3. **Inference**
   - Quenched end – maximum hardness – 100% martensite is the product at quenched end.
   - Cooling rate decreases – hardness also decreases.

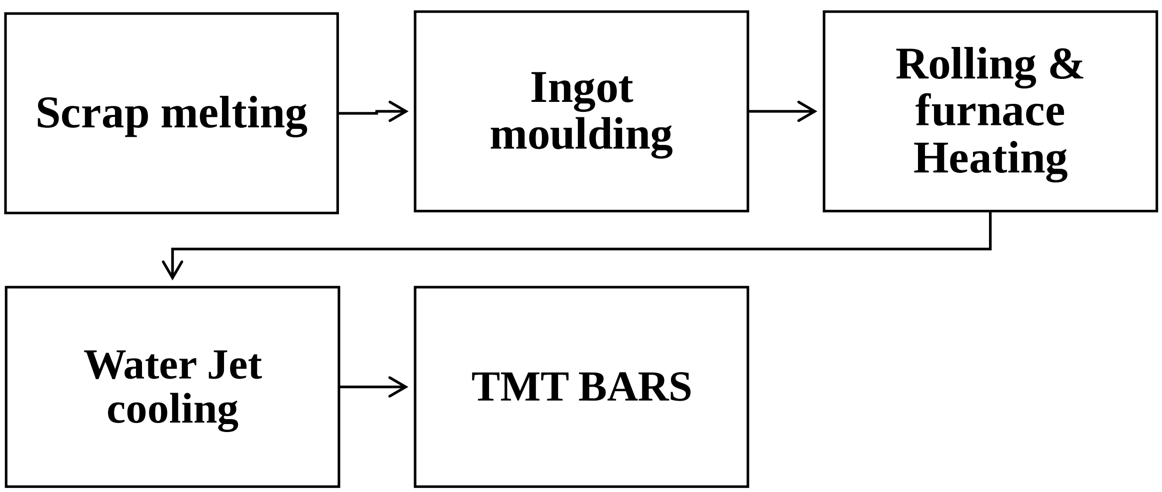
2.5 THERMO-MECHANICAL TREATMENTS(TMT)

- Thermo-mechanical treatment is the simultaneous heating and cooling of steel to develop better properties in steel by refining its micro structure.
- This heating technology is referred as hot rolling in this process vast quantities of steel can be handled.
- Temperature in rolling mill is between 1200 – 1300°C.

Purpose of thermo-mechanical treatment

- Steel gains high strength &ductility.
- Steel turns into ferrite pearlite structure which means that the outer core becomes strong and inside remain soft.

Steps involved in manufacturing TMT bars



Few important facts on Thermo mechanical Treatment

- Austenite is formed that is far superior to ordinary steels and hardening takes place during the controlled cooling process.
- Carbon ratio in TMT Bars is as low as 0.5% therefore the tensile strength is high and less brittle.
- Tempering is done at 100°C that increases the strength and ductility.
- During thermo- mechanical treatment superior ductility enhances in TMT bars therefore, the austenite causes the balance between Strength and Flexibility.
- The brittle strength increases in TMT Bar relatively. That is why it becomes usable for any type of construction purposes.
- The Martensite structure consists of consistent RIBS that give superior bonding quality of steel bars in RCC.

Advantages of TMT bars:

- TMT Bars comes with better strength & superior Elongation than any other type of steel bars.
- It saves up to 17% of steel.
- The cost of TMT Bars is lower than other types of steel bar.
- Better Ductility & Bendability favours it to use for any type of construction structure and saves time as well.
- TMT Bars are Resistant to Fire and Corrosion that is why worldwide the demand of TMT Steel Bars are higher.
- The fatigue strength in TMT Bar is high, so, during the construction it can bend as per the requirement.

(What are Iso-Thermal Transformation Diagram (TTT) diagrams? Explain the construction of TTT diagram.)

2.6 ISO – THERMAL TRANSFORMATION DIAGRAM

What is isothermal phase transformation?

- ➢ A phase transformation occurs at a constant temperature (isothermal); this is known as isothermal phase transformation.

Iso-Thermal Transformation Diagram

- ➢ generated from **percentage transformation Vs time measurements at fixed temperature.**
- ➢ useful for **understanding the transformations of an alloy steel at elevated temperatures.**
- ➢ Isothermal transformation diagram is otherwise known as S-curve, Bain's curve or T.T.T. (Time – Temperature- Transformation) diagram.

Steps to construct isothermal transformation diagram

Step 1:

- ➢ Obtain a large number of relatively small specimens of same material.

Step 2:

- ➢ Austenize the samples in a furnace at a temperature above the eutectoid temperature.

Step 3:

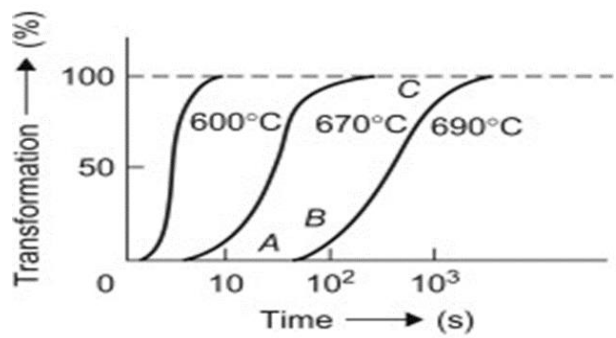
- ➢ Then quench the samples in a liquid salt bath at the desired temperature below the eutectoid temperature.

Step 4:

- ➢ At various time intervals, remove the samples from the salt bath one by one at a time and quench into water at room temperature.

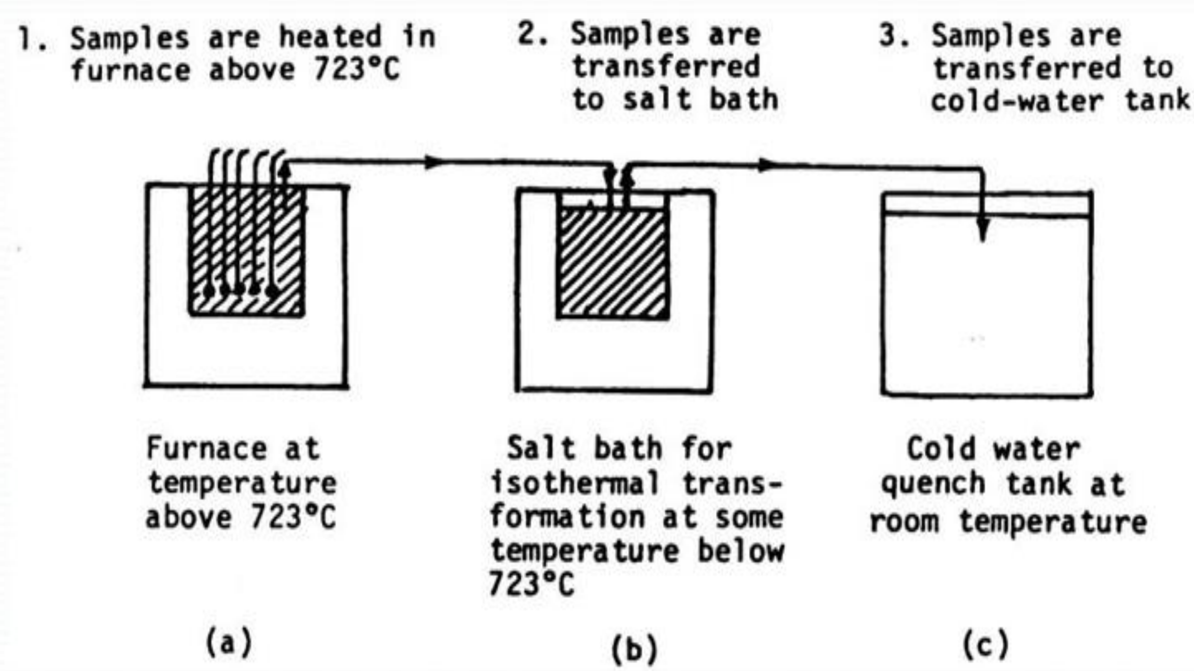
Step 5:

- Now, examine the microstructure after each transformation time at room temperature. The result obtained is the **reaction curve**.

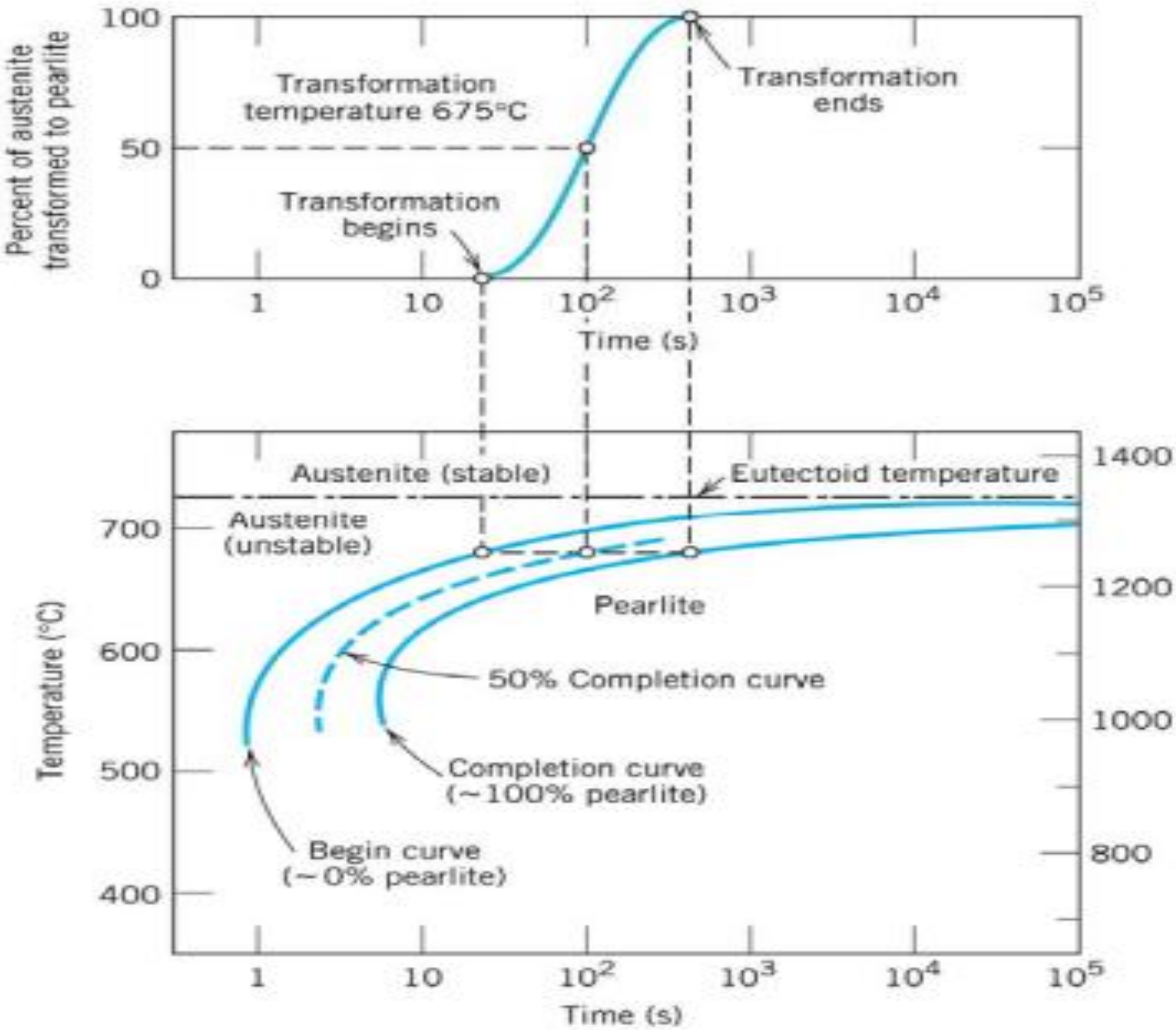


Step 6:

- Now, repeat the procedure at progressively low temperatures.
- The data obtained from a series of isothermal reaction curves over a whole range of austenite instability for a given composition of steel is the TTT diagram for steel.



Experimental arrangement for determining the microscopic changes that occur during the isothermal transformation of austenite in an eutectoid plain-carbon steel



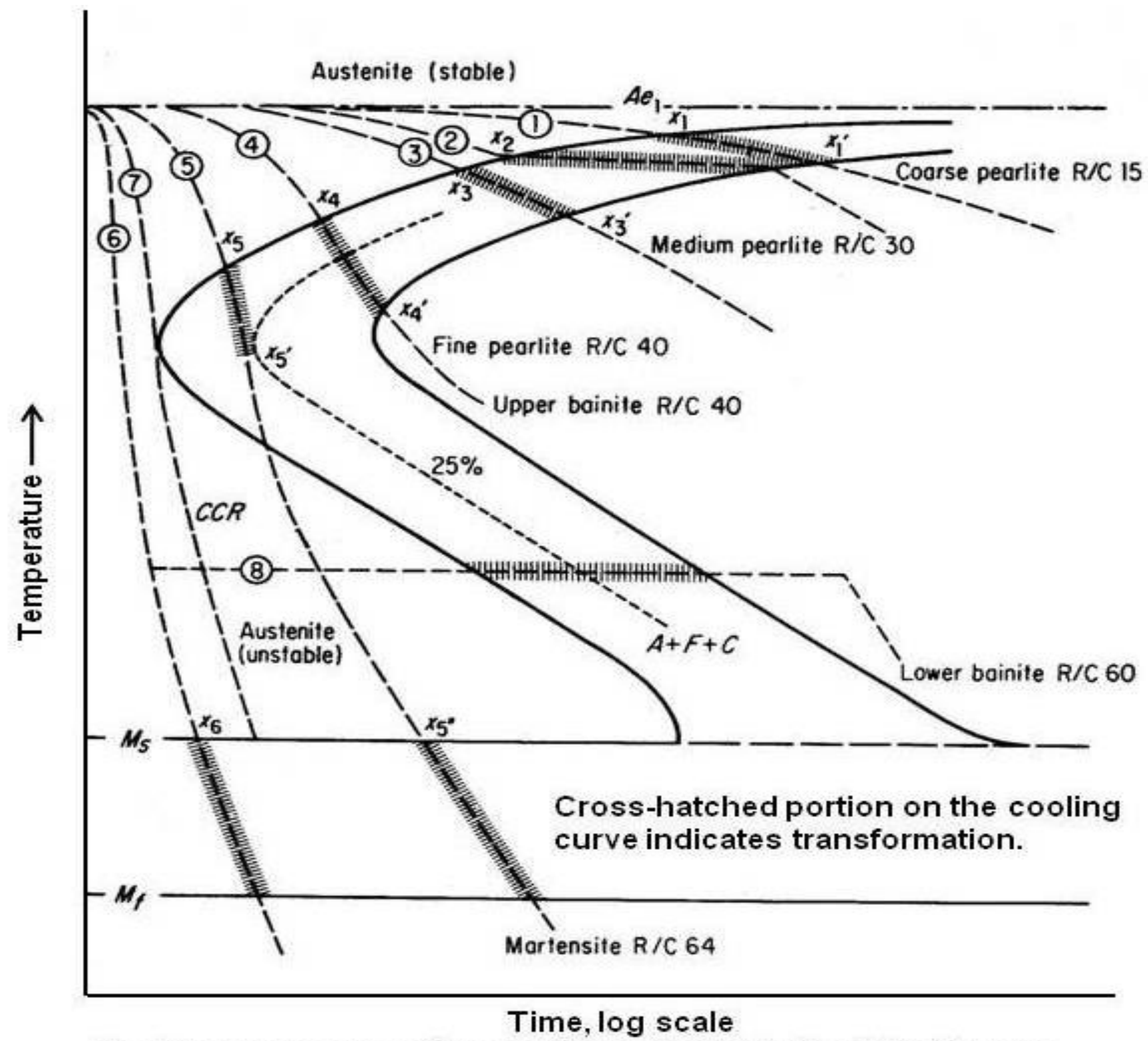
<u>(Explain the superimposition of cooling curves on TTT diagrams.)</u>

2.7 Cooling Curves superimposed on Isothermal Transformation Diagram

A cooling curve is determined experimentally by placing a thermocouple at a definite location in a steel sample and then measuring the variation of temperature with time.

1. Cooling Curve 1:

Cooling curve 1 shows a very slow cooling rate and this corresponds to conventional annealing. The transformation will start at point $\mathbf{x_1}$. The transformation product at that temperature coarse pearlite. The transformation will continue till point $\mathbf{x_1'}$.



Cooling curves superimposed on a hypothetical I-T diagram

2. **Cooling Curve 2:**

   Cooling curve 2 illustrates isothermal annealing.The process is carried out by cooling the material above A1 line and holding at that temperature to produce complete transformation. The transformation product is medium pearlite. This heat treatment produces more uniform structure and hardness.

3. **Cooling Curve 3:**

   This curve has a faster cooling rate than annealing. It may be considered as typical normalizing. Transformation starts at $\mathbf{x_3}$ and ends at $\mathbf{x_3'}$. The product formed is fine pearlite.

4. **Cooling Curve 4:**

   Cooling curve 4, typical of a slow oil quench, and the microstructure will be a mixture of medium and fine pearlite.

5. **Cooling Curve 5:**

Cooling curve 5, typical of an intermediate cooling rate, and austenite will start to transform to fine pearlite from**x_5**. As **Ms** line is crossed the remaining austenite will transform into martensite. The final microstructure at room temperature will consist of 75 percent martensite and 25 percent fine nodular pearlite.

6. **Cooling Curve 6:**

Cooling curve 6, typical of a drastic quench, is rapid enough to avoid transformation in the nose region. It remains austenitic until the M_s line is reached at x_6. Transformation to martensite will take place between M_s and M_f lines. The final microstructure will be entirely martensite of high hardness.

7. **Cooling Curve 7:**

This curve is tangent to the nose region and corresponds to critical cooling rate(CCR). Any cooling rate slower than the CCR will produce softer transformation product like pearlite. Any
cooling rate faster than the CCR will produce harder transformation product like marttesite. Steels can be classified based on their CCR's.

8. **Cooling Curve 8:**

It is possible to form 100% pearlite or martensite by slow cooling but it is impossible to form 100% bainite. This cooling curve obtains a bainite structure by cooling rapidly to avoid transformation at the nose region and then holding in the temperature range of 300-350°C at which bainite is formed until transformation is complete.

(What is critical cooling rate? Give its importance.)

2.8 CCR (CRITICAL COOLING RATE):

The slowest rate of cooling of austenite that will result in 100% martensite transformation is known as the critical cooling rate.

Importance:

- most important in hardening.
- To obtain 100% martensite structure on hardening the cooling must be much higher than the critical cooling rate.

Factors affecting CCR:

1. Chemical composition of steel.
2. Hardening temperature
3. purity of steel

(Explain about CCT diagrams.)

2.9 Continuous Cooling Transformation Diagram (CCT diagram)

- A continuous cooling transformation (CCT) phase diagram is often used when heat treating steel. These diagrams are used to represent which types of phase changes will occur in a material as it is cooled at different rates.
- CCT diagrams depict transformation, temperature and time relationship during continuous cooling.

- Specimen are cooled from austenitic range at a constant cooling rate and pearlitic start and finish are points are determined. Experiments with different cooling rates yield the locus of the two points and hence CCT diagrams are constructed.

Difference between TTT and CCT

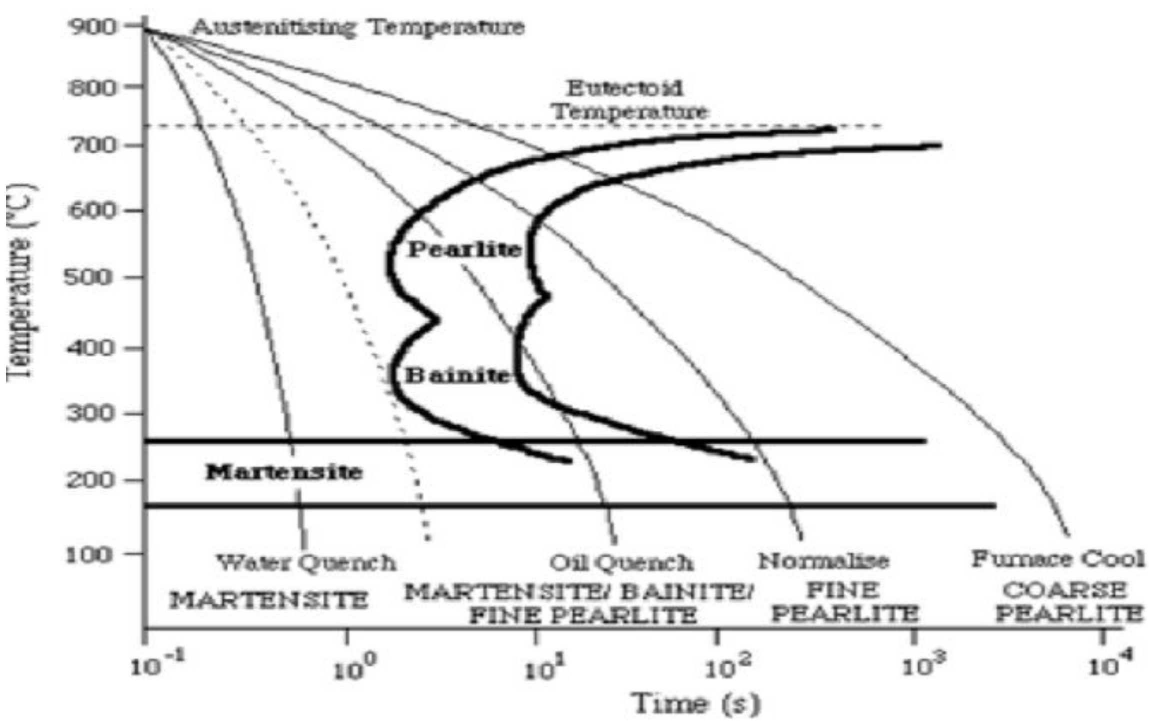
- TTT diagrams examine the progress of transformation as a function of time, at a fixed temperature.
- CCT diagrams examine the progress of transformation as a function of changing temperature**.**

Types of CCT diagrams

There are two types of CCT diagrams

1. Plot of transformation start, specific fraction of transformation and transformation finish temperature against transformation time on each cooling curve.
2. Plot of transformation start, specific fraction of transformation and transformation finish temperature against cooling rate.

CCT diagram for a eutectoid steel is given below,



Factors affecting CCT Diagram

1. **Grain Size**
2. **Carbon content**
3. **Alloying Elements**

1. **Grain Size**
   - Fine grain steels tend to promote formation of ferrite and pearlite from austenite.
   - Hence decrease in grain size shifts the TTT diagram towards left.
   - Therefore, CCR increases with decrease in grain size.

2. **Effect of carbon content**
    - An increase in carbon content shifts the CCT and TTT curves to the right. This corresponds to the increase in hardenability as it increases the ease of forming martensite.
    - An increase in carbon content decreases the MS, the martensite start temperature.

3. **Effect of Alloying Elements**
    - An increase in alloy content shifts the TTT and CCT to the right.
    - Alloying elements also modify the shape of TTT diagram and separate the ferrite + pearlite region from bainite region making the attainment of the bainitic structure more controllable.

2.10 Elementary Ideas on Sintering

What is sintering?

Sintering is a thermal process of converting loose fine particles into a solid coherent mass by heat and/or pressure without fully melting the particles to the point of melting.

Why is sintering done and why is it important?

Sintering is done to impart strength and integrity to a material as well as reducing porosity and enhancing electrical conductivity, translucency and thermal conductivity.

Which type of materials can be used for sintering?

1. **Iron and Carbon Steels**
2. **Iron-Copper and Copper Steels**
3. **Iron-Nickel and Nickel Steels**
4. **Low Alloy Steels**
5. **Sintered Hardened Steels**
6. **Diffusion Alloyed Steels**
7. **Copper Infiltrated Steels**
8. **300 Series Stainless Steel**
9. **400 Series Stainless Steels**
10. **Soft Magnetic Alloys**
11. **Copper and Copper Alloys**

What are the types of sintering process?

Sintering processes can be divided into two types:

1. **Solid state sintering**

    Solid state sintering occurs when the powder compact is densified wholly in a solid state at the sintering temperature

2. **Liquid phase sintering.**

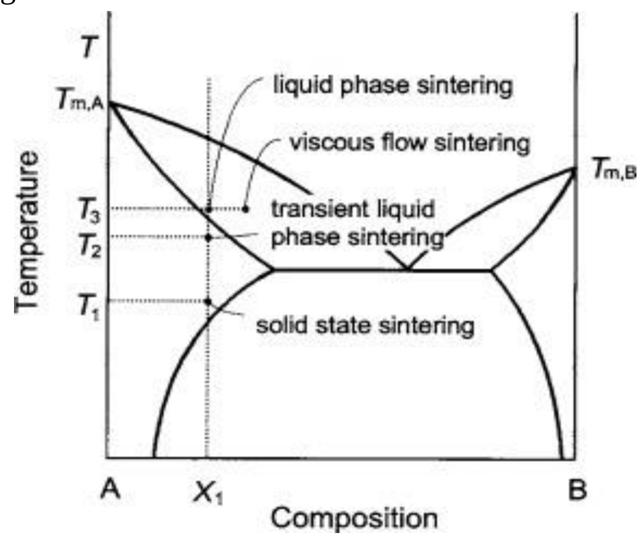
    Liquid phase sintering occurs when a liquid phase is present in the powder compact during sintering.

3. **Transient liquid phase sintering**

Transient liquid phase sintering is a combination of liquid phase sintering and solid state sintering.

4. **Viscous flow sintering**

Viscous flow sintering occurs when the volume fraction of liquid is sufficiently high.



What are steps of sintering process?

China Savvy's metal sintering process, also commonly known as the powder metallurgy process, is divided into three main steps:

I. **Blending**

- The process starts with the blending of powdered metals. To the iron based powder mix, alloying elements, additives and solid lubricant are added to the mix.
- This lubricant is needed in order to reduce the friction between the powder mass and the surface of the tool used for compaction.
- Blending in the powder metallurgy process enables the creation of a uniform mixture.

II. **Compaction**

- A filling shoe is used to deliver the powder metal to the cavity of the die and then compacted with a force of between 400 MPa to 800MPa.

III. **Sintering**

- Sintering is usually performed on a belt conveyor furnace in a controlled atmosphere.
- Parts are heated in the furnace to a temperature that is below the melting point of the main powdered metals used in the blending step of the process.