidus.*

Solution heat treatment: Heating an alloy to a suitable temperature, holding at that temperature long enough to cause one or more constituents to enter into solid solution, and then cooling rapidly enough to hold these constituents in solution.

Solvent: The component of either a liquid or solid solution that is present to a greater or major extent; the component that dissolves the solute.

Sour gas: A gaseous environment containing hydrogen sulfide and carbon dioxide in hydrocarbon reservoirs. Prolonged exposure to sour gas can lead to hydrogen damage, sulfide-stress cracking, and/or stress-corrosion cracking in ferrous alloys.

Spalling: (1) The separation of particles from a surface in the form of flakes. The term spalling is commonly associated with rolling-element bearings and with gear teeth. Spalling is usually a result of subsurface fatigue and is more extensive than pitting. (2) The spontaneous chipping, fragmentation, or separation of a surface or surface coating. (3) A chipping or flaking of a surface due to any kind of improper heat treatment or material dissociation.

Spark testing: A method used for the classification of ferrous alloys according to their chemical compositions, by visual examination of the spark pattern or stream that is thrown off when the alloys are held against a grinding wheel rotating at high speed.

Spatter: The metal particles expelled during arc or gas welding. They do not form part of the weld.

Specimen: A test object, often of standard dimensions and/or configuration that is used for destructive or nondestructive testing. One or more specimens may be cut from each unit of a sample.

Spheroidal graphite: Graphite of spheroidal shape with a polycrystalline radial structure. This structure can be obtained, for example, by adding cerium or magnesium to the melt. See also *ductile iron* and *nodular graphite.*

Spheroidized structure: A microstructure consisting of a matrix containing spheroidal particles of another constituent. Spheroidized steel consists of carbide particles in a ferrite matrix

Spot weld: A weld made between or upon overlapping members in which coalescence may start and occur on the faying surfaces or may proceed from the surface of one member. The weld cross section is approximately circular.

Spot welding: See *arc spot weld* and *resistance spot welding* sprite. (1) The mold channel that connects the pouring basin with the runner or, in the absence of a pouring basin, directly into which molten metal is poured, sometimes referred to as downspout or down gate. (2) Sometimes used to mean all gates, risers, runners, and similar scrap that is removed from castings after shakeout.

Sputtering: The bombardment of a solid surface with a flux of energetic particles (ions) that results in the ejection of atomic species. The ejected material may be used as a source for deposition. See also *physical vapor deposition.*

Stainless steel: Any of several steels containing at least 10.5% Cr as the principal alloying element; they usually exhibit passivity in aqueous environments.

Stampling: The general term used to denote all sheet metal pressworking. It includes blanking, shearing, hot or cold forming, drawing, bending, or coining.

Steadite: A hard structural constituent of cast iron that consists of binary eutectic of ferrite, containing some phosphorus in solution, and iron phosphide (Fe_3P). The eutectic consists of 10.2% P and 89.8% Fe. The melting temperature is 1050°C (1920°F).

Steel: An iron-base alloy, containing manganese, carbon, and often other alloying elements. In carbon steel and low-alloy steel, the maximum carbon is about 2.0%; in high-alloy steel, about 2.5%. The dividing line between low-alloy and high-alloy steels is generally regarded as being at about 5% metallic alloying elements.

Stiffness: (1) The rate of stress with respect to strain; the greater the s tress required to produce a given strain, the stiffer the material is said to be. (2) The ability of a material or shape to resist elastic deflection. For identical shapes, the stiffness is proportional to the modulus of elasticity. For a given material, the stiffness increases with increasing moment of inertia, which is computed from cross-sectional dimensions.

Stopping off: (1) Applying a resist. (2) Depositing a metal (copper, for example) in localized areas to prevent carburization, decarburization, or nitriding in those areas. (3) Filling in a portion of mold cavity to keep out molten metal.

Straightening: (1) Any bending, twisting, or stretching operation to correct any deviation from straightness in bars, tubes, or similar long parts or shapes. This deviation can be expressed as either camber (deviation from a straight line) or as total indicator reading (TIR) per unit of length. (2) A finishing operation for correcting misalignment in a forging or between various sections of a forging. See also *roll straightening.*

Strain: The unit of change in the size or shape of a body due to force. Also known as nominal strain. The term is also used in a broader sense to denote a dimensionless number that characterizes the change in dimensions of an object during a deformation or flow process. See also *engineering strain* and *true strain*.

Strain-age embrittlement: A loss in ductility accompanied by an increase in hardness and strength that occurs when low-carbon steel (especially rimmed or capped steel) is aged following plastic deformation. The degree of embrittlement is a function of aging time and temperature, occurring in a matter of minutes at about 200°C (400°F), but requiring a few hours to a year at room temperature.

Strain hardening: An increase in hardness and strength of metals caused by plastic deformation at temperatures below the recrystallization range. Also known as work hardening.

Strain rate: The time rate of straining for the usual tensile test. Strain as measured directly on the specimen gage length is used for determining strain rate. Because strain is dimensionless, the units of strain rate are reciprocal time.

Stress: The intensity of the internally distributed forces or components of forces that resist a change in the volume or shape of a material that is or has been subjected to external forces. Stress is expressed in force per unit area. Stress can be normal (tension or compression) or shear. See also *compressive stress, engineering stress, mean stress, nominal stress, normal stress, residual stress, shear stress, tensile stress,* and *true stress.*

Stress concentration: On a macromechanical level, the magnification of the level of an applied stress in the region of a notch, void, hole, or inclusion.

Stress-corrosion cracking (SCC): A cracking process that requires the simultaneous action of a corrodent and sustained tensile stress. This excludes corrosion reduced sections that fail by fast fracture. It also excludes interaystalline or transcrystalline corrosion, which can disintegrate an alloy without applied or residual stress. Stress-corrosion cracking jaw occur in combination with hydrogen embrittlement.

Stress raisers: Design features (such as sharp corners) or mechanical defects (such as notches) that act to intensify the stress at these locations.

Stress relieving: Heating to a suitable temperature, holding long enough to reduce residual stresses, and then cooling slowly enough to minimize the development of new residual stresses.

Stress-strain curve: A graph in which corresponding values of stress and strain from a tension, compression, or torsion test are plotted against each other. Values of stress are usually plotted vertically (ordinates or y-axis) and values of strain horizontally (abscissas or x-axis). Also known as deformation curve and stress-strain diagram.

Striation: A fatigue fracture feature, often observed in electron micrographs, that indicates the position of the crack front after each succeeding cycle of stress. The distance between striations indicates the advance of the crack front across that crystal during one stress cycle, and a line normal to the striations indicates the direction of local crack propagation. See also *beach marks.*

Stringer: In wrought materials, an elongated configuration of microconstituents or foreign material aligned in the direction of working. The term is commonly associated with elongated oxide or sulfide inclusions in steel.

Stringer bead: A continuous weld bead made without appreciable transverse oscillation (weaving motion). Contrast with *weave bead.*

Structural shape: A piece of metal of any of several designs accepted as standard by the structural branch of the iron and steel industries. Common examples include channels and I beams.

Structure: As applied to a crystal, the shape and size of the unit cell and the location of all atoms within the unit cell. As applied to microstructure, the size, shape, and arrangement of phases. See also *unit cell.*

Stud welding: A general term for joining a metal stud, or similar part to a work piece. Welding may be accommodated by arc, resistance, friction, or other processes with r without external gas shielding.

Subcritical annealing: An annealing treatment in which a steel is heated to a temperature below the at temperature, then cooled slowly to room temperature. See also *transformation temperature.*

Submerged arc welding (**SAW**): An arc welding process that produces coalescence of metals by heating them with an arc or arcs between a bare metal electrode or electrodes and the work pieces. The arc and molten metal are shielded by a blanket of granular, fusible material on the work pieces. Pressure is not used, and filler metal is obtained from the electrode and sometimes from a supplemental source (welding rod, flux, or metal granules).

Subsurface corrosion: Formation of isolated particles of corrosion products beneath a metal surface. This results from the preferential reactions of certain alloy constituents to inward diffusion of oxygen, nitrogen, or sulfur.

Sulfide stress cracking (**SSC**): Brittle fracture by cracking under the combined action of tensile stress and corrosion in the presence of water and hydrogen sulfide. See also *environmental cracking.*

Superalloys: Heat-resistant alloys based on nickel, iron-nickel, or cobalt that exhibit high strength and resistance to surface degradation at elevated temperatures.

Surface damage: In tribology, damage to a solid surface resulting from mechanical contact with another substance, surface, or surfaces moving relatively to it and involving the displacement or removal of material. In certain contexts, wear is a form of surface damage in which material is progressively removed. In another context, surface damage involves a deterioration of function of a solid surface even though there is no material loss from that surface. Surface damage may therefore precede wear.

Surface finish: (1) The geometric irregularities in the surface of a solid material. Measurement of surface finish shall not include inherent structural irregularities unless these are the characteristics being measured. (2) Condition of a surface as a result of a final treatment. See also *roughness.*

Surface hardening: A generic term covering several processes applicable to a suitable ferrous alloy that produces, by quench hardening only, a surface layer that is harder or more wear resistant than the core. There is no significant alteration of the chemical composition of the surface layer. The processes commonly used are carbonitriding, carburizing, induction hardening, flame hardening, nitriding, and nitrocarburizing. Use of the applicable specific process name is preferred.

Surface roughness: Fine irregularities in the surface texture of a material, usually including those resulting from the inherent action of the production process. Surface roughness is usually reported as the arithmetic roughness average, *Ra,* and is given in micrometers or micro inches.

Surface texture: The roughness, waviness, lay, and flaws associated with a surface. See also *lay.*

Surfacing weld: A type of weld composed of one or more stringer or weave beads deposited on an unbroken surface to obtain desired properties or dimensions.

Swarf: Intimate mixture of grinding chips and fine particles of abrasive and bond resulting from a grinding operation.

Tack weld: A weld made to hold parts of a weldment in proper alignment until the final welds are made.

Temper: (1) In heat treatment, reheating hardened steel or hardened cast iron to some temperature below the eutectoid temperature for the purpose of decreasing hardness and increasing toughness. The process also is sometimes applied to normalized steel. (2) In tool steels, temper is sometimes used, but inadvisedly, to denote the carbon content. (3) In nonferrous alloys and in some ferrous alloys (steels that cannot be hardened by heat treatment), the hardness and strength produced by mechanical or thermal treatment, or both, and characterized by a certain structure, mechanical properties, or reduction in area during cold working. (4) To moisten green sand for casting molds with water.

Temper carbon: Clusters of finely divided graphite, such as that found in malleable iron, that are formed as a result of decomposition of cementite, for example, by heating white cast iron above the ferrite austenite transformation temperature and holding at these temperatures for a considerable period of time, also known as annealing carbon.

Temper color: A thin, tightly adhering oxide skin (only a few molecules thick) that forms when steel is tempered at a low temperature, or for a short time, in air or a mildly oxidizing atmosphere. The color, which ranges from straw to blue depending on the thickness of the oxide skin, varies with both tempering time and temperature.

Tempered martensite: The decomposed products that result from heating martensite below the ferrite austenite transformation temperature.

Temper embrittlement: Embrittlement of low-alloy steels caused by holding within or cooling slowly through a temperature range (generally 300 to 600 °C, or 570 to 1110 °F) just below the transformation range. Embrittlement is the result of the segregation at grain boundaries of impurities such as arsenic, antimony, phosphorus, and tin; it is usually manifested as an upward shift in ductile-to-brittle transition temperature. Temper embrittlement can be reversed by retempering above the critical temperature range, then cooling rapidly. Compare with *tempered martensite embrittlement.*

Tensile strength: In tensile testing, the ratio of maximum load to original cross-sectional area, also called *ultimate tensile strength.* Compare with *yield strength.*

Tension testing: A method of determining the behavior of materials subjected to uniaxial loading, which tends to stretch the material. A longitudinal specimen of known length and diameter is gripped at both ends and stretched at a slow, controlled rate until rupture occurs, also known as tensile testing.

Thermal analysis: A method for determining transformations in a material by noting the temperatures at which thermal arrests occur. These arrests are manifested by changes in slope of the plotted or mechanically traced heating and cooling curves. When such data are secured under nearly equilibrium conditions of heating and cooling, the method is commonly used for determining certain critical temperatures required for the construction of phase diagrams.

Thermal spraying: A group of coating or welding processes in which finely divided metallic or nonmetallic materials are deposited in a molten or semi molten condition to form a coating. The surfacing material may be in the form of powder, rod, or wire. See also *electric arc spraying, flame spraying, plasma spraying,* and *powder flame spraying.*

Thermocouple: A device for measuring temperatures, consisting of lengths of two dissimilar metals or alloys that are electrically joined at one end and connected to a voltage-measuring instrument at the other end. When one junction is hotter than the other, a thermal electromotive force is produced that is roughly proportional to the difference in temperature between the hot and cold junctions.

TIG welding: Tungsten inert-gas welding; see preferred term *gas tungsten arc welding.*

Tool steel: Any of a class of carbon and alloy steels commonly used to make cutting tools or forming dies. Tool steels are characterized by high hardness and resistance to abrasion, often accompanied by high toughness and resistance to softening at elevated temperature. These attributes are generally attained with high carbon and alloy contents.

Total carbon: The sum of the free carbon and combined carbon (including carbon in solution) in a ferrous alloy.

Toughness: Ability of a material to absorb energy and deform plastically before fracturing. Toughness is proportional to the area under the stress-strain curve from the origin to the breaking point. In metals, toughness is usually measured by the energy absorbed in a notch impact test. See also *impact test.*

Tramp element: Contaminant in the components of a furnace charge, or in the molten metal or castings, whose presence is thought to be either unimportant or undesirable to the quality of the casting, also called trace element.

Transcrystalline cracking: Cracking or fracturing that occurs through or across a crystal.

Transformation temperature: The temperature at which a change in phase occurs. This term is sometimes used to denote the limiting temperature of a transformation range.

Transgranular: Through or across crystals or grains, also called transcrystalline.

Transgranular cracking: Cracking or fracturing that occurs through or across a crystal or grain, also called transaystalline cracking. Contrast with *intergranular cracking.*

Transition temperature: (1) An arbitrarily defined temperature that lies within the temperature range in which metal fracture characteristics (as usually determined by tests of notched specimens) change rapidly, such as the ductile-to-brittle transition temperature (DBTT). The DBTT can be assessed in several

ways, the most common being the temperature for 50% ductile and 50% brittle fracture (50% fracture appearance transition temperature, or FATT), or the lowest temperature at which the fracture is 100% ductile (100% fibrous criterion). (2) Sometimes used to denote an arbitrarily defined temperature within a range in which the ductility changes rapidly with temperature.

Transverse direction: Literally, "across," usually signifying a direction or plane perpendicular to the direction of working. In rolled plate or sheet, the direction across the width is often called long transverse; the direction through the thickness, short transverse.

True strain: (1) The ratio of the change in dimension, resulting from a given load increment, to the magnitude of the dimension immediately prior to applying the load increment. (2) In a body subjected to axial force, the natural logarithm of the ratio of the gage length at the moment of observation to the original gage length, also known as natural strain.

True stress: The value obtained by dividing the load applied to a member at a given instant by the cross sectional area over which it acts.

U-bend die: A die, commonly used in press-brake forming, that is machined horizontally with a square or rectangular cross-sectional opening that provides two edges over which metal is drawn into a channel shape.

Ultimate tensile strength (UTS): The ultimate or final (highest) stress sustained by a specimen in a tension test.

Ultrahigh-strength steels: Structural steels with minimum yield strengths of 1380 MPa (200 ksi).

Ultrasonic inspection: A nondestructive method in which beams of high-frequency sound waves are introduced into materials for the detection of surface and subsurface flaws in the material. Also used for thickness testing the sound waves travel through the material with some attendant loss of energy (attenuation) and are reflected at interfaces. The reflected beam is displayed and then analyzed to define the presence and location of flaws or discontinuities. Most ultrasonic inspection is done at frequencies between 0.1 and 25 MHz—well above the range of human hearing, which is about 20 Hz to 20 kHz.

Ultrasonic testing: See *ultrasonic inspection.*

Underbead crack: A crack in the heat-affected zone of a weld generally not extending to the surface of the base metal.

Underfilm corrosion: Corrosion that occurs under organic films in the form of randomly distributed threadlike filaments or spots. In many cases this is identical *to filiform corrosion.*

Uniform corrosion: (1) A type of corrosion attack (deterioration) uniformly distributed over a metal surface. (2) Corrosion that proceeds at approximately the same rate over a metal surface, also called general corrosion.

Vacuum carburizing: A high-temperature gas carburizing process using furnace pressures between 13 and 67 kPa (0.1 to 0.5 torr) during the carburizing portion of the cycle. Steels undergoing this treatment are austenitized in a rough vacuum, carburized in a partial pressure of hydrocarbon gas, diffused in a rough vacuum, and then quenched in either oil or gas.

Vacuum induction melting (**VIM**): A process for re-melting and refining metals in which the metal is melted inside a vacuum chamber by induction heating. The metal can be melted in a crucible and then poured into a mold vacuum melting. Melting in a vacuum to prevent contamination from air and to remove gases already dissolved in the metal; the solidification can also be carried out in a vacuum or at low pressure.

Vermicular graphite iron: Same as *compacted graphite iron.*

Vickers hardness number (**HV**): A number related to the applied load and the surface area of the permanent impression made by a square-based pyramidal diamond indenter having included face angles of 136°.

Vickers hardness test: A microindentation hardness test employing a 136° diamond pyramid indenter (Vickers) and variable loads, enabling the use of one hardness scale for all ranges of hardness—from very soft lead to tungsten carbide. Also known as diamond pyramid hardness test. See also *microindentation* and *microindentation hardness number.*

Warm working: Deformation of metals at elevated temperatures below the recrystallization temperature. The flow stress and rate of strain hardening are reduced with increasing temperature; therefore, lower forces are required than in cold working. See also *cold working* and *hot working.*

Water quenching: A quench in which water is the quenching medium. The major disadvantage of water quenching is its poor efficiency at the beginning or hot stage of the quenching process. It also causes more warping and may cause cracking because it is too drastic. See also *quenching.*

Wear: Damage to a solid surface, generally involving progressive loss of material, due to a relative motion between that surface and a contacting surface or substance. Compare with *surface damage.*

Weldability: The capacity of a material to be welded under the imposed fabrication conditions into a specific, suitably designed structure and to perform satisfactorily in the intended service.

Weld bead: A deposit of filler metal from a single welding pass.

Welding: (1) Joining two or more pieces of material by applying heat or pressure, or both, with or without filler material, to produce a localized union through fusion or recrystallization across the interface. The thickness of the filler material is much greater than the capillary dimensions encountered in brazing. (2) May also be extended to include brazing and soldering. (3) In tribology, adhesion between solid surfaces in direct contact at any temperature.

Welding rod: A form of filler metal used for welding or brazing that does not conduct the electrical current, and which may be either fed into the weld pool or preplaced in the joint.

Welding wire: A form of welding filler metal, normally packaged as coils or spools that may or may not conduct electrical current depending on the welding process with which it is used. See also *electrode (welding)* and *welding rod.*

Weld interface: The interface between weld metal and base metal in a fusion weld, between base metals in a solid-state weld without filler metal, or between filler metal and base metal in a solid-state weld with a filler metal and in a braze.

Weldment: An assembly whose component parts are joined by welding.

Weld pass: A single progression of a welding or surfacing operation along a joint, weld deposit, or substrate. The result of a pass is a weld bead, layer, or spray deposit

Whisker: (1) A short single crystal fiber or filament used as reinforcement in a matrix. Whisker diameters range from 1 to 25 pm, with aspect ratios (length to diameter ratio) generally between 50 and 150. (2) Metallic filamentary growths, often microscopic, sometimes formed during electrode position and sometimes spontaneously during storage or service, after finishing.

White-etching layer: A surface layer in a steel that, as viewed in a section after etching, appears whiter than the base metal. The presence of the layer may be due to a number of causes, including plastic deformation induced by machining or surface rubbing, heating during a metallographic preparation stage to such an extent that the layer is austenitized and then hardened during cooling, and diffusion of extraneous elements into the surface.

White iron: A wear resistant cast iron that is essentially free of graphite and most of the carbon content is present as separate grains of hard Fe_3C. White iron exhibits a white, crystalline fracture surface because fracture occurs along the iron carbide platelets.

White metal: (1) A general term covering a group of white-colored metals of relatively low melting points based on tin or lead. (2) A copper matte of about 77% Cu obtained from smelting of sulfide copper ores.

WidmanstAtten structure: A structure characterized by a geometrical pattern resulting from the formation of a new phase along certain crystallographic planes of the parent solid solution. The orientation of the lattice in the new phase is related crystallographically to the orientation of the lattice in the parent phase. The structure was originally observed in meteorites, but is readily produced in many alloys, such as titanium, by appropriate heat treatment.

Wire: (1) A thin, flexible, continuous length of metal, usually of circular cross section, and usually produced by drawing through a die. The size limits for round wire sections range from approximately 0.13 mm (0.005 in.) to 25 mm (1 in.). Larger rounds are commonly referred to as bars. (2) A length of single metallic electrical conductor, it may be of solid, stranded or tinsel construction, and may be either bare or insulated.

Work hardening: Same as *strain hardening.*

Wrought iron: An iron alloy consisting of slag (iron silicate) fibers entrained in a ferrite matrix. (No longer commercially produced)

Wrought metal: Metal that has been worked by rolling, forging, or some other metal forming process.

X-ray: A penetrating electromagnetic radiation, usually generated by accelerating electrons to high velocity and suddenly stopping them by collision with a solid body. Wavelengths of x-rays range from about 10^{-1} to 10^{-2} A, the average wavelength used in research being about 1A, also known as roentgen ray or x-radiation. See also *electromagnetic radiation.*

X-ray diffraction (XRD): An analytical technique in which measurements are made of the angles at which x-rays are preferentially scattered from a sample (as well as of the intensities scattered at various angles) in order to deduce information on the crystalline nature of the sample—its crystal structure, orientations, and so on.

X-ray fluorescence: Emission by a substance of its characteristic x-ray line spectrum on exposure to x-rays.

X-ray spectrometry: Measurement of wavelengths of x-rays by observing their diffraction by crystals of known lattice spacing.

Yellow brass: A name sometimes used in reference to the 33% zinc type of brass.

Yield: (1) Evidence of plastic deformation in structural materials, also known as plastic flow or creep. See also *flow.* (2) The ratio of the number of acceptable items produced in a production run to the total number that were attempted to be produced. (3) Comparison of casting weight to the total weight of metal poured into the mold.

Yield point: The first stress in a material, usually less than the maximum attainable stress, at which an increase in strain occurs without an increase in stress. Only certain materials—those that exhibit a localized, heterogeneous type of transition from elastic to plastic deformation—produce a yield point. If there is a decrease in stress after yielding, a distinction may be made between upper and lower yield points. The load at which a sudden drop in the flow curve occurs is called the upper yield point. The constant load shown on the flow curve is the lower yield point.

Yield strength: The stress at which a material exhibits a specified deviation from proportionality of stress and strain. An offset of 0.2% is used for many materials, particularly metals. Compare with *tensile strength.*

Young's modulus: A term used synonymously with Modulus of elasticity; the ratio of tensile or compressive stresses to the resulting strain. See also *modulus of elasticity.*