



Heat Treating

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Overview

Heat treating, as the name implies, is a series of treatments in which heat is used to alter the properties of a metal or alloy. Because time at temperature is also important, heat treatment can be further defined as a series of time-temperature treatments. Heat treatments are used for a variety of purposes, the most important being to control the mechanical properties, especially hardness, ductility, strength, toughness, and internal stresses.

Hardness is the resistance of a material to plastic indentation. Hardness values are roughly proportional to the strength of a metal and can give an indication of the wear properties of a material. Hardness values can be useful during the materials selection process and for quality-control evaluations, but the values cannot be applied directly during the design of a part.

Ductility is the capability of a material to deform plastically without fracturing, and it is usually measured by the amount that a bar under tensile load will elongate before fracturing. The elongation is expressed as a percentage of the original length of the bar.

Strength is the ability of a material to withstand an applied force, and three types are commonly discussed. Elastic strength, referred to as the elastic limit, is strength before the material deforms permanently. The yield strength is the strength of a material before appreciable plastic deformation occurs. The ultimate tensile strength is the maximum strength that a metal exhibits during tensile deformation.

Toughness is the ability of a metal to absorb energy in the plastic range. Although there are a number of approaches for defining toughness, one of the oldest is to consider it as the total area under the stress-strain curve. This area is an indication of the amount of work per unit area that can be done without causing it to fail. Because toughness is the area under the stress-strain curve, it is a function of both strength and ductility.

Residual or locked-in stresses arise in components from many sources and, if left untreated, can lead to component distortion, stress concentration, and failure. One of the most common causes of residual stresses is nonuniform cooling from elevated temperatures. On cooling, the surface cools quickly and contracts, while the inner core remains hotter longer and cools more slowly, thus setting up residual stresses. Components are heated to a suitable temperature and held at temperature for a time long enough to reduce residual stresses and are then cooled slowly enough so that new residual stresses are not introduced.

There are many types of heat treatment processes, some of which are applied only to steels and others that are applied only to other alloys. Heat treatment processes can be classified into four general categories:

- Annealing (softening)
- Hardening
- Surface hardening
- Miscellaneous

Annealing

When a metal is cold worked (deformed at room temperature), the microstructure becomes severely distorted because of an increased dislocation density resulting from the deformation. Cold working is also referred to as work hardening or strain hardening. As a metal is cold worked, the strength and hardness increase while ductility decreases. Eventually, it is necessary to anneal the piece to allow further forming operations without the risk of breaking it. In addition, some metals are strengthened primarily by cold working. In this case, it is important that the metal not soften appreciably when placed in service.

Cold-worked materials with highly distorted microstructures are in a high-energy state and are thermodynamically unstable. Annealing is the heat treatment process that softens a metal that has been hardened by cold working. Annealing consists of three stages: recovery, recrystallization, and grain growth. Although a reduction in stored energy provides the driving force, annealing usually does not spontaneously occur at room temperature. Because the reduction in stored energy must occur by diffusion, the activation energy needed to start the diffusion process is normally insufficient at room temperature. Therefore, heating is necessary to provide the thermal activation energy needed to transform the material to a lower-energy state. As the internal lattice strains are relieved during annealing, the strength decreases while the ductility increases. It should be noted that some low-melting-point metals have recrystallization temperatures lower than room temperature and cannot be hardened by cold working. For example, lead, tin, and zinc have recrystallization temperatures below room temperature.

The three distinct processes that occur during annealing—recovery, recrystallization, and grain growth—are described as follows.

Recovery. During recovery, there is a rearrangement of internal defects, known as dislocations, into lower-energy configurations; however, the grain shape and orientation remain the same. There is also a significant reduction in residual stresses, but the strength and ductility are largely unaffected. Because there is a large decrease in residual stress during recovery, recovery-type processes are usually conducted to reduce residual stresses, often to prevent stress-corrosion cracking or minimize distortion. During stress-relief operations, the temperature and time are controlled so there is not a major reduction in strength or hardness.

Asm Heat Treating Guide

D. Yogi Goswami

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