

Lecture 36 Heat treatment

Contents:

Preamble

Martensite

Isothermal decomposition of austenite

Continuous cooling

Full and process annealing

Key words: surface hardening, microstructure, vapour deposition, coating, spray deposition, heat treatment

Preamble

Heat treatment is another finishing operation which is done on the finished or semi-finished product to create desired properties by altering number, size and distribution of phases through heating and cooling. Steels are heated to a single phase region to form austenite and then cooled to form a particular structure. By changing the rate of cooling, different combinations of phases with different morphologies can be generated in all types of steel to obtain the desired property.

Martensite

Martensite is a metastable phase. It consists of a supersaturated interstitial solid solution of carbon in body centered tetragonal iron. Steel is heated to a temperature within the austenitic region and is then quenched. The temperature at which austenite to martensite transformation begins is called martensite start M_s , and the temperature at which transformation finishes is called martensite finish M_f temperature. Increase in weight percent carbon increases M_s temperature for Fe-C alloys.

The hardness and strength of Fe-C martensite increase with increase in carbon content. However, ductility and toughness decrease with increase in carbon content. Most martensitic plain carbon steels are tempered at 723°C , i.e. below the transformation temperature.

Isothermal decomposition of austenite

Let us consider isothermal decomposition of austenite. Steel in the austenitic condition is rapidly quenched to a particular temperature and then allowed to transform at that temperature. Depending on the quenching temperature, different phases can be formed. The figure 36.1 shows isothermal transformation diagram for a eutectoid plain carbon steel showing formation of different phases.

It must be emphasized that very slow cooling of steel from austenitic region will produce ferrite and cementite. However such small cooling rates are not practically kept.

Figure 36.1 Isothermal transformations for an eutectoid plain carbon steel

In the figure the lines a,b,c,d,e,f and g indicates the cooling rates. M_s and M_{90} are the temperatures to begin and 90% completion of martensitic transformation. Line a denotes a very fast cooling rate which will transform all austenite into martensite. The cooling rate and the type of transformation are given in the table

| Line | Type of transformation from austenite |
|------|--|
| a | All martensite |
| b | All coarse pearlite |
| c | All fine pearlite |
| d | Approximately 50% fine pearlite and 50% martensite |
| e | All upper bainite |
| f | Approximately 50% lower bainite and 50% martensite |
| g | All lower bainite. |

One notes from the figure that heat treatment of steels presents large opportunity to manipulate the number and proportion of different phases by predetermined cooling rates. Similar types of diagrams are available for hypo- and hypereutectoid steels. Any type of mechanical property in most of the steels can be obtained by designing suitable cooling rates.

Continuous cooling

In industrial heat treating operations, steel is not isothermally transformed at a temperature above the martensite start temperature but is continuously cooled from austenitic temperature to the room temperature. In continuous cooling of a plain carbon steel, austenite to pearlite transformation occurs over a range of temperatures rather than at a single isothermal temperature. Figure 36.2 compares transformation during continuous cooling with that at isothermal cooling. Note the following

Figure 36.2: comparison of continuous cooling with isothermal cooling for heat treatment of steel

a) In continuous cooling curve there are no transformation lines below about 450°C , for the austenite to pearlite transformation.

2. The start and finish transformation line is shifted to slightly longer times and to slightly lower temperatures in relation to isothermal diagrams.

Figure 36.3 shows different rates of cooling of eutectoid plain carbon steels cooled continuously from austenitic region to room temperature. It is assumed that there are no temperature gradients in the carbon steels in the austenitic region. This requires either a thin section or section has been soaked for a sufficient long time.

Figure 36.3 Continuous cooling of eutectoid plain carbon steels. The cooling rates are shown with different colors

| | |
|------------------|--|
| Cooling curve x: | very slow cooling and will result in coarse pearlite |
| Cooling curve y: | Slow cooling in air and fine pearlite will form. This heat treatment procedure is called normalizing. |
| Cooling curve Z: | Steel is quenched in oil. This will result in martensite and pearlite and is called split transformation |
| Cooling curve K: | Critical cooling rate at which a martensite is produced when steel is quenched in water. |

What is important is to appreciate that the system possesses unique possibility to produce materials with different number, and proportion of phases.

There are other heat treatment procedures like martempering and austempering.

Austempering is an isothermal treatment aimed to produce a bainite structure in some plain carbon steels. The steel is first austenitized and then quenched in a molten salt bath kept at temperature above the M_s temperature. Steel is held at that temperature to allow austenite to transform to bainite.

Advantages of austempering:

- I. Decrease in distortion
- II. Improved ductility and impact resistance.

Martempering is a modified quenching procedure used for steels to minimize distortion and cracking that may develop during uneven cooling of the heat treated material. The martensite process consists of austenitizing steel and then quenching in hot oil or molten salt at a temperature just slightly above (or slightly below) the M_s temperature. In the hot quenchant steel is soaked to attain the uniform temperature which is then followed by cooling at a moderate rate to room temperature to prevent temperature gradient.

Full and process annealing

Two most common types of annealing treatments that are applied to commercial plain carbon steels are a) full annealing and b) process annealing. Fig 36.4 illustrates the full annealing and process annealing.

Figure 36.4: Temperature ranges for annealing of plain carbon steels

In full annealing hypo eutectoid and eutectoid steels are heated to a temperature 40°C above the austenitic-ferrite boundary as shown in the figure. The steel is soaked and then cooled in the furnace. The hypereutectoid steels are heated between 40°C above the austenitic region

Process annealing is used to relieve internal stresses induced due to cold working of metal. It is normally applied to hypo eutectoid steels by heating to a temperature in between 550°C to 650°C .

Normalising

Steel is heated to austenitic temperature and then cooled in air. Purpose is

- To refine grain structure
- To increase strength of steel
- To reduce segregation in castings or forgings

Temperature regions are shown in the figure 36.4. In this lecture a very brief account of heat treatment procedure is discussed with the aim to understand steelmaking from the product-process integration point of view. Detailed discussions on heat treatment procedures can be found in any heat treatment book

References:

W.F. Smith: Principles of materials science and engineering

R.C. Sharma: Phase transformation in steel