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Internal Assessment Test 3 – Nov. 2019

Sub:	Material Science					Sub Code:	18ME34	Branch:	Mech	
Date:	16/11/2019	Duration:	90 min's	Max Marks:	50	Sem/Sec:	III/A&B		OBE	
<u>Answer ALL FOUR Questions</u>								MARKS	CO	RBT
1	With the help of a TTT curve explain the transformation of austenite to various phases.						[15]	CO3	L1	
2	Draw the Iron-Iron carbide phase diagram and explain all the phases in detail.						[15]	CO2	L1	
3	What are the different types of solid solutions? List the Hume Rothary rules to obtain complete solubility in solid solutions.						[10]	CO2	L1	
4	Explain Flame Hardening and Induction Hardening with neat sketches.						[10]	CO3	L1	

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Scheme of Internal Assessment Test 3 – Nov. 2019

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4	Explain Flame Hardening and Induction Hardening with neat sketches. Diagram – 6 marks Explanation – 4 Marks						[10]	CO3	L1	

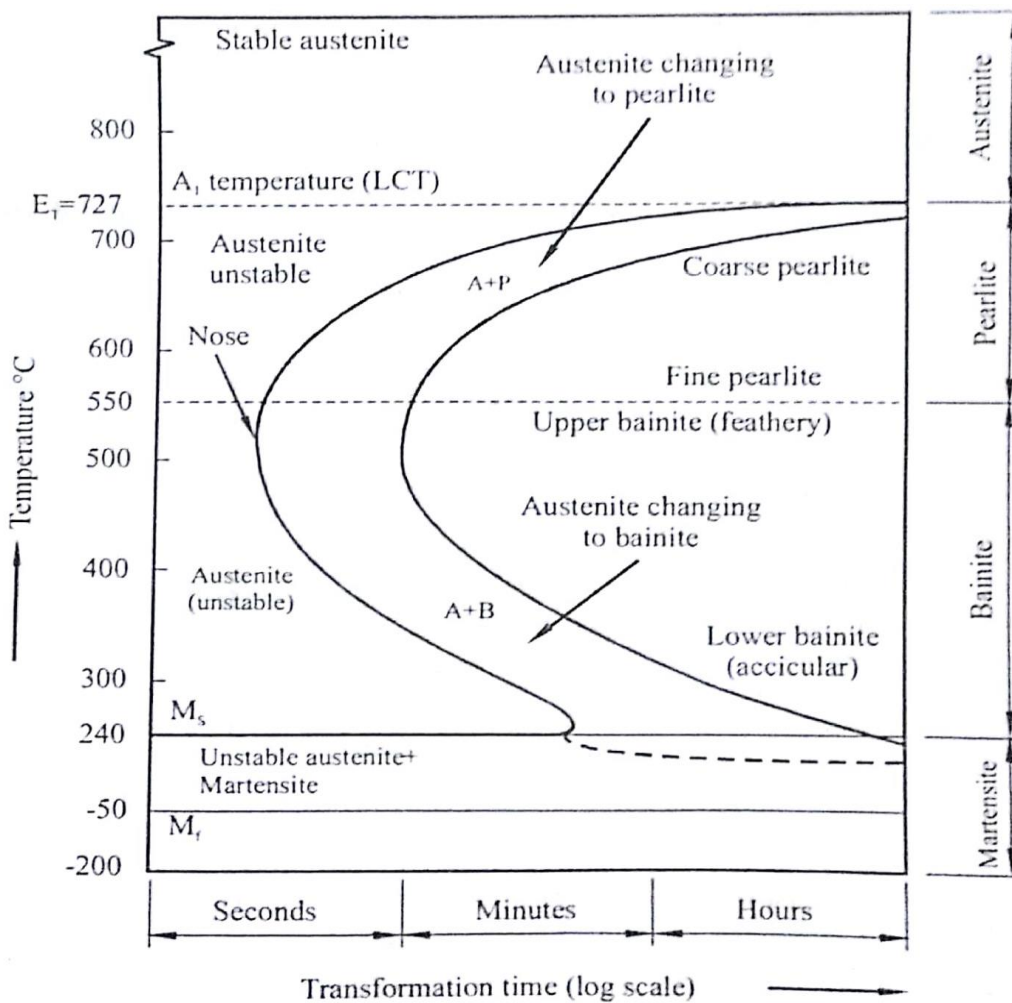
1.

3.3 T-T-T DIAGRAM for EUTECTOID STEEL

Figure 3.3 shows the TTT diagram for a eutectoid steel containing about 0.83 % C.

The microstructures obtained at different cooling rates is explained briefly as follows:

- Austenite is stable above 727°C , but unstable below 727°C , i.e., it can transform into pearlite, bainite or martensite structure.
- At temperatures between 727°C and approximately 550°C , transformation occurs to produce a lamellar microstructure of pearlite. At temperatures just below 727°C , nucleation of cementite from austenite will be very slow, but diffusion and growth of nuclei will proceed at a maximum speed to produce a coarse pearlite. As the transformation temperature is lowered to about 550°C , which is the *nose* or *knee* of the TTT curve, pearlite changes from a coarse to a fine structure.



M_s = Martensite start temperature
 M_f = Martensite finish temperature
A+P = Austenite + Pearlite (Pearlite forming from austenite)
A+B = Austenite + Bainite (Bainite forming from austenite)

Figure 3.3 TTT diagram for eutectoid steel containing 0.83% C

- c) At a temperature just below 550°C , diffusion is very slow, and as such, the transformation time increases. The slower rate of diffusion of carbon atoms in austenite transforms austenite to a new product called *bainite*. The microstructure consists of a non-lamellar eutectoid structure of α -ferrite and cementite (Fe_3C). Bainite, which forms just below 550°C is called *upper bainite*, & consists of typically open feathery structure, and bainite forming at lower temperatures is called *lower bainite*, and its structure is somewhat similar to lightly tempered martensite.
- d) In quenching down to about 240°C , the temperature drops rapidly to a point so low that the diffusion becomes too small for the formation of nuclei. Austenite changes incompletely into a distorted body centered structure (BCC) with little or no diffusion of the carbon into particles of cementite to form *martensite*.
- e) When the martensitic reaction ceases to M_f (martensitic final temperature), all the austenite should have transformed to martensite, but frequently, in practice, a small proportion of the austenite does not transform. Larger volume fractions of austenite are retained in some highly alloyed steels, where the martensitic final temperature (M_f) is well below the room temperature.

2.

2.18 IRON-CARBON DIAGRAM ($\text{Fe}-\text{C}$) or IRON-IRON CARBIDE PHASE DIAGRAM ($\text{Fe}-\text{Fe}_3\text{C}$)

Figure 2.30 shows the simplified iron-carbon ($\text{Fe}-\text{C}$) phase equilibrium diagram with carbon content up to 6.67 %, plotted on x -axis and temperature on the vertical y -axis. The origin of the x -axis (extreme left hand) represents 100 % iron (pure iron) and 0 % carbon. Moving towards right side from the origin indicates increasing percentage of carbon. The extreme right end of the x -axis stops at 6.67 % carbon instead of 100 % carbon concentrations. This is because, a maximum amount of 6.67 % carbon can only be added to molten iron at which it becomes saturated. Any further addition of carbon will not make it dissolve in iron, but rather floats or get blown away owing to its very low density.

Iron containing 6.67 % carbon forms a phase called *cementite* or *iron carbide* (Fe_3C), and it is for this reason, the iron-carbon diagram ($\text{Fe}-\text{C}$) is also known as iron-iron carbide ($\text{Fe}-\text{Fe}_3\text{C}$) equilibrium diagram with pure iron (Fe) and iron carbide (Fe_3C) forming the extremities of the phase diagram on the x -axis. The diagram is also known as *metastable Fe-Fe₃C* diagram.

E = Eutectic point E_1 = Eutectoid point γ = Austenite (γ -iron) α = Ferrite (α -iron) δ = Delta Iron

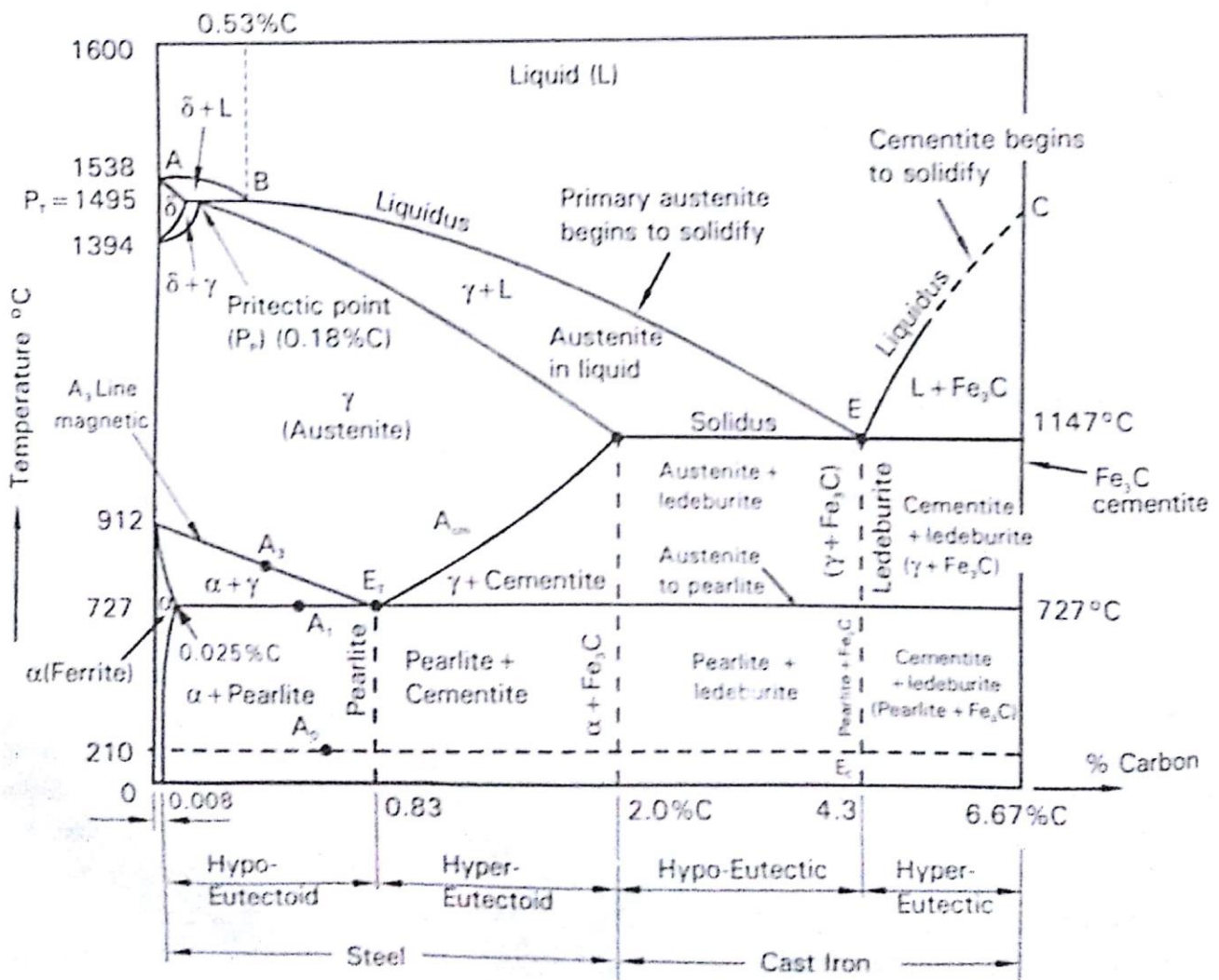


Figure 2.30 Iron-Carbon (Fe-C) phase diagram

2.18.1 Comments on Iron-Carbon Diagram

Following is a brief information on the iron - carbon diagram shown in figure 2.30.

- Point A in the phase diagram represents the melting point of pure iron, which is equal to 1538°C.
- The curve ABEC is called the *liquidus*. The alloy represented by a particular temperature and composition above the region ABEC are completely in the liquid phase.
- Iron containing carbon content from about 0.008 % to about 2 % is called *steel*, and between 2% and approximately 6.67 % C, is termed as *cast iron*. Further, steels and cast iron based on the carbon content are classified as follows:

Steels

- *Hypo-eutectoid steels* : Carbon content ranges from 0.008 % – 0.83 %.
- *Hyper-eutectoid steels* : Carbon content ranges from 0.83 % – 2 %.

Cast iron

- *Hypo-eutectic cast iron* : Carbon content ranges from 2 % – 4.3 %.
 - *Hyper-eutectic cast iron* : Carbon content ranges from 4.3 % – 6.67 %.
- 1) Carbon is an interstitial impurity in iron. It forms a solid solution with α , γ , and δ phases of iron.
- α – Iron is known as α – ferrite or just ferrite
 - γ – Iron is known as γ – austenite or just austenite, and
 - δ – Iron is known as δ – ferrite. The structure of δ – ferrite is similar to that of α – ferrite.
- 2) Point E is known as *eutectic point*, and the corresponding temperature and carbon concentrations are 1147°C and 4.3% carbon respectively.
- 3) Point P_p represents the *peritectic point*, and point E_T represents *eutectoid point*.
- 4) A_1 , A_3 , and A_{cm} represent the critical temperatures of steel. At the critical temperatures, phase changes occur during heating or cooling of the alloy. Refer section 2.18.4 for information.

2.18.2 Phases in Iron-Carbon Diagram

The possible phases existing in the Iron-Carbon diagram shown in figure 2.30 include:

- α - ferrite : solid solution of carbon in BCC iron
- γ - austenite : solid solution of carbon in FCC iron
- δ - ferrite : solid solution of carbon in BCC iron
- Iron carbide (Fe_3C) or Cementite : an intermetallic compound
- Ledeburite : $\gamma + Fe_3C$
- Pearlite : $\alpha + Fe_3C$

1) α -ferrite (α -iron)

α -ferrite also known as α -iron (alpha iron), or just ferrite, is an interstitial solid solution of a small amount of carbon dissolved in iron having a body centered cubic (BCC) crystal structure. The maximum solubility of carbon in iron is 0.025 % C at 727°C, and 0.008 % at room temperature.

α - ferrite is the softest structure on the iron - carbon phase diagram. It is the component which gives steel and cast iron their magnetic properties, and is the classic example of ferromagnetic material.

b) γ -austenite (γ -iron)

γ -austenite* is also known as γ -iron (gamma iron), which is an interstitial solid solution of carbon dissolved in iron with a face centered cubic structure (FCC). The maximum solubility of carbon in iron is approximately 2.0 % carbon at 1147°C.

Austenite is normally unstable at room temperature, and hence will not be normally present in the microstructure at room temperature. However, austenite can be made to be present at room temperature (make stable) by rapid cooling. Austenite, which is having an FCC structure, is non-magnetic in nature.

c) δ -ferrite (δ -iron)

δ -ferrite is also known as δ -iron (delta iron) has the same structure as α -ferrite, i.e., BCC structure. It is magnetic, and stable only at high temperatures, say above 1394°C .

d) Iron carbide or Cementite

Iron carbide (Fe_3C) or cementite containing 6.67 % C by weight is a typical hard and brittle intermetallic compound of low tensile strength, but high compressive strength. It is the hardest structure that appears on the iron – carbon phase diagram.

d) Ledeburite ($\gamma + \text{Fe}_3\text{C}$)

Ledeburite[†] is the eutectic mixture of austenite (γ) and cementite (Fe_3C). The eutectic reaction takes place at 1147°C (eutectic temperature) and 4.3 % carbon (eutectic composition).

Ledeburite exists when the carbon content is approximately greater than 2.0 %, which represents the dividing line on the phase diagram between steel and cast iron.

e) Pearlite ($\alpha + \text{Fe}_3\text{C}$)

Pearlite is the eutectoid mixture containing 0.83 % C, and is formed at 727°C . When austenite containing 0.83 % C is cooled very slowly to below 727°C , it transforms into Pearlite. The structure is called *pearlite*, because it has the appearance of *mother-of-pearl* when viewed under the microscope at low magnifications.

Pearlite is a very fine plate-like or lamellar (or layered) structure consisting of alternating layers of ferrite (α) and cementite (Fe_3C). The structure of pearlite includes a white matrix (ferrite background), which includes thin plates of cementite.

3.

Types of Solid Solutions

Based on the type of impurity point defects found in solid solutions, they are classified as:

- a) Substitutional solid solution
 - Dis-ordered substitutional solid solution
 - Ordered substitutional solid solution
- b) Interstitial solid solution

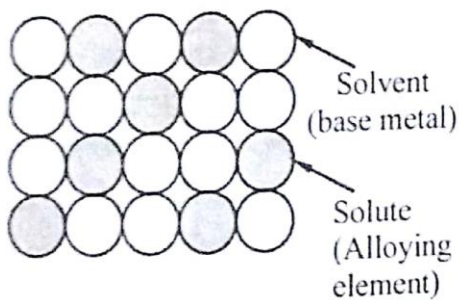
2.9.1 Substitutional Solid Solution

Substitutional solid solution forms when the atoms of the base metal (solvent) are replaced or substituted by the atoms of the alloying metal (solute). In this case, the atoms of the two metals in the alloy are approximately of equal size. For example, the atomic radius of *copper* is 0.128 nm and that of *nickel* is 0.125 nm. These two elements are completely soluble in each another. Thus, both of them combine to form *monel* - a substitutional solid solution (alloy).

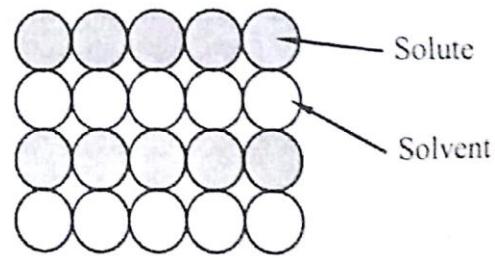
Substitutional solid solutions are further divided into two types based on the order in the substitution of the two metal elements. They are:

a) Dis-ordered substitutional solid solution

When the atoms of the alloying element (solute) do not occupy any specific position, but are distributed at random in the lattice structure of the base metal (solvent) as shown in figure 2.6 (a), the resulting solid solution is called random or *dis-ordered substitutional solid solution*. The process takes place at higher temperatures due to greater thermal agitation.



(a) Dis-ordered substitutional solid solution



(b) Ordered substitutional solid solution

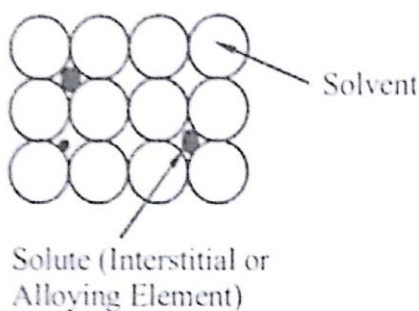
Figure 2.6 Substitutional solid solution

b) Ordered substitutional solid solution

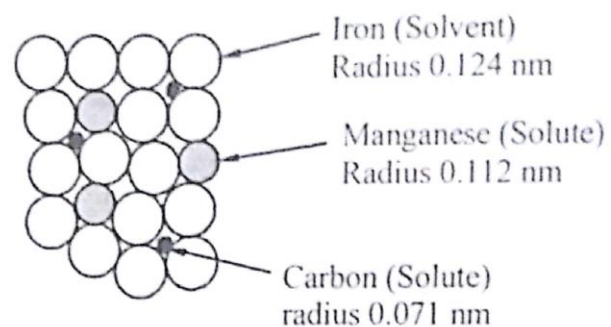
When the atoms of the alloying element (solute) substitute the atoms of the base metal (solvent) in an orderly manner, occupying fixed positions in the lattice structure of the base metal, the resulting solid solution is called *ordered substitutional solid solution*. Refer figure 2.6 (b). The process usually takes place when a solid solution is cooled slowly from the high temperature region. Ordering increases the electrical conductivity, hardness and strength, but decreases the ductility of the alloy.

2.9.2 Interstitial Solid Solution

When the atoms of the base metal (solvent) are bigger than the atoms of the alloying element (solute), substitutional of atoms is impossible, instead, the small sized atoms of the alloying element fit in the open spaces between the bigger base metal atoms (solvent) as shown in figure 2.7(a). In such cases, an interstitial solid solution is said to have formed.



(a)



(b)

Figure 2.7 Interstitial solid solution

2.11 HUME ROTHERY'S RULE (Factors Affecting Solubility) or (Rules Governing Formation of Substitutional Solid Solution)

In order to develop an alloy with favourable mechanical and other properties, it is essential to make a proper choice in the type and proportion of the alloying elements that will form a solid solution. Hume Rothery has formed empirical rules that govern the choice of alloying elements in the formation of substitutional solution. They are:

a) Crystal structure

Two or more elements (metals) should have the same crystal structure for complete solubility; otherwise the two solutions will not merge into each other. For example, copper and nickel both have FCC structure, and combine to form *monel*.

b) Atomic size

For complete solubility of two elements, they should have approximately the same atomic radius. The variation in the atomic radius should not differ by more than 15%. For example, copper having an atomic radius of 0.128 nm combines with nickel, which has an atomic radius of 0.125 nm to form *monel*. However, when the size difference is more than 15%, only limited solubility will be obtained.

c) Chemical affinity factor

For a substitutional solid solution to form, the two metals should have a low chemical affinity for each other. Generally, the nearer the elements are in the periodic table, the lower is their chemical affinity. When the chemical affinity of two metals is great, they tend to form an intermediate phase (intermediate compound) rather than solid solution.

d) Electro-negativity

For a substitutional solid solution to form, the atoms of the two elements must have approximately the same electro-negativity (tendency of an atom to gain an electron). For example, the electro-negativity of copper is 1.9, and that of nickel is 1.8, and the two (copper and nickel) form substitutional solid solution. However, great differences in electro-negativity of the two elements will encourage the formation of intermediate phase rather than a solid solution.

e) Valence factor

The valency of base metal and the alloying element should be the same; otherwise the valence electron difference encourages the formation of intermediate phase rather than solid solution. Generally, a metal of high valence can dissolve only a small amount of lower valence metal, whereas, the lower valence metal may have good solubility for a higher valence metal. For example, in the aluminum-nickel alloy system, nickel is *lower* in valence than aluminum, and thus, solid nickel dissolves 5% aluminum, but the higher valence aluminum dissolves only 0.04% nickel.

4.

3.22 FLAME HARDENING

Flame hardening as shown in figure 3.17 is a process of selective hardening, which involves heating the surface of a steel specimen with an oxyacetylene flame to the austenite range, and then immediately quenching the surface with cold water. Heating transforms the structure of the surface layers to austenite, while quenching changes austenite to martensite. Only the heated surface (to a certain depth) becomes hard, while the *core* remains soft and tough. The depth of hardening depends on the heat supplied per unit surface area per unit time. Thus the faster the flame is moved over the surface, the lesser the depth of hardening achieved. The temperatures used in this method are typically of the order of 850°C or more, i.e., above the upper critical temperature.

After hardening process, the steel specimen is subjected to low temperature tempering process in order to improve its ductility and toughness.

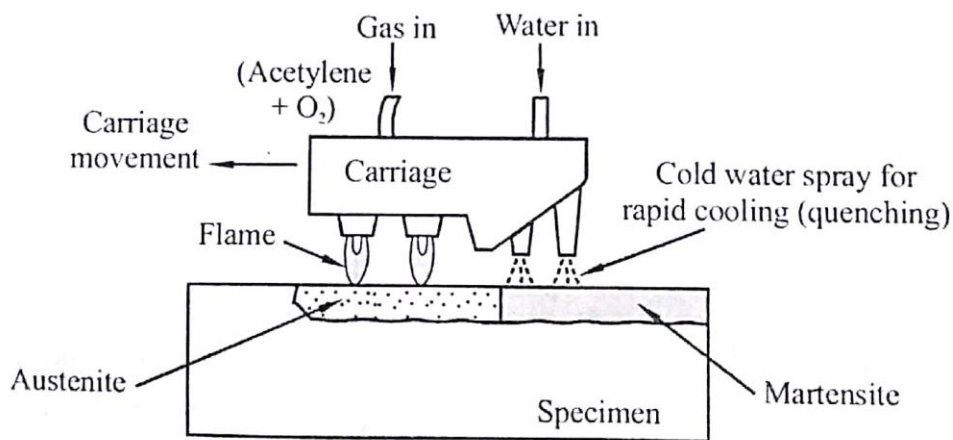


Figure 3.17 Progressive flame hardening

3.23 INDUCTION HARDENING

Induction hardening is a process of selective hardening used to produce a hard and wear resistant surface with a soft core in steel components. Figure 3.18 shows the principle of induction hardening. The process involves placing a steel specimen in an inductor coil that comprises several turns of copper tube. The copper tube acts as primary coil of the transformer and is water cooled. When a high frequency current of about $1000 - 10,000$ cycles/sec is passed through the inductor coil, it sets up a magnetic field. This magnetic field induces high frequency eddy currents and hysteresis currents in the steel specimen. The resistance offered by the steel specimen to the flow of currents through it results in rapid heating of the surface layers of the specimen. The temperature produced is in the range of about $700 - 800^{\circ}\text{C}$, which causes the surface layers to change to austenite. At this moment, the surface is sprayed with cold water to transform the austenite to martensite. Thus, only the surface of the specimen gets hardened, while the interior core remains soft.

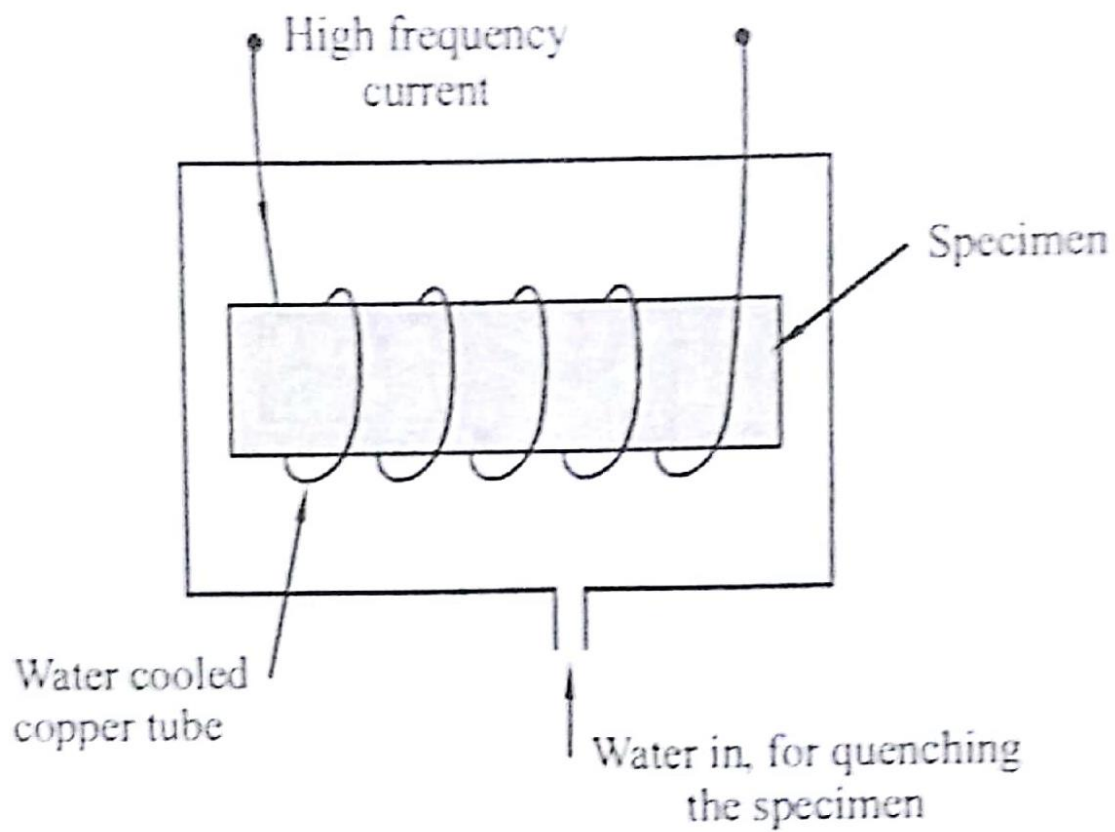


Figure 3.18 Principle of induction hardening