UNIT-II

PART A

1. What is the difference between stress relief and recrystallisation?

Stress relief	Recrystallisation
To neutralize residual stress and work stress	To refine crystal structure
To induce softness	To improve toughness
Material will be kept at high temperature at prolonged time and cooled in air.	Heated above

2. What makes nitriding different from rest of case hardening process, besides composition?

Nitriding will be performed in nitrogen atmosphere unlike other hardening process. Nitriding will form carbo nitride which is a very hard compound, which will prove wear resistance.

3. What are the needs of annealing process?

Stress relieving, grains refinement, residual stress removal and induce ductility.

4. What are the factors should be considered while selecting a quenching medium?

Thermal conductivity, flash point, fire point, heat capacity and density.

5. What is austempering?
   It refers to quenching steel to a temperature below the nose and holding it isothermally to produce bainite.
6. State any two surface hardening process.
   Case hardening, flame hardening and induction hardening.

7. What is quenching. List some of the quenching medium generally used in industries? (Nov/Dec 2014)

It is sudden and drastic cooling of material for the critical temperature. Water, oil and sand are the quenching medium used normally.

8. What is the significance of TTT diagram in the heat treatment of steel? (Nov/Dec 2014)

TTT diagram used to find the properties and microstructure of the material with various cooling rate.

9. Define recrystallization ? (May/June 2014)

Original grains size of the parent material will be restructured and reoriented to form a new grains of different size by heat treatment is called recrystallization.

10. What are the types of heat Treatment? (May/June 2014) Annealing

Normalizing

Hardening

Tempering

11. Differentiate annealing and normalizing treatment? (April/May 2015)

S.No	Annealing	Normalizing
1	Main purpose of annealing is to relieve internal stresses	Main purpose of normalizing is to improve mechanical properties of steel.
2	Less hardness, more tensile strength and toughness	Slightly more hardness, less tensile strength and toughness
3	Pearlite is coarse.	Pearlite is fine.
4	Grain size distribution is more	Grain size distribution is less.

12. Austempering is different from other hardening treatments. Explain the statement. (April/May 2015)

Austempering is heat treatment that is applied to ferrous metals, most notably steel and ductile iron. In steel it produces a bainite microstructure whereas in cast irons it produces a structure of acicular ferrite and high carbon, stabilized austenite known as ausferrite. It is primarily used to improve mechanical properties or reduce / eliminate distortion. Austempering is defined by both the process and the resultant microstructure. Typical austempering process parameters applied to an unsuitable material will not result in the formation of bainite or ausferrite and thus the final product will not be called austempered. Other hardening process will lead to some microstructure element other than austenized product.

13. What do you mean my Hardenability?

Hardenability refers to its ability to be hardened to a particular depth under a particular ser of conditions.

14. Which type of surface hardening process that does not involve composition change?

Induction hardening, forging, quenching. Shot peening.

15. What is austempering

Austempering is heat treatment that is applied to ferrous metals, most notably steel and ductile iron. In steel it produces a bainite microstructure whereas in cast irons it produces a structure of acicular ferrite and high carbon, stabilized austenite known as ausferite. It is primarily used to improve mechanical properties or reduce / eliminate distortion.

16. Name any two shallow hardening processes

(i) Carburizing

(ii) Nitriding

17. What is quenching. List some of the quenching medium generally used in industries?
It is sudden and drastic cooling of material for the critical temperature. Water, oil and sand are the quenching medium used normally.

18. What is the significance of TTT diagram in the heat treatment of steel?

TTT diagram used to find the properties and microstructure of the material with various cooling rate.

19. Define recrystallization ?

Original grains size of the parent material will be restructured and reoriented to form a new grains of different size by heat treatment is called recrystallization.

20. What are the types of heat Treatment? (May/June 2014) Annealing

Normalizing, Hardening and Tempering .

21. What are the principal advantages of austempering over conventional quenching and temper method? (Apr/May 2017)

Less distortion, greater ductility, uniform/ consistent hardness, good wear resistance and resistance to hydrogen embrittlement.

22. Mention few applications of induction hardening system? (Apr/May 2017)

Surface hardening of railway suspension springs, metallic conveyers, earth moves parts and slurry pumps.

23. What is the difference between stress relief and recrystallization heat treatment process (Nov/Dec 2017)

Stress Relieving consists of heating the steel to a temperature below the critical range to relieve the stresses resulting from cold working, shearing, or gas cutting. It is not intended to alter the micro-structure or mechanical properties significantly also a process for mak-ing material softer.

However stress relieving does not change the material properties as does annealing and normalizing. On the other hand, recrystallization heat treatment is the process that alters the physical and sometimes chemical properties of a material to increase its ductility and to make it more workable. It involves heating a material to above its recrystallization temperature, maintaining a suitable temperature, and then cooling.

24. Which has higher critical cooling rate: euctectoid steel or hypereutectoid steel? (Nov/Dec 2017)

As hypereutectoid steel has higher carbon content than the eutectoid steel, hypereutectoid steel will have higher critical cooling rate.

PART B

1. Brief on various phase transformation with continuous cooling transformation diagram super imposed on TTT diagram.

Refer question 12.

2. Brief on jominy end quench test and interpretation of results.

Refer question 13.

3. Brief on the tempering process.
   refer question no 10.
4. What is hardenability? Describe a test that is used for determination of hardenability of steel.
   Refer question 13
5. What is case hardening? Explain in details the carburizing processes.
6. Brief on hardening and tempering of steel with respect to rate of cooling and tempering temperature respectively.
7. Define hardenability? Explain Jominy end quench test. Explain carburization.

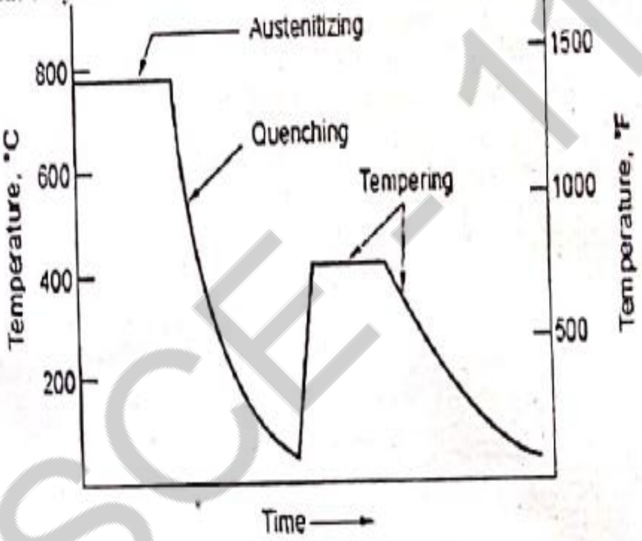
Refer question 11

8. Brief on hardening and tempering of steel with respect ot rate of cooling and tempering temperature respectively.

Hardening involves heating of steel, keeping it at an appropriate temperature until all pearlite is transformed into austenite, and then quenching it rapidly in water or oil. The temperature at which austentizing rapidly takes place depends upon the carbon content in the steel used. The heating time should be increased ensuring that the core will also be fully transformed into austenite. The microstructure of a hardened steel part is ferrite, martensite, or cementite.

Tempering involves heating steel that has been quenched and hardened for an adequate period of time so that the metal can be equilibrated. The hardness and strength obtained depend upon the temperature at which tempering is carried out. Higher temperatures will result into high ductility, but low strength and hardness. Low tempering temperatures will produce low ductility, but high strength and hardness. In practice, appropriate tempering temperatures are selected that will produce the desired level of hardness and strength. This operation is performed on all carbon steels that have been hardened, in order to reduce their brittleness, so that they can be used effectively in desired applications.

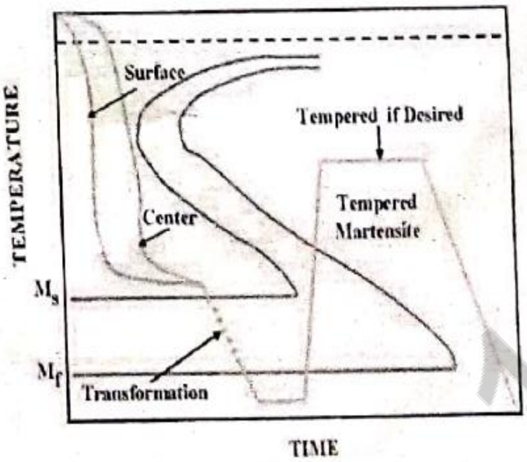
5 Marks



3 Marks

9. Discuss the concept involved in martempereing

(ii) **Martempering** is a heat treatment for steel involving austenitisation followed by step quenching, at a rate fast enough to avoid the formation of ferrite, pearlite or bainite to a temperature slightly above the martensite start (Ms) point **3 Marks**



2 Marks

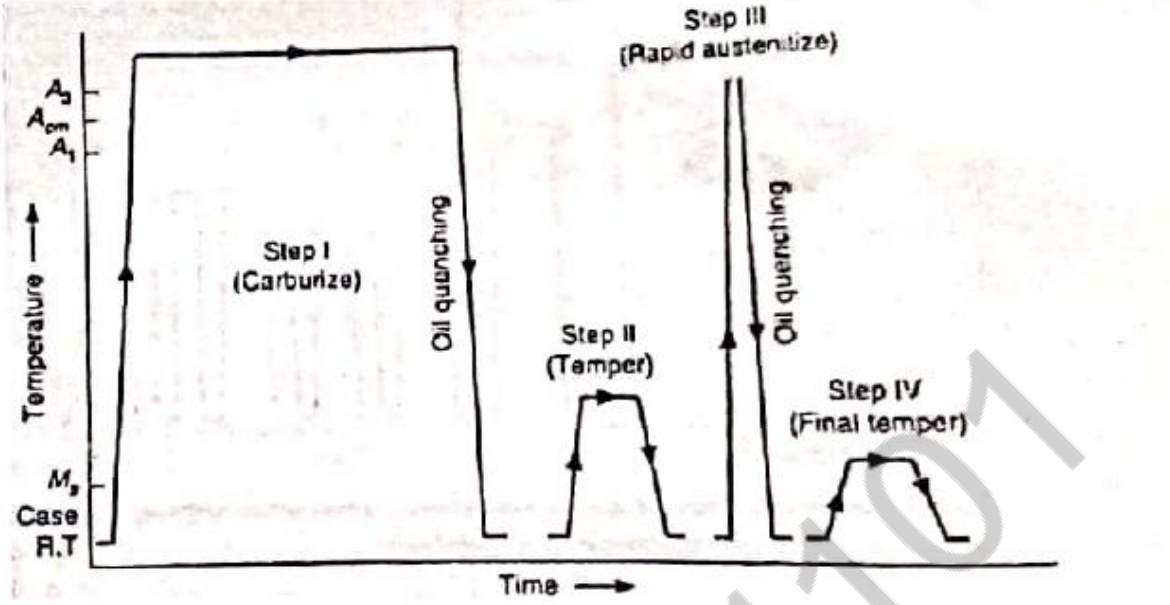
10. Brief on Jominy end quench test and interpretation of results.

11. Brief on the types of carburizing and need for post carburizing heat treatments.

There are plots in the literature that we can use that will give us the cooling rates experienced for any point in a steel specimen of a particular size, geometry and quench. (The standard quenches are water or oil. Once the cooling rate is known, the hardness can be determined from the Hardenability curve.

(ii) **carburization** is a heat treatment process in which iron or steel absorbs carbon while the metal is heated in the presence of a carbon-bearing material, such as charcoal or carbon monoxide. The intent is to make the metal harder. Depending on the amount of time and temperature, the affected area can vary in carbon content. Longer carburizing times and higher temperatures typically increase the depth of carbon diffusion.

The objectives of the post-carburizing heat treatment are to (i) Improve the microstructure and refine coarser grains of core and case of carburized steel (ii) Achieve high hardness at the surface; and (iii) break the carbide network in the carburized case, which may be formed due to higher carbon content (1.0%) **3 Marks**



12. **(a) Compare and contrast the process of full annealing, stress relief annealing, recrystallization annealing and spheroidise annealing. (Apr/May 2017)**

Annealing is one of the heat treatment processes, which is done to steels for obtaining some properties. Annealing plays a predominant role in deciding the strength toughness and various other physical factors of the steel produced. In general annealing is of different types. Each type plays a significant role in forming the steel with the required properties. Some of the annealing processes are

1) Full annealing
2) Bright annealing
3) Box annealing
4) Isothermal annealing
5) Spherodize annealing
6) Sub critical annealing
    a. Stress relief annealing
    b. Re crystallization annealing
    c. Process annealing

Full annealing

In general full annealing is one of the most commonly used annealing process. The purpose behind employing this heat treatment process is

1) To relieve internal stresses
2) To reduce hardness and increase ductility
3) For refining of grain size
4) To make isotropic in nature in mechanical aspects
5) For making the material having homogeneous chemical composition

6) For making the material suitable for high machining processes

7) To make steel suitable for undergoing other heat treatment processes like hardening, normalizing etc.

Full annealing is done by heating the steels to A3 temperature for hypo eutectoid steels and A1¬ for hyper eutectoid steels and then allowed to stay there for a time period and then subjected to slow cooling.

Bright annealing

In some cases surface brightness of the component is highly desired in such cases this process is used. In this process the heating process is done in the presence of inert media so as to prevent oxidation of the surface metal. In general the materials used to provide inert environment around the body are either argon, nitrogen. In addition to these any reducing media acts as a protective shield around the object. In this process even the color of the surface is retained.

Box annealing

This annealing process can be called by various names such as black annealing, pot annealing, close annealing. In this process keeping the steel to be annealed in a closed medium carries the annealing process. The surroundings of the steel material are covered with cast iron chips, sand, and charcoal. The final annealing process is same as that of full annealing but the only difference is the medium used for doing this process. The background of this process is to prevent oxidation of the steel metal.

Isothermal annealing

This process is other wise called as cycle annealing. In this process the material is heated to just above the temperature of A3¬ and then faster cooling rates are adopted than that of a normal annealing processes till the temperature reaches just below A1¬ temperature. The steel material is kept at that temperature for obtaining uniformity and then cooled to normal room temperature.

Isothermal annealing seems to be more advantageous over the conventional annealing processes some of the advantages of this process are

1) When slower cooling required materials are to be annealed then this process seems to be advantageous than the normal process. This process is even effective when the reduction of hardness is required.

2) Due to the generation of intermediate equalization of temperature homogeneity is more comparatively

3) The parts, which are annealed by this process, have high machinability and improved surface finish of the machined part can be obtained.

In general this process is used for low and medium carbon steels. This process is even used for some of the alloy steels for obtaining improved machinability. This improvement in the machinability is due to the formation of spheroidized structure.

Spheroidized annealing

Any methods through which spheroids are formed are called as spheroidized annealing. If an annealed product contains globules of cementite in the matrix of ferrite in the microstructure then it is termed as a spheroid. In general this microstructure is formed by various ways some of them are

1) Hardening and high temperature tempering

2) Holding the product at the temperature just below the A1¬ temperature

3) Thermal cycling around A1

Subcritical annealing

This process is done over cold worked steels. In this process the cold worked steel is heated to a temperature just above the lower critical temperature. Due to the heating of the steel to lower critical temperature this process is named as sub critical temperature. In general this process is done to

1) To relieve internal stresses developed due to cold working process

2) To refine the grain structure

3) To reduce hardness and to improve ductility of the material

Sub critical annealing is done by three processes for obtaining various varieties of properties on cold worked steels.

1) Stress relief annealing

2) Re crystallization annealing

3) Process annealing (intermediate annealing)

Stress relief annealing

In this process the cold worked steel is heated to a temperature around 5250C i.e. just below the recrystallization temperature. So due to this heating there arises no change in the microstructure of the material. The body is kept at that temperature for around two to three hours and then subjected to air-cooling. As there is no change in the microstructure this heating process has no adverse affect on the hardness and strength of the material. This annealing process reduces the risk of deformation of the product during machining.

Recrystallization annealing

In this annealing process the cold worked steel material is heated to a temperature above A1 i.e. around 625 to 6500C. During this annealing process the cementite present in the microstructure starts converting in to spheroids and hence high machining ability is obtained. Due to heating of temperature up to A¬1¬ the grain structure changes and not only this internal stresses developed in the cold working process is removed.

13. Define Hardenability. Describe the test procedure to determine **hardenability of steel. (Apr/May 2017)**

Refer Question Bank Page No.**40**, Question No.**2**.

14. **Brief of hardening and tempering of steel (Nov/Dec 2017)**

The term hardened steel is often used for a medium or high carbon steel that has been given heat treatment and then quenching followed by tempering. The quenching results in the formation of metastable martensite, the fraction of which is reduced to the desired amount during tempering.

This is the most common state for finished articles such as tools and machine parts. In contrast, the same steel composition in annealed state is softer, as required for forming and machining. Depending on the temperature and composition of the steel, it can be hardened or softened. To make steel harder, it must be heated to very high temperatures. The final result of exactly how hard the steel becomes depends on the amount of carbon present in the metal.

Only steel that is high in carbon can be hardened and tempered. If a metal does not contain the necessary quantity of carbon, then its crystalline structure cannot be broken, and therefore the physical makeup of the steel cannot be altered. Frequently, the term “hardening” is associated with tempered steel. Both processes are used hand in hand when hardening steel.

The two part process begins with hardening the steel so that it becomes hard and does not wear over time. However, very often, this process leaves the steel very brittle and susceptible to breaking during use. Tempering reduces the hardness of the forged steel very slightly but improves the overall product as it results in steel that is much less brittle.

The two major processes of hardening and tempering can be classified into four major steps. First, a piece of carbon steel is heated gradually until it reaches a temperature above the alloy’s critical temperature.

The steel is then quenched, usually in water or oil (though other quenches, such as brine or sodium hydroxide solutions, are sometimes used to achieve a particular result). The steel is now at that given alloy’s maximum hardness, but as discussed above, also brittle. At this point, tempering is usually performed to achieve a more useful balance of hardness and toughness. The steel is gradually heated until the desired temper colours are drawn, generally at a temperature significantly lower than the alloy’s critical point.

Different colours in the temper spectrum reflect different balances of hardness to toughness, so different temper levels are appropriate for different applications. The steel is then re-quenched to ‘fix’ the temper at the desired level. A talented smith or metalworker can fine-tune the performance of a steel tool or item to precisely what is required based solely on careful observation of temper colours.

Tempering

Tempering is a process of heat treating, which is used to increase the toughness of iron-based alloys. Tempering is usually performed after hardening, to reduce some of the excess hardness, and is done by heating the metal to some temperature below the critical point for a certain period of time, then allowing it to cool in still air. The exact temperature determines the amount of hardness removed, and depends on both the specific composition of the alloy and on the desired properties in the finished product.

For instance, very hard tools are often tempered at low temperatures, while springs are tempered to much higher temperatures. Tempering is applied to ferrous alloys, such as steel or cast iron, to achieve greater toughness by decreasing the hardness of the alloy. The reduction in hardness is usually accompanied by an increase in ductility, thereby decreasing the brittleness of the metal.

Tempering is usually performed after quenching, which is rapid cooling of the metal to put it in its hardest state. Tempering is accomplished by controlled heating of the quenched work-piece to a temperature below its “lower critical temperature”. This is also called the lower transformation temperature or lower arrest (A1) temperature; the temperature at which the crystalline phases of the alloy, called ferrite and cementite, begin combining to form a single-phase solid solution referred to as austenite.

Heating above this temperature is avoided, so as not to destroy the very-hard, quenched microstructure, called martensite.

Precise control of time and temperature during the tempering process is crucial to achieve the desired balance of physical properties. Low tempering temperatures may only relieve the internal stresses, decreasing brittleness while maintaining a majority of the hardness. Higher tempering temperatures tend to produce a greater reduction in the hardness, sacrificing some yield strength and tensile strength for an increase in elasticity and plasticity.

However, in some low alloy steels, containing other elements like chromium and molybdenum, tempering at low temperatures may produce an increase in hardness, while at higher temperatures the hardness will decrease. Many steels with high concentrations of these alloying elements behave like precipitation hardening alloys, which produces the opposite effects under the conditions found in quenching and tempering, and are referred to as maraging steels.

In carbon steels, tempering alters the size and distribution of carbides in the martensite, forming a microstructure called «tempered martensite». Tempering is also performed on normalized steels and cast irons, to increase ductility, machinability, and impact strength. Steel is usually tempered evenly, called «through tempering,» producing a nearly uniform hardness, but it is sometimes heated unevenly, referred to as «differential tempering,» producing a variation in hardness

15. **Compare different types of case hardening process (Nov/Dec 2017)**

Nitriding :

Nitriding is a heat treating process that diffuses nitrogen into the surface of a metal to create a case-hardened surface. These processes are most commonly used on low-carbon, low-alloy steels. They are also used on medium and high-carbon steels, titanium, aluminium and molybdenum.

Typical applications include gears, crankshafts, camshafts, cam followers, valve parts, extruder screws, die-casting tools, forging dies, extrusion dies, firearm components, injectors and plastic mold tools.

Carburizing:

Carburizing is a heat treatment process in which iron or steel absorbs carbon while the metal is heated in the presence of a carbon-bearing material, such as charcoal or carbon monoxide. The intent is to make the metal harder. Depending on the amount of time and temperature, the affected area can vary in carbon content.

Longer carburizing times and higher temperatures typically increase the depth of carbon diffusion. When the iron or steel is cooled rapidly by quenching, the higher carbon content on the outer surface becomes hard due to the transformation from austenite to martensite, while the core remains soft and tough as a ferritic and/or pearlite microstructure.

This manufacturing process can be characterized by the following key points: It is applied to low-carbon work pieces; work pieces are in contact with a high-carbon gas, liquid or solid; it produces a hard work piece surface; work piece cores largely retain their toughness and ductility; and it produces case hardness depths of up to 0.25 inches (6.4 mm).

In some cases it serves as a remedy for undesired decarburization that happened earlier in a manufacturing process.

Cyaniding:

Cyaniding is a case-hardening process that is fast and efficient; it is mainly used on low-carbon steels. The part is heated to 871-954 °C (1600- 1750 °F) in a bath of sodium cyanide and then is quenched and rinsed, in water or oil, to remove any residual cyanide.

$$2NaCN + O2 \rightarrow 2NaCNO$$

$2NaCNO + O_2 \rightarrow Na_2CO_3 + CO + N_2$

$2CO \rightarrow CO_2 + C$

This process produces a thin, hard shell (between 0.25 - 0.75 mm, 0.01 and 0.03 inches) that is harder than the one produced by carburizing, and can be completed in 20 to 30 minutes compared to several hours so the parts have less opportunity to become distorted. It is typically used on small parts such as bolts, nuts, screws and small gears. The major drawback of cyaniding is that cyanide salts are poisonous.

Carbonitriding:

Carbonitriding is a metallurgical surface modification technique that is used to increase the surface hardness of a metal, thereby reducing wear.

During the process, atoms of carbon and nitrogen diffuse interstitially into the metal, creating barriers to slip, increasing the hardness and modulus near the surface. Carbonitriding is often applied to inexpensive, easily machined low carbon steel to impart the surface properties of more expensive and difficult to work grades of steel. Surface hardness of carbonitrided parts ranges from 55 to 62 HRC.

Certain pre-industrial case hardening processes include not only carbon-rich materials such as charcoal, but nitrogen-rich materials such as urea, which implies that traditional surface hardening techniques were a form of carbonitriding

Flame or Induction Hardening:

Flame or induction hardening are processes in which the surface of the steel is heated very rapidly to high temperatures (by direct application of an oxy-gas flame, or by induction heating) then cooled rapidly, generally using water; this creates a “case” of martensite on the surface. A carbon content of 0.3–0.6 wt% C is needed for this type of hardening.

Typical uses are for the shackle of a lock, where the outer layer is hardened to be file resistant, and mechanical gears, where hard gear mesh surfaces are needed to maintain a long service life while toughness is required to maintain durability and resistance to catastrophic failure

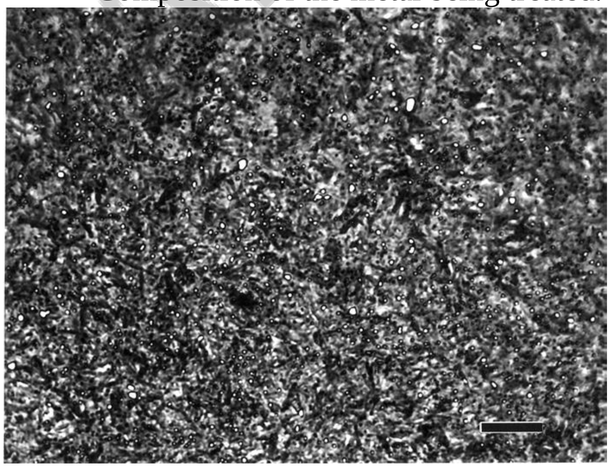
Flame hardening uses direct impingement of an oxy-gas flame onto a defined surface area. The result of the hardening process is controlled by four factors:

Design of the flame head.

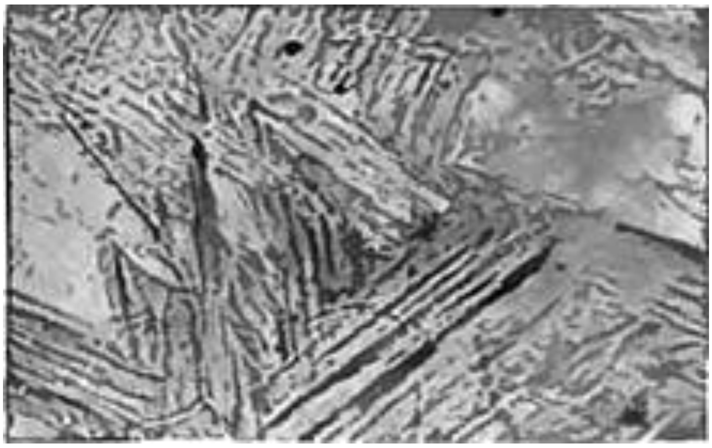
Duration of heating.

Target temperature to be reached.

Composition of the metal being treated.



Hardened steel



Tempered steel

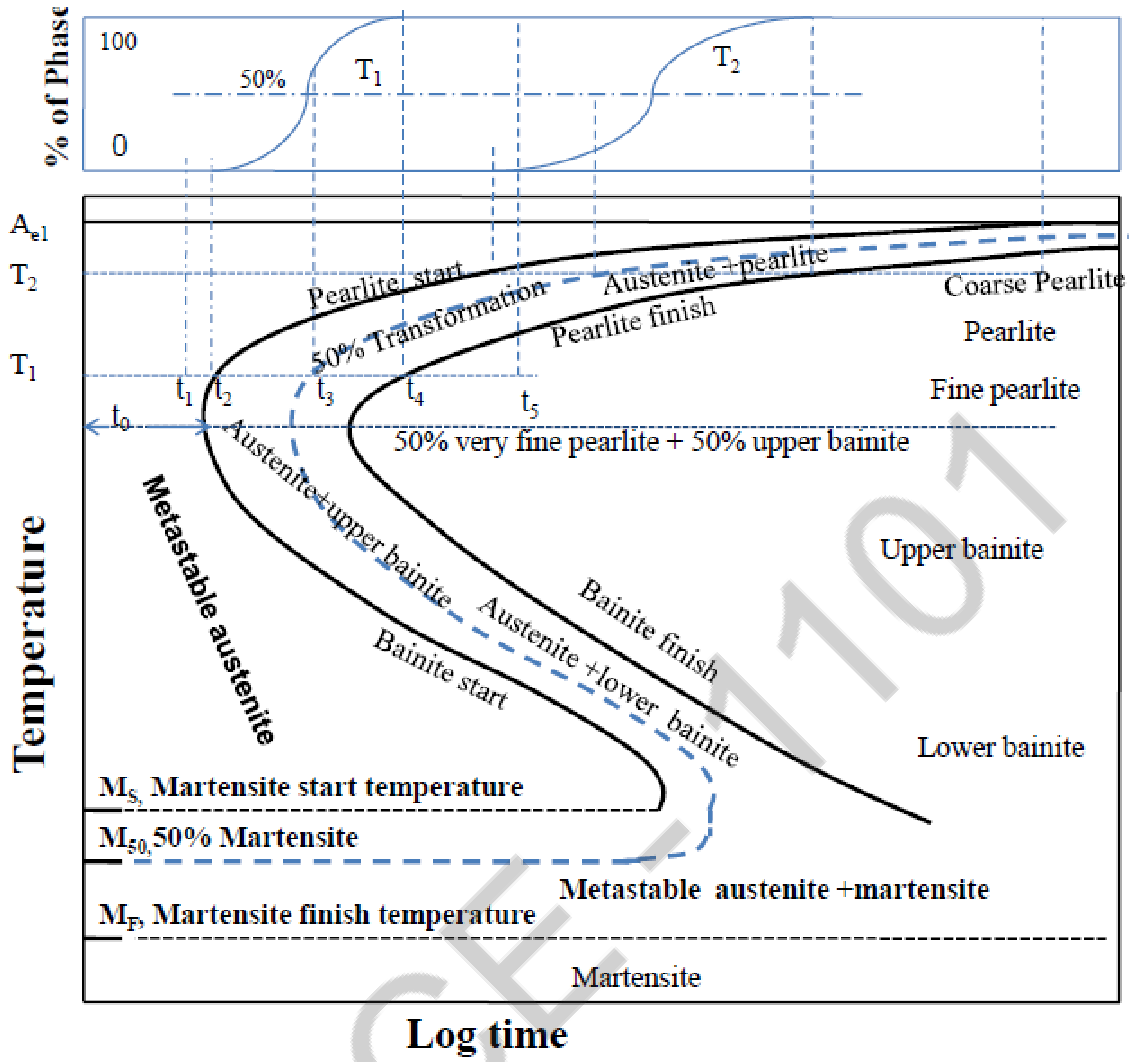
16. **Draw a neat sketch of the isothermal transformation diagram for eutectoid steel and explain the construction procedure. Label all the salient features on it. Superimpose on it a cooling curve to obtain bainitic phase. (April/May 2015)**

Isothermal transformation diagrams (also known as time-temperature-transformation (TTT) diagrams) are plots of temperature versus time (usually on a logarithmic scale). They are generated from percentage transformation-vs logarithm of time measurements, and are useful for understanding the transformations of an alloy steel that is cooled isothermally. An isothermal transformation diagram is only valid for one specific composition of material, and only if the temperature is held constant during the transformation, and strictly with rapid cooling to that temperature. Though usually used to represent transformation kinetics for steels, they also can be used to describe the kinetics of crystallization in ceramic or other materials. Time-temperature-precipitation diagrams and time-temperature-embrittlement diagrams have also been used to represent kinetic changes in steels.

Isothermal transformation (IT) diagram or the C-curve is associated with mechanical properties, micro constituents/microstructures, and heat treatments in carbon steels. Diffusional transformations like austenite transforming to a cementite and ferrite mixture can be explained using the sigmoidal curve; For example the beginning of pearlitic transformation is represented by the pearlite start (Ps) curve. This transformation is complete at Pf curve. Nucleation requires an incubation time. The rate of nucleation increases and the rate of micro constituent growth decreases as the temperature decreases from the liquidus temperature reaching a maximum at the bay or nose of the curve. Thereafter, the decrease in diffusion rate due to low temperature offsets the effect of increased driving force due to greater difference in free energy. As a result of the transformation, the micro constituents, Pearlite and Bainite, form; Pearlite forms at higher temperatures and bainite at lower.

Austenite is slightly under cooled when quenched below Eutectoid temperature. When given more time, stable micro constituents can form: ferrite and cementite. Coarse pearlite is produced when atoms diffuse rapidly after phases that form pearlite nucleate. This transformation is complete at the pearlite finish time (Pf).However, greater under cooling by rapid quenching results in formation of martensite or bainite instead of pearlite. This is possible provided the cooling rate is such that the cooling curve intersects the martensite start temperature or the bainite start curve before intersecting the Ps curve. The martensite transformation being a diffusionless shear transformation is represented by a straight line to signify the martensite start temperature.

1. The kinetic aspects of phase transformations are as important as the equilibrium diagrams for the heat treatment of steels. The metastable phase martensite and the morphologically metastable micro constituent bainite, which are of extreme importance to the properties of steels, can generally form with comparatively rapid cooling to ambient temperature. That is when the diffusion of carbon and alloying elements is suppressed or limited to a very short range. Bainite is a eutectoid decomposition that is a mixture of ferrite and cementite. Martensite, the hardest constituent, forms during severe quenches from supersaturated austenite by a shear transformation. Its hardness increases monotonically with carbon content up to about 0.7 wt%. If these unstable metastable products are subsequently heated to a moderately elevated temperature, they decompose to more stable distributions of ferrite and carbide. The reheating process is sometimes known as tempering or annealing. The transformation of an ambient temperature structure like ferrite-pearlite or tempered martensite tothe elevated-temperature structure of austenite or austenite-carbide is also of importance in the heat treatment of steel.One can conveniently describe what is happening during transformation with transformation diagrams. Four different types of such diagrams can be distinguished. These include: Isothermal transformation diagrams describing the formation of austenite, which will be referred to as IT diagrams. Isothermal transformation (IT) diagrams, also referred to as time-temperature-transformation (TTT) diagrams, describing the decomposition of austenite, Continuous heating transformation (CRT) diagrams , Continuous cooling transformation (CCT) diagrams. Isothermal Transformation Diagrams. This type of diagram shows what happens when a steel is held at a constant temperature for a prolonged period. The development of the microstructure with time can be followed by holding small specimens in a lead or salt bath and quenching them one at a time after increasing holding times and measuring the amount of phases formed in the microstructure with the aid of a microscope. During the formation of austenite from an original microstructure of ferrite and pearlite or tempered martensite, the volume decreases with the formation of the dense austenite phase. From the elongation curves, the start and finish times for austenite formation, usually defined as 1% and 99% transformation, respectively, can be derived. IT Diagrams (Decomposition of Austenite). The procedure starts at a high temperature, normally in the austenitic range after holding there long enough to obtain homogeneous austenite without un dissolved carbides, followed by rapid cooling to the desired hold temperature. The cooling was started from 850°C (1560°F). The A1 and A3 temperatures are indicated as well as the hardness. Above A3 no transformation can occur. Between A1 and A3 only ferrite can form from austenite.


% of Phase
100
50%
0
T1
T2
Ae1
T2
T1
Temperature
Pearlite start
50% Transformation
Austenite +pearlite
Pearlite finish
Coarse Pearlite
Pearlite
Fine pearlite
t1
t2
t3
t4
t5
t0
50% very fine pearlite + 50% upper bainite
Austenite+upper bainite
Metastable austenite
Upper bainite
Bainite finish
Austenite +lower bainite
Bainite start
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MS, Martensite start temperature
M50, 50% Martensite
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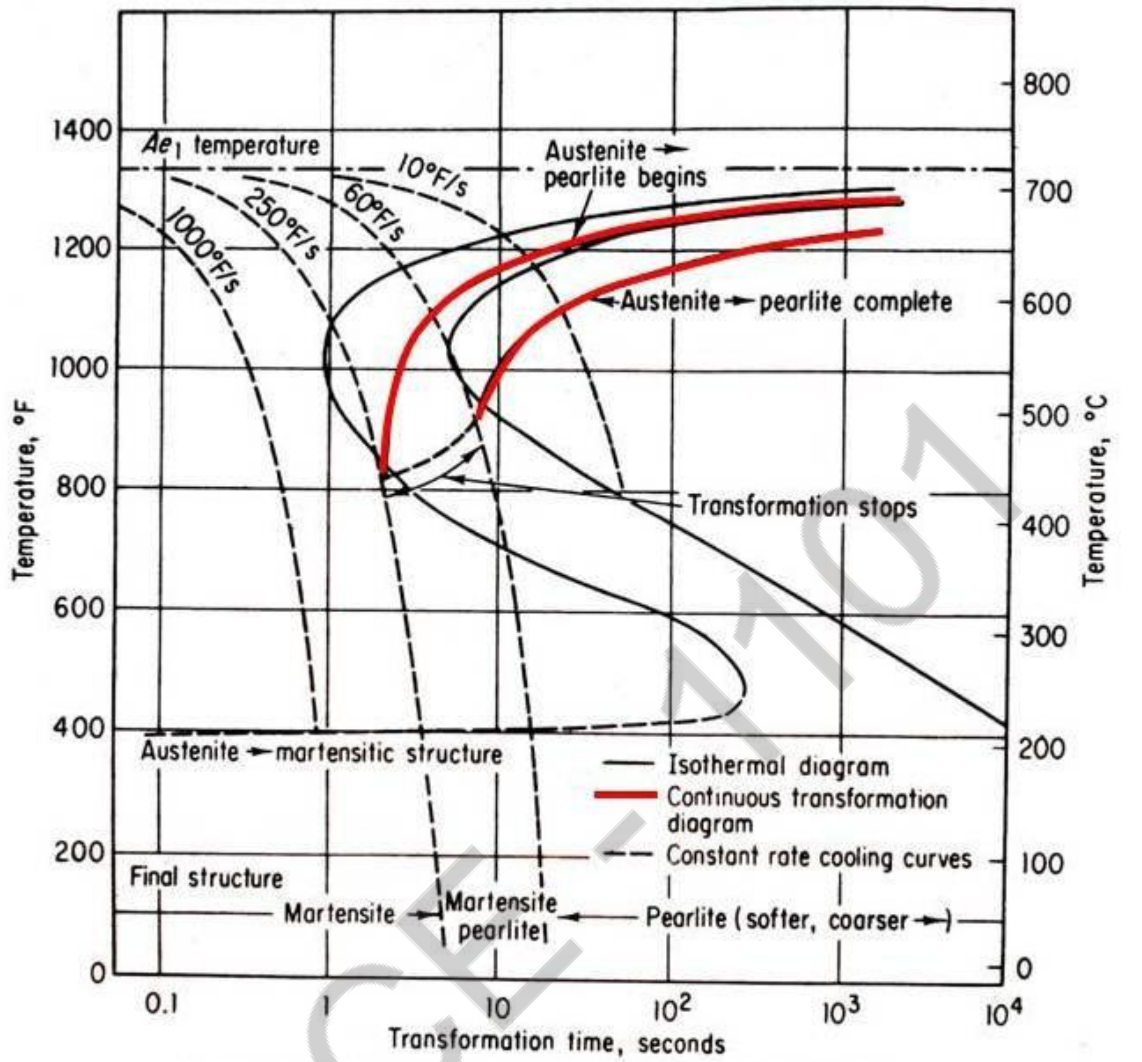
MF, Martensite finish temperature
Martensite
Log time



Continuous Cooling-Transformation (C-T) Diagram

(Derived from the isothermal-transformation diagram for a plain-carbon eutectoid steel)

17. **Differentiate hardness and hardenability. Explain with a neat sketch, the procedure to plot the hardenability curves for eutectoid steel in Jominy End Quench Test. (April/May 2015)**

HARDENABILITY	HARDNESS
The hardness of a steel is a measure of a sample's resistance to indentation or scratching.	Hardenability refers to its ability to be hardened to a particular depth under a particular ser of conditions.

The influence of alloy composition on the ability of a steel alloy to transform to martensite for a particular quenching treatment is related to a parameter called hardenability. For every different steel alloy there is a specific relationship between the mechanical properties and the cooling rate. Hardenability is used to describe the ability of an alloy to be hardened by the formation of martensite as a result of a given heat treatment. One standard procedure that is widely utilized to determine hardenability is the Jominy end quench test.

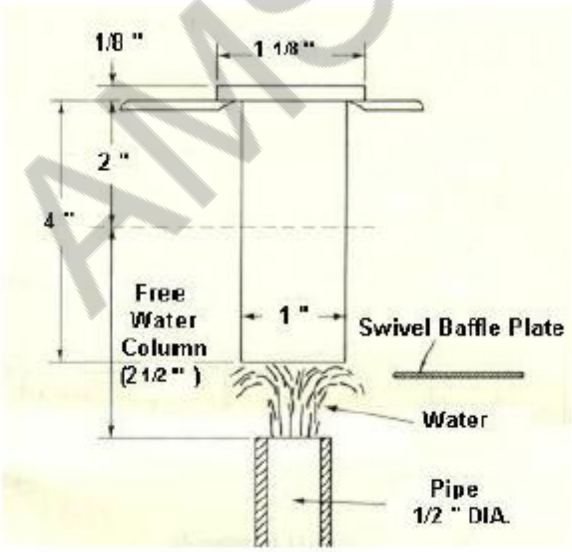
The heating and cooling treatment of the steel specimens have a great effect on the phase of the microstructure of the steel specimen. The addition of alloys or coarsening of the austenitic grain structure increase the hardenability of steel. Any steel that has low critical cooling rate will harden deeper than one that has a high cooling rate of quenching. The size of the part that is being quenched has a direct effect upon the hardenability of the material. The objective of the experiment is to take readings in the Rockwell C scale along the flat surface of the Jominy specimen and to plot Hardness versus distance from quenched end. Equipment: Electric Furnace, Jominy End Quench Test Fixture, Jominy specimens.

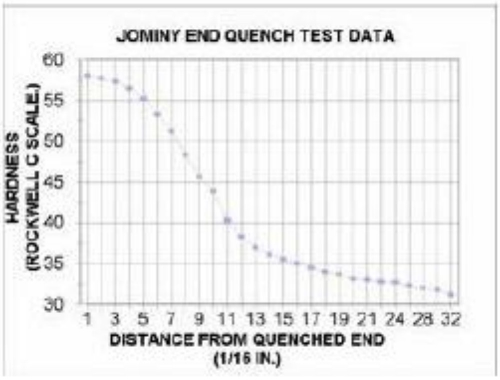
Procedure:

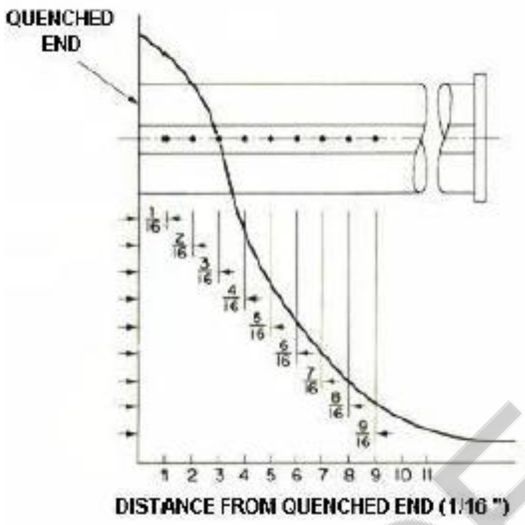
1. Preheat the furnace to 1700 F.
2. Place the Jominy specimen in the furnace and soak for one hour.
3. Turn the water on at the Jominy sink. Adjust the free water column to about 2.5 in. Swivel the baffle plate to block the water column so that there is no contact between water and the test specimen when the test specimen is initially placed on the fixture.
4. Remove the Jominy specimen from the furnace and place it in the fixture as shown in Figure Swivel the baffle out of position so that the water impinges on the bottom of the specimen withoutwetting the sides of the specimen. Leave water running for about 15 minutes.
5. Remove the Jominy specimen from the fixture and grind a flat on the side of the specimen.
6. Mark points on the ground surface at an interval of 1/16 in. up to 2 in. distance from the quenched end as shown in Figure
7. Take readings at an interval of 1/16 in. by measuring the Rockwell C hardness at each point

marked in the previous step.

8. Plot the data for Rockwell Hardness versus Distance from quenched end as shown in Figure.







18. **Brief on hardening and tempering of steel with respect to rate of cooling and tempering temperature respectively. (Nov/Dec 2015)**

The use of this treatment will result in an improvement of the mechanical properties, as well as an increase in the level of hardness, producing a tougher, more durable item. Alloys are heated above the critical transformation temperature for the material, then cooled rapidly enough to cause the soft initial material to transform to a much harder, stronger structure. Alloys may be air cooled, or cooled by quenching in oil, water, or another liquid, depending upon the amount of alloying elements in the material. Hardened materials are usually tempered or stress relieved to improve their dimensional stability and toughness.

Steel parts often require a heat treatment to obtain improved mechanical properties, such as increasing increase hardness or strength. The hardening process consists of heating the components above the critical (normalizing) temperature, holding at this temperature for one hour per inch of thickness cooling at a rate fast enough to allow the material to transform to a much harder, stronger structure, and then tempering. Steel is essentially an alloy of iron and carbon; other steel alloys have other metal elements in solution. Heating the material above the critical temperature causes carbon and the other elements to go into solid solution. Quenching “freezes” the microstructure, inducing stresses. Parts are subsequently tempered to transform the microstructure, achieve the appropriate hardness and eliminate the stresses. Material is heated up to the suitable temperature and then quenched in water or oil to harden to full hardness according to the kind of steels. Material is heated to the suitable temperature for hardening, then cooled rapidly by immersing the hot part is water, oil or another suitable liquid to transform the material to a fully hardened structure. Parts which are quenched usually must be aged, tempered or stress relieved to achieve the proper toughness, final hardness and dimensional stability.

Tempering is a process of heat treating, which is used to increase the toughness of iron-based alloys. Tempering is usually performed after hardening, to reduce some of the excess hardness, and is done by heating the metal to some temperature below the critical point for a certain period of time, then allowing it to cool in still air. The exact temperature determines the amount of hardness removed, and depends on both the specific composition of the alloy and on the desired properties in the finished product. For instance, very hard tools are often tempered at low temperatures, while springs are tempered to much higher temperatures.

Alloys may be air cooled, or cooled by quenching in oil, water, or another liquid, depending upon the amount of alloying elements in the material and final mechanical properties to be achieved. Hardened materials are tempered to improve their dimensional stability and toughness.

Tempering is a heat treatment technique applied to ferrous alloys, such as steel or cast iron, to achieve greater toughness by decreasing the hardness of the alloy. The reduction in hardness is usually accompanied by an increase in ductility, thereby decreasing the brittleness of the metal. Tempering is usually performed after quenching, which is rapid cooling of the metal to put it in its hardest state. Tempering is accomplished by controlled heating of the quenched work-piece to a temperature below its "lower critical temperature". This is also called the lower transformation temperature or lower arrest (A1) temperature; the temperature at which the crystalline phases of the alloy, called ferrite and cementite, begin combining to form a single-phase solid solution referred to as austenite. Heating above this temperature is avoided, so as not to destroy the very-hard, quenched microstructure, called martensite.

Precise control of time and temperature during the tempering process is crucial to achieve the desired balance of physical properties. Low tempering temperatures may only relieve the internal stresses, decreasing brittleness while maintaining a majority of the hardness. Higher tempering temperatures tend to produce a greater reduction in the hardness, sacrificing some yield strength and tensile strength for an increase in elasticity and plasticity. However, in some low alloy steels, containing other elements like chromium and molybdenum, tempering at low temperatures may produce an increase in hardness, while at higher temperatures the hardness will decrease. Many steels with high concentrations of these alloying elements behave like precipitation hardening alloys, which produces the opposite effects under the conditions found in quenching and tempering, and are referred to as maraging steels.

19. **Compare Austempering and martempering: (Nov/Dec 2015)**

martensite, forming a microstructure called "tempered martensite". Tempering is also performed on normalized steels and cast irons, to increase ductility, machinability, and impact strength. Steel is usually tempered evenly, called "through tempering," producing a nearly uniform hardness, but it is sometimes heated unevenly, referred to as "differential tempering," producing a variation in hardness.

Austempering forms bainite instead of martensite. Bainite is a slow isothermal transformation from austenite.

Bainite has increased ductility and toughness at the same strength levels as martensite.

Bainite has reduced distortion and residual stress which lowers subsequent processing costs.

Austempering provides the shortest cycle time to through –harden within the hardness range of Rockwell C 35-55 HRC. Not all steels can be austempered.

Austempering consists of the following processing steps. Heating to a temperature above A3 to transform the microstructure to austenite.

Quenching to a temperature above the Ms temperature and holding for a period of time to transform the austenite to bainite.

No tempering is required.

Steels for austempering: Plain carbon steels with carbon between 0.50 – 1.00% and manganese ≥ 0.60%

Carbon steels with manganese ≥ 1.00% and carbon slightly less than 0.50%.

Alloy steels with carbon ≥ 0.30% such as 5100 series.

Alloy steels with carbon ≥ 0.40% such as 1300 to 4000 series and 4140, 6145, 9440.

Martempering

To avoid residual stresses generated during quenching

Austenized steel is quenched above Ms (20-30°C above Ms i.e. 180 - 250°C)

Holding in salt bath for homogenization of temperature across the sample (large holding time is avoided to avoid forming bainite)

The steel is then quenched in air and the entire sample transforms simultaneously

Tempering follows

The process is called Martempering

The process is beneficial as: Steep temperature gradient is minimized

Thermal and structural stresses are minimal

More retained austenite – lesser volume change

20. Brief on the types of carburizing and need for post carburizing heat treatment? (Nov/Dec 2015)

Carburizing or carburization is a heat treatment process in which iron or steel absorbs carbon while the metal is heated in the presence of a carbon-bearing material, such as charcoal or carbon monoxide. The intent is to make the metal harder. Depending on the amount of time and temperature, the affected area can vary in carbon content. Longer carburizing times and higher temperatures typically increase the depth of carbon diffusion. When the iron or steel is cooled rapidly by quenching, the higher carbon content on the outer surface becomes hard due to the transformation from austenite to martensite, while the core remains soft and tough as a ferritic and/or pearlite microstructure.This manufacturing process can be characterized by the following key points: It is applied to low-carbon work pieces are in contact with a high-carbon gas, liquid or solid; it produces a hard work piece surface; work piece cores largely retain their toughness and ductility; and it produces case hardness depths of up to 0.25 inches (6.4 mm). In some cases it serves as a remedy for undesired decarburization that happened earlier in a manufacturing process.

Carburization of steel involves a heat treatment of the metallic surface using a source of carbon. Carburization can be used to increase the surface hardness of low carbon steel. Early carburization used a direct application of charcoal packed around the sample to be treated (initially referred to as case hardening), but modern techniques use carbon-bearing gases or plasmas (such as carbon dioxide or methane). The process depends primarily upon ambient gas composition and furnace temperature, which must be carefully controlled, as the heat may also impact the microstructure of the remainder of the material. For applications where great control over gas composition is desired, carburization may take place under very low pressures in a vacuum chamber.

Plasma carburization is increasingly used to improve the surface characteristics (such as wear, corrosion resistance, hardness, load-bearing capacity, in addition to quality-based variables) of various metals, notably stainless steels. The process is environmentally friendly (in comparison to gaseous or solid carburizing). It also provides an even treatment of components with complex geometry (the plasma can penetrate into holes and tight gaps), making it very flexible in terms of component treatment.

The process of carburization works via the diffusion of carbon atoms into the surface layers of a metal. As metals are made up of atoms bound tightly into a metallic crystalline lattice, the carbon atoms diffuse into the crystal structure of the metal and either remain in solution (dissolved within the metal crystalline matrix — this normally occurs at lower temperatures) or react with elements in the host metal to form carbides (normally at higher temperatures, due to the higher mobility of the host metal's atoms). If the carbon remains in solid solution, the steel is then heat treated to harden it. Both of these mechanisms strengthen the surface of the metal, the former by forming pearlite or martensite, and the latter via the formation of carbides. Both of these materials are hard and resist abrasion. Gas carburizing is normally carried out at a temperature within the range of 900 to 950 °C.In oxy-acetylene welding, a carburizing flame is one with little oxygen, which produces a sooty, lower-temperature flame. It is often used to anneal metal, making it more malleable and flexible during the welding process. A main goal when producing carburized work pieces is to ensure maximum contact between the work piece surface and the carbon-rich elements. In gas and liquid carburizing, the work pieces are often supported in mesh baskets or suspended by wire. In pack carburizing, the work piece and carbon are enclosed in a container to ensure that contact is maintained over as much surface area as possible. Pack carburizing containers are usually made of carbon steel coated with aluminum or heat-resisting nickel-chromium alloy and sealed at all openings with fire clay.

21. **Distinguish 'hardness and hardenability'. With suitable sketches, explain the Jominy hardness test for hardenability:**

Refer : Question No.2 (April/May 2015)

22. **Discuss different types of annealing processes? (Nov/Dec 2015)**

Purpose of Annealing:

The purpose of annealing may involve one or more of the following aims:

1. To soften the steel and to improve machinability.
2. To relieve internal stresses induced by some previous treatment (rolling, forging, uneven cooling).
3. To remove coarseness of grain.

The treatment is applied to forgings, cold-worked sheets and wire, and castings. The operation consists of:

a. Heating the steel to a certain temperature,

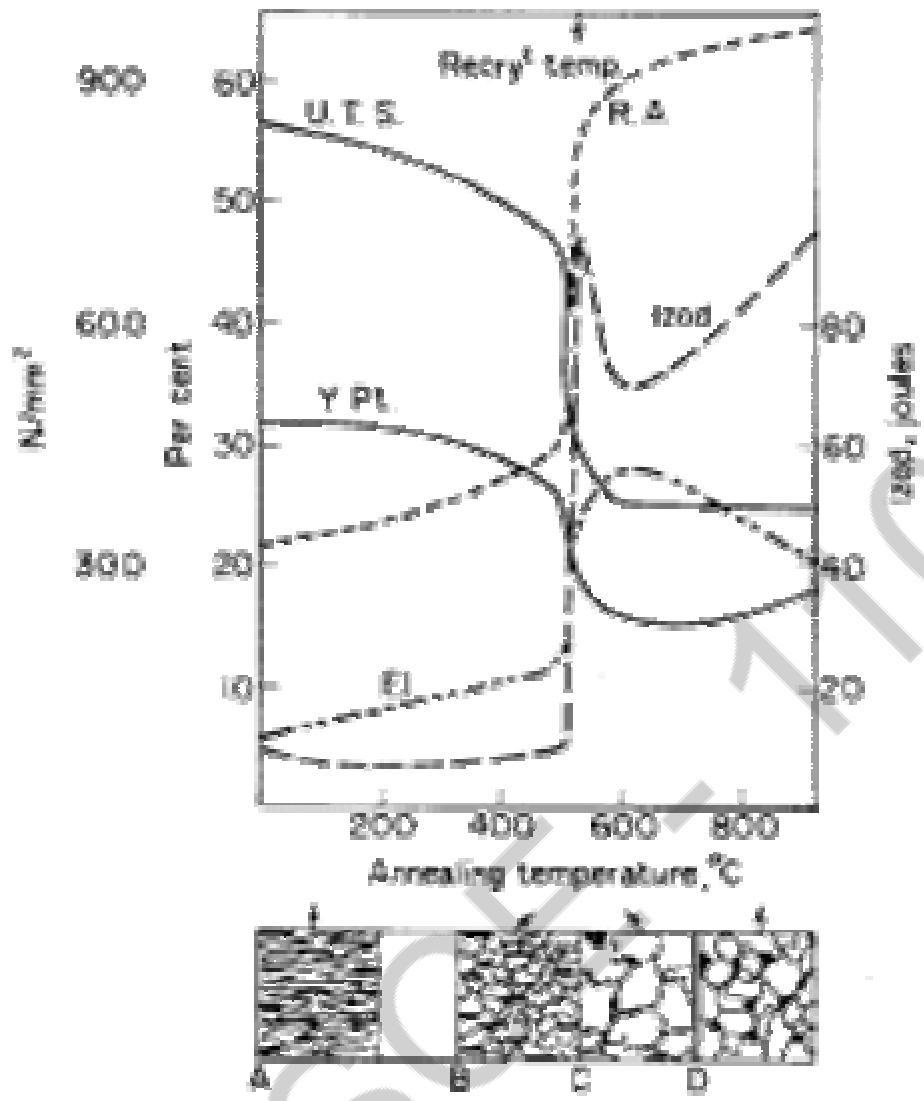
b. “Soaking” at this temperature for a time sufficient to allow the necessary changes to occur,

c. Cooling at a predetermined rate.

Sub-critical Annealing:

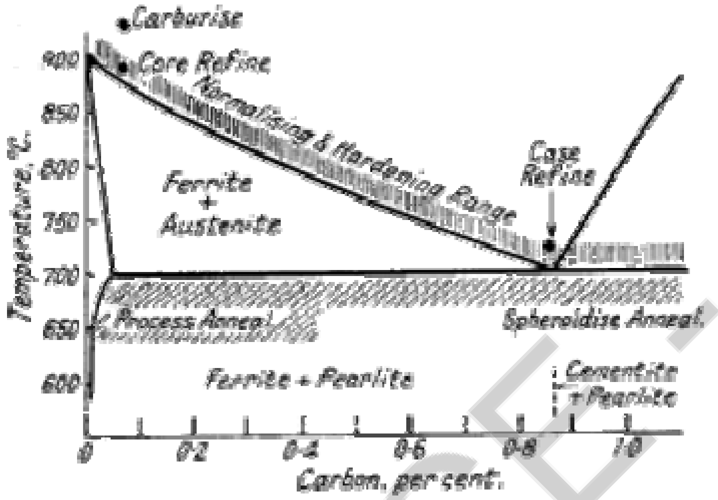
It is not always necessary to heat the steel into the critical range. Mild steel products which have to be repeatedly cold worked in the processes of manufacture are softened by annealing at 500° to650°C for several hours. This is known as “process” or “close” annealing, and is commonly employed for wire and sheets. The recrystallisation temperature of pure iron is in the region of 500°C consequently the higher temperature of 650°C brings about rapid recrystallisation of the distorted ferrite since mild steel contains only a small volume of strained pearlite a high degree of softening is induced. As shown, Fig. 1b illustrates the structure formed consisting of the polyhedral ferrite with elongated pearlite. Prolonged annealing induces greater ductility at the expense of strength, owing to the tendency of the cementite in the strained pearlite to “ball-up” or spheroidise, as illustrated in figure. This is known as “divorced pearlite”. The ferrite grains also become larger, particularly if the metal has been cold worked a critical amount. A serious embrittlement sometimes arises after prolonged treatment owing to the formation of cement tic films at the ferrite boundaries. With severe forming operations, cracks are liable to start at these cementite membranes. The modern tendency is to use batch or continuous annealing furnaces with an inert purging gas. Batch annealing usually consists of 24-30 hrs 670°C, soak 12 hrs, and slow cool it for 4-5 days. Open coil annealing consists in recoiling loosely with controlled space between wraps and it reduces sticker sand discoloration. Continuous annealing is used for thin strip (85% Red) running at about 400 m/min. The cycle is approximately up to 660°C 20 sec, soak and cool 30-40 sec. There is little chance for grain growth and it produces harder and stiffer strip; useful for cans and paneling.”Double reduced” steel is formed by heavy reduction (~50%) after annealing but it suffers from directionality. This can be eliminated by heating between 700- 920°C and rapidly quenching.

23. **Explain normalizing and induction hardening. (Nov/Dec 2015)**


Recry^t temp.
U.T.S.
R.A.
Izod
Y Pt.
El.
900
600
300
N/mm²
Per cent
60
50
40
30
20
10
80
60
40
20
Izod, joules
200
400
600
800
Annealing temperature, °C
A
B
C
D

Full Annealing and Normalizing Treatments

For steels with less than 0,9% carbon both treatments consist in heating to about 25-50°C above the upper critical point indicated by the Fe-Fe3C equilibrium diagram (Fig. 2.1). For higher carbon steels the temperature is 50°C above the lower critical point. These temperatures allow for the effects of slight variations in the impurities present and also the thermal lag associated with the critical changes. After soaking at the temperature for a time dependent on the thickness of the article, the steel is very slowly cooled. This treatment is known as full annealing, and is used for removing strains from forgings and castings, improving machinability and also when softening and refinement of structure are both required. Normalizing differs from the full annealing in that the metal is allowed to cool in still air. The structure and properties produced, however, varying with the thickness of metal treated. The tensile strength, yield point, reduction of area and impact value are higher than the figures obtained by annealing.



Changes on Annealing:

Consider the heating of a 0,3% carbon steel. At the lower critical point (Ac1) each "grain" of pearlite changes to several minute austenite crystals and as the temperature is raised the excess ferrite is dissolved, finally disappearing at the upper critical point (Ac3), still with the production of fine austenite crystals. Time is necessary for the carbon to become uniformly distributed in this austenite. The properties obtained subsequently depend on the coarseness of the pearlite and ferrite and their relative distribution. These depend on:

a) the size of the austenite grains; the smaller their size the better the distribution of the ferrite and pearlite. b) the rate of cooling through the critical range, which affects both the ferrite and the pearlite.

As the temperature is raised above Ac3 the crystals increase in size. On a certain temperature the growth, which is rapid at first, diminishes. Treatment just above the upper critical point should be aimed at, since the austenite crystals are then small.

By cooling slowly through the critical range, ferrite commences to deposit on a few nuclei at the austenite boundaries. Large rounded ferrite crystals are formed, evenly distributed among the relatively coarse pearlite. With a higher rate of cooling, many ferrite crystals are formed at the austenite boundaries and a network structure of small ferrite crystals is produced with fine pearlite in the centre. Overheated, Burnt and Under annealed structures when the steel is heated well above the upper critical temperature large austenite crystals form. Slow cooling gives rise to the Widmanstatten type of structure, with its characteristic lack of both ductility and resistance to shock. This is known as an overheated structure, and it can be refined by reheating the steel to just above the upper critical point. Surface decarburization usually occurs during the overheating. During the Second World War, aircraft engine makers were troubled with overheating (above 1250°C) in drop-stampings made from alloy steels. In the hardened and tempered condition the fractured surface shows dull facets. The minimum overheating temperature depends on the "purity" of the steel and is substantially lower in general for electric steel than for open-hearth steel. The overheated structure in these alloy steels occurs when they are cooled at an intermediate rate from the high temperature. At faster or slower rates the overheated structure may be eliminated. This, together with the fact that the overheating temperature is significantly raised in the presence of high contents of MnS and inclusions, suggests that this overheating is connected in some way with a diffusion and precipitation process, involving MnS. This type of overheating can occur in an atmosphere free from oxygen, thus emphasizing the difference between overheating and burning. As the steel approaches the solids temperature, incipient fusion and oxidation take place at the grain boundaries. Such steel is said to be burnt and it is characterized by the presence of brittle iron oxide films, which render the steel unfit for service, except as scrap for remelting.

24. **Explain in detail about spheroidizing. What is tempering of steel. Explain? (Nov/Dec 2014)**

Spheroidizing is a form of heat treatment for iron-based alloys, commonly carbon steels, in order to convert them into ductile and machinable alloys. It is conducted at temperatures that are slightly below the eutectoid temperature (temperature at which the solution is a solid solution rather than liquid), followed by a slow cooling process. The resulting spheroidite structure is a microstructure that contains sphere-like cementitie particles. Spheroidite is known as the most ductile and machinable form of steel. This article will look into the technique and applications of spheroidizing process.

Spheroidizing of high carbon steel is a method of prolonged heating at a temperature below the eutectoid temperature. By heating at this temperature pearlite, which is the lowest energy arrangement of steel, gets converted to ferrite and cementite. The graphite content of steel assumes a spheroidal shape after spheroidizing and after prolonged heating the pearlite layers are broken down and spherical lumps of cementite, or spheroidite, are formed.

The structures in spheroidite are one thousand times larger than those of pearlite and are spaced further apart. This means the spheroidite steel is extremely ductile. However, the process of spheroidizing does consume a lot of energy.

Advantages of Spheroidizing

Some of the advantages of spheroidizing are mentioned below:

- Increases ductility of high carbon steel
- Spheroidite structure reduces energy needed for subsequent operations
- Machinability is increased.

Industrial Applications

Some of the industrial applications of spheroidizing are listed below:

- Machinable steel
- Rail road tracks
- Tyre cords
- Bridge cables.

Tempering is a process of heat treating, which is used to increase the toughness of iron-based alloys. Tempering is usually performed after hardening, to reduce some of the excess hardness, and is done by heating the metal to some temperature below the critical point for a certain period of time, then allowing it to cool in still air. The exact temperature determines the amount of hardness removed, and depends on both the specific composition of the alloy and on the desired properties in the finished product. For instance, very hard tools are often tempered at low temperatures, while springs are tempered to much higher temperatures.

Tempering is a heat treatment technique applied to ferrous alloys, such as steel or cast iron, to achieve greater toughness by decreasing the hardness of the alloy. The reduction in hardness is usually accompanied by an increase in ductility, thereby decreasing the brittleness of the metal. Tempering is usually performed after quenching, which is rapid cooling of the metal to put it in its hardest state. Tempering is accomplished by controlled heating of the quenched work-piece to a temperature below its "lower critical temperature". This is also called the lower transformation temperature or lower arrest (A1) temperature; the temperature at which the crystalline phases of the alloy, called ferrite and cementite, begin combining to form a single-phase solid solution referred to as austenite. Heating above this temperature is avoided, so as not to destroy the very-hard, quenched microstructure, called martensite.

Precise control of time and temperature during the tempering process is crucial to achieve the desired balance of physical properties. Low tempering temperatures may only relieve the internal stresses, decreasing brittleness while maintaining a majority of the hardness. Higher tempering temperatures tend to produce a greater reduction in the hardness, sacrificing some yield strength and tensile strength for an increase in elasticity and plasticity. However, in some low alloy steels, containing other elements like chromium and molybdenum, tempering at low temperatures may produce an increase in hardness, while at higher temperatures the hardness will decrease. Many steels with high concentrations of these alloying elements behave like precipitation hardening alloys, which produces the opposite effects under the conditions found in quenching and tempering, and are referred to as maraging steels.

In carbon steels, tempering alters the size and distribution of carbides in the martensite, forming a microstructure called "tempered martensite". Tempering is also performed on normalized steels and cast irons, to increase ductility, machinability, and impact strength. Steel is usually tempered evenly, called "through tempering," producing a nearly uniform hardness, but it is sometimes heated unevenly, referred to as "differential tempering," producing a variation in hardness.

25. **What is CCR. Write difference between normalizing and tempering? (Nov/Dec 2014)**

Annealing and Normalizing are the primary processes which come under the category of heat treatment of steels.

Tempering is a secondary treatment which is done after the primary processes of heat treatment.

Quenching is the cooling of the material from the higher temperature of the room temperature.

When you take a untreated piece of steel and put it in a furnace to raise its temperature to around 723oC i.e to a single phase and after that turn off the furnace and let the piece of steel to cool inside a furnace, this process is known as annealing (Furnace cooling or slow cooling)

When you take a untreated piece of steel and put it in a furnace and raise the temp. to the around 723oC i.e to a single phase and take the piece out of the furnace and allow it to cool in air, this process is known as normalizing (air cooling).

After ant primary treatment especially after hardening(water or oil cooled),the material incurs such properties which are unfit for certain application ,in those cases we can in order to improve the property we need to heat the metal to a temp. less than 723oC temp. This is known as tempering.

Quenching is the cooling process generally, faster cooling like dipping in water, brine solution, oil etc.