

Heat treatment processIntroduction

The term of heat treatment is used to describe a process involving controlled heating and cooling of a metal or alloy in the solid state in order to change its microstructure and its properties.

Stages of heat treatments:

A heat treatment process consists of following stages

1) Heating:

Steel is heated to austenizing temperature, at this temperature previous structure of steel is converted into austenite.

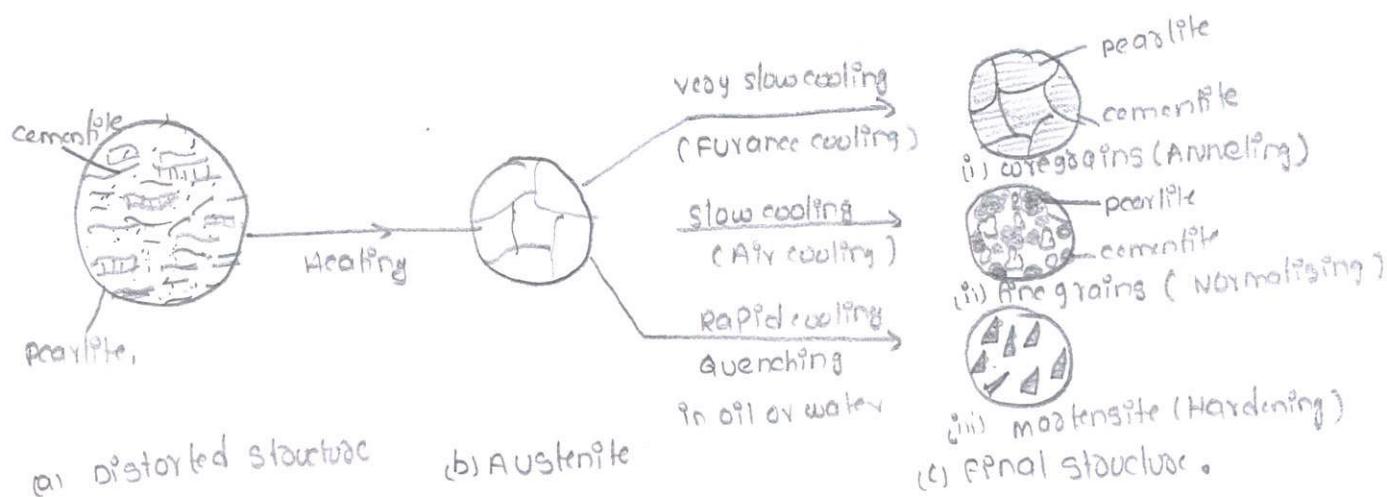
2) Soaking:

Steel is held at austenizing temperature to obtain homogenous austenite throughout the cross section.

3) Cooling:

Steel from austenite structure is cooled to room temperature at different cooling rates. The cooling rates depends upon the properties required.

→ Steel after cooling may or may not be reheated to a temperature below lower critical point and cooled again.



Purpose of heat treatments

Heat treatment is a major technic to obtain desired properties.

The intended purpos may be

- (1) relieving internal stresses softening for further p-formation.
- (2) refining the grain size to improve mechanical properties
- (3) improving the machinability
- (4) altering the surface conditions and increasing the corrosion and wear resistance.

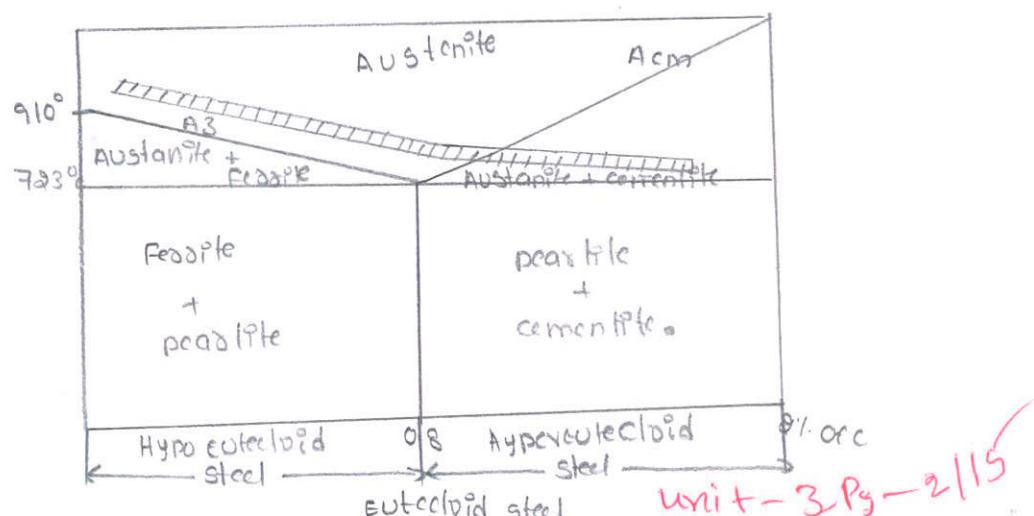
Annealing:

Annealing involves heating the steel to a suitable temperature and slow cooling in the furnace. As a result of slow cooling steel acquires a equilibrium structure. It causes softing of steel with an increase of ductility and relieving of residual stresses.

Different types of annealing processes are employed for different purposes. The important annealing processes are given below.

i) Full annealing:

Full annealing consists in heating the steel to a transformation range holding it at that temperature for considerable time, and then slowly cooling with in the furnace. The annealing temperature depends on the carbon constant in the steel. the steel with less than 0.8 percent carbon. i.e. hypoeutectoid steel is heated 30 to 50°C above A₃ point and it is held there for sufficient time for stabilising the austenite structure.



Annealing temperatures:

<u>Type of steel</u>	<u>carbon content</u>	<u>Annealing temperature °C</u>
1) Dead mild steel	less than 0.2	875 - 925
2) Mild steel	0.12 - 0.25	840 - 870
3) Medium carbon steel	0.25 - 0.5	815 - 840
4) High carbon steel	0.5 - 0.9	780 - 810
	0.9 - 1.3	760 - 780

Purpose of Full annealing:

The purpose of full annealing may be

- to soften the steel
- to define the grains
- to relieve the internal stress
- to improve electrical and magnetic properties
- to improve machinability
- to reduce the hardness.
- To improve the ductility.

Microstructures of Annealed steel:Types of steel

1. Hypoeutectoid steel
2. Eutectoid steel
3. Hypereutectoid steel

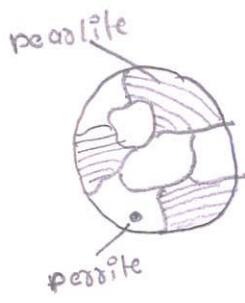
Microstructure

Ferrite + pearlite

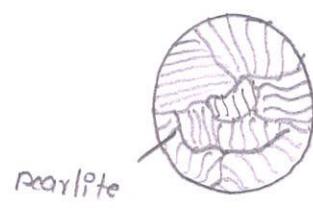
pearlite

pearlite + cementite

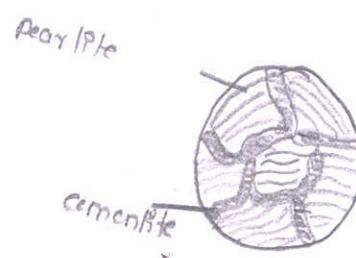
These microstructures are shown below.



(a) Hypoeutectoid



(b) Eutectoid



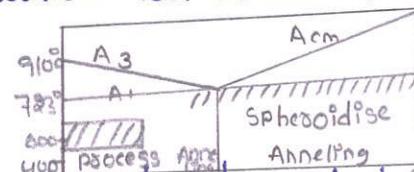
(c) Hypereutectoid

process Annealing:

→ process or sub-critical annealing is used during cold working process with low carbon ($C < 0.3\%$) steel

→ process annealing relieve the strain hardening for further working

→ The process annealing consists of heating the steel to a temperature about $80\text{--}100^\circ\text{C}$ below A_1 temperature and holding at this temperature for certain time, and then allowing the steel to cool in air.



→ The process annealing is used extensively in the treatment of sheet and wires, it is also applied to cold worked steel in order to restore ductility and softness.

Spheroidise annealing:

→ Spheroidise annealing is intended to increase the machinability of carbon and alloy steels.

→ It produce nodular or spheroidal form of carbide in a ferrite matrix. Various methods are used to obtained a spheroidal form of cementite.

→ In one method, the steel is heated to about 30°C below the low critical temperature where the result is spheroidal cementite in a matrix of ferrite.

→ In another method, the steel is heated just above the lower critical temperature and held there longer duration, and then slowly cooled to 600°C with in the furnace.

Isothermal Annealing:

→ In Isothermal annealing the steel is heated to austenitising temperature, then rapidly cooled to a temperature $50\text{--}100^\circ\text{C}$ below lower critical point.

→ at this temperature steel is held for completion of the transformation of austenite to paralite; and then is cooled in still air. It is called isothermal annealing.

Stress relief annealing:

→ Annealing process intended only to relieve internal stresses is called stress relief annealing. In this process the steel is heated below lower critical temperature and held there for sufficient time to relieve internal stresses. The steel is then cooled in still air. Heating to the range of $550\text{--}650^\circ\text{C}$ allows removal of internal stresses in carbon steel.

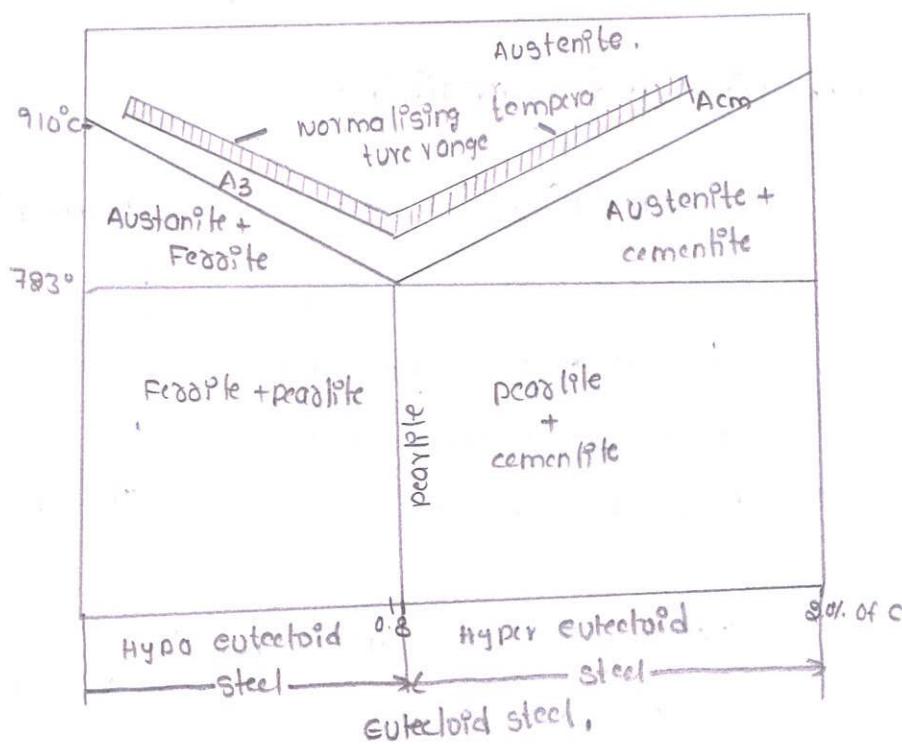
Normalising:

- Normalising is similar to full annealing, except that the steel is cooled in still air.
- The normalising consists of heating the steel to a temperature 30-50°C above A_3 or A_{cm} in order to obtain austenite structure.
- Steel is soaked at the temperature for sufficient time to obtain uniform structure. Soaking time depends on the section thickness of part. It determined as 1 hour per 25 mm of section thickness.

Normalising is usually carried out for the following purposes

- To refine the grain structure
- To obtain uniform structure
- To decrease residual stresses
- To improve machinability

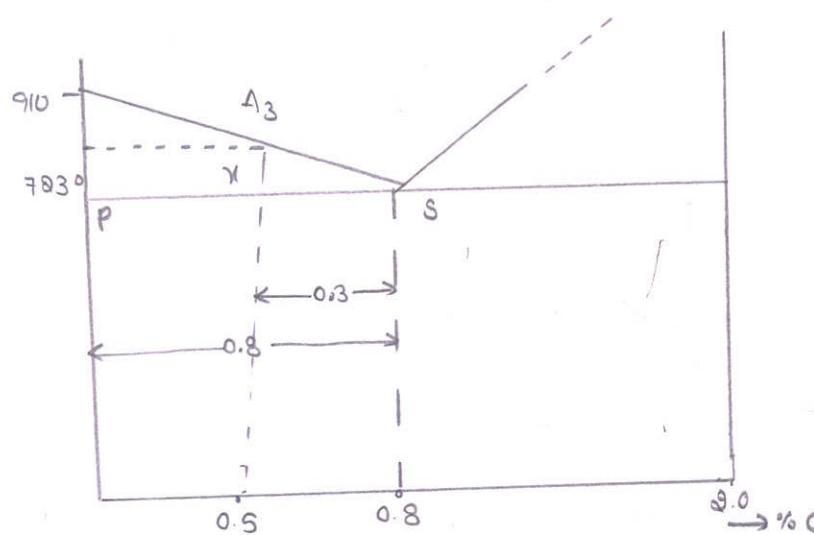
Normalised steels possess higher strength and hardness and lower ductility than annealed steels.



carbon percent	temperature
0.2	900
0.4	840
(E) 0.6	800
0.8	780

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For any composition the normalising temperature may be calculated as shown below.



normalising temperature

$$= 723 + \alpha + 30 \text{ to } 50^\circ$$

The value of α may be computed as

$$\frac{\alpha}{910 - 723} = \frac{0.3}{0.8}$$

$$\alpha = \frac{0.3 \times 187}{0.8}$$

$$\approx 70$$

\therefore normalising temperature for 0.5% C steel = $723 + 70 + 30 = 823^\circ\text{C}$

Difference between Annealing and normalising:

Comparison

Annealing

Normalising

1) Temperature range

30-50° C above A₃ for hypotectoid steel and same amount above A₁ for Hypoeutectoid steel

30-50° C above upper critical points (A₃ for hypoeutectic and A_m for hypereutectoid steel).

2) method of cooling:

cooled within the furnace i.e. slow rate of cooling

cooled in the air, i.e. fast rate of cooling

3) Grains structure

coarse grain

Fine grain

4) Properties

Annealed steels possess high ductility and low hardness

Normalised steels possess high strength, hardness and toughness.

5) cost

Takes costly furnace time
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cheaper, components spent less time in furnace.

Hardening :

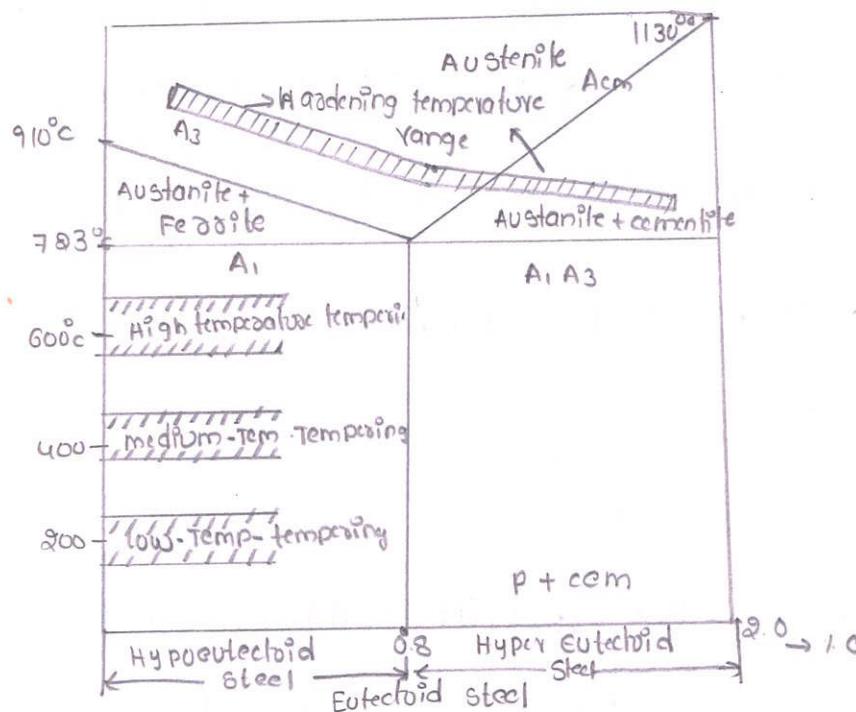
Hardening is a heat treatment process in which steel is rapidly cooled from austenitising temperature. As a result of hardening the hardness and wear resistance of steel are improved.

→ The hardening temperature depends upon the carbon content of the steel. Hypoeutectoid steel ($C < 0.8\%$) is heated to 30 to 50°C above A_3 point to form austenite and to prevent the retention of ferrite in quenched steel. Hypereutectoid steel ($C > 0.8\%$) is heated to 30 to 50°C above A_1 point to achieve partial transformation of Austenite and to set up a cementite network in quenched steel.

The purposes of hardening followed by tempering are

- To improve hardness, wear resistance, and ability to cut other materials.
- To improve strength and toughness.

Hardening is applied to cutting tools and machine parts where high hardness and wear resistance are important.



Process Variables

Properties of hardened steels are affected by several factors such as hardening temperature, soaking time, delay in quenching, rate of cooling etc.

i) Hardening temperature : The steel should be heated to the optimum austenitizing temperature. A lower temperature results lower hardness due to incomplete transformation to austenite. If this temperature is too high will also results lower hardness due to a coarse grained structure.

ii) Soaking time

Soaking time at hardening temperature should be long enough to form homogeneous austenite structure. Soaking time increases with increase in section thickness and the amount of alloying elements.

iii) Delay in quenching :

After soaking, the steel is immediately quenched. Delay in quenching may reduce hardness due to partial transformation of austenite.

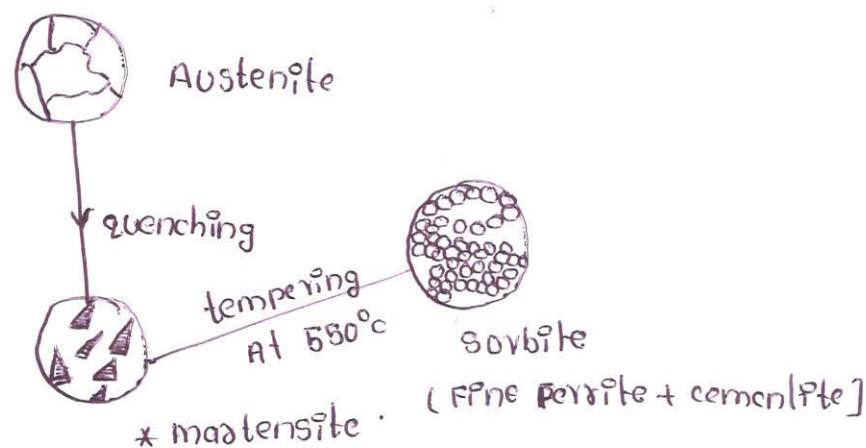
iv) Type of quenching medium :

The cooling rate is controlled by using proper quenching medium. Alloy steels required lower rates of quenching compared to plain carbon steels for a given section thickness. Therefore alloy steels are invariably quenched in oil which reduces the distortion and cracking tendency.

Temperings

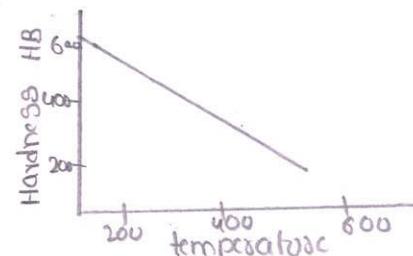
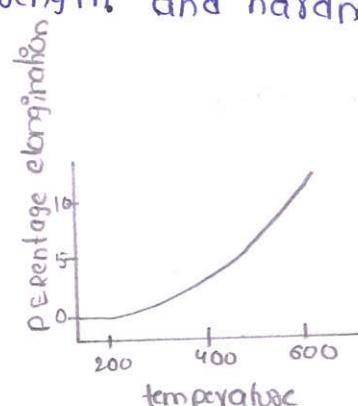
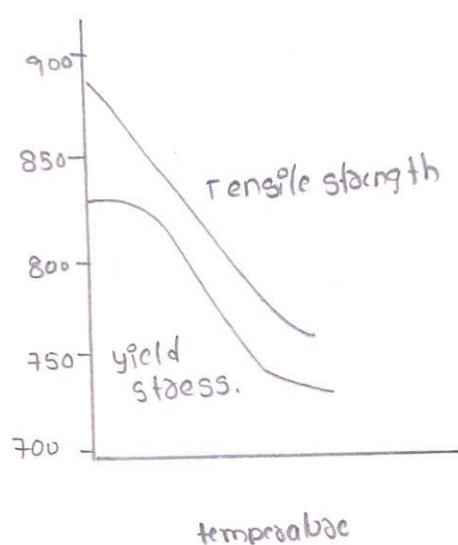
Hardened steels are so brittle that the slightest impact will cause fracture. Toughness of such a steel can be improved by tempering. However there is a small reduction in strength and hardness.

→ Tempering is a sub-critical heat treatment process used to improve the toughness and hardness of steel. Tempering consists of heating of hardened steels to any temperature below the lower critical temperature and is held for a period of time and then slowly cooled in air to room temperature. At tempering temperature carbon atoms diffuse out and form fine cementite and softer pearlite structure left behind.



Effects of tempering

- The tempering temperature must not exceed the critical points to prevent the formation of austenite and to preserve the benefit of hardening treatments. The tempering temperature affect the hardness, strength and ductility.
- The higher the temperature lower the strength and hardness but higher the percentage of elongation.



Effect of tempering temperatures on the properties of steel.

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Tempering colours and temperatures

Temperature °C	Tempering colour	Applications
0	pale straw	scribes, hand scrapers
220	pale straw	Hammer faces, turning tools
230	yellow brown	milling cutters, shear blades
240	Brown	drills
250	Red - Brown	tapes and diodes
260	Purple	center punches, reamers
270	Deep purple	press tools, axles
280	violet	chisels
290	Blue	screw driver blades
300	Deep blue	springs
400	Black red	constructional steels
500	Dull Red	shafts and axles
600		High strength bolts.

Classifications of tempering processes

Depending on the tempering temperature, the tempering processes can be classified as shown below.

- 1) Low-temperature tempering ($150\text{--}250^\circ\text{C}$)
- 2) medium-temperature tempering ($350\text{--}450^\circ\text{C}$)
- 3) High-temperature tempering ($500\text{--}650^\circ\text{C}$)

(1) Low-temperature tempering:

This process is carried out in the temperature interval from 150°C to 250°C . The purpose is to relieve internal stresses, and to increase ductility without changing the structure. Low-temperature tempering is applied to cutting tools measuring tools the parts that have been carburized and surface hardened. This process is not suitable for the parts subjected to impact loads.

Medium-temperature tempering

In this process, the hardened steel is heated between the temperature range of 350 to 450°C. At this temperature the martensite is transformed to troostite and the steel may become more tough and ductile, but hardness is important than extreme hardness and wear resistance. Medium temperature tempering is commonly applied for coil and laminated springs.

High-temperature tempering

This process consists of reheating the hardened steel foams formed upto sorbit. In this process the internal stresses are commonly relieved and the toughness is improved.

High temperature tempering is applied to gear wheels, axles, shafts and connecting rods.

Verdict -
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1) Ferrite:

Ferrite is the interstitial solid solution of carbon in alpha iron. It has BCC structure, it has very limited solubility for carbon (maximum 0.088% at 787°C) and 0.008% at room temperature. Ferrite is soft and ductile.

2) Austenite:

Austenite is the interstitial solid solution of carbon in gamma(γ) iron. It has FCC structure; Austenite can have maximum 2.14% carbon at 1143°C. Austenite is normally not stable at room temperature; Austenite is non magnetic and soft.

3) Cementite:

Cementite or iron carbide (Fe_3C) is an intermetallic compound of iron and carbon. It contains 6.67% carbon. It is very hard and brittle. This intermetallic compound is a meta-stable phase and it remains as a compound indefinitely at room temperature.

4) δ-ferrite:

It is a solid solution of carbon in δ-iron. It is stable at high temperatures. It has BCC structure.

Phase mixture is observed in Fe-C diagram.

1) Pearlite:

The pearlite consists of alternative layers of ferrite and cementite. It has properties somewhere between ferrite and cementite. The average carbon content in pearlite is 0.76%.

2) Ledeburite:

Ledeburite is an eutectic mixture of austenite and cementite in the form of alternative layers. The average carbon content in ledeburite is 4.3%.

A few comments on Fe-C system:

* carbon occupies interstitial positions in Fe. It forms a solid solution with δ, γ, or

phase of iron

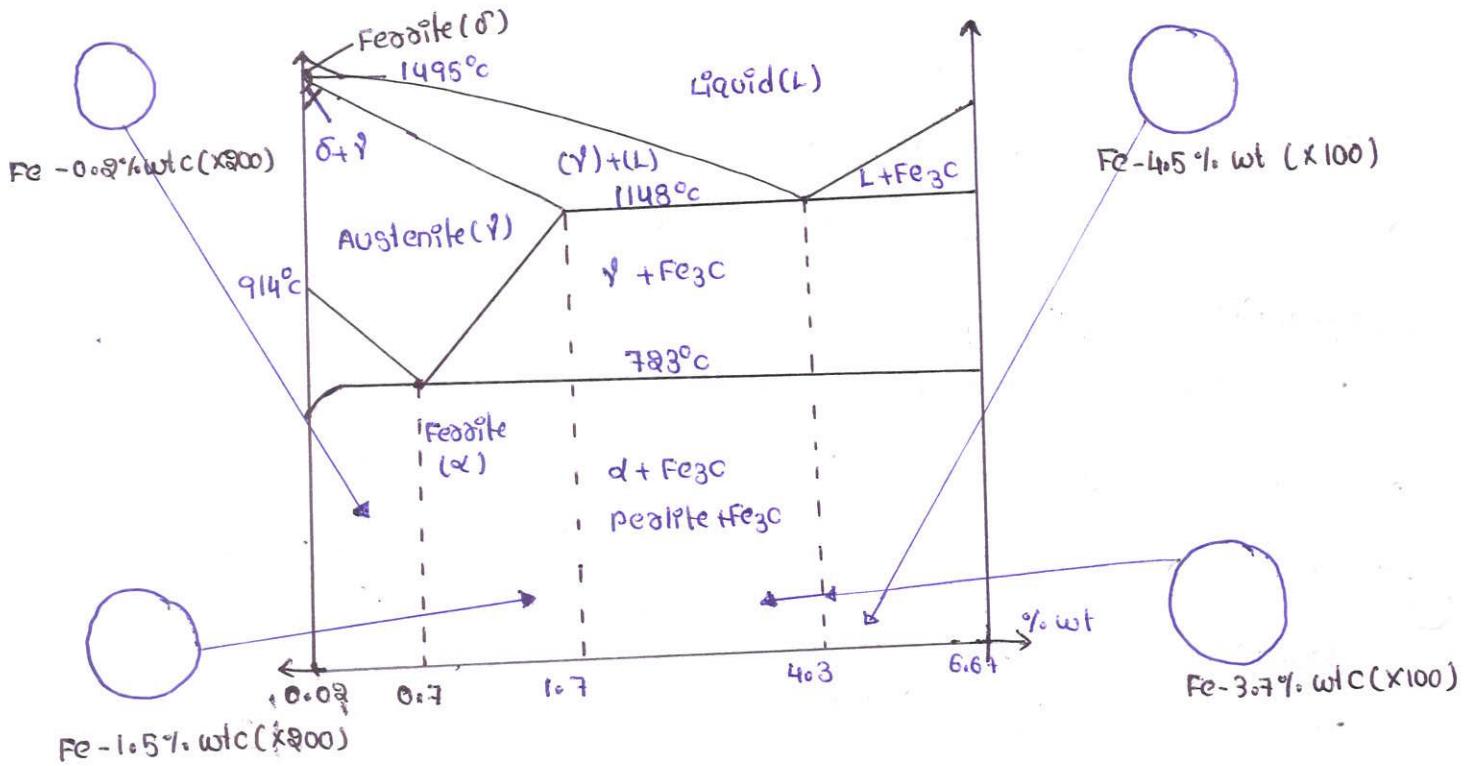
* maximum solubility in BCC-ferrite is limited (max. 0.085% at 787°C) as BCC has

relatively small interstitial positions

* maximum solubility in FCC austenite is 2.14% at 1147°C as FCC has larger interstitial positions.

Microstructure development:

Isothermal transformation diagram for Fe-C:



Reactions:

$$\Rightarrow \text{peritectic } L + \delta = \gamma$$

at $T = 1495^\circ\text{C}$ and 0.02 wt% C

$$\Rightarrow \text{Eutectic } L = \gamma + \text{Fe}_3\text{C}$$

at $T = 1148^\circ\text{C}$ and 4.3 wt% C

$$\Rightarrow \text{Eutectoid } \gamma = \alpha + \text{Fe}_3\text{C}$$

at $T = 914^\circ\text{C}$ and 0.77 wt% C

Microstructure development for Fe-C:

Phases:

- 1) Ferrite
- 2) Austenite
- 3) cementite
- 4) δ -ferrite.

Phase mixtures:

- 1) pearlite
- 2) ledeburite.

Fe-C alloys

Fe-C alloys can be of two types

1) steels:

steels are alloys of iron and carbon containing upto 2.14% C. Other alloying elements may also be present in steels.

2) cast irons:

cast irons are alloys of iron and carbon containing more than 2.14% C. Other alloying elements may also be present in cast irons.

Important reactions in Fe-C system:

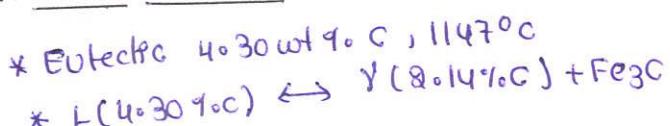
These are three important reactions taking place in Fe-C system

1. Eutectic reaction

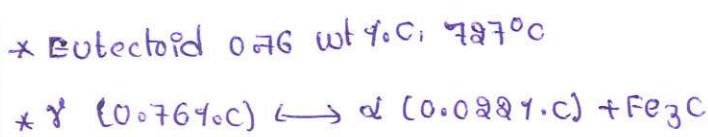
2. Eutectoid reaction

3. peritectic reaction.

1. Eutectic reaction



2. Eutectoid reaction:



3. peritectic reaction:

