

# GLOSSARY OF TERMS USED IN THE HEAT TREATMENT OF METALS

## A

**A<sub>cm</sub>, A<sub>1</sub>, A<sub>3</sub>, A<sub>4</sub>** - Same as Ae<sub>cm</sub>, Ae<sub>1</sub>, and Ae<sub>3</sub> and Ae<sub>4</sub>.

**Ac<sub>cm</sub>, Ac<sub>1</sub>, Ac<sub>3</sub>, Ac<sub>4</sub>** - Defined under *transformation temperature*.

**ACICULAR FERRITE** - A highly substructure non-equiaxed ferrite that forms upon continuous cooling by a mixed diffusion and shear mode of transformation that begins at a temperature slightly higher than the temperature transformation 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.

**Ae<sub>cm</sub>, Ae<sub>1</sub>, Ae<sub>3</sub>, Ae<sub>4</sub>** - Defined under *transformation temperature*.

**AERATED BATH NITRIDING** - A type of liquid nitriding in which air is pumped through the molten bath creating agitation and increased chemical activity.

**AGE HARDENING** - Hardening by aging usually after rapid cooling or cold water. See *aging*.

**AGE SOFTENING** - Spontaneous decrease of strength and hardness that takes place at room temperature in certain strain hardened alloys especially those of aluminum.

**AGING** - 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 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.

Aging is a structural change, usually by precipitation, that occurs in some

alloys after a preliminary heat treatment or cold working operation. Aging may take place in some alloys at room temperature in moderate time (days) or in others may be done in shorter time at furnace temperatures. Over-aging may be done at a temperature above normal to produce some desirable modification of physical properties.

See also *age hardening, artificial aging, interrupted aging, natural aging, over aging, precipitation hardening, precipitation heat treatment, progressive aging, quench aging and step aging*.

**AIR-HARDENING STEEL** - A steel containing sufficient carbon and other alloying elements to harden fully during cooling in air or other gaseous mediums from a temperature above its transformation range. An alloy steel which will harden when cooled in air from its proper hardening temperature. The terms should be restricted to steels that are capable of being hardened by cooling in air in fairly large sections, about 2 inches (50mm) or more in diameter. Same as self-hardening steel.

**ALLOTROPY** - 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. The capacity of an element to exist in two or more different crystalline forms.

**ALLOYING ELEMENTS** - Elements added to or comprising a basic alloy. Some of the common alloying elements in steels are manganese, chromium, nickel, molybdenum and vanadium.

**ALPHA FERRITE** - See *ferrite*.

**ALPHA IRON** - The allotropic form of iron that exists at temperatures up to about 1670°F. The atoms are arranged in body-centered cubic arrangements. The body-centered cubic form of pure iron stable below 910°C (1670°F).

**ANNEALING** - A generic term denoting 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 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 without qualification, 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 in both 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, intercritical annealing, isothermal annealing, malleablizing, order hardening, process annealing, quench annealing, spheroidizing and 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 © 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 and anneal to temper.*

**ANNEALING CARBON** - Fine, apparently amorphous carbon particles, formed in white cast iron and certain steels during prolonged annealing. Also called *temper carbon*.

**ANNEALING TWIN** - A twin formed in a crystal during recrystallization.

**ANNEAL TO TEMPER** - A final partial anneal that softens a cold worked nonferrous alloy to a specified level of hardness or tensile strength.

**Ar<sub>cm</sub>, Ar<sub>1</sub>, Ar<sub>3</sub>, Ar<sub>4</sub>, Ar', Ar''** - Defined under transformation temperature.

**ARTIFICIAL AGING** - Aging above room temperature. See *aging*. Compare with *natural aging*.

**ATHERMAL TRANSFORMATION** - A reaction that proceeds without benefit of thermal fluctuations; that is, thermal activation is not required. In contrast, a reaction that occurs at constant temperature is an *isothermal transformation*. Thermal activation is necessary in this case and the reaction proceeds as a function of time.

**ATMOSPHERE** - The gaseous environment in which the metal being treated is heated for processing. Atmospheres are used to protect from chemical change or to alter the surface chemistry of steel through the addition or removal of carbon, nitrogen, hydrogen and oxygen, or to add certain metallic elements as chromium or silicon.

**AUSFORMING** - Thermomechanical treatment of steel in the metastable

austenitic condition below the recrystallization temperature followed by quenching to obtain martensite and/or bainite.

**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  $M_s$  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.

A heat treating operation in which austenite is quenched to and held at a constant temperature (usually between 450°F and 800°F) until transformation to bainite is complete. In some steels at certain hardness levels, bainite is tougher than quenched and tempered structures of the same hardness.

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

Austenite is the name given any solid solution in which gamma iron is the solvent. Austenite is a structure name and means nothing as to composition. In one steel, austenite may have a composition of 0.9% carbon and no alloy, and in another, it may have 18% of chromium and 8% nickel. Austenite is the structure from which all hardening heat treatments must start.

**AUSTENITIC GRAIN SIZE** - The size attained by the grains of steel when heated to the austenitic region; may be revealed by appropriate etching of cross sections after cooling to room temperature.

**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.

**AUSTENITIZING TEMPERATURE** - The temperature at which a steel is substantially all austenite.

## **B**

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**BAINITE** - A metastable aggregate consisting of dispersed carbide in ferrite resulting from the transformation of austenite at temperatures below the pearlite range but above  $M_s$ . Its appearance is in the form of relatively coarse ferrite laths between which carbides are precipitated as platelets if formed in the upper part of the bainite transformation range; acicular, resembling tempered martensite, if formed in the lower part.

The product formed when austenite transforms between 450°F and 900°F. Bainite is a very fine aggregate of ferrite and carbide and varies in hardness between Rc 30 and Rc 55.

**BAINITIC HARDENING** - Quench hardening treatment resulting principally in the formation of bainite.

**BANDED STRUCTURE** - A layering effect that is sometimes developed during the hot rolling of steel. Frequently causes longitudinal splitting.

**BARK** - An older term used to describe the decarburized skin that develops on steel bars heated in a non-protective atmosphere.

**BATCH FURNACE** - A furnace used to heat treat a single load at a time. Batch-type furnaces are necessary for large parts such as heavy forgings and are preferred for complex alloy grades

requiring long cycles. See *car furnace*, *horizontal batch furnace*.

**BELT FURNACE** - A continuous-type furnace which uses a mesh-type or cast-link belt to carry parts through the furnace.

**BETA ANNEALING** - Producing a beta phase by heating certain titanium alloys in the temperature range of which this phase forms followed by cooling at an appropriate rate to prevent its decomposition.

**BINARY ALLOY** - An alloy containing two elements apart from minor impurities.

**BLACK ANNEALING** - Box annealing or pot annealing ferrous alloy sheet, strip, or wire to impart a black color to the oxidized surface. See *box annealing*.

**BLACK OXIDE** - A black finish on metal produced by immersing it in hot oxidizing salts or salt solutions.

**BLANK CARBURIZING** - Simulating the carburizing operation without introducing carbon. This is usually accomplished by using an inert material in place of the carburizing agent, or by applying a suitable protective coating to the ferrous alloy.

**BLANK NITRIDING** - Simulating the nitriding operation without introducing nitrogen. This is usually accomplished by using an inert material in place of the nitriding agent or by applying a suitable protective coating to the ferrous alloy.

**BLOWHOLE** - An internal void produced by the entrapment of gas released during the freezing of a metal.

**BLUE ANNEALING** - Heating hot-rolled ferrous sheet in an open furnace to a temperature within the transformation range and then cooling in air in order to soften the metal. The formation of a bluish oxide on the surface is incidental.

**BLUE BRITTLINESS** - 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.

**BLUING** - Subjecting the scale-free surface of a ferrous alloy to the action of air, steam or other agents at a suitable temperature, thus forming a thin blue film of oxide and improving the appearance and resistance to corrosion. NOTE: This term is ordinarily applied to sheet, strip or finished parts. It is used also to denote the heating of springs after fabrication to improve their properties.

**BODY-CENTERED CUBIC** - Arrangement of atoms in space such that if lines were drawn connecting the centers of their activity, the lines would form a cube with an atom at each corner and one additional atom in the very center of the cube body. Chromium, manganese and molybdenum are body-centered cubic metals.

**BORIDING** - Thermochemical treatment involving the enrichment of the surface layer of an object with borides. This surface hardening process is performed below the  $A_c1$  temperature.

**BORONIZING** - See *boriding*.

**BOX ANNEALING** - Annealing a metal or alloy in a sealed container under conditions that minimize oxidation. In box annealing of a ferrous alloy, the charge is usually heated slowly to a temperature below the transformation range, but sometimes above or within it and is then cooled slowly. This process is also called close annealing or pot annealing.

An annealing process in which work is heated in closed metal boxes, usually surrounded by an inert material to protect the surface during heating. See *black annealing*.

**BREAKS** - Creases or ridges usually in "untempered" or in aged material where the yield point has been exceeded. Depending on the origin of the break, it may be termed a cross break, a coil

break, an edge break or a sticker break.

**BRIGHT ANNEALING** - Annealing in a protective medium to prevent discoloration of the bright surface.

Annealing work in a protective atmosphere or vacuum so that there is no discoloration as the result of heating. In some atmospheres surface oxides may be reduced resulting in a surface improvement.

**BRIGHT NITRIDING** - Nitriding in a protective medium to prevent discoloration of the bright surface. Compare with *blank nitriding*.

**BRINE QUENCHING** - A quench in which brine (salt water-chlorides, carbonates and cyanides) is the quenching medium. The salt addition improves the efficiency of water at the vapor phase or hot stage of the quenching process.

**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 TEMPERING RANGE** - Some hardened steels show an increase in brittleness when tempered in the range of about 450°F to 700°F even though such tempering causes some softening.

**BURNING** - (1) Permanently damaging a metal or alloy by heating to cause either incipient melting or intergranular oxidation. See overheating, grain-boundary liquitation. (2) In grinding, getting the work hot enough to cause discoloration or to change the microstructure by tempering or hardening.

## C

**CALORIZING** - Imparting resistance to oxidation to an iron or steel surface by heating in aluminum powder at 800 to 1000°C (1470 to 1830°F).

**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 process is completed by cooling at a rate that produces the desired properties in the work piece.

A heat treatment for steel which adds to carbon and nitrogen to the surface from gaseous atmosphere rich in these elements.

**CARBONIZATION** - Conversion of an organic substance into elemental carbon. (Should not be confused with *carburization*.)

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

**CARBON RESTORATION** - Replacing the carbon lost in the surface layer from previous processing by carburizing this layer to substantially the original carbon level. Sometimes called recarburizing.

**CARBON STEEL** - Steel which is essentially iron plus carbon, but usually containing small amounts of manganese, silicon or aluminum which have been intentionally added to improve the quality. Also known as ordinary steel, straight carbon steel or plain carbon steel.

**CARBURIZING** - Absorption and diffusion of carbon into solid ferrous alloys by heating to a temperature usually above  $A_{c3}$ , 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 re-austenitizing and quenching.

Adding carbon to the surface of steel by heating it in contact with carbon-rich solids, liquids or gases.

**CARBURIZING FLAME** - A gas flame that will introduce carbon into some heated metals, as during a gas welding operation. A carburizing flame is a reducing flame, but a *reducing flame* is not necessarily a carburizing flame.

**CAR FURNACE** - A batch-type furnace using a car on rails to enter and leave the furnace area. Car furnaces are used for lower stress relieving ranges.

**CASE** - That portion of a ferrous alloy, extending inward from the surface, whose composition has been altered so that it can be case hardened. Typically considered to be the portion of the alloy (a) whose composition has been measurably altered from the original composition, (b) that appears dark on an etched cross section, or © that has a hardness, after hardening, equal to or greater than a specified value.

The surface layer of a steel whose composition has been changed by the addition of carbon, nitrogen, chromium or other minerals. 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.

A heat treatment in which the surface layer of a steel is made substantially harder than the interior. May be done by

heating and quenching only the surface area of a hardenable steel, or by changing the surface composition.

**CAUSTIC QUENCHING** - Quenching with aqueous solutions of 5 to 10% sodium hydroxide (NaOH).

**CCT DIAGRAM** - See *continuous cooling transformation diagram*.

**CEMENTATION** - The introduction of one or more elements into the outer portion of a metal object by means of diffusion at high temperature.

**CEMENTITE** - A compound of iron and carbon, known chemically as iron carbide, having the approximate chemical formula  $Fe_3C$ . It is characterized by an orthorhombic crystal structure. When it occurs as a phase in steel, the chemical composition will be altered by the presence of manganese and other carbide forming elements.

**CHECKS** - 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, checking, *heat checks*.

**CHROMIZING** - A heat treatment for steel which alloys chromium with the surface. The result is achieved by contacting the steel with halogen gases rich in chromium.

**CLOSE ANNEALING** - Same as box annealing.

**COALESCENCE** - 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 re-precipitation.

**COARSENING** - An increase in the grain size, usually, but not necessarily by *grain growth*.

**COHERENT PRECIPITATE** - A crystalline precipitate that forms from solid solution with an orientation that maintains continuity between the crystal lattice of

the precipitate and the lattice of the matrix, usually accompanied by some strain in both lattices. Because the lattices fit at the interface between precipitate and matrix, there is no discernible phase boundary.

**COLD DIE QUENCHING** - A quench utilizing cold, flat or shaped dies to extract heat from a part. Cold die quenching is slow, expensive and is limited to smaller parts with large surface areas.

**COLD DRY DIE QUENCHING** - Same as *cold die quenching*.

**COLD TREATMENT** - Treatment carried out after quenching to transform retained austenite into martensite, involving cooling and holding at a temperature below ambient.

**COLD TREATING** - Cooling to a low temperature, usually minus 100°F or lower, to stabilize structure and dimensions.

**COLD WORKING** - Plastic deformation of a metal at a temperature low enough so that recrystallization does not occur during cooling.

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

**COMBINED CARBON** - The part of the total carbon in steel or cast iron that is present as other than *free carbon*.

**CONDITIONING HEAT TREATMENT** - A preliminary heat treatment used to prepare a material for desired reaction to a subsequent heat treatment. For the term to be meaningful, the exact heat treatment must be specified.

**CONGRUENT TRANSFORMATION** - An isothermal or isobaric phase change in which both of the phases concerned have the same composition throughout the process.

**CONSTITUTION DIAGRAM** - See *phase diagram*.

**CONTINUOUS COOLING TRANSFORMATION (CCT) DIAGRAM** - Set of curves drawn using logarithmic time and linear temperature as coordinates, which define for each cooling curve the beginning and end of the transformation of the initial phase.

**CONTINUOUS PRECIPITATION** - Precipitation from a supersaturated solid solution in which the precipitate particles grow by long-range diffusion without recrystallization of the matrix. Continuous precipitates grow from nuclei distributed more or less uniformly throughout the matrix. They usually are randomly oriented, but may form a Widmanstätten structure. Also called general precipitation. Compare with discontinuous precipitation, localized precipitation.

**CONTINUOUS-TYPE FURNACE** - A furnace used for heat treating materials that progress continuously through the furnace, entering one door and being discharged from another. See *belt furnace, rotary retort furnace, and shaker-hearth furnace*.

**CONTROLLED COOLING** - Cooling from an elevated temperature in a predetermined manner to avoid hardening, cracking or internal damage, or to produce desired microstructure or mechanical properties.

**COOLING CURVE** - A curve showing the relation between time and temperature during the cooling of a material.

**COOLING STRESSES** - Residual stresses resulting from nonuniform distribution of temperature during cooling.

**CORE** - 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 to light on an etched cross section, (b) has an essentially unaltered chemical composition, or © has a hardness, after

hardening, less than a specified value.

The interior part of a steel whose composition has not been changed in a case hardening operation.

**CRITICAL COOLING RATE** - The rate of continuous cooling required to prevent undesirable transformation. For steel, it is the minimum rate at which austenite must be continuously cooled to suppress transformations above the  $M_s$  temperature.

**CRITICAL DIAMETER (D)** - Diameter of the bar than can be fully hardened with 50% martensite at its center.

**CRITICAL POINT** - (1) The temperature or pressure at which a change in crystal structure, phase or physical properties occurs. Same as transformation temperature. (2) In an equilibrium diagram, that specific value of composition, temperature and pressure, or combinations thereof, at which the phases of a heterogeneous system are in equilibrium.

A temperature point at which a structure change either starts, is completed, or both, when a material is being heated or cooled.

**CRITICAL RANGE** - The temperature range between an upper and lower critical point for a given material.

**CRITICAL STRAIN** - The strain just sufficient to cause recrystallization; because the strain is small, usually only a few percent, recrystallization takes place from only a few nuclei, which produces a recrystallized structure consisting of very large grains.

**CRITICAL TEMPERATURE** - (1) Synonymous with critical point if the pressure is constant. (2) The temperature above which the vapor phase cannot be condensed to liquid by an increase in pressure.

**CRITICAL TEMPERATURE RANGES** - Synonymous with *transformation ranges*, which is the preferred term.

**CRYOGENIC TREATMENT** - See *cold treatment*.

**CURIE TEMPERATURE** - The temperature of magnetic transformation below which a metal or alloy is ferromagnetic and above which it is paramagnetic.

**CYANIDING** - A case-hardening process in which a ferrous material is heated above the lower transformation range in a molten salt containing cyanide to cause simultaneous absorption of carbon and nitrogen at the surface and, by diffusion, create a concentration gradient. Quench hardening completes the process.

A liquid salt process for case hardening of steel by the addition of carbon and nitrogen to the surface.

**CYCLE ANNEALING** - An annealing process employing a predetermined and closely controlled time-temperature cycle to produce specific properties or microstructures.

## **D**

**DEAD SOFT** - A *temper* of nonferrous alloys and some ferrous alloys corresponding to the condition of minimum hardness and tensile strength produced by *full annealing*.

**DECALESCENCE** - A phenomenon, associated with the transformation of alpha iron to gamma iron on the heating (super heating) of iron or steel, revealed by the darkening of the metal surface owing to the sudden decrease in temperature caused by the fast absorption of the latent heat of transformation. Contrast with *recalescence*.

**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.

**DECARBURIZING** - The process (usually



unintentional) of removing carbon from the surface of a steel. Usually at high temperature when in contact with certain types of atmospheres.

**DEGREES OF FREEDOM** - The number of independent variables (such as temperature, pressure or concentration within the phases present) that may be altered at will without causing a phase change in an alloy system at equilibrium; or, the number of such variables that must be fixed arbitrarily to define the system completely.

**DELTA FERRITE** - See *ferrite*.

**DEW POINT** - The temperature and pressure at which a gas begins to condense to a liquid.

**DEW POINT ANALYZER** - An atmosphere monitoring device that measures the partial pressure of water vapor in an atmosphere.

**DIFFERENTIAL HARDENING** - A heat treating process designed to develop different hardness in different areas of a given piece. Can be accomplished in three different ways. (1) Heat entire piece, quench only the section to be hard. (2) Harden entire piece, temper only the section to be soft. (3) Heat only the section to be hard, quench.

**DIFFERENTIAL HEATING** - Heating that intentionally produces a temperature gradient within an object such that, after cooling, a desired stress distribution or variation in properties is present within the object.

**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.

**DIFFUSION COEFFICIENT** - A factor of proportionality representing the amount of substance diffusion across a unit area through a unit concentration gradient in unit time.

**DILATOMETER** - An instrument for

measuring the linear expansion or contraction in a metal resulting from changes in such factors as temperature and allotropy.

#### **DIRECT-FIRED TUNNEL-TYPE FURNACE**

A continuous type furnace where the work is conveyed through a tunnel type heating zone, and the parts are hung on hooks or fixtures to minimize distortion.

**DIRECT QUENCHING** - (1) Quenching carburized parts directly from the carburizing operation. (2) Also used for quenching pearlitic malleable parts directly from the malleablizing operation.

**DISCONTINUOUS PRECIPITATION** - Precipitation from a supersaturated solid solution in which the precipitate particles grow by short range diffusion accompanied by recrystallization of the matrix in the region of precipitation. Discontinuous precipitates grow into the matrix from nuclei near grain boundaries, forming cells of alternate lamellae of precipitate and depleted (and recrystallized) matrix. Often referred to as cellular or nodular precipitation. Compare with *continuous precipitation*, *localized precipitation*.

**DISSOCIATION** - As applied to heterogeneous equilibria, the transformation of one phase into two or more new phases of different composition.

The chemical breakdown of a compound into simpler compounds or elements. A common example is the dissociation of ammonia (NH<sub>3</sub>) into nitrogen and hydrogen when anhydrous ammonia is heated. Compare with *order-disorder transformation*.

**DISSOLVED CARBON** - Carbon so finely dispersed in another material that the largest individual piece of carbon is an atom. If so dispersed in gamma iron (face-centered cubic), the resulting solution is called austenite. If so dispersed in alpha iron (body-centered

cubic), the resulting solution is called ferrite.

**DOUBLE AGING** - Employment of two different aging treatments to control the type of precipitate formed from a supersaturated matrix in order to obtain the desired properties. The first aging treatment, sometimes referred to as intermediate or stabilizing, is usually carried out at higher temperature than the second.

**DOUBLE TEMPERING** - A treatment in which a quench-hardened 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.

**DRAW/DRAWING** - The common term used interchangeably with "temper".

**DRY CYANIDING** - (obsolete) Same as carbonitriding.

**DUCTILE CAST 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 SG iron.

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

**DUCTILITY** - The ability of a material to deform plastically without fracturing, measured by elongation or reduction of area in a tensile test, by height of cupping in an Erichsen test, or by other means.

**ELASTIC LIMIT** - The maximum stress that a material is capable of sustaining without any permanent strain (deformation) remaining upon complete release of the stress.

**ELECTRON-BEAM HEAT TREATING** - A selective surface hardening process that rapidly heats a surface by direct bombardment with an accelerated stream of electrons.

**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*, *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 embrittlement 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.

**EMBRITTLEMENT 885°F (475°C)** - *Embrittlement* of stainless steels upon extended exposure to temperatures between 400 to 510°C (750 and 950°F). This type of embrittlement is caused by fine, chromium-rich precipitates that segregate at grain boundaries; time at temperature directly influences the amount of segregation. Grain-boundary segregation of the chromium-rich precipitates increases strength and

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## E

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hardness, decreases ductility and toughness, and changes corrosion resistance. This type of embrittlement can be reversed by heating above the precipitation range.

**ENANTiotROPY** - The relation of crystal forms of the same substance in which one form is stable above a certain temperature and the other form stable below that temperature. For example, ferrite and austenite are enantiotropic in ferrous alloys.

**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.

**EQUILIBRIUM DIAGRAM** - A graphical representation of the temperature, pressure and composition limits of phase fields in an alloy system as they exist under conditions of complete equilibrium. In metal systems, pressure is usually considered constant.

**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 an equilibrium diagram. (3) An alloy structure of intermixed solid constituents formed by a eutectic reaction.

**EUTECTIC CARBIDE** - Carbide formed during freezing as one of the mutually

insoluble phases participating in the eutectic reaction of ferrous alloys.

**EUTECTIC MELTING** - Melting of localized microscopic areas whose composition corresponds to that of the eutectic in the system.

**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 an equilibrium diagram. (3) An alloy structure of intermixed solid constituents formed by an eutectoid reaction.

**EUTECTOID STEEL** - The only steel that has only one critical point and, therefore, no critical range. In plain carbon steels, it has about 0.85% carbon. In alloy steels it may be somewhat lower in carbon.

**EXTRA HARD** - A *temper* of nonferrous alloys and some ferrous alloys characterized by tensile strength and hardness about one-third of the way from *full hard* to *extra spring temper*.

**EXTRA SPRING** - A *temper* of nonferrous alloys and some ferrous alloys corresponding approximately to a cold-worked state above *full hard* beyond which further cold work will not measurably increase the strength and hardness.

## **F**

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**FACE-CENTERED CUBIC** - Arrangement of atoms in space such that if lines were drawn connecting the centers of their activity, the lines would form a cube. One atom would be at each corner of the cube and one would be in the center of each cube face. Aluminum, copper, nickel, gold and silver are face-centered cubic

metals as is iron above 1670°F.

**FATIGUE** - Failure by progressive fracture caused by repeated applications or reversals of stress.

**FERRITE** - 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 alpha ferrite; the upper is delta ferrite. If there is no designation, alpha ferrite is assumed.

Ferrite is the name given any solid solution in which alpha iron is the solvent. Ferrite is strictly a structure name and means nothing as to composition.

**FERRITIZING ANNEAL** - A treatment given as cast-gray or ductile (nodular) iron to produce an essentially ferritic matrix. For the term to be meaningful, the final microstructure desired or the time-temperature cycle used must be specified.

**FINAL ANNEALING** - An imprecise term used to denote the last anneal given to a nonferrous alloy prior to shipment.

**FINISH ANNEALING** - A *subcritical annealing* treatment applied to cold-worked low or medium carbon steel. Finish annealing, which is a compromise treatment, lowers residual stresses, thereby minimizing the risk of distortion in machining while retaining most of the benefits to machinability contributed by cold working. Compare with *final annealing*.

**FINISH TEMPERING** - The temperature at which hot working is completed.

**FIXTURING** - The placing of parts to be heat treated in a constraining or semiconstraining apparatus to avoid heat-related distortions. See *racking*.

**FLAME ANNEALING** - Annealing in which the heat is applied directly by flame.

**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, whereupon the work piece is immediately quenched.

A heat treating method in which pre-selected areas of the part being treated are heated by direct flame impingement prior to quenching.

**FLAME STRAIGHTENING** - Correcting distortion in metal structures by localized heating with a gas flame.

**FLUIDIZED BED HEATING** - Heating carried out in a medium of solid particles suspended in a flow of gas.

**FOG QUENCHING** - Quenching in a fine vapor or mist.

**FORCED AIR QUENCH** - A quench utilizing blasts of compressed air against relatively small parts such as a gear.

**FORGING** - The process of shaping a part by hammering or squeezing, usually while hot.

**FRACTURE** - The irregular surface produced when a piece of metal is ruptured or broken.

**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 CUTTING STEEL** - Steels whose composition has been modified, usually by the addition of lead or sulfur, to be free machining. Continuous cuts of free cutting steel will produce chips instead of long shavings.

**FREE FERRITE** - Ferrite that is formed directly from the decomposition of hypoeutectoid austenite during cooling, without the simultaneous formation of cementite. Also proeutctoid ferrite.

**FREEZING RANGE** - That temperature range between liquids and solidus temperatures in which molten and solid constituents coexist.

**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 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%.

## **G**

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

**GAS CYANIDING** - A misnomer for *carbonitriding*.

**GRAIN** - Individual crystals in metals.

**GRAIN-BOUNDARY LIQUIDATION** - An advanced stage of overheating in which material in the region of austenitic grain boundaries melts. Also termed *burning*.

**GRAIN COARSING** - A heat treatment that produces excessively large austenitic grains.

**GRAIN GROWTH** - An increase in the average size of the grains in polycrystalline metal, usually as a result of heating at elevated temperature.

Growth of some grains at the expense of others resulting in an overall increase in average grain size.

**GRAIN REFINER** - A material added to a

molten metal to induce a finer-than-normal grain size in the final structure.

**GRAIN SIZE** - 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, the grain size refers to that of the matrix unless otherwise specified. Grain sizes are reported in terms of number of grains per unit area or volume, average diameter, or as a grain-size number derived from area measurements.

**GRAPHITIC CARBON** - Free carbon in steel or cast iron. See *graphitization*.

**GRAPHITIZATION** - Formation of graphite in iron or steel. Where graphite is formed during solidification, the phenomenon is called primary graphitization; where formed later by heat treatment, secondary graphitization.

**GRAPHITIZING** - Annealing a ferrous alloy in such a way that some or all of the carbon is precipitated as graphite.

Heating a cast iron (usually) so that some or all of the carbide is dissociated to form graphite.

**GRAY CAST IRON** - Cast iron with some of its carbon in the form of graphite and some in the form of carbide. The graphite is usually in the form of thin, curved flakes. The strength of any particular gray iron is largely determined by the amount of graphite and the way it is distributed.

**GROSSMANN CHART** - A chart describing the ability of a quenching medium to extract heat from a hot steel work-piece in comparison to still water.

**GUINIER-PRESTON (G-P) ZONE** - A small precipitation domain in a supersaturated metallic solid solution. A G-P zone has no well-defined crystalline structure of its own and contains an abnormally high concentration of solute atoms. The formation of G-P zones constitutes the

first stage of precipitation and is usually accompanied by a change in properties of the solid solution in which they occur.

## **H**

**HALF HARD** - A *temper* of nonferrous alloys and some ferrous alloys characterized by tensile strength about mid-way between that of dead soft and full hard temper.

**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 where the metal exhibits a specific hardness (for example, 50 HRC) or a specific percentage of martensite in the microstructure.

A measure of the ability of steel to become hard as the result of heat treatment.

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

A heat treating process designed to increase the hardness of a material usually steel. Involves heating to an austenitizing temperature, holding for uniformity and cooling at a rate fast enough to develop high hardness.

**HARDNESS PROFILE** - Hardness as a function of distance from a fixed reference point (usually from the surface).

**HARD TEMPER** - Same as *full hard temper*.

**HEAT TINTING** - Coloration of a metal

surface through oxidation by heating to reveal details of the microstructure.

**HEAT TREATABLE ALLOY** - An alloy that can be hardened by heat treatment.

**HEAT TREATING FILM** - A thin coating or film, usually an oxide, formed on the surface of metals during heat treatment.

**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.

An operation or combination of operations involving the heating, holding and cooling of a metal or alloy in the solid state for the purpose of obtaining certain desirable properties.

**HOLDING** - The portion of the thermal cycle during which the temperature of the object is maintained constant.

**HOLDING TEMPERATURE** - The constant temperature at which the object is maintained.

**HOLDING TIME** - Time for which the temperature of the object is maintained constant.

**HOMOGENEOUS CARBURIZING** - Use of a carburizing process to convert a low-carbon ferrous alloy to one of uniform and higher carbon content throughout the section.

**HOMOGENIZING** - Holding at high temperature to eliminate or decrease chemical segregation by diffusion.

An annealing treatment at fairly high temperatures designed to eliminate or reduce chemical segregation.

**HORIZONTAL BATCH FURNACE** - A versatile batch-type furnace that can give light or deep case depths, and because the parts are not exposed to air, horizontal batch furnaces can give surfaces almost entirely free of oxides.

**HOT QUENCHING** - An imprecise term used to cover a variety of quenching procedures in which a quenching medium

is maintained at a prescribed temperature above 70°C (160°F).

**HOT WIRE ANALYZER** - An electrical atmosphere analysis device that is based on the fact that the electrical resistivity of steel is a linear function of carbon content over a range from 0.05%C to saturation. The device measures the carbon potential of furnace atmospheres (typically). This term is not to be confused with the *hot-wire test* which measures heat extraction rates.

**HOT WIRE TEST** - Method used to test heat extraction rates of various quenchants. Faster heat-extracting quenchants will permit more electric current to pass through a standard wire because it is cooled more quickly. Compare with *hot-wire analyzer*.

**HOT WORKING** - Plastic deformation of a metal at a temperature high enough so that recrystallization occurs spontaneously during or before cooling.

**HYDROGEN EMBRITTLEMENT** - The brittleness induced in steel by the absorption of hydrogen most commonly from a pickling or plating operation.

**HYPEREUTECTIC ALLOY** - In an alloy system exhibiting a eutectic, any alloy whose composition has an excess of alloying element compared with the eutectic composition, and whose equilibrium microstructure contains some eutectic structure.

**HYPEREUTECTOID ALLOY** - In an alloy system exhibiting a eutectoid, any alloy whose composition has an excess of alloying element compared with the eutectoid composition, and whose equilibrium microstructure contains some eutectoid structure.

**HYPEREUTECTOID STEEL** - Steel with carbon content higher than eutectoid composition. Above about 0.85% carbon.

**HYPOEUTECTIC ALLOY** - In an alloy system exhibiting a eutectic, any alloy whose composition has an excess of

base metal compared with the eutectic composition, and whose equilibrium microstructure contains some eutectic structure.

**HYPOEUTECTOID STEEL** - Steel with carbon content lower than eutectoid composition. Below about 0.85% carbon.

## I

**IDEAL CRITICAL DIAMETER ( $D_i$ )** - Under an ideal quench condition, the bar diameter that has 50% martensite at the center of the bar when the surface is cooled at an infinitely rapid rate (that is, when  $H = \infty$ , where  $H$  is the quench severity factor).

**IMMERSED-ELECTRODE FURNACES** - A furnace used for liquid carburizing of parts by heating molten salt baths with the use of electrodes immersed in the liquid. See *submerged-electrode furnace*.

**IMPACT TUBE** - Same as *Pitot tube*.

**INCLUSIONS** - Particles of impurities (usually oxides, sulphides, silicates and such) which fail to separate from the liquid steel and are mechanically held during solidification. In some grades of steel, inclusions are made intentionally high to aid machinability.

**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.

A form of hardening in which the heating is done by induced electrical current.

**INDUCTION HEATING** - Heating by combined electrical resistance and hysteresis losses induced by subjecting a metal to the varying magnetic field surrounding a coil carrying alternating current.

**INDUCTION TEMPERING** - Tempering of

steel using low-frequency electrical induction heating.

**INFRARED ANALYZER** - An atmosphere-monitoring device that measures a gas (usually carbon monoxide, carbon dioxide, and methane) presence based on specific wavelength absorption of infrared energy.

**INTENSE QUENCHING** - Quenching in which the quenching medium is cooling the part at a rate at least two and a half times faster than still water. See *Grossmann Chart*.

**INTERCRITICAL ANNEALING** - Any annealing treatment that involves heating to, and holding at, a temperature between the upper and lower critical temperatures to obtain partial austenitization, followed by either slow cooling or holding at a temperature below the lower critical temperature.

**INTERGRANULAR** - Between crystals or grains. Also called *intercrystalline*. Contrast with *transgranular*.

**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 FRACTURE** - Brittle fracture of a metal in which the fracture is between the grains, or crystals, that form the metal. Also called *intercrystalline fracture*. Contrast with *transgranular fracture*.

**INTERMEDIATE ANNEALING** - Annealing wrought metals at one or more stages during manufacture and before final treatment.

**INTERRUPTED AGING** - Aging at two or more temperatures, by steps and cooling to room temperature after each step. See *aging* and compare with *progressive aging* and *step aging*.

**INTERRUPTED QUENCHING** - A quenching procedure in which the work piece is

removed from the first quench at a temperature substantially higher than that of the quenchant and is then subjected to a second quenching system having a different cooling rate than the first.

Stopping the cooling cycle at a predetermined temperature and holding at this temperature for a specific time before cooling to room temperature. Usually done to minimize the likelihood of cracking or to produce a particular structure in the part.

**INTERVAL TEST** - Method used to test heat extraction rates of various quenchants. This test measures the increase in temperature of a quenchant when a standard bar of metal is quenched for five seconds. Faster quenchants will exhibit greater temperature increases.

**ION CARBURIZING** - A method of surface hardening in which carbon ions are diffused into a work piece in a vacuum through the use of high-voltage electrical energy. Synonymous with plasma carburizing or glow-discharge carburizing.

**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 glow-discharge carburizing.

**ISOTHERMAL ANNEALING** - Austenitizing a ferrous alloy and then cooling to and holding at a temperature at which austenite transforms to a relatively soft ferrite carbide aggregate.

**ISOTHERMAL TRANSFORMATION** - A change in phase that takes place at a constant temperature. The time required for transformation to be completed, and in some instances the time delay before transformations begins, depends on the amount of supercooling below (or superheating above) the equilibrium temperature for the same transformation.

**ISOTHERMAL TRANSFORMATION (IT) DIAGRAM** - Set of curves drawn using



logarithmic time and linear temperature as coordinates, which define for each level of temperature the beginning and end of the transformation of the initial phase under isothermal conditions.

**ISOTHERMAL TREATMENT** - A type of treatment in which a part is quenched rapidly down to a given temperature, then held at that temperature until all transformation is complete. Austempering is the most common isothermal treatment applied to steel.

## J

**JOMINY TEST** - See *end-quench Hardenability test*.

## K

**KISH** - Free graphite that forms in molten hypereutectic cast iron as it cools. In castings, the kish may segregate toward the cope surface, where it lodges at or immediately beneath the casting surface.

## L

**LAP** - A surface defect formed when a mechanical irregularity like a fin or a part of a sharp corner is folded over during drawing, rolling or forging operations, and is not welded shut.

**LASER HARDENING** - A surface-hardening process which uses a laser to quickly heat a surface. Heat conduction into the interior of the part will quickly cool the surface, leaving a shallow martensitic layer.

**LATENT HEAT** - Thermal energy absorbed or released when a substance undergoes a phase change.

**LEDEBURITE** - The eutectic of the iron-carbon system, the constituents being austenite and cementite. The austenite decomposes into ferrite and cementite on cooling below the  $Ar_1$ .

**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.

**LIQUIDATION TEMPERATURE** - The lowest temperature at which partial melting can occur in an alloy that exhibits the greatest possible degree of segregation.

**LIQUID CARBURIZING** - Surface hardening of steel by immersion into a molten bath consisting of cyanides and other salts.

**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 NITROCARBURIZING** - A nitrocarburizing process (where both carbon and nitrogen are absorbed into the surface) utilizing molten liquid salt baths below the lower critical temperature.

**LIQUID SPRAY QUENCH** - Same as *spray quenching*.

**LOCAL PRECIPITATION** - Precipitation from a supersaturated solid solution similar to continuous precipitation except that the precipitate particles form at preferred locations, such as along slip planes, grain boundaries or incoherent twin boundaries.

## M

**MACROSCOPIC** - Visible either with the naked eye or under low magnifications (up to about 10 diameters).

**MACROSTRUCTURE** -- The structure of a metal as revealed at low magnifications, usually under about 10x.

**MAGNETIC TEST** - Method used to test heat extraction rates of various quenchants. The test works by utilizing the change in magnetic properties of metals at their *Curie* point - the temperature above which metals lose their magnetism.

**MALLEABLE CAST IRON** - A cast iron made by prolonged annealing of white cast iron in which decarburization or 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". Ferritic malleable has a predominantly ferritic matrix; pearlite malleable may contain pearlite; spheroidite or tempered martensite depending on heat treatment and desired hardness.

Malleable iron is made in the foundry as white cast iron with all of the carbon in the combined form (no graphite). Controlled annealing of the white iron castings will graphitize part of the carbon to produce pearlitic malleable or all of the carbon to produce ordinary malleable.

**MALLEABILIZING** - Annealing white cast iron in such a way that some or all of the combined carbon is transformed to graphite or, in some instances, part of the carbon is removed completely.

**MARAGING** - A precipitation-hardening treatment applied to a special group of iron base alloys to precipitate one or more intermetallic compounds in a matrix of essentially carbon-free martensite.

**MARAGING STEELS** - A series of very low carbon high nickel steels which transform to martensite on air cooling from about

1500°F. The comparatively soft carbon-free martensite is machinable as quenched. After machining it is aged at 900°F to develop higher hardness and very high strength. The aging at 900°F is practically distortion free.

**MARQUENCHING** - See *martempering*.

**MARQUENCHING OR MARTEMPERING** -

Marquenching is a form of interrupted quenching in which the steel is quenched rapidly from its hardening temperature to about 450°F, held at 450°F until the temperature is uniform, then cooled in air to room temperature. Actual hardening does not occur until the air cooling starts and is accomplished with a minimum temperature differential and, therefore, with a minimum tendency to go out of shape. Marquenching is indicated for low to medium alloy steels when distortion may be a problem.

(1) A hardening procedure in which an austenitized ferrous work piece is quenched into an appropriate medium whose temperature is maintained substantially at the  $M_s$  of the work piece, held in the medium until its temperature is uniform throughout - but not long enough to permit bainite to form - and then cooled in air. The treatment is frequently followed by tempering. (2) When the process is applied to carburized material, the controlling  $M_s$  temperature is that of the case. This variation of the process is frequently called marquenching.

**MARTENSITE** - A generic term for microstructures formed by diffusion less 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 martensite 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 ( $M_s$ ) and a temperature at which the transformation is essentially complete ( $M_f$ ).

The very hard structure that forms when austenite is quenched so as to transform below about 450°F. Technically, martensite can be considered to be a supersaturated solution of carbon in tetragonal (distorted cubic) iron. Under the microscope it appears as an acicular or needle like structure. Hardness of martensite will vary from Rc 30 to Rc 68 depending on the carbon content.

**MARTENSITE RANGE** - The temperature interval between  $M_s$  and  $M_f$ .

**MARTENSITIC TRANSFORMATION** - A reaction that takes place in some metals on cooling, with the formation of an acicular structure called *martensite*.

**MCQUAID-EHN TEST** - A test to reveal grain size after heating into the austenitic temperature range. Eight standard McQuaid-Ehn grain sizes rate the structure, No. 8 being finest, No. 1 coarsest.

**$M_f$  TEMPERATURE** - For any alloy system, the temperature at which martensite formation in cooling is essentially finished. See *transformation temperature* for the definition applicable to ferrous alloys.

**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 the hardness of different microconstituents within a

structure, or of measuring steep hardness gradients such as those encountered in case hardening.

**MICROSCOPIC STRESSES** - Residual stresses that vary from tension to compression in a distance (presumably approximating the grain size) that is small compared with the gage length in ordinary strain measurements. They are not detectable by dissection methods, but can sometimes be measured from line shift or line broadening in an X-Ray diffraction pattern.

**MICROSEGREGATION** - Segregation within a grain, crystal or small particle.

**MICROSTRUCTURE** - The structure of a metal as revealed at high magnification, usually at 100% and higher.

**MILL SCALE** - The heavy oxide layer formed during hot fabrication or heat treatment of metals.

**MONOTROPISM** - The ability of a solid to exist in two or more forms (crystal structures), but in which one form is the stable modification at all temperatures and pressures. For example, ferrite and martensite are a monotropic pair below  $A_c1$  in steels. May also be spelled *monotrophism*.

**$M_s$  TEMPERATURE** - For any alloy system, the temperature at which martensite starts to form on cooling. See *transformation temperature* for the definition applicable to ferrous alloys.

## **N**

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**NATURAL AGING** - Spontaneous aging of a supersaturated solid solution at room temperature. See *aging*, and compare with *artificial aging*.

**NEUTRAL FLAME** - A gas flame in which there is no excess of either fuel or oxygen in the inner flame. Oxygen from ambient air is used to complete the combustion of

CO<sub>2</sub> and H<sub>2</sub> produced in the inner flame.  
**NEUTRALIZATION NUMBER** - An ASTM number given to quenching oils that reflects the oil's tendency towards oxidation and sludging. See *Saponification number*.

**NITRIDING** - Introducing nitrogen into the surface layer of a solid ferrous alloy by holding at a suitable temperature (below AC<sub>1</sub> 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 *aerated bath nitriding, bright nitriding, and liquid nitriding*.

The process of adding nitrogen to the surface of a steel, usually from dissociated ammonia as the source. Nitriding develops a very hard case after a long time at comparatively low temperature without quenching.

**NITROCARBURIZING** - Any several processes in which both nitrogen and carbon are absorbed into the surface layers of a ferrous material at temperatures below the critical temperature and, by diffusion, create a concentration gradient. Nitrocarburizing is done mainly to provide an antiscuffing surface layer and to improve fatigue resistance. Compare with *carbonitriding*.

**NODULAR IRON** - A variety of cast iron on which the graphite occurs as rounded particles. Considerably higher in ductility than gray cast iron.

**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.

The process of heating steel to a temperature above its transformation range, followed by cooling in still air.

**NUCLEATION** - The initiation of phase transformation at discrete sites, the new phase growing on nuclei. See *nucleus*.

**NUCLEUS** - 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 matrix. The term is also applied to a foreign particle that initiates such action.

## **O**

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**OIL HARDENING** - Quench hardening treatment involving cooling in oil.

**OIL QUENCHING** - Hardening of carbon steel in an oil bath. Oils are categorized as conventional, fast, martempering, or hot quenching.

**OPTICAL PYROMETER** - An instrument for measuring the temperature of heated material by comparing the intensity of light emitted with a known intensity of an incandescent lamp filament.

**ORDER-DISORDER TRANSFORMATION** - A phase change among two solid solutions having the same crystal structure, but in which the atoms of one phase (disordered) are randomly distributed; in the other, the different kinds of atoms occur in a regular sequence upon the crystal lattice, that is, in an ordered arrangement. Compare with *dissociation*.

**ORDER HARDENING** - A low temperature *annealing* treatment that permits short range ordering of solute atoms within a matrix, which greatly impedes dislocation motion.

**ORSAT ANALYZER** - An atmosphere analysis device in which gases are absorbed selectively (volumetric basis) by passing them through a series of preselected solvents.

**OVERAGING** - Aging under conditions of time and temperature greater than those required to obtain maximum change in a certain property, so that the property is altered in the direction of the initial value.

See *aging*.

**OVERHEATING** - Heating a metal or alloy to such a high temperature that its properties are impaired. When the original properties cannot be restored by further heat treating, by mechanical working, or by a combination of working and heat treating, the overheating is known as *burning*.

**OUT GASSING** - Removal of entrapped gases from a metal by heating under vacuum.

**OXIDATION** - (1) A reaction in which there is an increase in valence resulting from a loss of electrons. (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.

**OXIDIZED SURFACE (ON STEEL)** - Surface having a thin, tightly adhering, oxidized skin (from straw to blue in color), extending in from the edge of coil or sheet. Sometimes called annealing border.

**OXIDIZING AGENT** - A compound that causes oxidation, thereby, itself becoming reduced.

**OXIDIZING FLAME** - A gas flame produced with excess oxygen in the inner flame.

**OXYGEN PROBE** - An atmosphere monitoring device that electronically measures the difference between the partial pressure of oxygen in a furnace or furnace supply atmosphere and the external air.

## **P**

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**PACK CARBURIZING** - A method of surface hardening of steel in which parts are packed in a steel box with the carburizing compound and heated to elevated temperatures.

**PACK NITRIDING** - A method of surface

hardening of steel in which parts are packed in a steel box with the nitriding compound and heated to elevated temperatures.

**PARTIAL ANNEALING** - An imprecise term used to denote a treatment given cold-worked material to reduce the 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.

**PATENTING** - In wiremaking, a heat treatment applied to medium carbon or high carbon steel before the drawing of wire or between drafts. This process consists of heating to a temperature above the transformation range and then cooling to a temperature below  $A_c1$  in air or in a bath of molten lead or salt.

**PEARLITE** - A metastable lamellar aggregate of ferrite and cementite resulting from the transformation of austenite at temperatures above the bainite range.

The lamellar aggregate of ferrite and carbide formed when austenite transforms above about 1000°F. Pearlite may vary in hardness from about Rc 15 to Rc 30 depending on the coarseness of the lamellae.

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

**PIPE** - A cavity formed along the center line when liquid metal solidifies. Caused by the shrinkage occurring during solidification. Pipe that develops in ingots is elongated in rolling and may appear in

almost the full length of the resulting bar.  
**PIRANI GAGE** - An instrument used to measure the pressure inside a vacuum chamber. The gage measures electrical resistance in a wire filament which will change in temperature depending on atmosphere pressure.

**PIT** - A sharp depression in the surface of metal.

**PITOT TUBE** - An instrument that measures the stagnation pressure of a flowing fluid, consisting of an open tube pointing into the fluid and connected to a pressure indicating device. Also known as *impact tube*.

**PLASMA CARBURIZING** - Same as *ion carburizing*.

**PLASMA NITRIDING** - Same as *ion nitriding*.

**PLASTIC DEFORMATION** - The permanent (inelastic) distortion of metals under applied stresses that strain the material beyond its *elastic limit*.

**POLYMORPHISM** - The property of a chemical substance crystallizing into two or more forms having different structures, such as, diamond and graphite.

**POSTHEATING** - Heating weldments immediately after welding, for tempering, for stress relieving, or for providing a controlled rate of cooling to prevent formation of a hard or brittle structure.

**POT ANNEALING** - Same as *box annealing*.

**PRECIPITATION HARDENING** - Hardening caused by the precipitation of a constituent from a supersaturated solid solution. See also *age hardening and aging*.

**PRECIPITATION HEAT TREATMENT** - Artificial aging in which a constituent precipitates from a supersaturated solid solution.

**PREHEATING** - 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, to homogenize the structure before working. In welding and related processes, heating to an intermediate temperature for a short time immediately before welding, brazing, soldering, cutting or thermal spraying.

**PRESS QUENCHING** - A quench in which hot dies are pressed and aligned with a part before the quenching process begins. Then the part is placed in contact with a quenching medium in a controlled manner. This process avoids part distortion.

**PROCESS ANNEALING** - An imprecise term denoting various treatments used to improve workability. For the term to be meaningful, the condition of the material and the time-temperature cycle used must be stated.

**PROGRESSIVE AGING** - Aging by increasing the temperature in steps or continuously during the aging cycle. See *aging* and compare with *interrupted aging and step aging*.

**PSEUDOCARBURIZING** - See blank carburizing.

**PSEUDONITRIDING** - See *blank nitriding*.

**PUSHER FURNACE** - A type of continuous furnace in which parts to be heated are periodically charged into the furnace in containers, which are pushed along the hearth against a line of previously charged containers thus advancing the containers toward the discharge end of the furnace, where they are removed.

**PYROMETER** - A device for measuring temperatures above the range of liquid thermometers.

## **Q**

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**QUARTER HARD** - A temper of nonferrous alloys and some ferrous alloys characterized by tensile strength about midway between that of *dead soft* and

*half hard tempers.*

**QUENCH-AGE EMBRITTLEMENT** -

*Embrittlement* of low carbon steels resulting from precipitation of solute carbon at existing dislocations of solute carbon at existing dislocations and from precipitation hardening of the steel caused by differences in ferrite at different temperatures. Quench-age embrittlement usually is caused by rapid cooling of the steel from temperatures slightly below  $A_c1$  (the temperature at which austenite begins to form), and can be minimized by quenching from lower temperatures.

**QUENCH AGING** - Aging induced by rapid cooling after *solution heat treatment*.

**QUENCH ANNEALING** - Annealing in austenitic ferrous alloy by *solution heat treatment* followed by rapid quenching.

**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 stresses due to the volume changes accompanying transformation to martensite.

**QUENCH HARDENING** - (1) Hardening suitable alpha-beta alloys (most often certain copper to titanium alloys) by solution treating and quenching to develop a martensitic-like structure. (2) In ferrous alloys, hardening by austenitizing and then cooling at a rate such that a substantial amount of austenite transforms to martensite.

**QUENCHING** - Rapid cooling. When applicable, the following more specific terms should be used: brine quenching, caustic quenching, cold quenching, forced-air quenching, intense quenching, oil quenching, press quenching, spray quenching, direct quenching, fog quenching, hot quenching, interrupted

quenching, selective quenching, time quenching, and water quenching.

Cooling from high temperatures usually at a fast rate.

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## R

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**RACKING** - A term used to describe the placing of parts to be heat treated on a rack or tray. This is done to keep parts in a proper position to avoid heat related distortions and to keep the parts separated. See *fixturing*.

**RECALESCENCE** - A phenomenon, associated with the transformation of gamma iron to alpha iron on the cooling (supercooling) of iron or steel, revealed by the brightening (reglowing) of the metal surface owing to the sudden increase in temperature caused by the fast liberation of the latent heat transformation. Contrast with *decalescence*.

**RECARBURIZE** - (1) To increase the carbon content of molten cast iron or steel by adding carbonaceous material, high carbon pig iron or a high carbon alloy. (2) To carburize a metal part to return the surface carbon lost in processing; also, known as *carbon restoration*.

**RECOVERY** - Reduction or removal of work hardening effects, without motion of large angle grain boundaries.

**RECRYSTALLIZATION** - (1) The formation of a new, strain-free 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.

**RECRYSTALLIZATION ANNEALING** - Annealing cold-worked metal to produce a new grain structure without phase change.

**RECRYSTALLIZATION TEMPERATURE -**

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

**RECUPERATOR -**

Equipment for transferring heat from gaseous products of combustion to incoming air or fuel. The incoming material passes through pipes surrounded by a chamber through which the outgoing gases pass.

**REDUCING FLAME -**

A gas flame produced with excess fuel in the inner flame.

**REFRACTORY -**

(1) A 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.

**REGENERATOR -**

Same as recuperator except the gaseous products of combustion heat brick checkerwork in a chamber connected to the exhaust side of the furnace while the incoming air and fuel are being heated by the brick checkerwork in a second chamber, connected to the entrance side. At intervals, the gas flow is reversed so that incoming air and fuel contact hot checkerwork while that in the second chamber is being reheated by exhaust gases.

**RESIDUAL STRESS -**

An internal stress not depending on external forces resulting from such factors as cold working, phase changes or temperature gradients.

**RETORT -**

A vessel used for distillation of volatile materials, as in separation of some metals and in destructive distillation of coal.

**REVERBERATORY FURNACE -**

A furnace with a shallow hearth, usually nonregenerative, having a roof that deflects the flame and radiates heat toward the hearth or the surface of the charge.

**ROCKWELL HARDNESS TEST -**

An indentation hardness test based on the

depth of penetration of a specified penetrator into the specimen under certain arbitrarily fixed conditions.

**ROTARY RETORT FURNACE -**

A continuous type furnace in which the work advances by means of an internal spiral, which gives good control of the retention time within the heated chamber.

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**S**

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**SALT BATH HEAT TREATMENT -**

Heat treatment carried out in a bath of molten salt.

**SAPONIFICATION NUMBER -**

A number given to quenching oils that reflects the oil's amount of compounding with fatty materials, which thereby helps evaluate the condition of these oils in service. See *neutralization number*.

**SEAM -**

A surface defect developed in rolling or forging, formed when a section of a bar, perhaps a corner, is folded over and rolled flat without being welded. Similar to a lap.

**SECONDARY HARDNESS -**

The higher hardness developed by certain alloy steels when they are given a second tempering treatment at a temperature higher than the first treatment, for about the same length of time.

**SELECTIVE HARDENING -**

See *Differential Hardening*.

**SELECTIVE HEATING -**

Intentionally heating only certain portions of a workpiece.

**SELECTIVE QUENCHING -**

Quenching only certain portions of workpiece.

**SELF-HARDENING STEEL -**

See preferred term, *air hardening steel*.

**SENSITIZATION -**

In austenitic stainless steels, the precipitation of chromium carbides, usually at grain boundaries, on exposure to temperatures of about 540°C to 845°C (about 1000 to 1550°F), leaving



the grain boundaries depleted of chromium and, therefore, susceptible to preferential attack by a corroding (oxidizing) medium.

**SEVERITY OF QUENCH** - Ability of quenching medium to extract heat from a hot steel workpiece; expressed in terms of the  $H$  value.

**SHAKER HEARTH FURNACE** - A continuous type furnace that uses a reciprocating shaker motion to move the parts along the hearth.

**SHELL HARDENING** - A surface hardening process in which a suitable steel workpiece, when heated through and quench hardened, develops a martensitic layer or shell that closely follows the contour of the piece and surrounds a core of essentially pearlitic transformation product. This result is accomplished by a proper balance among section size, steel hardenability and severity of quench.

**SHIM** - A thin piece of material placed between two surfaces to obtain a proper fit, adjustment or alignment. The piece can also be analyzed to measure furnace carbon potential (that is, because while in the furnace, it will quickly carburize to a level equal to the furnace carbon potential).

**SIGMA PHASE** - A hard, brittle, nonmagnetic intermediate phase with a tetragonal crystal structure, containing 30 atoms per unit cell, space group  $P4_2/mnm$ , 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. Alloying with a third transition element usually enlarges the field of homogeneity and extends it deep into the ternary section.

**SIGMA-PHASE EMBRITTLEMENT** - *Embrittlement* of iron-chromium alloys (most notably austenitic stainless steels) caused by precipitation at grain

boundaries of the hard, brittle intermetallic *sigma phase* during long periods of exposure to temperatures between approximately 565 and 980°C (1050 and 1800°F). Sigma-phase embrittlement results in severe loss in *toughness and ductility* and can make the embrittlement material structure susceptible to *intergranular corrosion*. See also *sensitization*.

**SIGNAL-TO-NOISE RATIO** - Ratio of the average response to the root-mean-square variation about the average response. Ratio of variances associated with the two parts of the performance measurement.

**SILICONIZING** - Diffusing silicon into solid metal, usually steel, at an elevated temperature.

**SINTERING** - The bonding of adjacent surfaces in a mass of particles by molecular or atomic attraction on heating at high temperatures below the melting temperature of any constituent in the material. Sintering strengthens a powder mass and normally produces densification and, in powdered metals, recrystallization.

**SHORTNESS**- Brittleness. Hot short; brittle when hot. Cold short; brittle when cold.

**SLACK QUENCHING** - The incomplete hardening of steel due to quenching from the austenitizing temperature at a rate slower than the critical cooling rate for the particular steel, resulting in the formation of one or more transformation products in addition to martensite.

**SLOT FURNACE** - A common batch furnace where stock is charge and removed through a slot or opening.

**SNAP TEMPER** - A precautionary interim stress-relieving treatment applied to high-hardenability steels immediately after quenching to prevent cracking because of delay in tempering them at the prescribed higher temperature.

**SOAKING** - Prolonged holding at a selected temperature to effect homogenization of

structure or composition.

**SOFT TEMPER** - Same as *dead soft* temper.

**SOLUTION** - A solution is a very fine dispersion of one or more materials in another. Many solutions are solid, and in solid solutions the largest piece of the dispersed (dissolved) material is one atom. Austenite is such a solution.

**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.

Heating an alloy to high temperature to form a solution from an aggregate, followed by fast cooling to prevent precipitation on cooling. The solution that was formed at high temperature is retained in unstable form at room temperature.

**SORBITE** - (obsolete) A fine mixture of ferrite and cementite produced either by regulating the rate of cooling the steel or by tempering steel after hardening. The first type is very fine pearlite difficult to resolve under the microscope; the second type is tempered martensite.

**SPALLING** - A chipping or flaking of a surface due to any kind of improper heat treatment or material dissociation.

**SPINODAL HARDENING** - See *aging*.

**SPHEROIDITE** - An aggregate of iron or alloy carbides of essentially spherical shape dispersed throughout a matrix dissociation.

**SPHEROIDIZING** - Heating and cooling to produce a spheroidal or globular form of carbide in steel. Spheroidizing methods frequently used are:

1. Prolonged holding at a temperature just below  $Ae_1$ .
2. Heating and cooling alternately between temperatures that are just above and just below  $Ae_1$ .
3. Heating to a temperature above

$Ae_1$  or  $Ae_3$  and then cooling very slowly in the furnace or holding at a temperature just below  $Ae_1$ .

4. Cooling at a suitable rate from the minimum temperature at which all carbide is dissolved, to prevent the reformation of carbide network, and then reheating in accordance with method 1 or 2 above. (Applicable to hypereutectoid steel containing a carbide network).

A heat treating process used to change all of the carbides in steel to rounded particles or spheroids. A completely spheroidized structure is the softest and most workable structure for any composition.

**SPINODAL STRUCTURE** - A fine homogeneous mixture of two phases that form by the growth of composition waves in a solid solution during suitable heat treatment. The phases of a spinodal structure differ in composition from each other and from the parent phase but have the same crystal structure as the parent phase.

**SPLIT TRANSFORMATION** - The result of quenching a steel too slowly to form all martensite. The rate of cooling permits some austenite to transform to pearlite above about 1000°F the balance of the austenite transforming to martensite at a lower temperature.

**SPRAY QUENCHING** - A quenching process using spray nozzles to spray water or other liquids on a part. The quench rate is controlled by the velocity and volume of liquid per unit area, per unit of time of impingement.

**SPRING TEMPER** - A *temper* of nonferrous alloys and some ferrous alloys characterized by tensile strength and hardness about two-thirds of the way from *full hard* to *extra spring* temper.

**STABILIZING TREATMENT** - (1) Before finishing to final dimensions, repeatedly heating a ferrous or nonferrous part to slightly above its normal operating

temperature and then cooling to room temperature to ensure dimensional stability in service. (2) Transforming retained austenite in quenched hardenable steels, usually by *cold treatment*. (3) Heating a solution-treated stabilized grade of austenitic stainless steel to 870 to 900°C (1600 to 1650°F) to precipitate all carbon as TiC, NbC, or TaC so that *sensitization* is avoided on subsequent exposure to elevated temperature.

**STATISTICAL PROCESS CONTROL** - The application of statistical techniques for measuring and analyzing the variation in processes.

**STATISTICAL QUALITY CONTROL** - The application of statistical techniques for measuring and improving the quality of processes and products (includes statistical process control, diagnostic tools, sampling plans, and other statistical techniques).

**STEAD'S BRITTLINESS** - A condition of brittleness that causes transcrystalline fracture in the coarse grain structure that results from prolonged annealing of thin sheets of low-carbon steel previously rolled at a temperature below about 705°C (1300°F). The fracture usually occurs at about 45° to the direction of rolling.

**STEP AGING** - Aging at two or more temperatures, by steps, without cooling to room temperature after each step. See *aging*, and compare with *interrupted aging* and *progressive aging*.

**STRAIN-AGE EMBRITTLENESS** - 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 AGING** - Aging following plastic deformation.

**STRESS EQUILIZING** - A low-temperature heat treatment used to balance stresses in cold-worked material without an appreciable decrease in the mechanical strength produced by cold working.

**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.

**SUBCRITICAL ANNEALING** - A process anneal performed on ferrous alloys at a temperature below  $A_c1$ .

**SUBLIMATION** - Evaporation from the solid state without first becoming liquid.

**SUBMERGED-ELECTRODE FURNACE** - A furnace used for liquid carburizing of parts by heating molten salt baths with the use of electrodes submerged in the ceramic lining. See *immersed-electrode furnace*.

**SUPERCOOLING** - Cooling below the temperature at which an equilibrium phase transformation can take place without actually obtaining the transformation.

**SUPERHEATING** - Heating above the temperature at which an equilibrium phase transformation should occur without actually obtaining the transformation.

**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*.

## **T**

**TEMPER** - (1) In heat treatment, reheating hardened steel or hardened cast iron to some 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 in advisedly, 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.

**TEMPER BRITTLINESS** - Brittleness that develops when certain quenched steels are held within or slowly cooled from tempering temperatures in the neighborhood of 850°F to 1100°F.

**TEMPER CARBON** - Same as *annealing carbon*.

Carbon (graphite) that has formed from the decomposition of cementite. Temper carbon appears in the form of rounded particles.

**TEMPER COLOR** - A thin, tightly adhering oxide skin 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 in both tempering time and temperature.

**TEMPERING** - Reheating quenched steel to a temperature below the critical range, followed by any desired rate of cooling. Tempering is done to relieve quenching stresses, to relieve the brittleness of fully hardened steel, or to develop desired strength characteristics. The words "temper" and "draw" are used interchangeably.

## **TEMPERED MARTENSITE EMBRITTLEMENT**

- *Embrittlement* of ultrahigh-strength steels caused by tempering in the temperature range of 205 to 400°C (400 to 750°F); also, called 350°C or 500°F embrittlement. Tempered martensite embrittlement is thought to result from the combined effects of cementite precipitation on prior-austenite grain boundaries or interlath boundaries and the segregation of impurities at prior-austenite grain boundaries.

**TEMPER EMBRITTLEMENT** - *Embrittlement* of alloy steels caused by holding within or cooling slowly through a temperature range 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.

**TERNARY ALLOY** - An alloy containing three principal elements.

**THERMAL ANALYSIS** - A method for determining transformations in a metal 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 equilibrium diagrams.

**THERMAL ELECTROMOTIVE FORCE** - The electromotive force generated in a circuit containing two dissimilar metals when one junction is at a temperature different from that of the other. See also *thermocouple*.

**THERMAL FATIGUE** - Fracture resulting from the presence of temperature

gradients that vary with time in such a manner as to produce cyclic stresses in a structure.

**THERMAL SHOCK** - The development of a steep temperature gradient and accompanying high stresses within a structure.

**THERMAL STRESSES** - Stresses in metal resulting from nonuniform temperature distribution.

**THERMOCHEMICAL TREATMENT** - Heat treatment carried out in a medium suitably chosen to produce a change in the chemical composition of the object by exchange with the medium.

**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.

**THERMOMECHANICAL WORKING** - A general term covering a variety of processes combining controlled thermal and deformation treatments to obtain specific properties. Same as thermal-mechanical treatment.

**THREE-QUARTERS HARD** - A *temper* of nonferrous alloys and some ferrous alloys characterized by tensile strength and hardness about midway between those of *half-hard* and *full-hard* tempers.

**TIME QUENCHING** - A term used to describe a quench in which the cooling rate of the part being quenched must be changed abruptly at some time during the cooling cycle.

**TIME-TEMPERATURE TRANSFORMATION (TTT) DIAGRAM** - See *isothermal transformation (IT) diagram*.

**TOTAL CARBON** - The sum of the free and combined carbon (including carbon in

solution) in a ferrous alloy.

**TOTAL INDICATOR READING** - See preferred term, *total indicator variation*.

**TOTAL INDICATOR VARIATION** - The difference between the maximum and minimum indicator readings during a checking cycle.

**TORR** - A unit of pressure as measured in a vacuum furnace. One atmosphere of pressure is 760mm of mercury (on the barometer). One Torr is a pressure of 1mm of mercury. One micron is a pressure of 0.001 mm of mercury or 0.001 Torr, which is written as  $10^{-3}$  Torr.

**TOUGHNESS** - The ability of a metal to absorb energy and deform plastically before fracturing.

**TRANSCRYSTALLINE** - See *transgranular*.

**TRANSFORMATION HARDENING** - Heat treatment comprising austenitization followed by cooling under conditions such that the austenite transforms more or less completely into martensite and possibly into bainite.

**TRANSFORMATION-INDUCED PLASTICITY** - A phenomenon, occurring chiefly in a certain highly alloyed steels that have been heat treated to produce metastable austenite or metastable austenite plus martensite, whereby, on subsequent deformation, part of the austenite undergoes strain-induced transformation to martensite. Steels capable of transforming in this manner, commonly referred to as TRIP steels, are highly plastic after heat treatment, but exhibit a very high rate of strain hardening, and thus, have high tensile and yield strengths after plastic deformation at temperatures between about 20 and 500°C (70 to 930°F). Cooling to -195°C (-320°F) may or may not be required to complete the transformation to martensite. Tempering usually is done following transformation.

**TRANSFORMATION RANGES** - Those ranges of temperature within which a

phase forms during heating and transforms during cooling. The two ranges are distinct, sometimes overlapping but never coinciding. The limiting temperatures of the ranges depend on the composition of the alloy and on the rate of change of temperature, particularly during cooling. See *transformation temperature*.

**TRANSFORMATION TEMPERATURE** - The temperature at which a change in phase occurs. The term is sometimes used to denote the limiting temperature of transformation range. The following symbols are used for iron and steels.

$A_{cm}$  - In hypereutectoid steel, the temperature at which the solution of cementite in austenite is completed during heating.

$A_c1$  - The temperature at which austenite begins to form during heating.

$A_{c3}$  - The temperature at which transformation of ferrite to austenite is completed during heating.

$A_{c4}$  - The temperature at which austenite transforms to delta ferrite during heating.

$A_{ecm}$ ,  $A_{e1}$ ,  $A_{e3}$ ,  $A_{e4}$  - The temperatures of phase changes at equilibrium.

$A_{r_{cm}}$  - In hypereutectoid steel, the temperature at which precipitation of cementite starts during cooling.

$A_{r1}$  - The temperature at which transformation of austenite to ferrite or to ferrite plus cementite is completed during cooling.

$A_{r3}$  - The temperature at which austenite begins to transform to ferrite during cooling.

$A_{r4}$  - The temperature at which delta ferrite transforms to austenite during cooling.

$A_r'$  - The temperature at which transformation of austenite to

pearlite starts during cooling.

$M_s$  - The temperature at which transformation of austenite to martensite finishes during cooling.

$M_s$ , (or  $A_r'$ ) - The temperature at which transformation of austenite to martensite starts during cooling.

**NOTE:** All these changes except formation of martensite occur at lower temperatures during cooling than during heating, and depend on the rate of change of temperature.

**TRANSGRANULAR** - Through or across crystals or grains. Also called intracrystalline or transcrystalline.

**TRANSGRANULAR CRACKING** - Cracking or fracturing that occurs through or across a crystal or grain. Also called transcrystalline cracking. Contrast with *intergranular cracking*.

**TRANSGRANULAR FRACTURE** - Fracture through or across the crystals or grains of metal. Also called transcrystalline fracture or intracrystalline fracture. Contrast with *intergranular fracture*.

**TRANSITION TEMPERATURE** - (1) An arbitrarily defined temperature that lies within the temperature range in which the metal fracture characteristics (as usually determined by tests of notched specimens) change rapidly, such as from primarily fibrous (shear) to primarily crystalline (cleavage) fracture. Commonly used definitions are "transition temperature for 50% cleavage fracture", "10ft. • lbf transition temperature", and "transition temperature for half maximum energy". (2) Sometimes used to denote an arbitrarily defined temperature within a range in which the ductility changes rapidly with temperature.

**TRIP STEEL** - A commercial steel product exhibiting *transformation-induced plasticity*.

**TROOSTITE** - (obsolete) A previously

unresolvable rapidly etching fine aggregate of carbide and ferrite produced whether by tempering martensite at low temperature or by quenching a steel at a rate slower than the critical cooling rate. Preferred terminology for the first product is tempered martensite; for the latter, fine pearlite.

## **U**

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**UNDERCOOLING** - Same as *supercooling*.

## **V**

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**VACUUM ANNEALING** - Annealing carried out at subatmospheric pressure.

**VACUUM CARBURIZING** - A high-temperature gas carburizing process using furnace pressures between 7 and 55 kPa during the carburizing portion of the cycle.

**VACUUM FURNACE** - A furnace using low atmospheric pressure instead of a protective gas atmosphere like most heat-treating furnaces. Vacuum furnaces are categorized as hot wall or cold wall, depending on the location of the heating and insulating components.

**VACUUM NITROCARBURIZING** - A subatmospheric nitrocarburizing process using a basic atmosphere of 50% ammonia and 50% methane, containing controlled oxygen additions of up to 2%.

**VACUUM PROCESSES FOR METALS** - Processes in which a near vacuum is used as the environment in which metal is heated, cooled, joined, outgassed or melted. Used primarily for the purpose of removing or avoiding gases which are reactive with the surface of the metal being processed.

## **W**

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**WALKING BEAM FURNACE** - A continuous type furnace consisting of two sets of rails, one stationary and the other movable. Only the work being processed has to be heated because trays or fixtures are not needed.

**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.

**WHITE LAYER** - Compound layer that forms as a result of the *nitriding* process.

**WORK** - As applied to metals, "working" is any operation that changes the external shape of the piece without changing its volume. Such operations as drawing, rolling, forging, swaging, extruding and bending are common ways of working metals.

**WORK HARDNESS** - Hardness developed in metal resulting from cold working.