

# Heat Treating of Non Ferrous Alloys

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**Abstract**—Non ferrous alloys are the most versatile engineering materials. The combination of physical properties such as strength, ductility, conductivity, corrosion resistance and machinability makes these suitable for a wide range of applications. These properties can be further enhanced with variations in composition and manufacturing processes. Present paper gives a clear idea about various strengthening processes of non ferrous alloys and prepares it as per the need of the user.

**Keywords**—hardening, heat treatment, properties, processes, grain structure, solid solution

## INTRODUCTION

The hardenability of a steel is broadly defined as the property which determines the depth and distribution of hardness induced by quenching. Hardenability is a characteristic determined by the following factors The hardenability is the depth and evenness of hardness of a steel upon quenching from austenite [1].

Heat treatment is an operation or combination of operations involving heating at a specific rate, soaking at a temperature for a period of time and cooling at some specified rate. The aim is to obtain a desired microstructure to achieve certain predetermined properties (physical, mechanical, magnetic or electrical) [3].

Heat treating is a group of industrial and metalworking used to alter the physical, and sometimes chemical, properties of a material. The most common application is metallurgical. Heat treatments are also used in the manufacture of many other materials, such as glass. Heat treatment involves the use of heating or chilling, normally to extreme temperatures, to achieve a desired result such as hardening or softening of a material. It is noteworthy that while the term heat treatment applies only to processes where the heating and cooling are done for the specific purpose of altering properties intentionally, heating and cooling often occur incidentally during other manufacturing processes such as hot forming or welding [4].

## OBJECTIVE

- To increase strength, harness and wear resistance
- To increase ductility and softness
- To increase toughness
- To obtain fine grain size
- To remove internal stresses induced by differential deformation by cold working, non-uniform cooling from high temperature during casting and welding
- To improve machineability
- To improve cutting properties of tool steels
- To improve surface properties
- To improve electrical properties
- To improve magnetic properties

## PHYSICAL PROCESS

Metallic materials consist of a microstructure of small crystals called 'grains'. The nature of the grains (i.e. grain size and composition) is one of the most effective factors that can determine the overall mechanical behavior of the metal. Heat treatment provides an efficient way to manipulate the properties of the metal by controlling the rate of diffusion and the rate of cooling within the microstructure. Heat treating is often used to alter the mechanical properties of an alloy, manipulating properties such as the hardness, strength, toughness, ductility, and elasticity [7].

There are two mechanisms that may change an alloy's properties during heat treatment. The martensite causes the crystals to deform intrinsically. The diffusion mechanism causes changes in the homogeneity of the alloy.

Non ferrous metals and alloys exhibit a martensite transformation when cooled quickly. When a metal is cooled very quickly, the insoluble atoms may not be able to migrate out of the solution in time. This is called a 'diffusionless transformation'. When the crystal matrix changes to its low temperature arrangement, the atoms of the solute become trapped within the lattice. The trapped atoms prevent the crystal matrix from completely changing into its low temperature allotrope, creating shearing stresses within the lattice. When some alloys are cooled quickly, such as steel, the martensite transformation hardens the metal, while in others, like aluminum, the alloy becomes softer [15].

### **Effect of Composition:**

The specific composition of an alloy system will usually have a great effect on the results of heat treating. If the percentage of each constituent is just right, the alloy will form a single, continuous microstructure upon cooling. Such a mixture is said to be eutectoid. However, If the percentage of the solutes varies from the eutectoid mixture, two or more different microstructures will usually form simultaneously. A hypoeutectoid solution contains less of the solute than the eutectoid mix, while a hypereutectoid solution contains more [20].

### **Effect of Time and Temperature:**

Proper heat treating requires precise control over temperature, time held at a certain temperature and cooling rate. Most heat treatments begin by heating an alloy beyond the upper transformation ( $A_3$ ) temperature. The alloy will usually be held at this temperature long enough for the heat to completely penetrate the alloy, thereby bringing it into a complete solid solution. Since a smaller grain size usually enhances mechanical properties, such as toughness, shear strength and tensile strength, these metals are often heated to a temperature that is just above the upper critical temperature, in order to prevent the grains of solution from growing too large. For instance, when steel is heated above the upper critical temperature, small grains of austenite form. These grow larger as temperature is increased. When cooled very quickly, during a martensite transformation, the austenite grain size directly affects the martensitic grain size. Larger grains have large grain-boundaries, which serve as weak spots in the structure. The grain size is usually controlled to reduce the probability of breakage.

The diffusion transformation is very time dependent. Cooling a metal will usually suppress the precipitation to a much lower temperature. Austenite, for example, usually only exists above the upper critical temperature. However, if the austenite is cooled quickly enough, the transformation may be suppressed for hundreds of degrees below the lower critical temperature. Such austenite is highly unstable and, if given enough time, will precipitate into various microstructures of ferrite and cementite. The cooling rate can be used to control the rate of grain growth or can even be used to produce partially martensitic microstructures. However, the martensite transformation is time-independent. If the alloy is cooled to the martensite transformation ( $M_s$ ) temperature before other microstructures can fully form, the transformation will usually occur at just under the speed of sound.

When austenite is cooled slow enough that a martensite transformation does not occur, the austenite grain size will have an effect on the rate of nucleation, but it is generally temperature and the rate of cooling that controls the grain size and microstructure. When austenite is cooled extremely slowly, it will form large ferrite crystals. This microstructure is referred to as "spheroidite." If cooled a little faster, then coarse pearlite will form. Even faster, and fine pearlite will form. If cooled even faster, bainite will form. Similarly, these microstructures will also form if cooled to a specific temperature and then held there for a certain time.

Most non-ferrous alloys are also heated in order to form a solution. Most often, these are then cooled very quickly to produce a martensite transformation, putting the solution into a supersaturated state. The alloy, being in a much softer state, may then be cold worked. This cold working increases the strength and hardness of the alloy, and the defects caused by plastic deformation tend to speed up precipitation, increasing the hardness beyond what is normal for the alloy. Even if not cold worked, the solutes in these alloys will usually precipitate, although the process may take much longer. Sometimes these metals are then heated to a temperature that is below the lower critical ( $A_1$ ) temperature, preventing recrystallization, in order to speed-up the precipitation [14].

## **TECHNIQUES**

### **Strain hardening**

The phenomenon where ductile metals become strong and hard when they are deformed plastically is called strain hardening (or) work hardening. The application of cold work, usually by rolling, forging or drawing operations, strengthens copper and its alloys, while strength, hardness and elastic modulus increase and ductility decreases during this process. The effect of cold work can be removed by annealing. Strain hardening is used for hardening/strengthening materials that are not responsive to heat treatment.

### **Solid solution hardening**

Solid solution hardening of copper is a common strengthening method. In this method a small amount of alloying elements such as zinc, aluminum, tin, nickel, silicon, beryllium etc. are added to the molten copper to completely dissolve them and to form a homogeneous microstructure (a single phase) upon solidification. This is because stress fields generated around the solute atoms

present in the substitutional sites interact with the stress fields of moving dislocations, thereby increasing the stress required for plastic deformation. Traditional Brasses and Bronzes fall into this category. It is to be noted that these alloys are not heat treatable.

### **Grain boundary hardening**

In a poly-crystalline metal, grain size has a tremendous influence on the mechanical properties. Because grains usually have varying crystallographic orientations, grain boundaries arise. While undergoing deformation, slip motion will take place. Grain boundaries act as an impediment to the dislocation motion for the following two reasons: (a) dislocation must change its direction of motion due to the differing orientation of grains and (b) discontinuity of slip planes one grain to another. The stress required to move a dislocation from one grain to another in order to plastically deform a material depends on the grain size. The average number of dislocations per grain decreases with average grain size. A lower number of dislocations per grain results in a lower dislocation 'pressure' building up at the grain boundaries. This makes it more difficult for dislocations to move into adjacent grains. This relationship is called the Hall-Petch equation.

### **Dual-phase hardening**

Bronze is usually a single phase alloy. Aluminium Bronze is a type of Bronze in which aluminium is the main alloying element added to copper, in contrast to standard Bronze (Cu and Sn) or Brass (Cu and Zn). A variety of aluminium Bronzes of differing compositions have found industrial use, with most ranging 5wt. % to 11wt. % aluminium. Other alloying agents such as iron, nickel, manganese, and silicon are also sometimes added to aluminium Bronzes. When adding aluminium above 10%, another phase forms. The second phase also contributes the strengthening of the alloy.

### **Precipitation hardening**

Precipitation hardening refers to a process where a supersaturated solid solution is heated at a low temperature for a period (aging) so as to allow the excess solute to precipitate out in the form of a second phase. This process is often used for Cu alloys containing Be. Precipitation hardening has several distinct advantages. Many combinations of ductility, impact resistance, hardness, conductivity and strength can be obtained by varying the heat treatment time and temperature. The Cu-Be alloy possesses a remarkable combination of properties such as tensile strength, electrical conductivity and corrosion resistance and wear resistance. They may be cast and hot or cold worked. Despite its excellent properties, it is high cost because of addition of Be. Moreover, it is a health hazardous material.

### **Order hardening**

When the atoms of a disordered solid solution arrange themselves in an orderly manner at a lower temperature ordered structure forms. Lattice strain develops due to the ordered nature of the structure and this strain contributes to the hardening and the strengthening of these alloys.

### **New approach of hardening**

The various new approaches of hardening of copper and its alloys are (a) Dispersion hardening/Metal matrix composites (b) Surface modification and (c) Spinodal decomposition [17].

### **Dispersion hardening**

Conventional strengthening mechanisms, such as cold working and precipitation hardening, are ineffective at high temperature, owing to the effects of recrystallization, and particle coarsening and dissolution respectively. Applications require materials with a high thermal conductivity in combination with high elevated temperature strength in oxygen or hydrogen rich environments, for which copper based alloys are natural choices. In addition to its high thermal conductivity, copper has the advantage of a low elastic modulus, which minimizes thermal stresses in actively cooled structures. Copper also offers good machinability, good formability and, for fusion applications, it is attractive for its excellent resistance to neutron

displacement damage. However, copper requires a considerable improvement in strength to meet the design requirements for high temperature applications. A substantial amount of recent work has emphasized particle and fiber strengthening of copper composites, with up to 40 vol. % of reinforcing phase. The dispersion hardening is also called Metal Matrix Composites in the recent literatures. Copper based composites appear to be a promising material for engineering applications due to their excellent thermo-physical properties coupled with better high temperature mechanical properties as compared to pure copper and its alloys. In the copper based metal matrix composite, SiCp is widely used as reinforcing element to the matrix to enhance their various properties.

Further, the metal matrix composites, in which hard ceramic particles are dispersed in a relatively ductile matrix, exhibit a superior combination of properties such as high elastic modulus, high specific strength, desirable co-efficient of thermal expansion, high temperature resistance and wear resistance. Metal matrix composites are being increasingly used for structural, automobile and aerospace industry, sporting goods and general engineering industries. Copper matrix composites have the potential for use as wear resistance and heat resistant materials; brush and torch nozzle materials and for applications in electrical sliding contacts such as those in homopolar machines and railway overhead current collector systems where high electrical/thermal conductivity and good wear resistant properties are needed.

Dispersion particles such as oxides, carbides and borides, which are insoluble in the copper matrix and thermally stable at high temperature, are being increasingly used as the reinforcement phase.

### Surface modification

In the surface modification process, hard-facing is a commonly employed method to improve surface properties. An alloy is homogeneously deposited onto the surface of a soft material usually by welding, with the purpose of increasing hardness and wear resistance without significant loss in ductility and toughness of the substrate.

A wide variety of hard-facing alloys is commercially available for protection against wear.

Spray forming or spray atomization and deposition is a newly emerging science and technology in the field of materials development and production in recent years. Spray forming technology, as an advanced processing, combined the advantages of rapid solidification, semi-solid processing and near net shape processing. Spray forming attracted great attention lately because it would bring about a distinct improvement in microstructure and properties of materials. It can be used for developing new types of materials and for improving microstructure and properties of commercial materials. The spray formed Cu-15Ni-8Sn alloy is an example of developing new types of materials, in which Ni and Sn are sprayed over the Cu substrate. This alloy is of particular interest because high strength can be

achieved with fairly high conductivity and good corrosion resistance. The alloy may replace Cu-Be alloys in highly demanding applications in electronic equipment, e.g. electrical switchgear, spring, contacts, connectors etc.

### Spinodal Decomposition

The theory of spinodal decomposition as developed by Cahn–Hilliard has been discussed in detail by several authors. The principal concept of the theory is described below.

A pair of partially miscible solids, i.e. solids that do not mix in all proportions at all temperatures, show a miscibility gap in the temperature-composition diagram. Figure 1.1 (Favvas et al., 2008) shows a phase diagram with a miscibility gap (lower frame) and a diagram of the free energy change (upper frame). Line (1) is the phase boundary. Above this line the two solids are miscible and the system is stable (region-s). Below this line there is a meta-stable region (m). Within that region (point a to b) the system is stable (where,  $\partial^2\Delta G/\partial x_B^2 > 0$ ;  $\Delta G$  = Free energy of mixing;  $x_B$  = Concentration of element B). Line (2) is the spinodal. Below this line, the system is unstable (region-u) (where,  $\partial^2\Delta G/\partial x_B^2 < 0$ ). With the spinodal region (u), the unstable phase will decompose into solute rich and solute lean regions. This process is called spinodal decomposition. The spinodal decomposition depends on the temperature. For example above  $T_c$  (Figure 1.1) the spinodal decomposition will not take place.

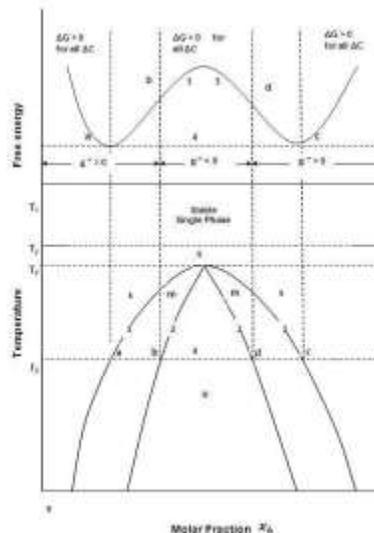


Figure 1.1 Phase diagram with a miscibility gap (Favvas et al., 2008)

## CONCLUSION

The Hall-Petch method, or grain boundary strengthening, is to obtain small grains. Smaller grains increase the likelihood of dislocations running into grain boundaries after shorter distances, which are very strong dislocation barriers. In general, smaller grain size will make the material harder. When the grain size approach sub-micron sizes, some materials may however become softer. This is simply an effect of another deformation mechanism that becomes easier, e.g. grain boundary sliding. At this point, all dislocation related hardening mechanisms become irrelevant.

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