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Background Information About Heat Treatment of Metals

Mamataliyeva Zulfiyakhon Khusanovna
e-mail: mszulya66@mail.ru
Andijan Machine-Building Institute

Annotation: This source provides general information about the process associated with heating and cooling metals and alloys to make the necessary changes in their structure and properties. The process can also involve deformation and chemical and magnetic effects. Information is given about the phases formed in the heat treatment of metals and their known properties. explains certain parts of some properties and possibilities of heat treatment of metals. For example, Annealing, stress relieving, and heating for homogenization or annealing with phase transformations.

Key words: Annealing, treatment of metals, cementation, homogenization, recrystallization, duralumin and copper alloys.

Man has heat-treated metals since antiquity. In the Aeneolithic period, primitive man, in forging native gold and copper without heat, discovered the change in structure known as cold working. This effect hampered the production of articles with thin edges and sharp tips, and to restore ductility the smith would have to heat the forged copper in a hearth. The earliest evidence of the use of annealing to soften cold-worked metal dates from the end of the fifth millennium B.C. This annealing was the first instance of the heat treatment of metals. In making weapons and implements from iron obtained by blooming, the smith would heat the semifinished shape packed in charcoal as preparation for hot working (forging).[1] The heating would carbur-ize the iron; that is, cementation—a form of chemical treatment—would occur. Upon cooling the forged article of car-burized iron in water, the smith would see an increase in hardness and an improvement in other properties. The process of hardening carburized iron by quenching in water was used from the end of the second to the beginning of the first millennium B.C. In Homer's Odyssey (eighth-seventh centuries B.C.), we see the lines "As the smith dips the glowing ax or poleax into the cold water, the iron hisses and with gurgling becomes stronger, tempered in fire and water." In the fifth century B.C., the Etruscans quenched mirrors made of bronze having a high content of tin in water, mainly to improve the shine after polishing.[2]

Cementation of iron in charcoal or other organic matter, followed by hardening and tempering of the steel obtained, came to be widely used in the Middle Ages to produce knives, swords, files, and other implements.[5] Not understanding the changes occurring within the metal, the medieval artisan often ascribed the improved properties obtained by heat treatment to supernatural causes. Until the mid-19th century, knowledge of heat treatment was limited to a number of set procedures accumulated from many centuries of experience.

Technological needs, especially the need to produce steel cannons, transformed heat treatment[4] from an art into a science. In the mid-19th century, when the military was seeking to replace bronze and cast-iron cannons with stronger, steel counterparts, the problem of producing high-strength barrels took on greater urgency. Even though metallurgists knew procedures for melting and casting steel, gun barrels often exploded for no apparent reason. At the Obukhov Plant in St. Petersburg, D. K. Chernov, in examining microscopically pickled sections from a gun muzzle and observing under a magnifying glass the metal structure at the place of fracture, concluded that steel becomes stronger as its structure becomes finer. In 1868, Chernov discovered the internal structural transformations that occur in cooled steel at certain temperatures that he called critical points a and b. If the steel is heated to a temperature below point a, it cannot be hardened, and the steel must be heated to a temperature above point b to produce a fine-grained structure. Chernov's discovery of critical points for structural transformations in steel provided the scientific basis for the choice of a heat-treatment cycle for obtaining the required properties in steel articles.

In 1906, A. Wilm of Germany discovered Duralumin and, in the process, age hardening—a highly important method for hardening alloys based on such metals as aluminum, copper, nickel, and iron.

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Thermomechanical treatment of copper alloys undergoing aging was developed in the 1930's, and the 1950's saw thermochemical treatment of steel, making possible a significant increase in the strength of steel articles. Among the combined methods of heat treatment is thermomagnetic treatment,[3] which can bring about an improvement in magnetic properties by cooling an article in a magnetic field.

An elegant theory of heat treatment has been developed through numerous studies on changes in the structure and properties of metals and alloys upon heating.

Figure 1. TERMIC PROCESSING PROCESS

The classification of the types of heat treatment is based[8] on the nature of the changes occurring in the metal's structure. The classification comprises heat treatment per se, chemical heat[6] treatment, which combines thermal and chemical effects, and thermomechanical treatment, which includes both thermal effects and plastic deformation. Heat treatment per se encompasses annealing, stress relieving, and heating for homogenization, annealing with phase transformations, hardening with and without polymorphic transformations, age hardening, and tempering.[9]

Annealing, stress relieving, and heating for homogenization. Distortions in structure arising from casting, welding, forming, or other technological processes can be wholly or partly corrected by annealing, stress relieving, and heating for homogenization. The processes that remove the distortions proceed on their own, and heating merely effects an acceleration. Key factors in annealing, stress relieving, and heating for homogenization are the temperature[7] and the length of time that the metal is held at the temperature.

Figure 2. HEAT PROCESSING OF METAL MATERIALS

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Heating for homogenization is an operation for removing the effects of dendritic segregation, as a result of which the chemical composition within the crystals of the solid solution after crystallization is nonuniform. Segregation can also be accompanied by the appearance of a nonequilibrium phase, for example, a chemical compound that embrittles the alloy. The diffusion that occurs with the heating applied to effect homogenization leads to the dissolution of the nonequilibrium excess phases, resulting in a more homogeneous alloy. Heating for homogenization also raises ductility and corrosion resistance.

Recrystallization annealing removes deviations in structure from the equilibrium state caused by plastic deformation. When the metal is hardened through cold (pressure)[10] working, there is a rise in strength but a drop in ductility owing to an increase in the density of dislocations within the crystals. Upon heating the cold-worked metal above a certain temperature, primary recrystallization commences and then gives way to secondary recrystallization, whereupon the density of the dislocations falls sharply. As a result, the metal becomes more ductile at the expense of strength. Recrystallization annealing is used to improve formabil-ity and to impart to the metal the necessary combination of hardness, strength, and ductility. The goal in recrystallization, as a rule, is to produce a textureless material devoid of anistotropy. Recrystallization annealing is used in the production of plates from transformer steel to obtain a desired metal texture upon recrystallization.

Stress relieving is used for articles in which during forming, casting, welding, heating, and other technological processes excessively high residual stresses are introduced. Residual stresses can cause distortions in the shape and dimensions of articles during processing, use, or storage. The yield point decreases upon heating, and when it becomes less than the residual stresses, the stresses are quickly relieved by plastic flow in various layers of the metal.

Annealing with phase transformations. Annealing involving phase transformations is used only for metals and alloys that undergo phase transformations with changes in temperature. With this type of annealing, qualitative or purely quantitative changes in the phase composition (types and volumes of the phases) occur with heating, and reverse changes are seen upon cooling. The main parameters of this type of annealing are temperature, length of time that the temperature is held, and cooling rate. The annealing temperature and time are chosen so as to ensure the necessary phase changes, for example, polymorphic transformations or dissolution of an excess phase. The operation is usually conducted so as to prevent the growth of large grains in the phase that is stable at the annealing temperature. The cooling rate should be low enough so that reverse phase transformations, for which diffusion forms the basis, can occur upon lowering the temperature[11]. Either furnace cooling or air cooling can be used, and in the latter case the process is called normalization. Annealing with phase transformations is used most frequently in steels to effect grain refinement, softening, and better machinability.

Hardening without polymorphic transformations. Hardening without polymorphic transformations is used for any alloy in which, upon heating, the excess phase either wholly or partly dissolves in the main phase. Again, the most important parameters are temperature, length of time that the temperature is held, and cooling rate. The cooling rate should be high enough to avoid separation of the excess phase. (The process of phase separation is brought about by the redistribution through diffusion of the components of a solid solution.) This rate will be high enough in the case of Duralumin and copper alloys if the alloys are quenched in water; magnesium alloys and certain austenitic steels can be hardened through air cooling. A supersaturated solid solution is formed as a result of hardening.

Conclusion

Heat treatment, in bringing about various types of structural changes, permits a control over the structure of metals and alloys and makes possible the production of articles with the required combination of mechanical, physical, and chemical properties. This ability, together with the simplicity and inexpensiveness of the equipment used, has made heat treatment the most common industrial method for modifying properties of metallic materials.

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