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(R) DEFINITIONS OF HEAT TREATING TERMS

***Foreword*—**This Document has not changed other than to put it into the new SAE Technical Standards Board Format.

***1. Scope*—**(These definitions were prepared by the Joint Committee on Definitions of Terms Relating to Heat Treatment appointed by the American Society for Testing and Materials, The American Society for Metals, the American Foundrymen's Association, and the SAE.) This SAE revision emphasizes the terms used in heat treating ferrous alloys, but also includes for reference some non-ferrous definitions at the end of the document.

This glossary is not intended to be a specification, and it should not be interpreted as such. Since this is intended to be strictly a set of definitions, temperatures have been omitted purposely.

2. References

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J418—Grain Size Determination
SAE J763—Aging of Carbon Steel Sheet and Strip
SAE J940—Glossary of Carbon Steel Sheet and Strip Terms

3. Definitions

3.1 Ac_{cm}, Ac_1, Ac_3, Ac_4——Defined under Transformation Temperature.

3.2 Ae_{cm}, Ae_1, Ae_3, Ae_4——Defined under Transformation Temperature.

3.3 Age Hardening—Hardening by aging, usually after rapid cooling or cold working. See Aging.

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3.4 Aging—A generic term denoting a time-temperature-dependent change in the properties of certain alloys. Except for strain aging and age softening, it is the result of precipitation from a solid solution of one or more compounds whose solubility decreases with decreasing temperature. For each alloy system susceptible to aging, there is a unique range of time-temperature combinations to which the system will respond. See also Age Hardening, Artificial Aging, Age Softening, Natural Aging, Overaging, Peak Aging, Precipitation Hardening, Precipitation Heat Treatment, Quench Aging, Strain Aging, and Underaging.

3.5 Annealing—A generic term denoting a treatment, consisting of heating at an appropriate rate to a suitable temperature, holding for an appropriate time, and cooling at a suitable rate. Used primarily to soften metallic materials, but also to simultaneously produce desired changes in other properties or in microstructure. The purpose of such changes may be, but is not confined to, one or more of: (a) improvement of machinability; (b) facilitation of cold work; (c) improvement of mechanical or electrical properties or increase in stability of dimensions.

The time-temperature cycles used vary widely in heating rate, maximum temperature attained, and in cooling rate employed, depending on the composition of the material, its condition, and the results desired. When applicable, the following more specific commercial process names should be used: Black Annealing, Blue Annealing, Box Annealing, Bright Annealing, Cycle Annealing, Flame Annealing, Full Annealing, Graphitizing, In-Process Annealing, Isothermal Annealing, Malleabilizing, Orientation Annealing, Process Annealing, Quench Annealing, and Spheroidizing. When the term is used without qualification full annealing is implied. Any process of annealing will usually reduce stresses, but when applied only for the relief of stress, the process is properly called stress relief annealing.

3.6 Artificial Aging—Aging above room temperature. See Aging and Precipitation Heat Treatment. Compare with Natural Aging.

3.7 Ausforming—Mechanically working an appropriate high hardenability steel after quenching from above the upper critical temperature to a temperature between the lower critical and the M_S temperature, and isothermally transforming or quenching to produce the desired properties.

3.8 Austempering—Quenching a ferrous alloy from a temperature above the transformation range, in a medium having a rate of heat extraction sufficient to prevent the formation of ferrite or pearlite, and then holding the alloy just above M_S until transformation to bainite is complete.

3.9 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.

3.10 Austentic Nitrocarburizing—A lower-temperature variant of carbonitriding, austenitic nitrocarburizing is applied to ferrous materials at typical processing temperatures of 676 °c to 774 °C (1250 °F to 1425 °F). The process involves the diffusion of nitrogen and carbon into the surface of the work piece and the formation of a thin white layer of epsilon carbonitrides. Subsurface microstructure includes martensite and bainite which improve the load carrying capability when compared to ferritic nitrocarburizing.

3.11 Baking—Heating to a low temperature usually to remove gases such as hydrogen. Aging may result from baking treatments.

3.12 Black Annealing—Box annealing or pot annealing ferrous alloy sheet, strip, or wire. See Box Annealing.

3.13 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.

3.14 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.

3.15 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, normally with the formation of a bluish oxide on the surface.

3.16 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 and adhesive wear.

NOTE—This term is ordinarily applied to sheet, strip, or finished parts. It is used also to denote the heating of springs after fabrication, in order to improve their properties.

3.17 Box Annealing—Annealing a metal or alloy in a sealed container under conditions that minimize oxidation. In box annealing 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." See Black Annealing and SAE J940.

3.18 Bright Annealing—Annealing in a protective medium to prevent discoloration of the bright surface or to produce a bright surface.

3.19 Burning—Permanently damaging a metal or alloy by heating to cause either incipient melting or intergranular oxidation. See Overheating.

3.20 Carbon Potential—A measure of the ability of an environment containing active carbon to alter or maintain, under prescribed conditions, the carbon content of the steel exposed to it.

NOTE—In any particular environment, the carbon level attained will depend on such factors as temperature, time, and steel composition.

3.21 Carbon Restoration—Replacing the carbon lost in the surface layer from previous processing by adding carbon to this layer to substantially the original carbon level.

3.22 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 which produces the desired properties in the workpiece.

3.23 Carburizing—A process in which an austenitized ferrous material is brought into contact with a carbonaceous atmosphere of sufficient carbon potential to cause absorption of carbon at the surface and, by diffusion, create a concentration gradient.

3.24 Case—In a ferrous alloy workpiece, the outer discrete layer whose composition has been altered by one of the processes of case hardening.

3.25 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 surface is characteristically harder than the subsurface material. The use of the applicable specific process name is preferred.

3.26 Cementation—The introduction of one or more elements into the outer portion of a metal object by means of diffusion at high temperature.

3.27 Close Annealing—See Box Annealing.

3.28 Cold Treatment—Exposing to suitable low temperatures (usually below –40 °C) for the purpose of obtaining desired conditions or properties, such as dimensional or microstructural stability. When the treatment involves the transformation of retained austenite, it is usually followed by a tempering treatment.

3.29 Conditioning Heat Treatmtnt—A preliminary heat treatment used to prepare a material for a desired reaction to a subsequent heat treatment. For the term to be meaningful, the treatment used must be specified.

3.30 Continuous Annealing—Process of passing a strand or sheet through a controlled atmosphere furnace that has both heating and cooling zones. Temperatures, line speeds, and cooling rates are varied to obtain the desired properties. Can also refer to a continuous heat treating process (e.g., belt furnaces.)

3.31 Controlled Cooling—Cooling from an elevated temperature in a predetermined manner, to avoid hardening, cracking, or internal damage, or to produce a desired microstructure or mechanical properties.

3.32 Core—(a) Surface Hardening: Interior portion of unaltered composition, or microstructure, or both, of a surface treated steel article. (b) Clad Products: The central portion of a multilayer composite metallic material.

3.33 Critical Cooling Rate—The minimum rate of continuous cooling to prevent undesirable transformations. For steel, unless otherwise specified, it is the minimum rate at which austenite must be continuously cooled to suppress transformations above the M_S temperature.

3.34 Critical Tempurature Range—Synonymous with Transformation range, which is preferred.

3.35 Cryogenic Treatments—Same as cold treatment only specifically related to temperatures at or below that of liquid nitrogen (–196 °C).

3.36 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.

3.37 Cycle Annealing—An annealing process employing a predetermined and closely controlled time-temperature cycle to produce specific properties or microstructure.

3.38 Decarburation—The loss of carbon from the surface of a ferrous alloy usually as a result of heating in a medium that reacts with the carbon.

3.39 Die Quenching or Press Quenching—Rigidly fixturing a ferrous workpiece during quench hardening to minimize distortion produced by transformation of austenite.

3.40 Diferential 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.

3.41 Diffusion Coating—Any process whereby a base metal or alloy is either: (a) coated with another metal or alloy and heated to a sufficient temperature in a suitable environment or (b) exposed to a gaseous or liquid medium containing the other metal or alloy, to cause diffusion of the coating or of the other metal or alloy into the base metal with resultant change in the composition and properties of its surface.

3.42 Direct Quenching—Quenching carburized parts directly from the carburizing or austenitizing temperature.

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

3.44 Double Tempering—A treatment in which quench hardened steel is given two complete tempering cycles at substantially the same temperature for the purpose of assuring completion of the tempering reaction and transformation of untransformed austenite, promoting stability of the resulting microstructure.

3.45 Drawing—A misnomer for Tempering.

3.46 Ductile Nitriding—See nitriding.

3.47 Ferritic Nitrocarburizing—A process applied to ferrous materials that involves the diffusion of nitrogen and carbon into the ferrite phase and the formation of thin white layer of epsilon carbonitrides. Low process temperatures (below 676 °C (1250 °F)) contribute to low distortion of the workpiece. Resultant properties of the process include improved adhesive wear properties (due to the thin white layer of epsilon carbonitrides), improved fatigue resistance, and improved corrosion resistance.

3.48 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.

3.49 Flame Annealing—Annealing in which the heat is applied directly by a flame.

3.50 Flame Hardening—A surface hardening process in which only the surface layer of a suitable workpiece is heated by a suitably intense flame to above the upper transformation temperature and immediately quenched.

3.51 Full Annealing—An imprecise term used to denote the annealing cycle required to produce minimum strength and hardness. For the term to be meaningful, the composition, starting condition of the material, and the time-temperature cycle used must be stated.

3.52 Grain Growth—An increase in the average size of the grains (see Notes 1 and 2) in polycrystalline metal, usually as a result of heating at elevated temperature.

NOTE 1—A grain is an individual crystal in a polycrystalline metal and includes twined regions and subgrains when present.

NOTE 2—Grain size is a measure of the mean diameter, area, or volume of all individual grains observed in a polycrystalline metal. In metals containing two or more phrases, the grain size refers to that of the matrix unless otherwise specified. For further information on grain size and its measurement, see SAE J418.

3.53 Graphitizing—Annealing a ferrous alloy in such a way that some or all of the carbon is precipitated as graphite.

3.54 Hardenability—The capacity of a ferrous alloy to transform partially or completely from austenite to some percentage of martensite at a given depth when cooled under some given condition.

3.55 Hardening—Increasing the hardness by suitable treatment, usually involving heating and cooling. When applicable, the following more specific terms should be used: Age Hardening, Case Hardening, Flame Hardening, Induction Hardening, Precipitation Hardening, Quench Hardening, and Surface Hardening.

3.56 Heat Treatment—Heating and cooling of metals and/or alloys in the solid state for the purpose of changing their physical and mechanical properties. Heating for the sole purpose of hot working is excluded from the meaning of this definition.

3.57 Homogenizing—Soaking at a temperature sufficient to improve chemical and structural uniformity, usually applied prior to mechanical working.

3.58 Hot-Cold Working—Mechanical deformation of austenitic and precipitation hardening alloys at a temperature just below the recrystallization range to increase the yield strength and hardness by either plastic deformation or precipitation hardening effects induced by plastic deformation or both. See Warm Working.

3.59 Hot Quenching—An imprecise term used to cover a variety of quenching procedures in which a quenching medium is maintained at a prescribed temperature usually above 70 °C (160 °F).

3.60 Induction Hardening—A surface hardening process in which only the surface layer of a suitable ferrous workpiece is heated by electrical induction to a temperature above the upper critical temperature and immediately quenched. Induction heating can also be used for hardening the entire cross section.

3.61 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..

3.62 Intermediate Annealing—Annealing wrought metals at one or more stages during manufacture and before final thermal treatment.

3.63 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.

3.64 Interrupted Quenching—A quenching procedure in which the workpiece 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. See also Time Quenching.

3.65 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.

3.66 Isotermal Transformation—A solid state phase transformation at constant temperature.

3.67 Malleablizing—A process in which the as-cast malleable-type (white) iron is thermally treated for the purpose of converting most of all of the carbon in Fe_3C to graphite (temper carbon) to produce a family of products with improved ductility.

3.68 Maraging—A precipitation hardening treatment applied to a special group of iron base alloys to precipitate one or more intermetallic compounds in matrix of essentially low carbon martensite.

3.69 Marquenching—See martempering (b).

3.70 Martempering—(a) A hardening procedure in which an austenitized ferrous workpiece is quenched into an appropriate medium whose temperature is maintained substantially at the M_S of the workpiece, 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. (b) When the process is applied to carburized material, the part is quenched to a temperature below the core M_S but above the case M_S temperature. This variation of the process is frequently called marquenching.

3.71 Martensite Range—The temperature interval between M_s and M_f.

3.72 M_f—Defined under Transformation Temperature.

3.73 M_s—Defined under Transformation Temperature

3.74 Natural Aging—Spontaneous aging of a supersaturated solid solution at room temperature over time. See Aging and compare with Artificial Aging.

3.75 Nitriding—A case hardening process in which a ferrous-base material is heated to approximately the iron-nitrogen eutectoid temperature in either a gaseous or a liquid medium containing active nitrogen, thus causing absorption of nitrogen at the surface and, by diffusion, creating a concentration gradient. Within the capabilities of the particular material, slow cooling produces full hardness of the case.

In *conventional nitriding* a hardened and tempered alloy steel or tool steel is treated for sufficient time to produce highly saturated nitrides in the case.

In an important variation of the process, sometimes called *ductile nitriding*, applied to any ferrous-base material, the amount of active nitrogen and the time of exposure are so controlled as to produce a case of lower nitrogen content which, within the capabilities of the material, is fully hard on a microscale but lower in hardness on a macroscale and relatively ductile.

3.76 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 usually to improve machinability or impart specific mechanical properties.

3.77 Orientation Anneal—A final, high-temperature anneal applied principally to flat-rolled electrical steel to develop secondary grain growth and directionality of magnetic properties.

3.78 Overaging—Aging at any combination of time and temperature in excess of that required to obtain the optimum strength and hardness.

3.79 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.

3.80 Patenting—In wire making, 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 Ae_1 in air or in a bath of molten lead or salt.

3.81 Peak Aging—Aging at whatever combination of time and temperature produces maximum strength or hardness. See Aging.

3.82 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.

3.83 Pot Annealing—See Box Annealing.

3.84 Precipitation Hardening—Hardening caused by the precipitation of a constituent from a supersaturated solid solution. See also Age Hardening and Aging.

3.85 Precipitation Heat Treating—Artificial aging in which a constituent precipitates from a supersaturated solid solution. See Artificial Aging, Interrupted Aging, and Progressive Aging.

3.86 Preheating—(a) An imprecise term meaning heating to an appropriate temperature in preparation for mechanical work, for welding, or for further thermal treatment. (b) Heating to an appropriate temperature immediately prior to austenitizing when hardening high hardenability constructional steels, many of the tool steels, and heavy sections.

3.87 Process Annealing—An imprecise term used to denote 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.

3.88 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.

3.89 Quench Aging—Natural or artificial aging of a ferrous material caused by the precipitation of an iron carbide or an iron nitride or a complex of both in alpha iron supersaturated with these compounds. Supersaturation is achieved by rapidly cooling the heated material.

3.90 Quench Annealing—Annealing an austenitic ferrous alloy by Solution Heat Treatment.

3.91 Quench Hardening—Hardening a suitable ferrous alloy by austenitizing and then cooling at a rate such that a substantial amount of austenite transforms to martensite.

3.92 Quenching—Rapid cooling. When applicable, the following more specific terms should be used: Direct Quenching, Fog Quenching, Hot Quenching, Interrupted Quenching, Selective Quenching, Spray Quenching, and Time Quenching.

3.93 Recrystallization—The formation of a new, strain-free grain structure from that existing in cold-worked metal, usually accomplished by heating.

3.94 Recrystallization Annealing—Annealing cold-worked metal to produce a new grain structure without phase change.

3.95 Recrystallization Temperature—The approximate minimum temperature at which complete recrystallization of a cold-worked metal occurs within a specified time, dependent upon the composition, microstructure, heating rate, and amount of prior cold work.

3.96 Reheating—An imprecise term denoting an additional heating applied between different mechanical operations or successive steps of the same operation or for hardening after carburizing.

3.97 Secondary Hardening—The hardening phenomenon that occurs during high temperature tempering of certain steels containing one or more specific carbide forming alloying elements. Up to an optimum combination of tempering time and temperature, the reaction results either in the retention of hardness or an actual increase in hardness.

3.98 Selective Carburizing—Carburizing only selected surfaces of a workpiece by preventing absorption of carbon by all other surfaces.

3.99 Selective Heating—Intentional heating of only certain portions of a workpiece.

3.100 Selective Quenching—Quenching only certain portions of a workpiece.

3.101 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 between section size, steel hardenability, and severity of quench.

3.102 Slack Quenching—The incomplete hardening of steel due to quenching from the austenizing 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.

3.103 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. It is also used prior to fixture tempering to prevent cracking.

3.104 Soaking—Holding at a selected temperature.

3.105 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.

3.106 Soft Nitriding—A misnomer for ductile nitriding.

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

a. Prolong holding at a temperature just below Ae_1.
b. Heating and cooling alternately between temperatures that are just above and just below Ae_1.
c. 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.
d. Cooling at a suitable rate from the minimum temperature at which all carbide is dissolved, to prevent the reformation of a carbide network and then reheating in accordance with Method a or b. (Applicable to hypereutectoid steel containing a carbide network.)

3.108 Spray Quenching—Quenching in a spray of liquid.

3.109 Stabilizing Treatment—A treatment applied for the purpose of stabilizing the dimensions of a workpiece or the structure of a material such as (a) before finishing to final dimensions, heating a workpiece to or somewhat beyond its operating temperature and then cooling to room temperature a sufficient number of times to insure stability of dimensions in service, (b) transforming retained austenite in those materials which retain substantial amounts when quench hardened (see cold treatment), (c) heating a solution treated austenitic stainless steel that contains controlled amounts of titanium or columbium plus tantalum to a temperature below the solution heat treating temperature to cause precipitation of finely divided, uniformly distributed carbides of those elements, thereby substantially reducing the amount of carbon available for the formation of chromium carbides in the grain boundaries upon subsequent exposure to temperatures in the sensitizing range.

3.110 Strain Aging—A change in mechanical properties of a ferrous material during (dynamic strain aging) or after (static strain aging) cold plastic strain. When tested in tension, strain-aged low-carbon sheet exhibits discontinuous yielding, a decrease in ductility, and an increase in yield strength and hardness without substantial change in tensile strength as compared with unaged sheet. Appropriate restraining (temper rolling) temporarily restores continuous yielding. See SAE J763.

3.111 Stress Relieving—Heating to a suitable temperature, holding long enough to reduce residual stresses and then cooling at a rate to minimize the development of new residual stresses.

NOTE—Stress relief may be accomplished by the application of other forms of energy, principally mechanical, either alone or in combination with thermal energy.

3.112 Subcritical Annealing—A process anneal performed at a temperature below Ac_1.

3.113 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 induction hardening, flame hardening, and shell hardening. Use of the applicable specific process name is preferred.

3.114 Temper Brittleness—Brittleness that results when certain steels are held within, or are cooled slowly through, a certain range of temperature below the transformation range. The brittleness is manifested as an upward shift in ductile-to-brittle transition temperature in notched-bar impact tests, but only rarely produces a low value of reduction in area in a smooth-bar tension test of the embrittled material.

3.115 Tempering—(a) Reheating a quench hardened or normalized ferrous alloy to a temperature below the transformation range (Ac_1) and then cooling at any desired rate. (b) A term used in conjunction with a qualifying adjective to designate the relative properties of a particular metal or alloy induced by cold work or heat treatment, or both.

3.116 Time Quenching—Interrupted quenching in which the duration of holding in the quenching medium is controlled.

3.117 Transformation Ranges or Transformation Temperature Ranges—Those ranges of temperature within which austenite 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.

3.118 Transformation Temperature—The temperature at which a change in phase occurs. The term is sometimes used to denote the limiting temperature of a transformation range. The following symbols are used for iron and steels:

Ac_{cm}—In hypereutectoid steel, the temperature at which the solution of cementite in austenite is completed during heating.
Ac_1—The temperature at which transformation of ferrite to austenite begins during heating.
Ac_3—The temperature at which transformation of ferrite to austenite is completed during heating.
Ac_4—The temperature at which austenite transforms to delta ferrite during heating.
Ae_1, Ae_3, Ae_{cm}, Ae_4—The temperatures of phase changes in equilibrium.
Ar_{cm}—In hypereutectoid steel, the temperature at which precipitation of cementite starts during cooling.
Ar_1—The temperature at which transformation of austenite to ferrite or to ferrite plus cementite is completed during cooling.
Ar_3—The temperature at which austenite begins to transform to ferrite during cooling.
Ar_4—The temperature at which delta ferrite transforms to austenite during cooling.
M_s—The temperature at which transformation of austenite to martensite starts during cooling.
M_f—The temperature at which transformation of austenite to martensite is substantially completed during cooling.

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

3.119 Underaging—Aging at any combination of time and temperature insufficient to produce maximum strength to hardness.

NOTE—This treatment is used to improve workability in some precipitation hardening copper alloys.