UNIT II

HEAT TREATMENT

Constitution of alloys - Definition - full annealing, stress relief, recrystallisation and spheroidising - normalising, hardening and tempering of steel. Isothermal transformation diagrams - cooling curves superimposed on I.T. diagram CCR - Hardenability, Jominy and quench test - Austempering, martempering - case hardening, carburising, Nitriding, cyaniding, carbo-nitriding - Flame and induction hardening - Vacuum and plasma hardening.

(Reference Material Science and Metallurgy - Pearson - V.C.Jindal, Atish Mozumder - Pg. 235 - Parashivamoorthy K.I - Pg. 167)

INTRODUCTION

Most of the engineering properties of metals and alloys are related to their structure.

Varying the relative properties of microconstituents can change the mechanical properties.

In practice, change in mechanical properties can be achieved by a process called heat treatment.

Heat treatment can be defined as a heating and cooling operation applied to metals and alloys in solid state so as to obtain the desired properties.

PURPOSES OF HEAT TREATMENT

- Improvement in ductility
- Relieving internal stress
- Refinement of grain
- Increasing the hardness
- Improvement in machinability
- Alteration in magnetic and electrical properties.
- Improvement in toughness.

Heat Treament Processes

1. Annealing
2. Surface hardening
3. Spheroidizing
4. Normalizing
5. Hardening
6. Tempering.

In the process of annealing, the steel is exposed to an elevated temperature and soaked at this temperature for some time and then very slowly cooled so as to relieve stresses, to increase ductility and toughness and to produce desired micro-structure.

The purpose of annealing are specified as follows:

1. To improve mechanical properties
2. To improve machinability
3. To restore ductility, particularly after the steel has been subjected to cold working.
4. To remove or minimize segregation of the essential constituents of steel.
5. To alter the microstructure to make it suitable for hardening.
6. To relieve internal stresses.

The process of annealing is of the following two types:

FULL ANNEALING –

The main objective of full annealing is to soften the metal, to refine its grain structure, to relieve the stresses and to remove gases trapped in the metal.

This process consist of heating the steel 30°C to 50°C above the upper critical temperature for hypoeutectoid steel and by the same temperature above the lower critical temperature for hyper-eutectoid steels.

The steel is then held at this temperature for sometime to enable the internal changes to take place.

The time allowed is approximately 3 to 4 minutes for each millimetre of thickness of the longest section, and then slowly cooled in the furnace.

The rate of cooling varies from 30°C to 200°C per hour, depending upon the composition of steel.

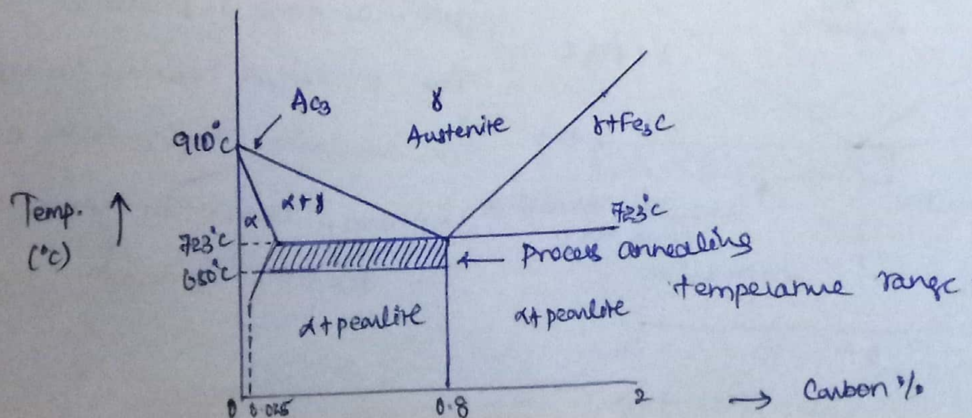
Also, full annealing process removes all structural imperfections by complete recrystallization.

PROCESS ANNEALING :-

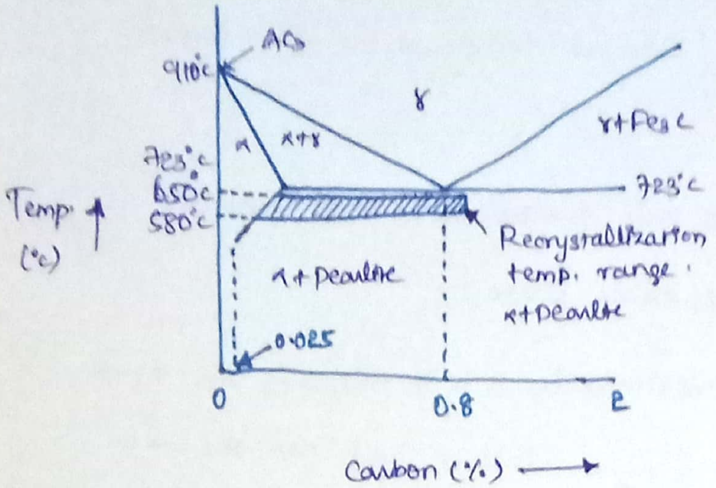
Process annealing is usually carried out to remove the effects of cold working and to soften the steel.

Process annealing consists of heating steel uniformly to a temperature of 650°C - 723°C. and holding at that temperature for sufficient time, followed by slow cooling.

This process is very useful for mild steel, low carbon steel for removing cold working effects.



Recrystallization or Stress-relieving Annealing :-



This process is used to relieve internal stress which develops during different operations like welding, solidification of casting, machining, etc.

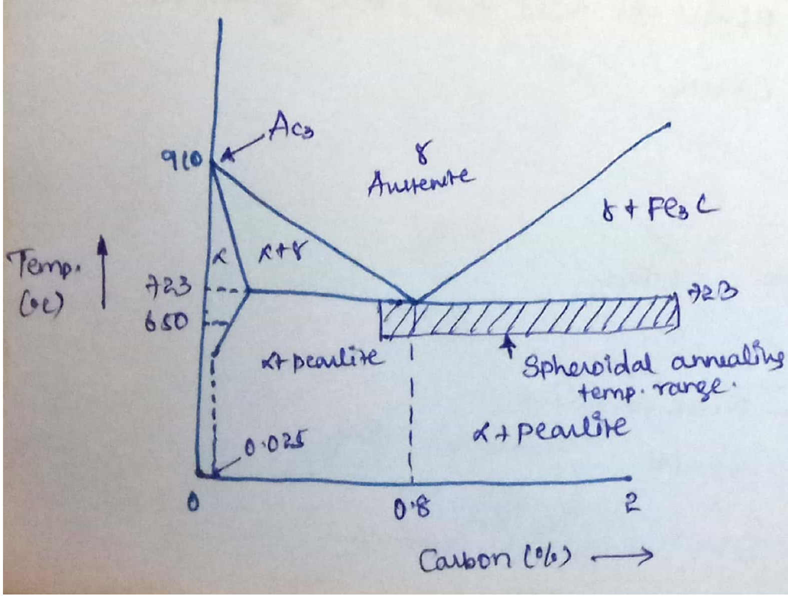
This process of recrystallization annealing consists of heating steel uniformly to a temperature 50°c-80°c below 723°c as shown in figure; and holding at this temperature for sufficient time followed by slow cooling.

Uniform cooling is most important as non-uniform cooling results in the development of internal stress.

Recrystallization or stress-relieving annealing is widely used for annealing steel wires, sheets, etc.

It can be used for both ferrous and non-ferrous metals and alloys.

Spheroidal Annealing or Spheroidising :-



In Spheroidal Annealing, graphite with iron in the granular form is produced. The prolonged heating causes the cementite to coalesce into spheres, completely destroying the pearlitic formation.

The actual structure is a matrix of ferrite with Fe_3C in the form of spheroidal globules. The heat treatment that follows after machining should be done easily.

This process is usually applied to high carbon steel which is difficult to machine.

The process consist of heating steel between 650°C and 723°C, holding at this temperature and then cooling very slowly.

The rate of cooling in furnace is 25°C - 30°C per hour.

Diffusion Annealing

- In this process steel is heated uniformly and the component is held at a temperature between 1000°C and 1200°C and then cooled very slowly in order to remove the heterogeneity in composition of heavy castings.

During this, the homogeneous structure appear. Diffusion annealing process is followed by full annealing.

Normalizing

- It is done on steels for grain refinement and improvement in mechanical properties.

- Hardness and strength of steels obtained after normalizing process are higher than those obtained by annealing process.

Normalizing temperatures are higher than annealing and hardening temperatures of steels.

For hypoeutectoid steels, normalizing temperature is above A_3 and for hypereutectoid steels, normalizing temperature lies between A_{c_1} and A_{cm}, Normalizing is done on cast or forged products.

The process of normalizing is suggested for manufacturing operations such as hot rolling and forging

This is useful in refining coarse-grained structure in castings and removing internal stresses in forgings.

Hardening

A heat treatment process that produces a microstructure, which is predominantly a martensite is known as hardening.

Steel is heated to 30-50°C above A_{c3}, temperature for hypoeutectoid steels and 30-50°C above A_{c1}, temperature for hypereutectoid steels, holding for sometime at that temperature and then quenching in water, oil or salt bath in the hardening process.

On quenching, Carbon is trapped in the crystal structure to make martensite.

During quenching, the outer surface of the component cools faster than the inner region, as a result tensile stresses are developed on the surface of steel part and compressive stresses are developed in the inner region of steel part.

So, residual stresses are developed after heating process and at the same time ductility is reduced and brittleness is greatly increased rendering the part useless for any practical use:

Therefore, brittleness and residual stresses are reduced by a subsequent process called tempering.

Hardening process is carried out on cutting tools, machine parts, alloy steels, high-carbon steels and high-speed steels to produce desired hardness for cutting operation or for wear resistance.

Steels with low carbon % do not respond to hardening process, therefore, minimum 0.5 % carbon must be present in the steel for the production of martensitic structure.

Following factors must be considered for effective hardening of the steels:

1. Carbon % in steel.
2. Heating rate and time of heating.
3. Quenching medium and quenching rate.
4. Size of the machine part.
5. Surface conditions.

Tempering

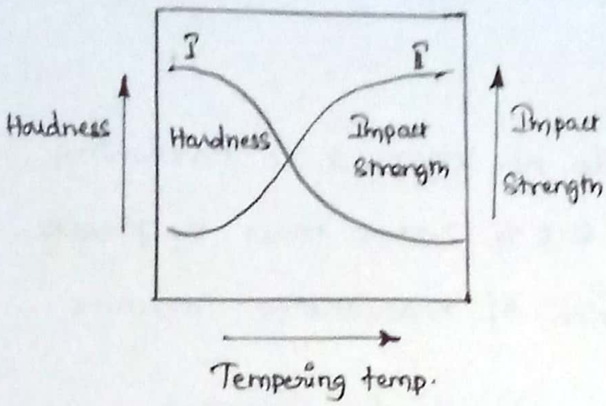
After quench hardening, steel becomes brittle. Moreover, quench cracks are developed and residual stresses due to warping are induced in steel.

To remove all these defects, hardening is always followed by tempering.

Tempering is a subcritical heat treatment process used to improve the toughness of the hardened steels.

Tempering temperatures are less than the lower critical temperature, but proper tempering temperature depends on the composition of steels and mechanical properties desired.

The following figure shows the variation of impact strength and hardness on the variation of tempering temperature.



In the tempering process, the article is heated in a furnace to a desired temperature, soaked for 2h and slowly cooled in air.

If the tempering is performed above 300°C, the residual stresses are completely removed. There are generally three tempering temperature ranges as follows:

1. Low tempering temperature : 200°C
2. Medium tempering temperature : 175 - 275°C
3. High tempering temperatures : 275 - 375°C

A shock-resisting steel should possess adequate toughness, which is provided by the tempering process after hardening.

Hardenability

"The ease with which a steel will transform to hardened structure on quenching is called hardenability."

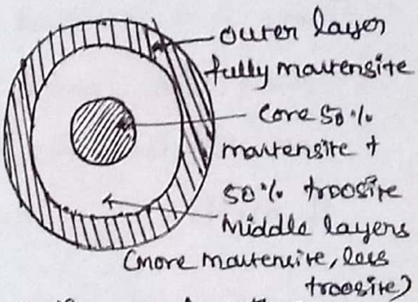
"Ability of a steel to harden (by forming martensite) throughout its cross section without having to resort to drastic quenching".

For a steel which is hardenable, a letter H is added to its designation.

That is, the steel is hardenable to provide more strength and wear resistance.

The materials, which have a lower critical cooling rate have higher hardenability and the materials, which have a higher critical cooling rate have lower hardenability.

When a steel piece is water quenched, if the cooling rate at the core of the piece is more than the critical cooling rate, then whole C.S of the piece will transform into martensitic structure.



Cooling rate less than critical cooling rate.

But if the cooling rate is less than the critical cooling rate, then the work is hardened upto a certain depth from the surface towards the core, the outer surface is transformed into martensite but the core contains martensite plus troosite structure and the middle layers with less percentage of troosite and more percentage of martensite as shown in figure.

Steels alloyed with elements like Mg, Cr, Mo and B have lower critical cooling rate, but addition of cobalt raises the critical cooling rate.

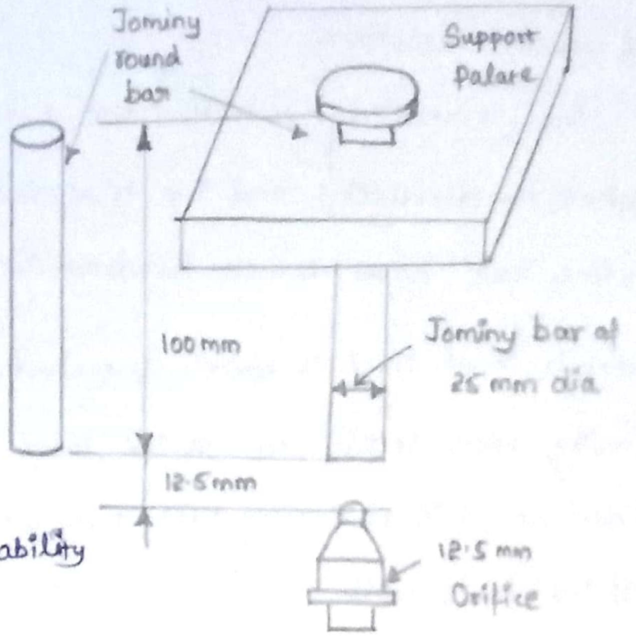
Grain size also affects the hardenability of steels. Larger grain size increases the hardenability or the depth of hardened layer and can be increased by two times by controlling the grain size.

A steel, which is highly hardenable will retain larger hardness values for a relatively longer distances from the outer surface.

Jominy End-Quench Tests

When Steel is quenched, the Cooling rate decreases from the Surface to the interior and the hardness is highest at the Surface and lowest in the central portion.

There is a Standard test called the Jominy end-quench test to determine the hardenability of Steel.



JOMINY END-QUENCH FOR EUTECTOID STEEL

In this test, a round bar of a Specified Size is heated to form Austenite and is then end quenched with water Stream of Specified flow rate and pressure as shown in figure.

Hardness values along the cooling rate gradient are determined on a Rockwell hardness tester and hardenability curve is plotted.

The quenched end is Cooled very fast and therefore, has the maximum possible hardness for the particular carbon content of the Specimen.

Hence, it follows that the Surface of the bar is hardened so that on the Surface martensite Structure is obtained. The hardness will decrease towards the centre of the Section. The centre will remain Soft and ductile.

Critical Temperatures :-

It is the temp. at which the phase changes occur during heating and Cooling in an equilibrium diagram.

CRITICAL TEMP. OF IRON- IRON CARBIDE EQUILIBRIUM DIAGRAM

Sl. No.	Symbols of Critical temp.	Temperature (°c)	Significance during heating
1.	A_0 (Curie temp. for cementite)	210°c	
2.	A_1 (Lower Critical temperature)	727° c	
3.	A_2 (curie temp. for ferrite)	768°c	
4.	A_3 Critical temp. for hypo-eutectoid steels)	727°c to 910°c	
5.	A_{cm} Critical temp. for hyper-eutectoid steels)	727°c to 1147° c	
6.	A_4 (upper critical temp.)	1400°c to 1492°c	

Martempering

It is also known as Stepped quenching.

In this process, steel is first heated to a hardening temp., then it is quenched in salt bath, the temperature of which is maintained constant, slightly above the point where martensite starts forming.

The component is held in hot salt bath until it reaches the temperature of salt bath for sufficient time.

Now the component is removed from salt bath and cooled in air.

During this second step of cooling, austenite gets transformed into martensite.

In this process, the outer surface is fully transformed into martensite, but the inner region retains some austenite, i.e toughness of inner portion is improved.

Following are the main advantages of martempering,

1. Less warping because of simultaneous transformation in all regions of the article.
2. Less danger of quenching cracks, because there is no water quenching; there is salt bath quenching, which is at a much higher temperature than room temperature.

Austempering (or) Isothermal Quenching.

Heating Source :-

Heating of material must be carried out uniformly and in controlled atmosphere. The heating of components can be done in any one of the following mediums:

(i) **Air:-**

Leads to non-uniform heating - slow process - leads to oxidation & decarburisation at above 850°c. - can be prevented by using controlled atmosphere, covering with cast iron chips, coating of boric acid, anti-scaling compounds, etc...

(ii) **Oil :-**

Provide uniform and rapid heating of material. But cannot be used above 200°c.

(iii) Salt bath :-

For temperature above 200°c.