

Material Science

Internal Assessment Test 3

Date :- 14/12/2020

Note :- Answer any 5 full questions. All questions carry 10 marks.

1. Draw the TTT curve and the cooling curves in one graph and explain it.
2. Define annealing and explain its various types.
3. Explain all the three carburizing processes.
4. With a neat diagram explain flame hardening and induction hardening process.
5. Define composites and classify it based on the reinforcement and matrix. Also state the roles of matrix and reinforcement.
6. With the help of a neat sketch explain spray layup process and pultrusion process.

Solution

1.

3.6 CONTINUOUS COOLING TRANSFORMATION (CCT) DIAGRAMS

TTT diagrams measure the rate of transformation at constant temperature. However, in certain situations, it becomes more convenient to cool materials at a certain rate rather than to cool quickly and hold it at a constant temperature. The disadvantage of TTT diagrams has been overcome with the development of CCT diagrams.

CCT diagrams record the progress of transformation with reducing temperature for a series of cooling rates. These diagrams are used to represent the type of phase changes that occur when a material is cooled at different rates. CCT diagrams are produced by determining the microstructure produced in steel at various rates of cooling.

Figure 3.6 shows the CCT diagram for a 0.8 % plain carbon steel. For a fast rate of cooling at $140^\circ \text{C}/\text{s}$, from the stable austenite state (at point A), the only transformation that occurs is from austenite to martensite. The cooling line is not passing through the area indicating the austenite to pearlite transformation.

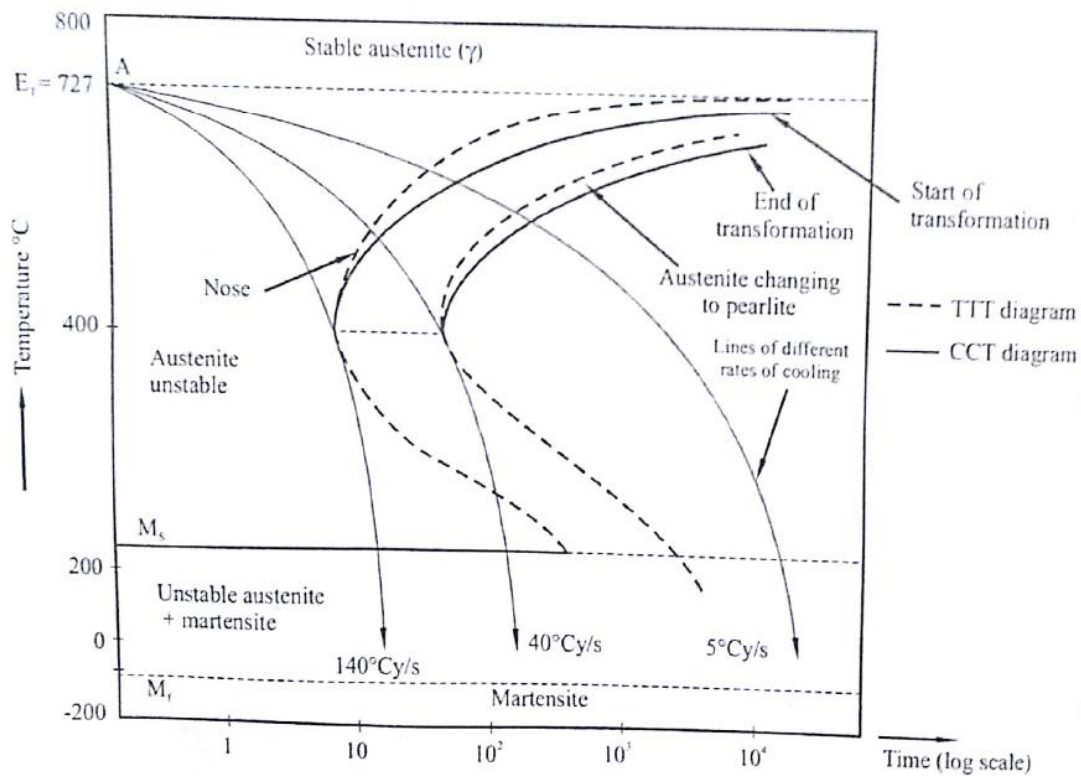


Figure 3.6 CCT diagram for 0.8% carbon steel

For a cooling rate between 140 and $40^\circ \text{C}/\text{s}$, austenite starts transforming to pearlite, but the transformation is not completed. The remaining austenite is then transformed to martensite.

For a slow rate of cooling at $40^\circ \text{C}/\text{s}$, austenite starts to transform to pearlite, and the transformation is completed, resulting in a completely pearlitic structure.

Thus, it is clear from the CCT diagram that, for a 0.8 % C, if the structure is to be entirely martensitic, and hence show maximum hardness, the cooling rate must be faster than $140^\circ \text{ cycles/sec}$. On the other hand, for the structure to be entirely pearlite, the cooling rate must be approximately at $40^\circ \text{ cycles/sec}$.

2.

Annealing is a heat treatment process, in which the metal is heated to a high temperature, holding (soaking) it there for a considerable time, and then allowing it to cool to room temperature at a predetermined rate. Heating the metal to high temperatures allow diffusion process to occur fast. Also, the holding time (soaking time) at the high temperature is long enough to allow the desired phase transformation to occur. The metal is then cooled slowly to room temperature to avoid the distortion (warping) of the metal piece, or even cracking, caused by stresses induced by differential contraction due to thermal inhomogenities.

Purpose of annealing

The purpose of annealing is to achieve one or more of the following objectives:

- To relieve internal stresses induced by some primary processes, say rolling, forging, uneven cooling etc.
- To remove coarseness of grains (refine grain structure).
- Soften the metal, so as to improve machinability, formability, and sometimes to control magnetic properties.
- To improve ductility.

Types of annealing

- 1) Full annealing
- 2) Process annealing or sub-critical annealing
- 3) Spheroidizing annealing
- 4) Stress-relief annealing

3.10.1 Full Annealing

The term *full annealing* is used for the treatment that involves heating steel to its austenitic state before subjecting it to very slow cooling. Refer figure 3.7

Purpose To relieve internal stresses, improve ductility and grain refinement.

Process The process consists of heating the metal (steel) above the upper critical temperature- A_3 line (austenitic zone), holding it there for a considerable time, so that it becomes completely austenitic, and then allowing it to cool slowly in the furnace. Slow cooling associated with full

annealing enables the austenite to decompose to form the following structures:

- A *pearlite + ferrite* structure in case of hypo-eutectoid steels
- A *pearlite + cementite* structure in hyper-eutectoid steels.

The phases re-crystallize completely in this process, and the structure is refined. The metal gets softened with improved mechanical properties.

Temperature range

For hypo-eutectoid steels ($< 0.83\%C$), the metal is heated to about $50 - 90^\circ C$ above the *upper critical temperature* A_1 line, i.e., to the austenitic phase.

For hyper-eutectoid steels ($> 0.83\%C$), the metal is heated to about $50 - 90^\circ C$ above the *lower critical temperature* A_1 line, i.e., above eutectoid temperature $727^\circ C$.

Applications Full annealing is used for low and medium carbon steels that will be machined, or will experience extensive plastic deformation during a forming operation.

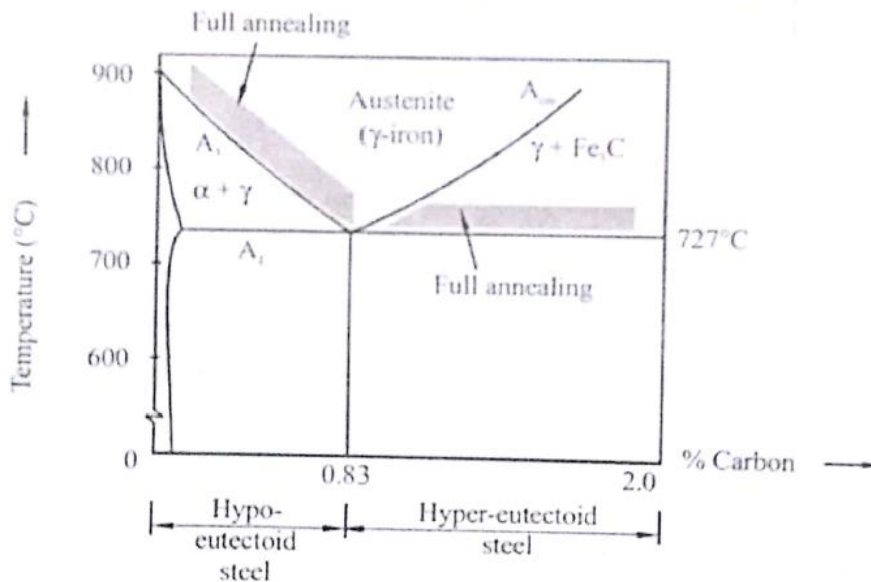


Figure 3.7 Full annealing

3.10.2 Process Annealing or Sub-critical Annealing

Process annealing or sub-critical annealing is a process carried out on low carbon steels to revert the effect of cold work¹, i.e., to soften and increase the ductility of a previously strain or work hardened (cold work) metal, thereby permitting further deformation.

Purpose To soften and increase the ductility of a previously strain hardened metal.

Process The process as shown in figure 3.8 consists of heating the metal in the range of $550 - 550^\circ C$, which is just below the lower critical temperature A_1 line. The metal is held at this

¹ Cold working – The plastic deformation of a metal at a temperature below that at which it recrystallizes.

temperature for certain duration and then cooled slowly usually in *air* in order to soften the metal for further cold working, as in the case of wire drawing operation.

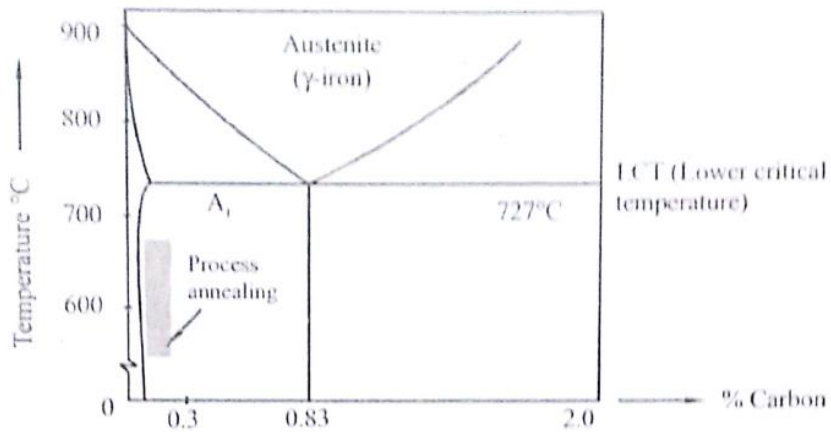


Figure 3.8 Process or Sub-critical annealing

Applications Process annealing is often used during cold working process with low carbon steels (less than about 0.3 %C), where the material has to be made more ductile and stresses have to be relieved for the deformation process to continue.

3.10.3 Spheroidizing Annealing

When sub-critical or process annealing is applied to steels having carbon concentration greater than 0.3 %, the effect of the heating is to cause the cementite to assume globular or spherical shapes – hence the name *spheroidizing annealing*. Refer figure 3.9.

Purpose To improve machinability, and facilitate a subsequent cold working operation.

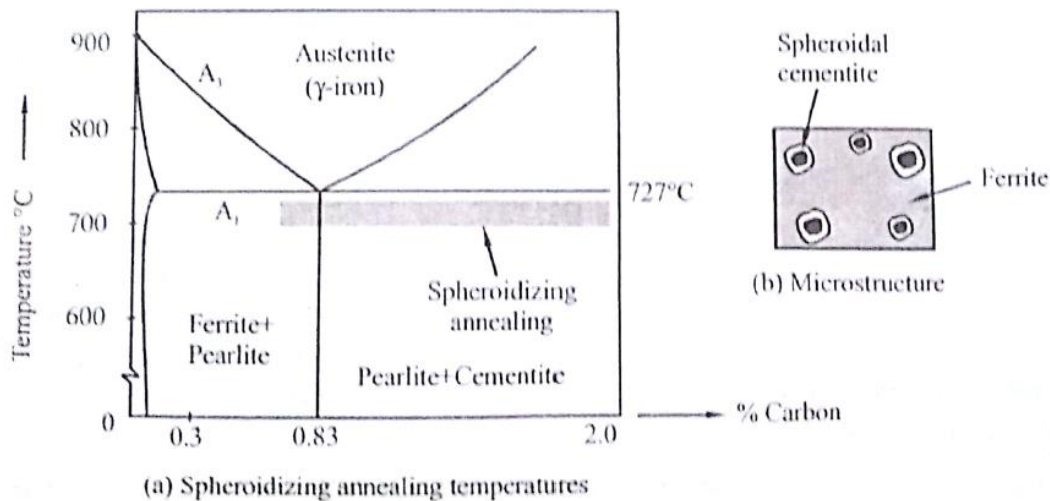


Figure 3.9 Spheroidizing annealing

Process The metal is heated to about 30°C below the lower critical temperature– A_1 line, held there for several hours to allow the cementite to change into spherical form, and then allowed to cool slowly in the furnace. Refer figure 3.9(a). The result is spheroidal cementite in a matrix of ferrite as shown in figure 3.9(b). Spheroidite structure is desirable when minimum hardness, maximum ductility and maximum machinability are required.

3.10.4 Stress Relief Annealing

Stress relief annealing is used to eliminate or minimize the internal residual stresses arising from the following:

- Plastic deformation during machining and grinding.
- Non-uniform cooling of a metal that was processed or fabricated at an elevated temperature, such as in welding or casting, and
- Phase transformation that is induced upon cooling, wherein, the parent and product phases have different densities.

Purpose To remove (relieve) internal residual stresses.

Process The process consists of heating the metal much below the lower critical temperature A_1 line, about $400\text{--}600^{\circ}\text{C}$, held there long enough to attain a uniform temperature, and then finally cooled to room temperature in air. Annealing temperatures are relatively low, so that the effects resulting from cold working and other heat treatment are not affected. Since heating is below A_1 line, there is no phase transformation. The internal stresses are relieved to major extent without loss in strength and hardness of the material.

3.

3.19 CARBURIZING

Carburizing is a method of introducing (adding) carbon to the surface of low-carbon steels in order to produce a hard case (surface), while the inner core remains soft and ductile. Components such as gears, cams, cam shafts, pins, pistons, etc., are hardened by this method.

Carburizing process is usually carried out on low-carbon steels containing less than about 0.2 %C. The process increases the carbon content to about 0.7 – 0.8 % in the surface layers (to a certain depth). The surface carbon is however limited to about 0.9 %, because too high a carbon content can result in retained austenite and brittle martensite. There are three general methods of carburizing based on the carburizing medium or atmosphere. These include:

- a) Pack carburizing, employing solid carburizing medium
- b) Gas carburizing, employing suitable hydro-carbon gases.
- c) Liquid carburizing, employing fused baths of carburizing salts.

3.19.1 Pack Carburizing

In this process, the steel specimen to be carburized is packed in a sealed metal container in such a way that it is completely surrounded by granules of charcoal (carbon-rich material). Refer figure 3.15. The charcoal is treated with an activating chemical such as Barium carbonate, which energizes or accelerates the carburizing process.

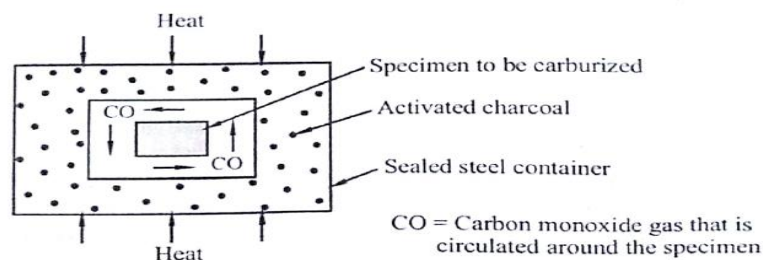


Figure 3.15 Pack carburizing process

In operation, the steel specimen is heated to about $900 - 950^{\circ}\text{C}$, which is above the upper critical temperature (A_1 line). It is held at this temperature for a certain period depending on the depth of the case (depth of hardening) desired. The oxygen present in the container reacts with the carbon content present in charcoal to produce carbon monoxide (CO). This carbon-rich atmosphere in contact with the hot steel results in carbon diffusing into the surface layers of the steel specimen.

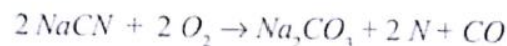
After allowing the steel specimen to cool inside the container for a certain time duration, it is removed and subsequently hardened and tempered by heat treating accordingly.

3.19.2 Gas Carburizing

In this process, the component to be carburized is heated to about 900°C (above upper critical temperature) for a duration of about 3 – 4 hours in a furnace in an atmosphere of carbon-rich gas like methane, ethane, propane, or natural gas. The hydro carbons in the carburizing gas decompose at high temperatures, and the carbon diffuses into the surface austenite layers. The depth of hardened case depends on the rate of gas flow. Gas carburizing is the most widely used method of carburizing.

3.19.3 Liquid Carburizing

Liquid carburizing is the modification of *cyaniding* heat treatment process. The process is employed primarily for relatively shallow cases ($0.1 - 0.25\text{ m}$), which can be produced at a cost lower than that done by pack or gas carburizing. The process is carried out in baths containing 20 – 50 % sodium cyanide (NaCN), together with up to 40 % sodium carbonate, and varying amounts of sodium and barium chloride. This cyanide-rich mixture is heated to a temperature of about 950°C , and the steel specimen contained in wire basket is immersed into the liquid bath for periods varying from about 5 min to 1 hour depending on the depth of case required. The reaction that takes place during the process is given below:



The carbon from the molten salt diffuses into the steel specimen. In addition, there is also diffusion of *some* nitrogen into the specimen. Both the carbon and nitrogen can result in a microstructure that can be hardened by further cooling the steel specimen. Cycle times for liquid carburizing is much shorter (1 – 4 hours) than that for gas and pack carburizing processes. Safe disposal of salt (poisonous elements) is a major disadvantage of the process.

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.

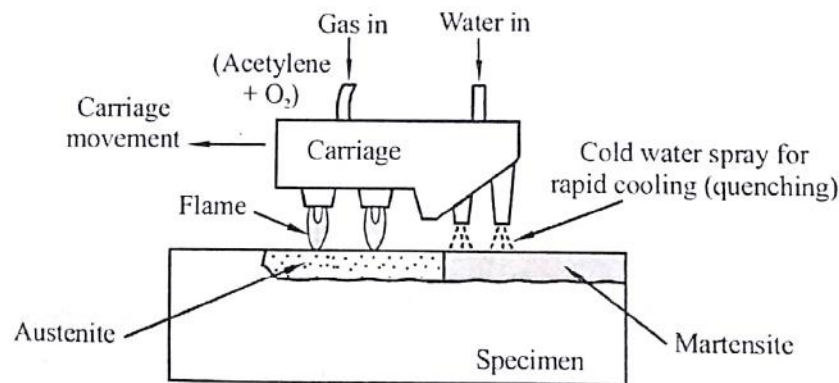


Figure 3.17 Progressive flame hardening

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°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.

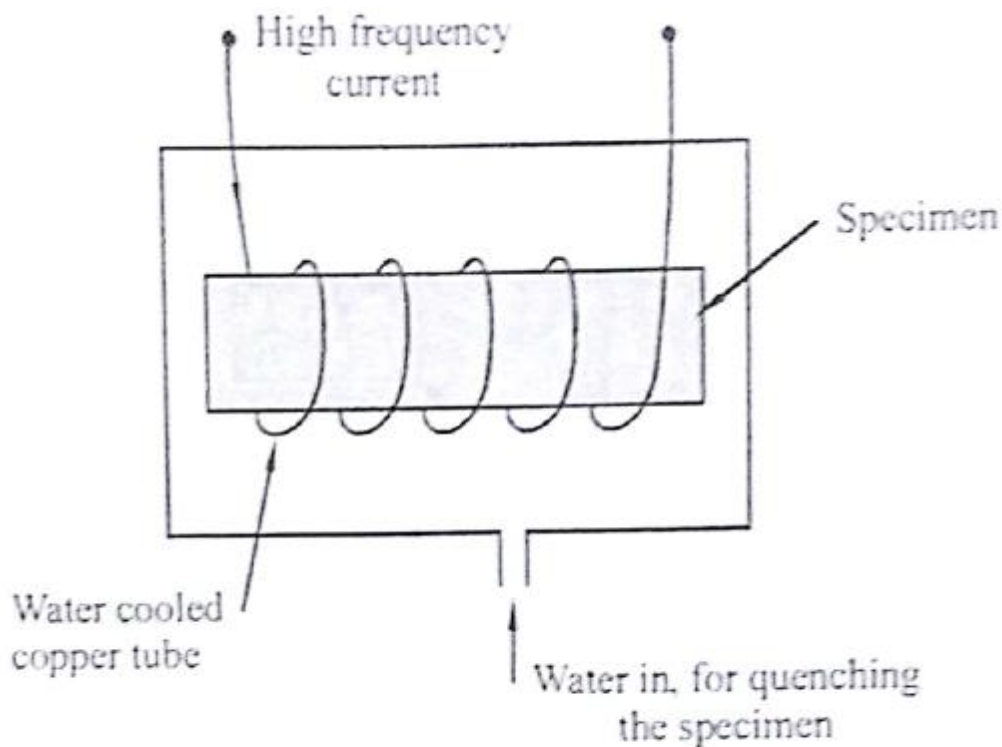


Figure 3.18 Principle of induction hardening

The depth of heating produced by this method, and hence the depth of hardening is related to the frequency of the AC (alternating current) used. The higher the frequency is, the lesser the hardened depth. The major advantage of this process is its speed and ability to confine heating on small parts. However, the cost and maintenance is higher. Also, low carbon steels ($< 0.4\%C$) cannot be hardened by this process.

5.

A *composite material*, or *composites* for short, can be defined as a combination of two or more *constituent materials* (*individual materials*) with different physical or chemical properties, and which remain separate and distinct on a microscopic or macroscopic* level within the finished structure. In other words, the constituents do not dissolve or merge into each other, although they act together to form a single material.

5.2 ROLE of CONSTITUENTS in a COMPOSITE

A composite is made up of two constituent materials, *matrix* and *reinforcement*. However, the *interface* between the matrix and the reinforcement has also some specific role to perform, which is discussed in the present section. Refer figure 5.1(b).

a) Role of Matrix

In a composite, the matrix performs the following functions:

- Holds the reinforcement material together and keep them aligned in a predetermined direction.
- Protects the reinforcement from mechanical and environmental attack.
- Distributes the loads evenly between the reinforcement material so that the entire reinforcement is subjected to the same amount of strain.
- Provides shape and form to the composite material.
- Improves impact and fracture resistance of the composite material.
- Helps to avoid propagation of crack growth through the reinforcement by providing alternate failure path along the interface between the reinforcement and the matrix.
- Carry interlaminar shear.

b) Role of Reinforcement

In a composite, the reinforcement performs the following functions:

- Carry the load and provide strength and stiffness to the composite.
- Helps the composite to obtain the desired property in the direction preferred.
- Serve certain additional purpose of heat resistance or conduction, resistance to corrosion, and provide rigidity to the composite. Reinforcement can be made to perform all or one of these functions as per the requirements.
- Reinforcement helps to deflect the crack front in matrix thereby restricting crack growth.

5.3 CLASSIFICATION of COMPOSITES

Composite materials are commonly classified at two distinct levels:

1) With respect to *matrix* constituent

- Polymer matrix composite – matrix is made from a *polymer resin* material
- Metal matrix composite – matrix is made from a *metal* or *alloy*
- Ceramic matrix composite – *matrix* is made from a *ceramic material*

2) With respect to *reinforced* constituent

- Fibre reinforced composite – reinforcement is in the form of fiber (thread like structure)
- Particle (Particulate) reinforced composites – reinforcement is in the form of small particles.
- Laminated composites – reinforcement consists of layers of material held together.

Composites classified with respect to matrix constituents are discussed as follows.

6.

5.11.1 Pultrusion Process

Pultrusion* is a continuous fiber reinforcement plastic molding process, used for producing parts that have a constant cross-section profile, such as I-beam, channels, tubes, pipes, etc. Figure 5.13 shows the process in its simplest form.

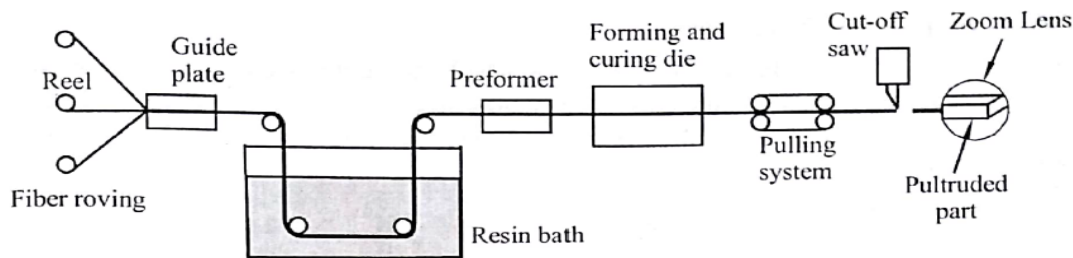


Figure 5.13 Pultrusion process

The pultrusion process starts with raw fibers or fiber roving being pulled off the reels and guided through a resin bath or resin impregnation system (matrix). The resin is usually a thermosetting resin, and is sometimes combined with fillers, catalysts, and pigments. The fiber reinforcement becomes fully impregnated (wetted-out) with the resin such that all the fiber filaments are thoroughly saturated with the resin mixture.

The wet fibers exit the bath and enter the preformer where the excessive resin is squeezed out from the fibers and pre-compacted to the approximate profile. The preformed fiber passes through a heated steel or ceramic die, which has the shape similar to the part to be produced. The heat energy transferred inside the metal die activates the curing or polymerization of the thermoset resin changing it from liquid to solid state. The part that exits the die is now a cured pultruded Fiber Reinforced Polymer (FRP) composite. The cured product is cut to the desired length by the cut-off saw as shown in the figure.

Advantages

- High productivity.
- Process parameters are easily controllable.
- Low waste (Material scrap rate is low).
- Low labour cost.
- Precise cross-section dimensions of the products.
- Good surface quality of the products.
- Homogeneous distribution and high concentration of the reinforcing fibers in the material is achieved.

Disadvantages

- High investment cost.
- Long tooling time.
- Limited to constant or near constant cross-section profiles

Applications Used in the fabrication of constant cross-section profile components like I-beam, channels, tubes, pipes, poles, tanks, etc.