Part VI. : Heat treatment
Module 5 : Some standard heat treatments

5 Some standard heat treatments

5.1 Annealing

Consider the TTT diagram as shown in Fig. 9 and the cooling curves imposed on the TTT diagram. The curve 1, where the cooling is very slow is called annealing; annealing, in this case, results in coarse pearlite, as indicated.

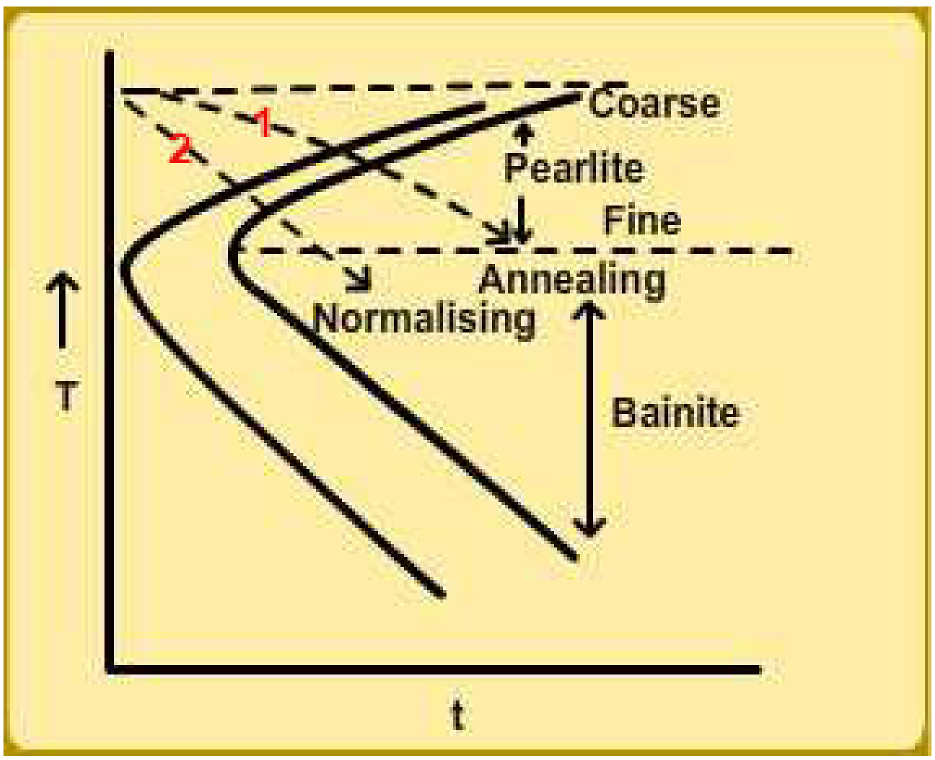

Figure 9: Annealing and normalising.

Annealing is, in general, an operation that results in softening of the given material; such softening might be a result of annihilation of defects, recrystallisation (if the material is sufficiently cold worked), and growth of grains (and, in general, coarser microstructural features). When annealing process removes the stresses in a cold worked material, such a heat treatment process is known as stress relieving operation.

Normalising is a type of annealing with relatively faster cooling rates; normalising, in steels, as shown, leads to fine pearlite.

5.2 Homogenising, solutionising and austenitising

Homogenising is a heat treatment process in which an alloy is taken to an elevated temperature and held at that temperature for relatively long times so that chemical composition is homogeneous everywhere in the workpiece.

Taking a two phase alloy to a higher temperature (above solvus) and holding it at that temperature for longer times so that the second phase is completely dissolved is known as solution treating; in this process also the microstructure is made homogeneous chemically by the dissolution of precipitates etc.

In steels, heating above the transformation temperature and holding it at the higher temperature for longer times so that the material completely transforms to the austenite phase, is known as austenitizing.

5.3 Age hardening

Consider a schematic phase diagram of an age hardenable alloy as shown 10. The heat treatment process of cooling of the system from the single phase *alpha* region to the two phase region as shown and holding at the two phase region for long times is known as age hardening; this is because, with increasing times, the hardness of the system changes as shown in Fig. 11. As we have seen in Part IV, such hardening behaviour is due to precipitation; the decrease in strength after peak aging is a result of coarsening of precipitates (to be discussed in the next part, namely, Part VII).

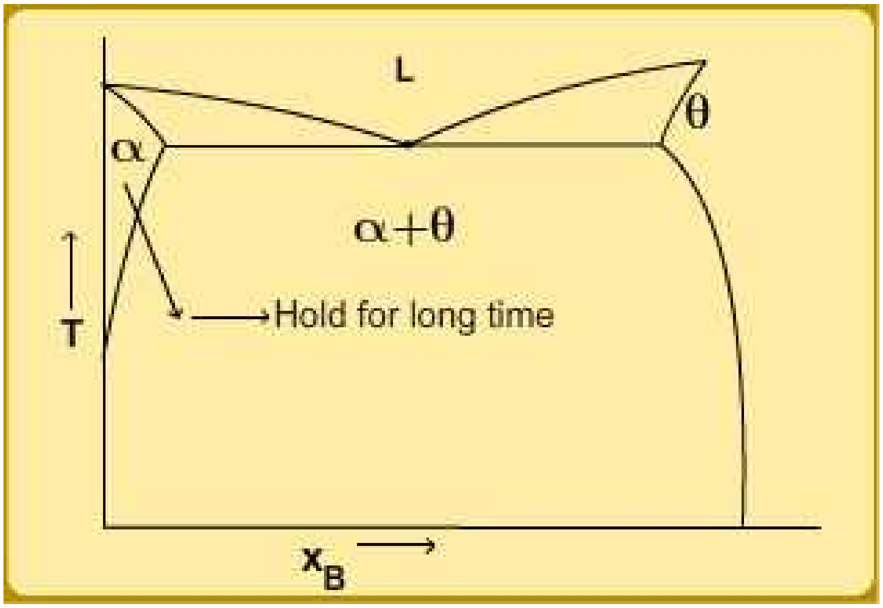

Figure 10: Phase diagram for an age-hardenable alloy.

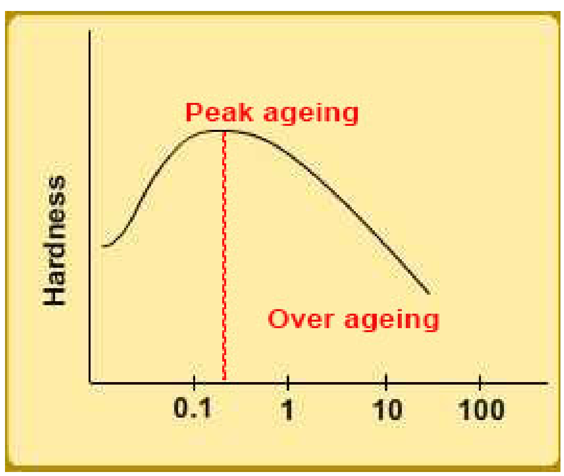

Figure 11: Aging.

5.4 Tempering

Tempering is a heat treatment process in which the hardness of a hardened alloy is reduced by the appropriate heat treatment process; for example, a steel hardened by the formation of martensite formation can be tempered using the heat treatment process shown in Fig. 12.

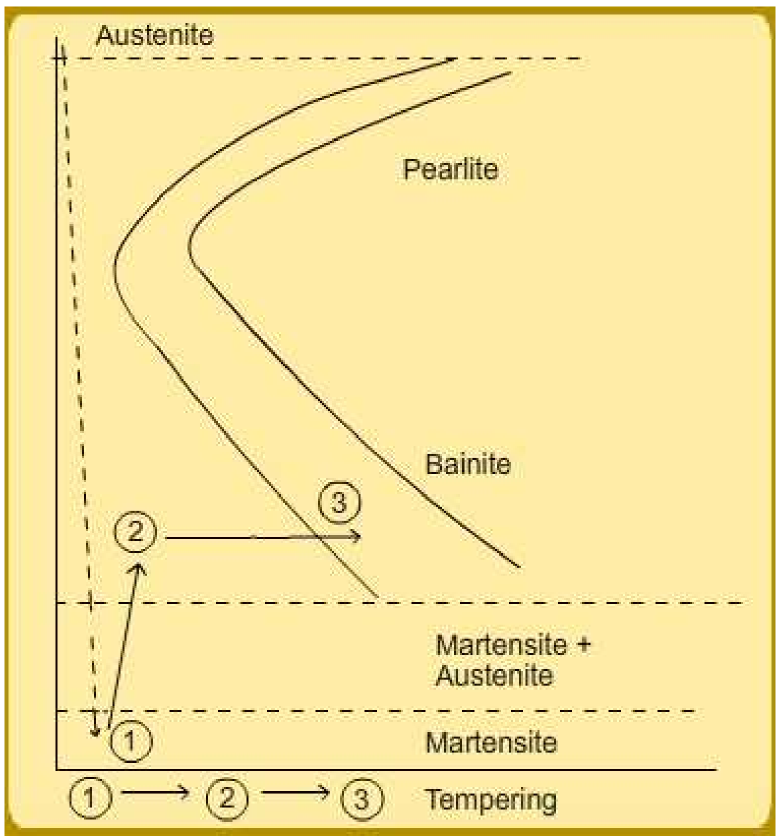

Figure 12: Tempering.

In steels the process of forming bainite using a heat treatment as shown in Fig. 13 is known as austempering.

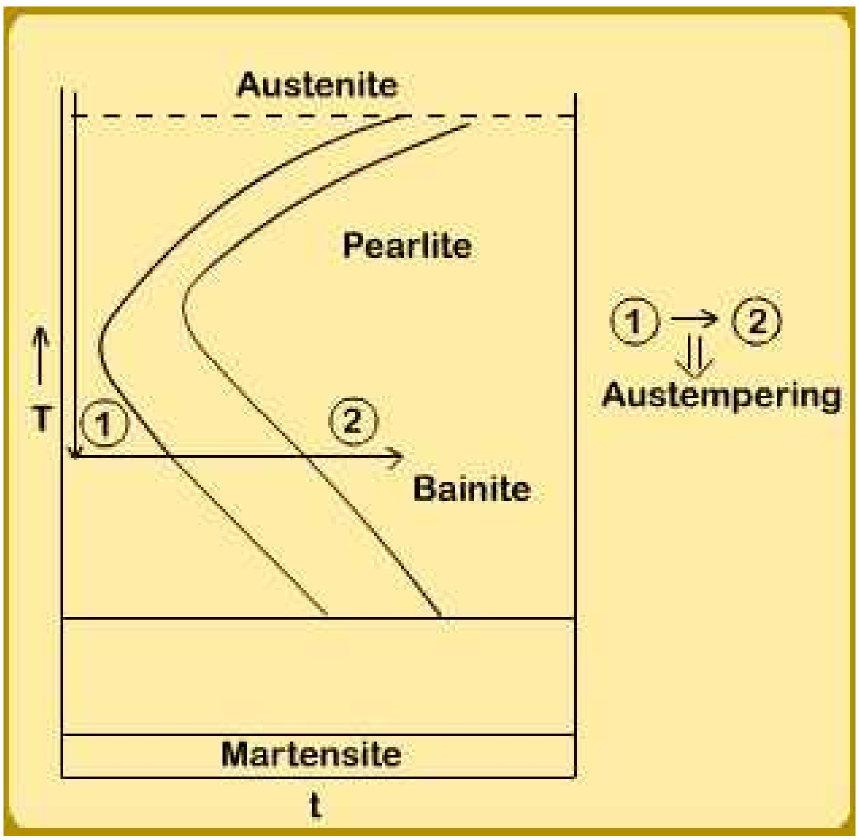

Figure 13: Austempering.

Similarly, a steel sample can be quenched past the nose of the C curve and held just above the martensitic start temperature till the entire sample attains an uniform temperature and then air cooling to achieve tempered martensites. This process is known as martempering.

5.5 Heat treatments for mass diffusion

There are several heat treatments which are carried out to achieve controlled mass diffusion. Here we list a few cases.

There are several processes in which by diffusing carbon or nitrogen into steels (along with appropriate heat treatments, if need be) can be used to obtain hardened surfaces. These processes are carburizing, nitriding, carbonitriding, cyaniding, and so on.

The opposite process of removal of carbon atoms from the surface of a steel sample is known as decarburizing.

There are processes similar to carburizing which is used in the semi-conductor industry to carry out doping. Similarly, an effect similar to that of decarburization takes place in alclad (duralumin with pure aluminium layer on top) due to the diffusion of copper from duralumin to pure aluminium layer.

5.6 Tutorial problems and questions

1. Consider a carbon steel which is kept at 950° for about 8 hours. The diffusivity of carbon in steel at this temperature is about 10^{-11} m^2/s. What is the depth to which considerable decarburization would have taken place?

2. If it takes about an hour to achieve the required boron doping concentration at a depth of 2 microns in silicon, at the same temperature, how long will it take to achieve the same boron concentration at a depth of 4 microns?

3. Consider a cast specimen with an dendritic arm spacing of about 100 microns. The spaces between these dendritic arms are enriched in solutes while the dendrite itself is nearly pure. This type of chemical segregation is known as coring. If at high temperatures, the typical

diffusivities are of the order 10^{-13} m^{2}s^{-1}, what is the time required for the homogenisation heat treatment?

5.7 Solutions to the tutorial

1. From the given data, the characteristic time associated with diffusion is found to be $(100 \times 10^{-6})^2/10^{-13} = 10^5$ seconds; this roughly corresponds to about 28 hours or so of homogenisation.

2. Given the diffusivity and time; hence, the depth is given by $\sqrt{(Dt)} =$ 0.54 mm;

3. The ratios of time will be proportional to the ratios of the squares of distances. Hence, it will take about 4 hours.

References

[1] H E Boyer and J L Dossett, Practical heat treating, ASM International, 2006.

[2] David A. Porter, Kenneth E. Easterling, and Mohamed Y. Sherif, Phase transformations in metals and alloys, CRC press, Third edition, 2009.

[3] D R Poirier and G H Gieger, Transport phenomena in materials processing, TMS 1994.