AIRCRAFT MATERIALS AND PROCESSES

MODULE IV – METAL WORKING PROCESS, HEAT TREATMENT, MACHINING PROCESS

John George

Asst. Professor

Dept. of Aeronautical Engineering

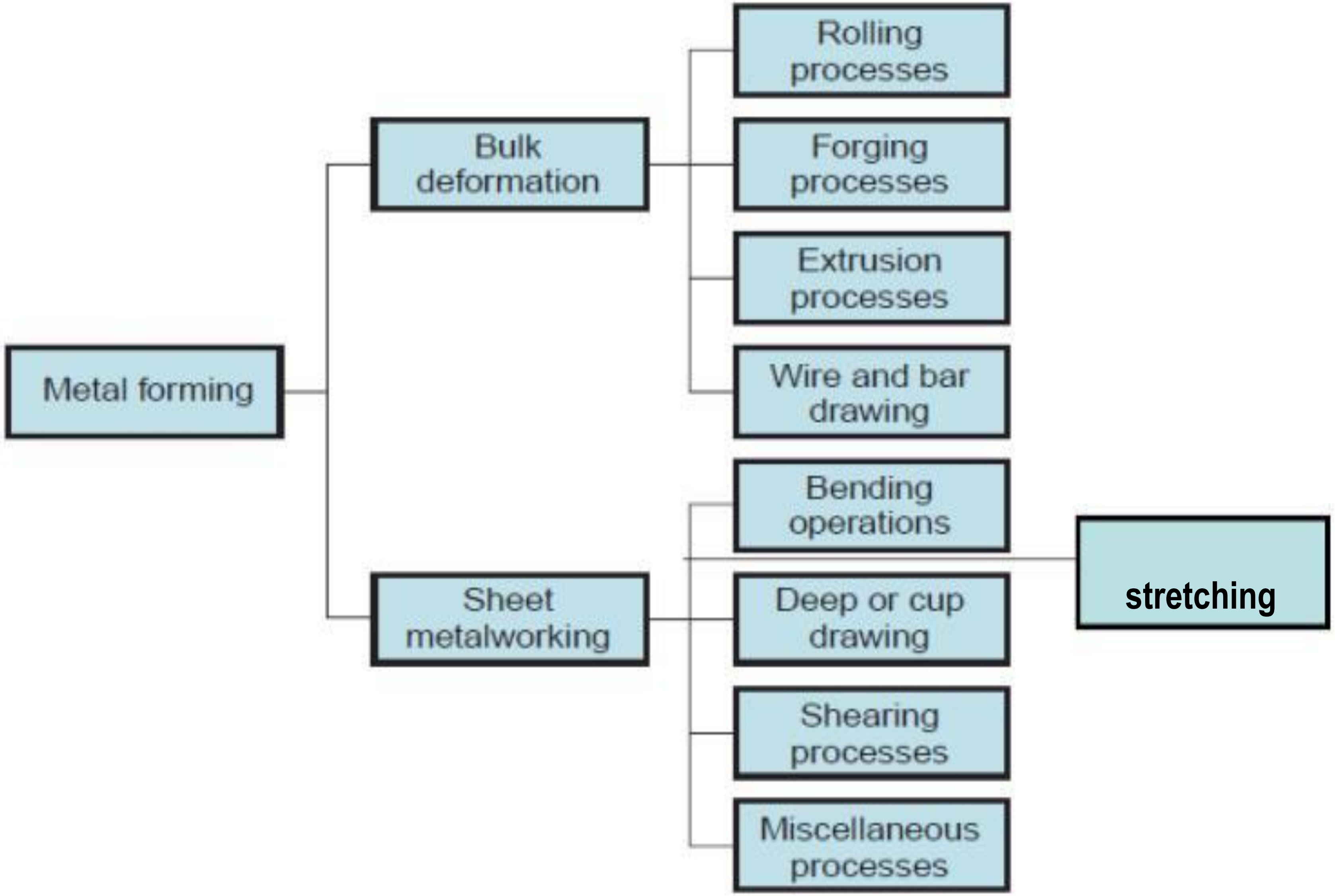
Jawaharlal College of Engineering & Technology

Metal Working Processes

- Metal working process creates useful shapes by plastic forming processes and control mechanical properties.
- Mechanical property of the specimen are improved after metal working process.
- Metal working processes are classified on different bases like type of forces applied, temperature, strain hardening etc.

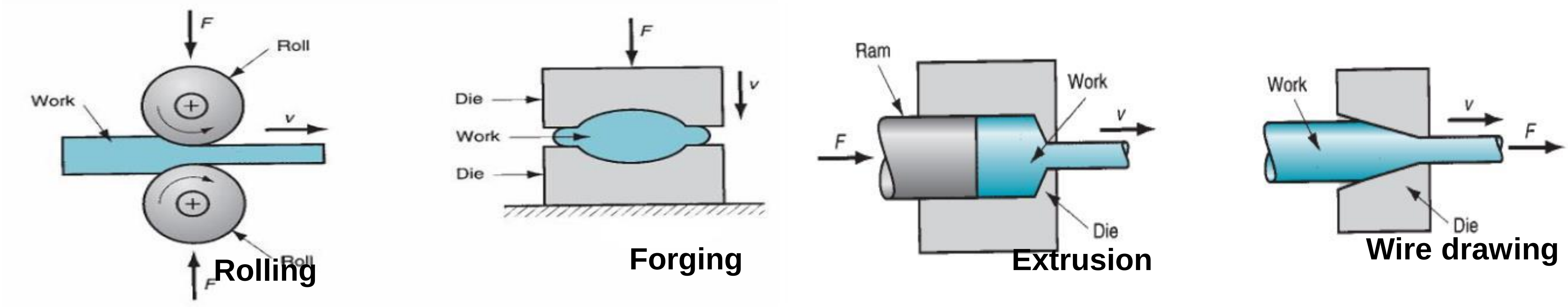
Classification of Metal Working Processes

- Based on type of forces applied:
  - Direct compression type processes: Rolling, Forging
  - Indirect compression type processes: Wire or bar drawing, Extrusion, Deep drawing.
  - Tension type processes: Stretch forming
  - Bending processes: Bending of sheet
  - Shearing processes: In sheet metal forming applications.



classification of metal forming processes

Classification of basic bulk forming processes



Bulk forming: It is a severe deformation process resulting in massive shape change. The surface area-to-volume of the work is relatively small. Mostly done in hot working conditions.

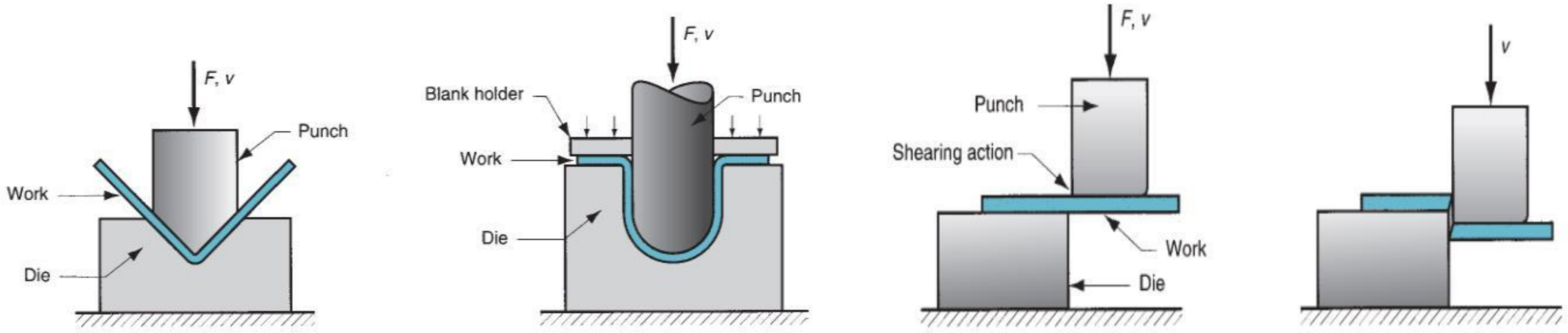
Rolling: In this process, the workpiece in the form of slab or plate is compressed between two rotating rolls in the thickness direction, so that the thickness is reduced. The rotating rolls draw the slab into the gap and compresses it. The final product is in the form of sheet.

Forging: The workpiece is compressed between two dies containing shaped contours. The die shapes are imparted into the final part.

Extrusion: In this, the workpiece is compressed or pushed into the die opening to take the shape of the die hole as its cross section.

Wire or rod drawing: similar to extrusion, except that the workpiece is pulled through the die opening to take the cross-section.

Classification of basic sheet forming processes



Bending **Deep drawing** **Shearing**

Sheet forming: Sheet metal forming involves forming and cutting operations performed on metal sheets, strips, and coils. The surface area-to-volume ratio of the starting metal is relatively high. Tools include punch, die that are used to deform the sheets.

Bending: In this, the sheet material is strained by punch to give a bend shape (angle shape) usually in a straight axis.

Deep (or cup) drawing: In this operation, forming of a flat metal sheet into a hollow or concave shape like a cup, is performed by stretching the metal in some regions. A blank-holder is used to clamp the blank on the die, while the punch pushes into the sheet metal. The sheet is drawn into the die hole taking the shape of the cavity.

Shearing: This is nothing but cutting of sheets by shearing action.

Cold working, Warm working, Hot working

Cold working: Generally done at room temperature or slightly above at room temperature.

Advantages compared to hot forming:

(1) closer tolerances can be achieved; (2) good surface finish; (3) because of strain hardening, higher strength and hardness is seen in part; (4) grain flow during deformation provides the opportunity for desirable directional properties; (5) since no heating of the work is involved, furnace, fuel, electricity costs are minimized, (6) Machining requirements are minimum resulting in possibility of near net shaped forming.

Disadvantages: (1) higher forces and power are required; (2) strain hardening of the work metal limit the amount of forming that can be done, (3) sometimes cold forming-annealing-cold forming cycle should be followed, (4) the work piece is not ductile enough to be cold worked.

Warm working: In this case, forming is performed at temperatures just above room temperature but below the recrystallization temperature. The working temperature is taken to be 0.3 T_m where T_m is the melting point of the workpiece.

Advantages: (1) enhanced plastic deformation properties, (2) lower forces required, (3) intricate work geometries possible, (4) annealing stages can be reduced.

Hot working: Involves deformation above recrystallization temperature between $0.5T_m$ to $0.75T_m$.

Advantages: (1) significant plastic deformation can be given to the sample, (2) significant change in workpiece shape, (3) lower forces are required, (4) materials with premature failure can be hot formed, (5) absence of strengthening due to work hardening.

Disadvantages: (1) shorter tool life, (2) poor surface finish, (3) lower dimensional accuracy, (4) sample surface oxidation.

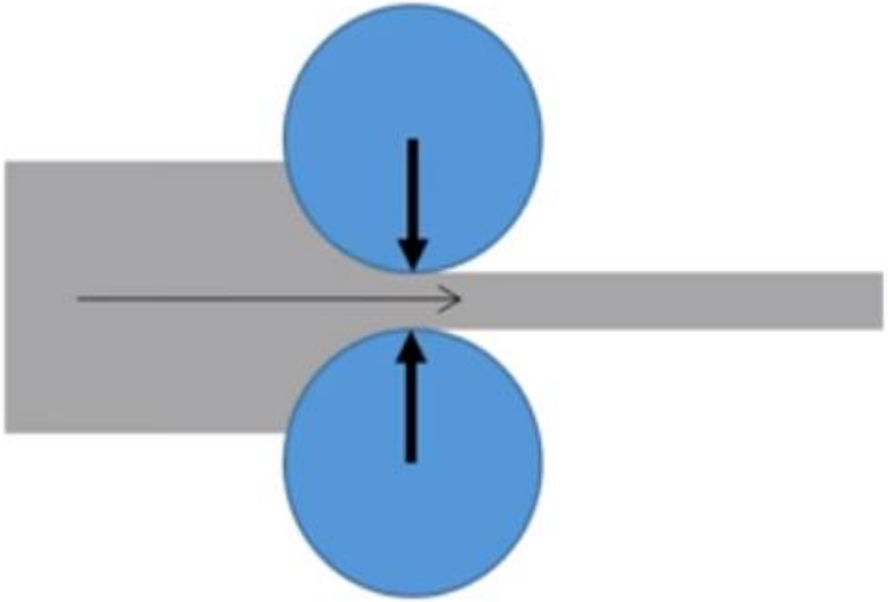
- Primary and Secondary metal working processes.
  - Primary working processes are used for reducing the standard large dimension products to simple shape, like sheet bar on plate.
  - Secondary working processes are used for final finishing and shape.

Hot Rolling Versus Cold Rolling

Process of reducing the thickness or changing the cross sectional area of a work piece by compressive forces.

Hot Rolling

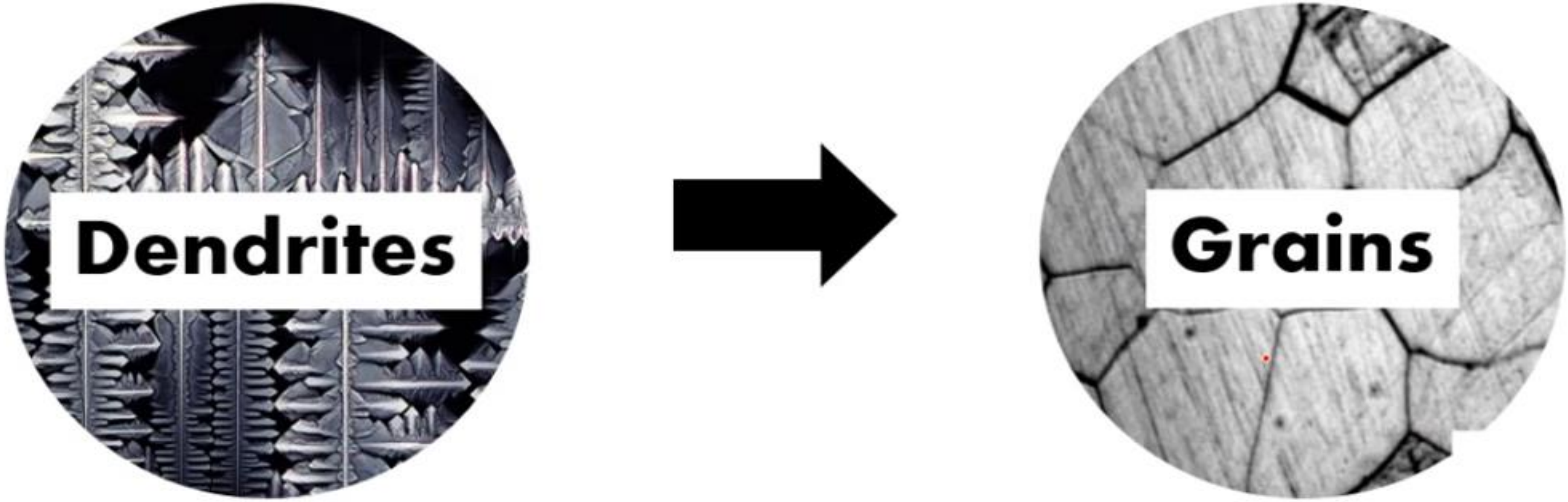
Elevated temperature



Cold Rolling

Room temperature

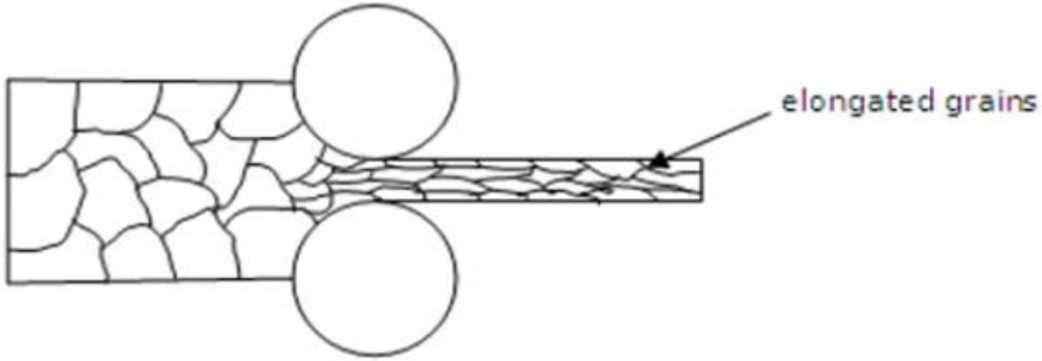
Hot Rolling

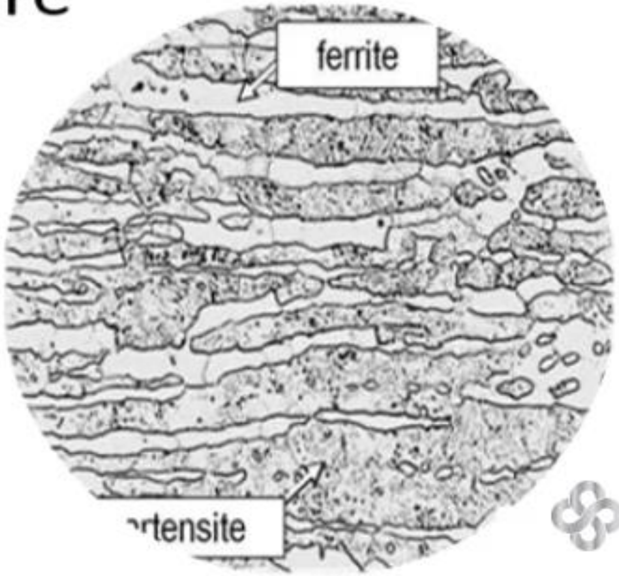


Hot Rolling

Above crystallization temperature

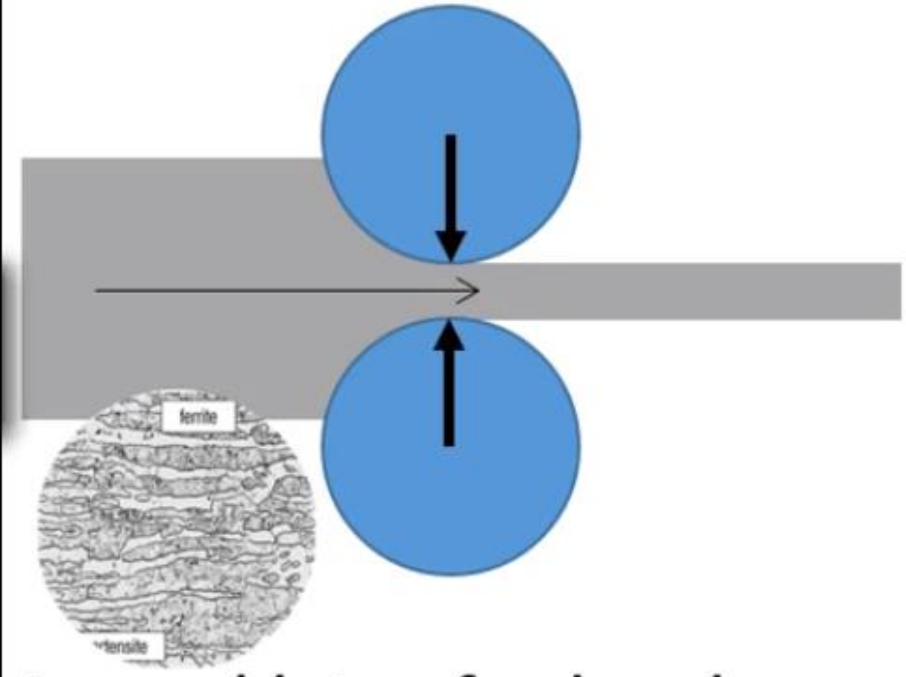
Elevated temperature





Cold Rolling

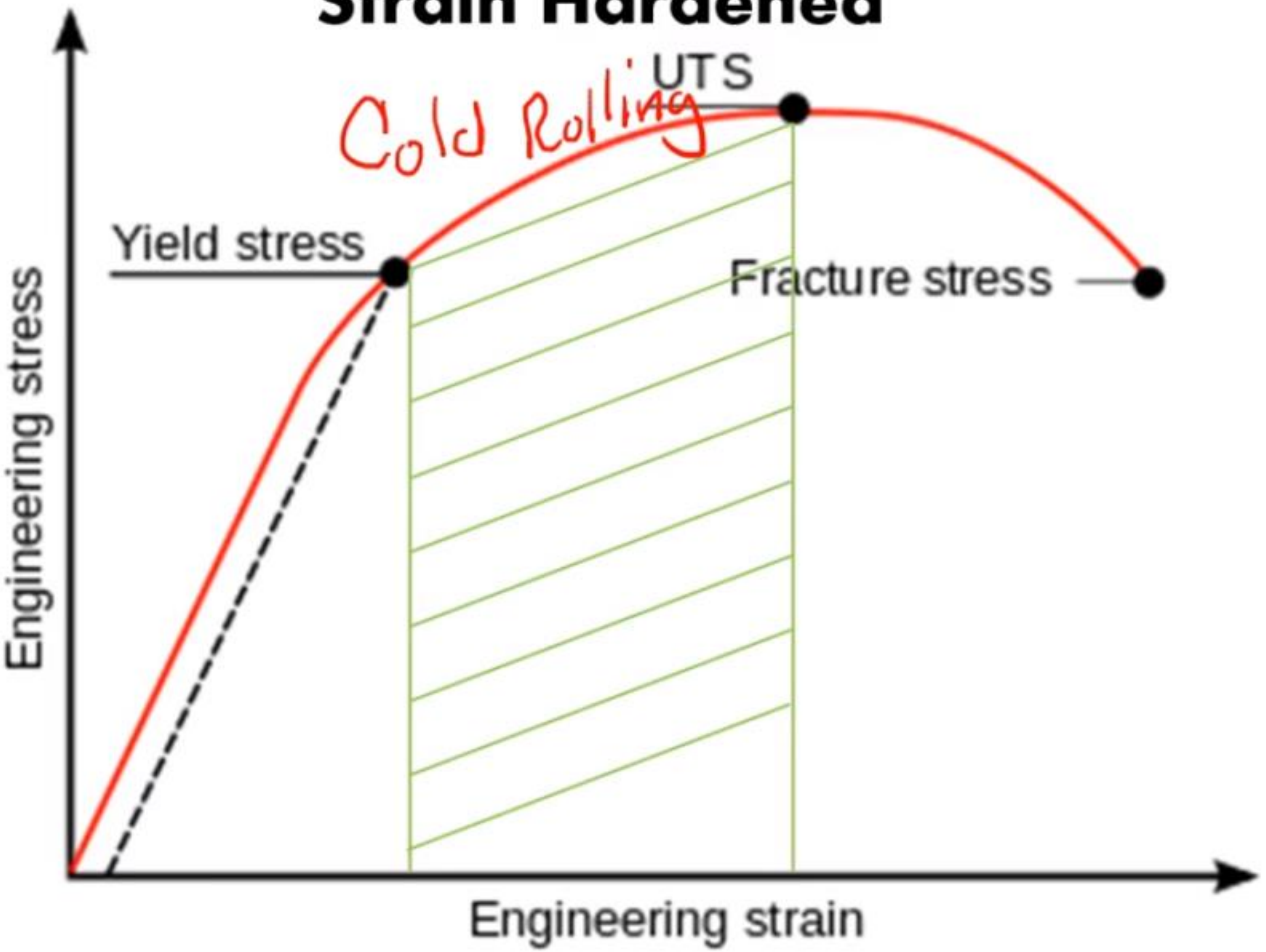
Room temperature



Anneal later for hardness

Better surface finish

Strain Hardened



Hot Rolled	Cold Rolled
Wider tolerance (0.010”)	Tighter tolerance (0.005”)
Lower strength	High strength and hardness
Less expensive	More processing
	More expensive

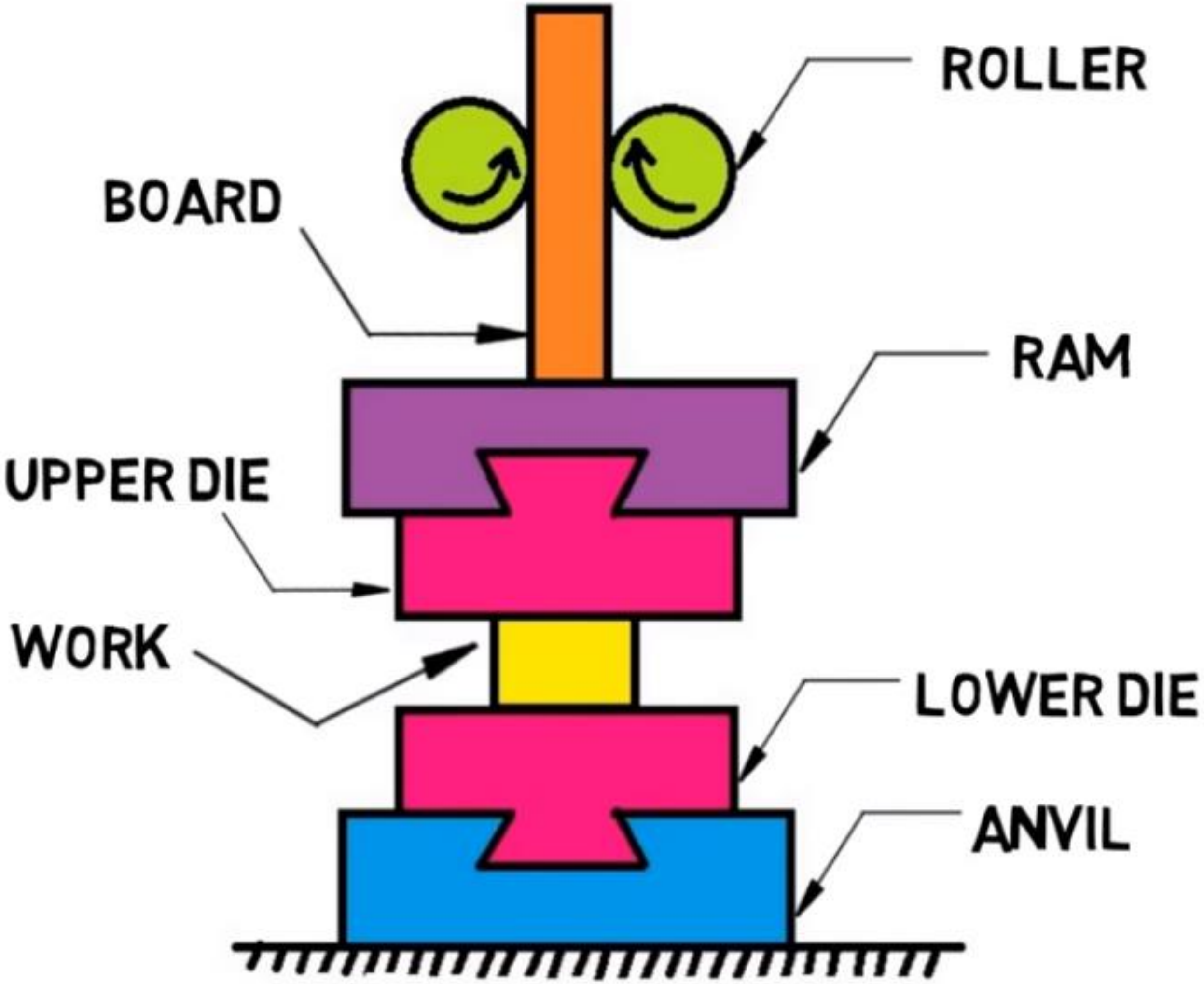
FORGING:-

THE PROCESS IN WHICH THE MATERIAL IS SHAPED BY COMPRESSIVE FORCES AND THE FORCE CAN BE EXERTED BY MANUALLY OR WITH POWER HAMMER OR BY SPECIAL FORGING MACHINES.

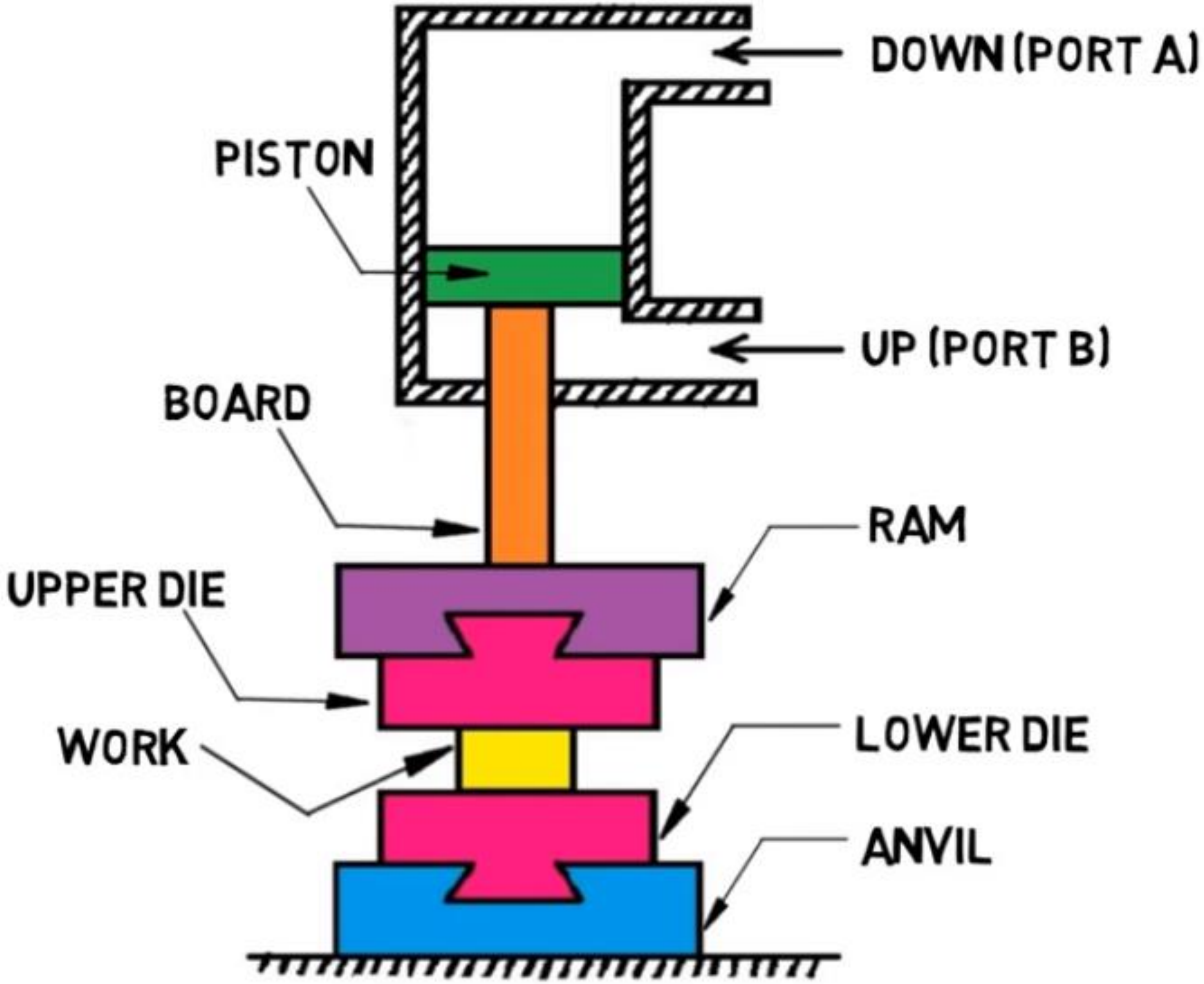
FORGING

HOT	COLD
(ABOVE RECRYSTALLIZATION)	(BELOW RECRYSTALLIZATION)

DROP FORGING



PRESS FORGING



HEAT TREATMENT

- Heat treatment is the process of heating (but never allowing the metal to reach the molten state) and cooling a metal in a series of specific operations which changes or restores its mechanical properties.
- Heat treatment makes a metal more useful by making it stronger and more resistant to impact, or alternatively, making it more malleable and ductile.
- However, no heat-treating procedure can produce all of these characteristics in one operation; some properties are improved at the expense of others. For example, hardening a metal may make it brittle, or annealing it may make it too soft.

HEAT TREATMENT THEORY

- All heat-treating processes are similar because they all involve the heating and cooling of metals. However, there are differences in the methods used, such as the heating temperatures, cooling rates, and quenching media necessary to achieve the desired properties.
- The heat treatment of ferrous metals (metals with iron) usually consists of annealing, normalizing, hardening, and/or tempering.
- Most nonferrous metals can be annealed, but never tempered, normalized, or case hardened.

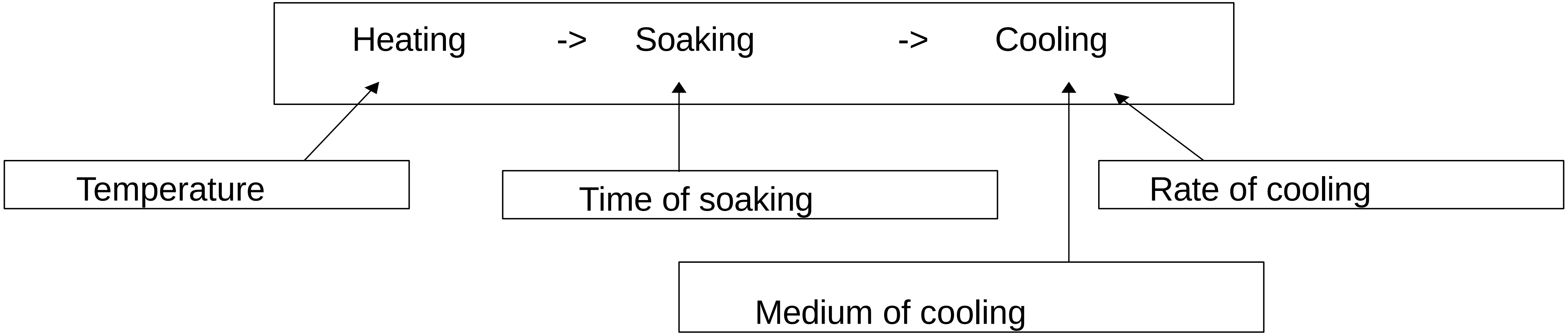
Purpose of heat treatment

- To increase **ductility**, strength, toughness
- Increase machinability
- Relieve **internal stresses**
- To improve corrosion resistance and **hardness**

Process of heat treatment

Heating → Soaking → cooling

STAGES OF HEAT TREATMENT



- Different combinations of the above parameters
- Different compositions of materials and initial phases of materials

Give rise to different heat treatments

STAGES OF HEAT TREATMENT

heat treatment is accomplished in three major stages:

• Stage I — Heat the metal slowly to ensure a uniform temperature.

• Stage 2 — Soak (hold) the metal at a given temperature for a given time.

• Stage 3 — Cool the metal to room temperature.

Heating Stage

In the heating stage, the primary objective is to heat uniformly, and you attain and maintain uniform temperatures by slow heating. If you heat unevenly, one section can expand faster than another, resulting in a distorted or cracked part.

The appropriate heating rate will depend on several factors:

• The metal's heat conductivity. A metal with a high-heat conductivity heats at a faster rate than one with a low conductivity.

• The metal's condition. The heating rate for hardened (stressed) tools and parts should be slower than the heating rate for unstressed or untreated metals.

• A metal part's size and cross section. To prevent warping or cracking, you need to heat large cross-sectioned parts slowly to allow the interior temperature to remain close to the surface temperature. Parts with uneven cross sections will naturally tend to heat unevenly, but they are less apt to crack or excessively warp when you keep the heating rate slow.

Soaking Stage

- In the soaking stage, the objective is to hold the metal to the proper temperature until the desired internal structural changes take place. “Soaking period” is the term you use for the time the metal is held at the proper temperature. The chemical analysis of the metal and the mass of the part will determine the appropriate soaking period. (Note: For steel parts with uneven cross sections, the largest section determines the soaking period.)
- Except for the rare variance, you should not bring the temperature of a metal directly from room temperature to soaking temperature in one operation. Instead, heat the metal slowly to a temperature just below the point at which the internal change occurs and hold it at that temperature until you have equalized the heat throughout. Following this process (called “preheating”), quickly heat the metal to its final required temperature.
- When a part has an intricate design, you may have to preheat it to more than one temperature stage to prevent cracking and excessive warping. For example, assume an intricate part needs to be heated to 1500°F for hardening.
- To heat this part slowly to a 600°F stage and soak it at this temperature for a defined period, then heat it slowly and soak it at a 1200°F stage, and then heat it quickly to the hardening temperature of 1500°F.

Cooling Stage

- In the cooling stage, the objective is self-explanatory, but there are different processes to return a metal to room temperature, depending on the type of metal.
- To cool the metal and attain the desired properties, you may need to place it in direct contact with a cooling medium (a gas, liquid, solid, or a combination), and any cooling rate will depend on the metal itself and the chosen medium. Therefore, the choice of a cooling medium has an important influence on the properties desired.
- Cooling metal rapidly in air, oil, water, brine, or some other medium is called quenching.
- Quenching is usually associated with hardening since most metals that are hardened are cooled rapidly during the process. However, neither quenching nor rapid cooling always results in increased hardness. For example, a water quench is usually used to anneal copper, and some other metals are cooled at a relatively slow rate for hardening, such as air-hardened steels.
- Some metals crack or warp during quenching, while others suffer no ill effects; so the quenching medium must fit the metal. Use brine or water for metals that require a rapid cooling rate; use oil mixtures for metals that need a slower cooling rate.

VARIOUS TYPES OF HEAT TREATMENT

1. **ANNEALING**

   a. FULL ANNEALING
   b. STRESS RELIEF ANNEALING
   c. PROCESS ANNEALING
   d. SPHEROIDIZING ANNEALING

2. **HARDENING**

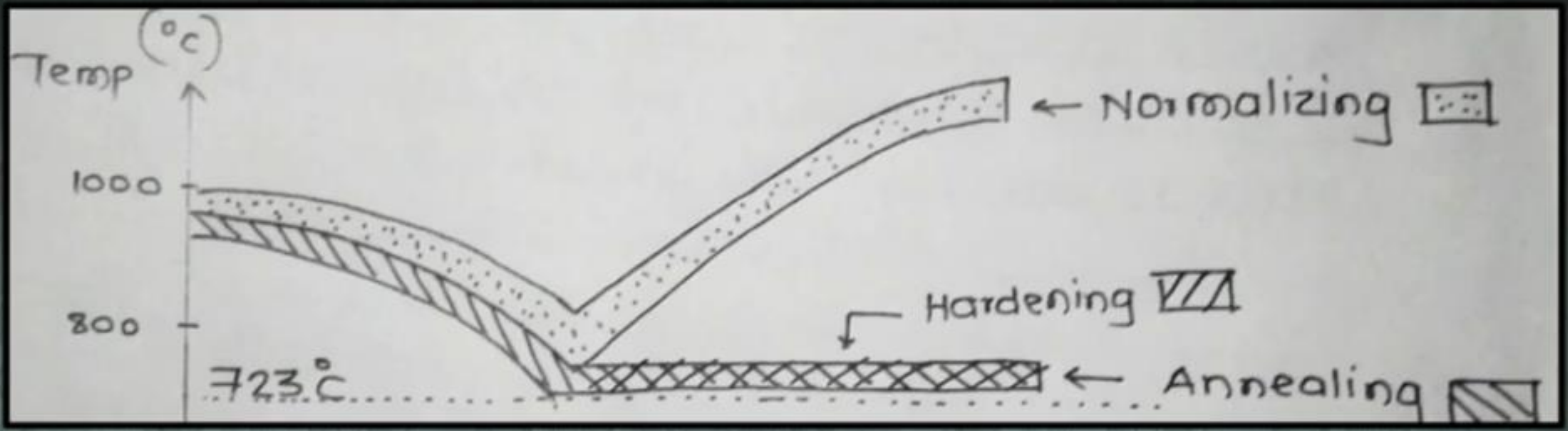
   a. CASE HARDENING
   b. FLAME HARDENING
   c. INDUCTION HARDENING
   d. AGE HARDENING

3. **NORMALIZING**

4. **TEMPERING**

   a. AUSTEMPERING
   b. MARTEMPERING
   c. Low, Medium and High Temp. based.

1. Annealing



- Heating above critical temperature
- Soaking for 1 to 2 hours
- **Slow cooling** to release internal stresses and rearrange ferrite or pearlite structure.

1. Annealing

- Annealing is a heat treatment in which the metal is heated to a temperature above its recrystallization temperature, kept at that temperature for some time for homogenization of temperature followed by very slow cooling to develop equilibrium structure in the metal or alloy.

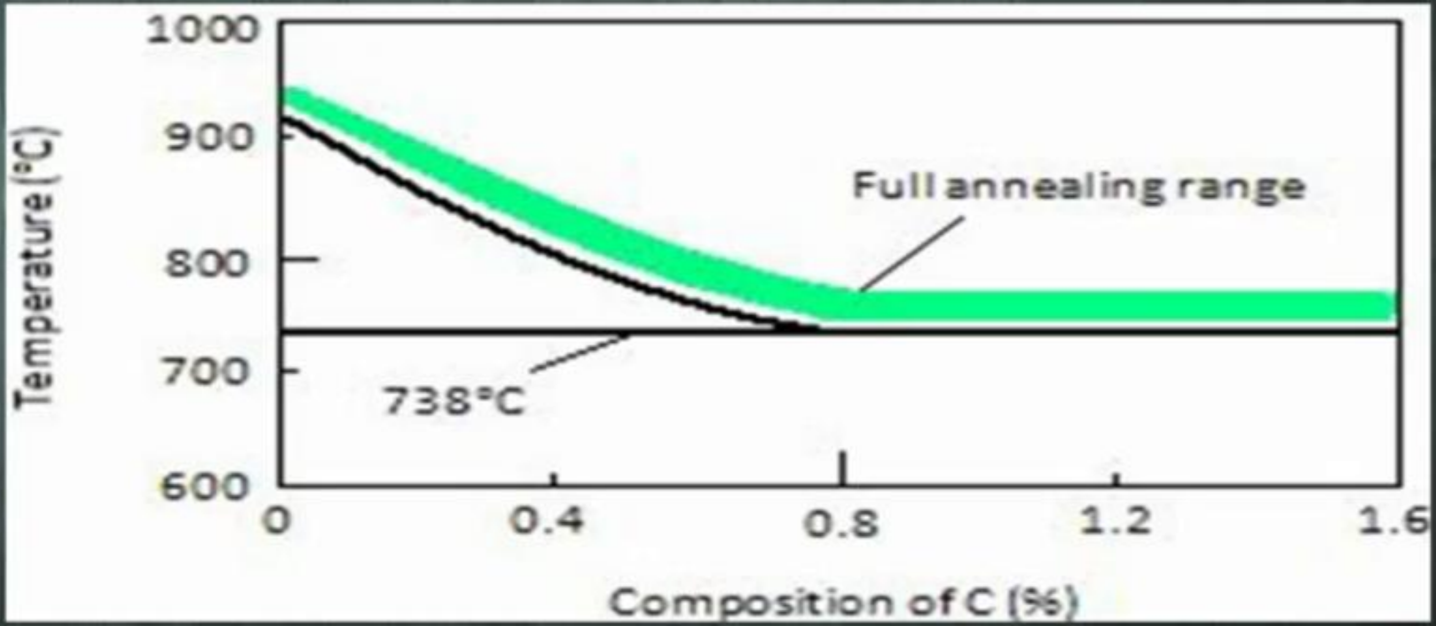
- The objective of annealing to relieve internal stresses, soften them, make them more ductile, and refine their grain structures.

- The steel is heated 30 to 50^oC above A_3 temperature in case of hypo-eutectoid steels and 30 to 50^oC above A_1 temperature in case of hyper-eutectoid temperature. The cooling is done in the furnace itself.

- The process includes all three stages of heat treatment already covered (heat the metal to a specific temperature, hold it at a temperature for a set length of time, cool it to room temperature), but the cooling method will depend on the metal and the properties desired.

Purpose of Annealing

- Relieve internal stresses and **refine grain structure**
- Increase ductility
- Increase **toughness**
- Increase machinability



Full annealing temperature range for steel

Aims of Annealing

1. Increase ductility
2. Reduce hardness
3. Improving formability
4. Recrystallize cold worked (strain hardened) metals
5. Remove internal stresses
6. Increase toughness
7. Decrease brittleness
8. Increase machinability
9. Decrease electrical resistance
10. Improve magnetic properties

TYPES OF ANNEALING

a. FULL ANNEALING
b. STRESS RELIEF ANNEALING
c. PROCESS ANNEALING
d. SPHEROIDIZING ANNEALING

a) Full Annealing

- Full annealing consists of heating steel to above the upper critical temperature, and slow cooling, usually in the furnace. It is generally only necessary to apply full annealing cycles to the higher alloy or higher carbon steels.
- In some instances a special form of full annealing called isothermal annealing is used, to obtain maximum softening response.
- This consists of holding the steel at a selected temperature above the upper critical temperature for sufficient time to allow transformation to pearlite before cooling the steel.
- Long cycle times are required to do this with many high alloy steels and it is therefore expensive.
- It is heating the steel 30 to 50ºC above A_3 temperature in case of hypo-eutectoid steels and 30 to 50ºC above A_1 temperature in case of hyper-eutectoid temperature, keeping it at that temperature for some time for homogenization of temperature followed by cooling at a very slow rate (furnace cooling).
- The cooling rate may be about 10ºC per hour.

Full Annealing Heat treatment.

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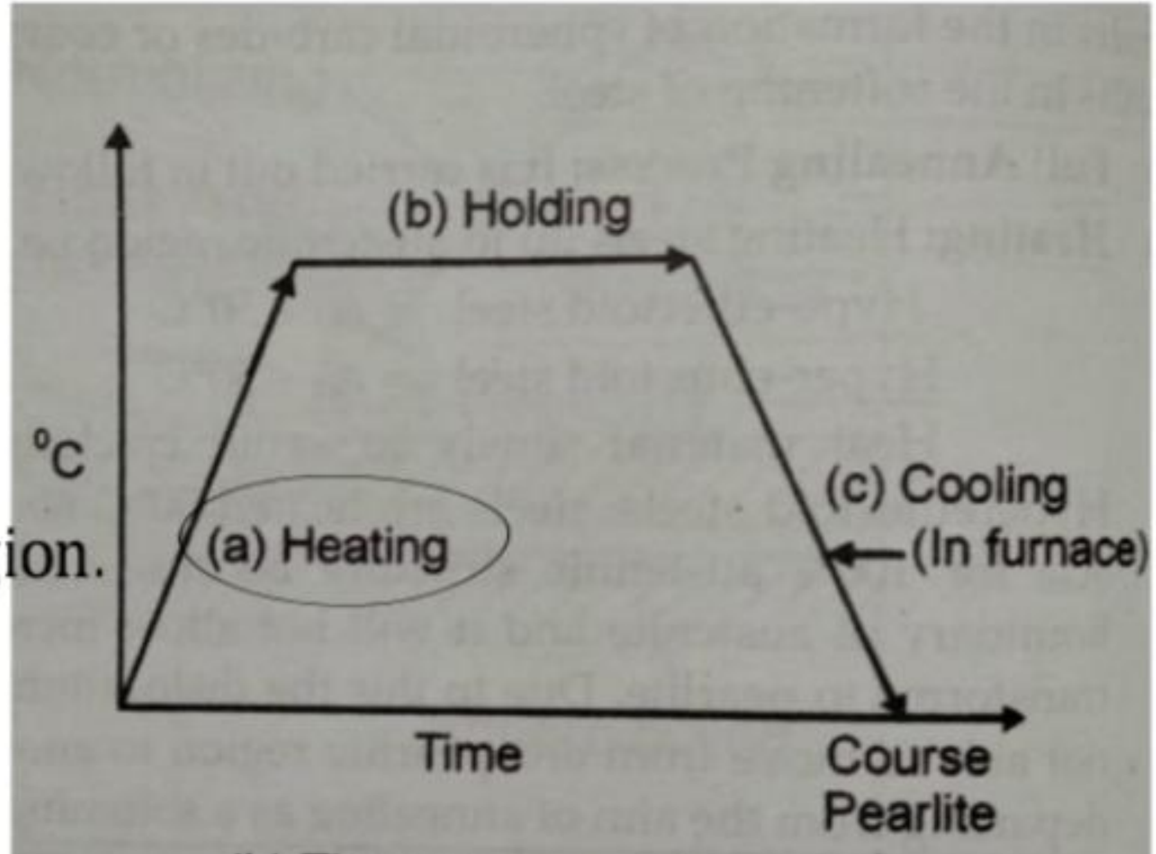
3 Stages

Heating Steels upto Austenitic Region.

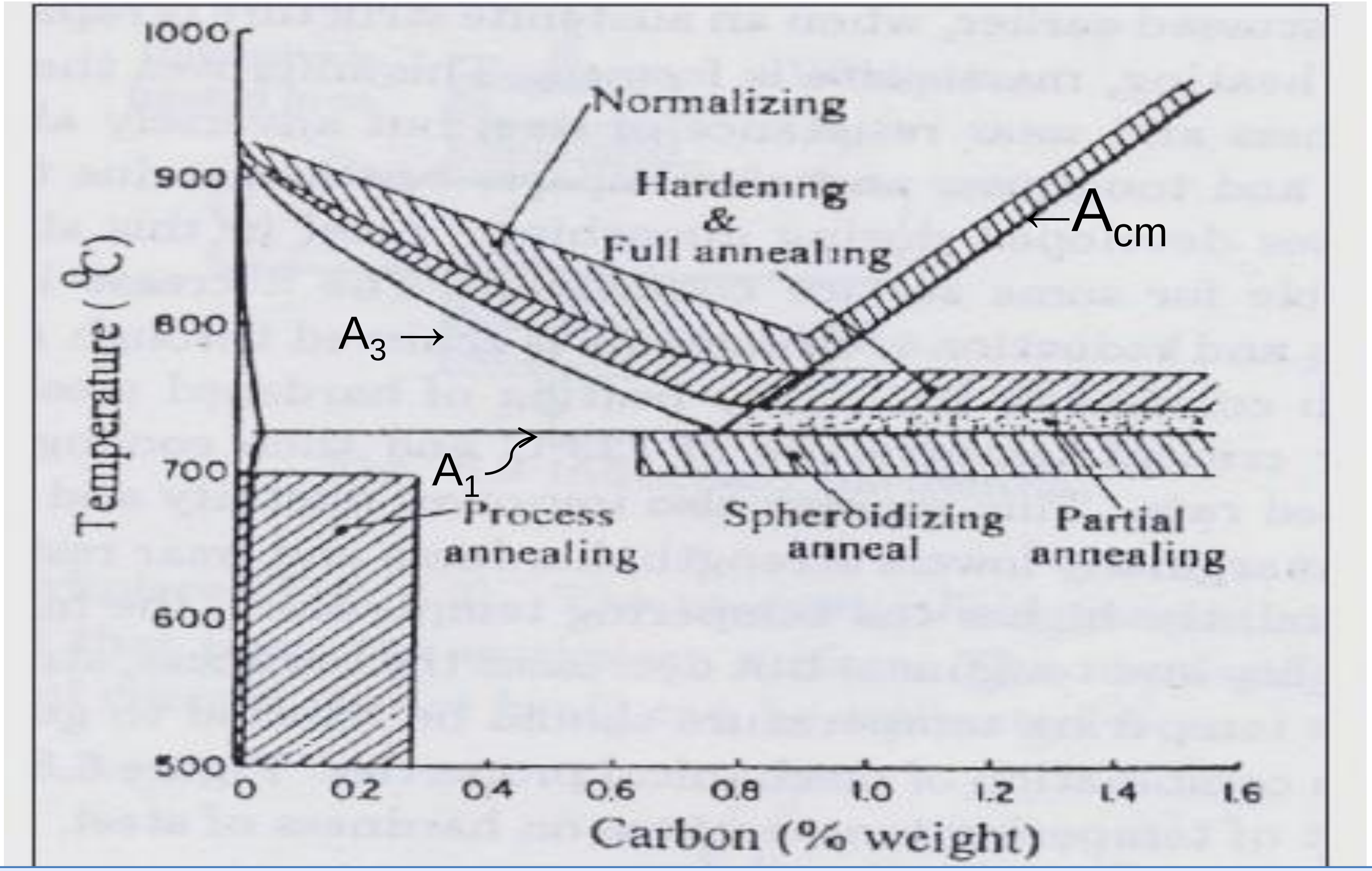


(b) Three stages of Annealing

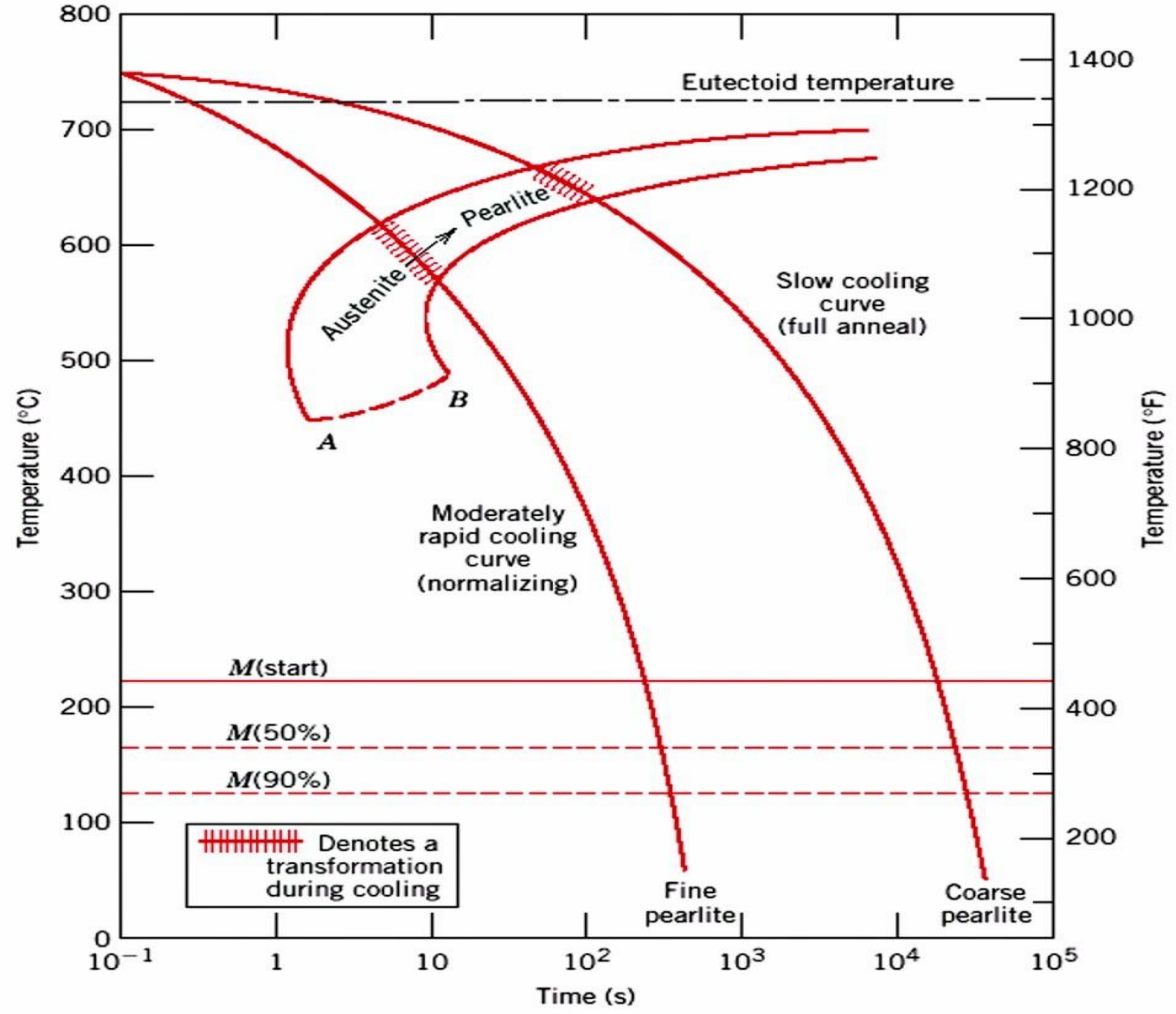
- It is to get all the changes in the properties of the metals like
  - Producing equilibrium microstructure,
  - Increase in ductility,
  - Reduction in hardness, strength, brittleness and
  - Removal of internal stresses.
- The microstructure after annealing contains coarse ferrite and pearlite.

Heat Treatment Temperature Range.

The temperature ranges to which the steel has to be heated for different heat treatments



Annealing on Time- Temperature-Transformation (TTT) Diagram



The cooling rate during annealing is very slow, about 10^0C per hour.

b) Stress Relief Annealing

- In stress relief annealing, the metal is heated to a lower temperature and is kept at that temperature for some time to remove the internal stresses followed by slow cooling.
- The aim of the stress relief annealing is to remove the internal stresses produced in the metal due to
  - Plastic deformation
  - Non-uniform cooling
  - Phase transformation
- No phase transformation takes place during stress relief annealing.
- A low-temperature stress relieving process in which the time at temperature is followed by very slow cooling.
- Some large components and those with thick and thin sections would cool at varying rates during rapid or uncontrolled cooling. This could result in too high a level of residual stress, even after the stress relieving operation. Controlled, slow cooling gives the lowest level of residual stress.
- The term is sometimes used as a synonym for stress relieving.

c) Spheroidizing Annealing

- This treatment involves subjecting steel to a selected temperature cycle usually within or near the transformation range in order to produce a suitable globular form of carbides for such purposes as:
  (a) Improved machinability
  (b) Facilitating subsequent cold working
  (c) Obtaining a desired structure for hardening the steel
- These treatments are frequently used on hypereutectoid steels to overcome grain boundary carbide networks, which are brittle and unsuitable for subsequent hardening of these high carbon steels (i.e. hypereutectoid steels contain more than 0.80% carbon.
- In spheroidizing annealing, the steel is heated to a temperature below A1 temperature, kept at that temperature for some time followed by slow cooling.
- The aim of spheroidizing annealing is to improve the machinability of steel.
- In this process the cementite is converted into spheroidal form.
- The holding time varies from 15 – 25 hours.

d) Process Annealing

- A heat treatment used to soften material in preparation for further cold working, without significantly changing its structure.
- Process annealing is carried out at a temperature just below the transformation temperature. It is generally used in the production of thin sheet and wire where cold working is used to produce material to very close tolerances.
- In process annealing, the cold worked metal is heated above its recrystallization temperature, kept for some time followed by slow cooling.
- The aim of process annealing is to restore ductility of the cold worked metal.

deformed crystal → undeformed crystal

↑

recrystallization annealing

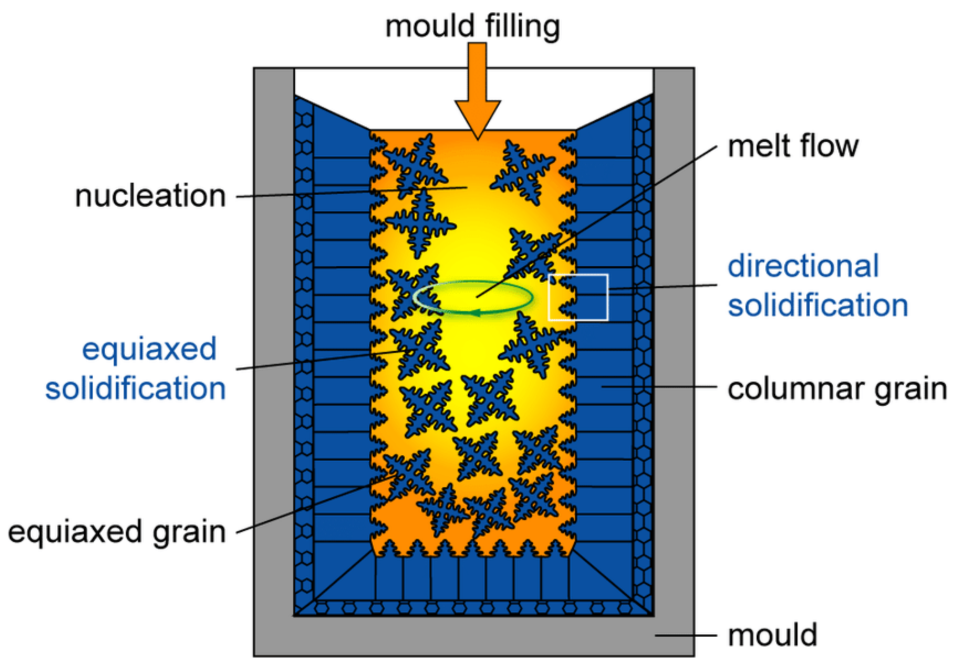
- During process annealing, recovery and recrystallization takes place.
- During process annealing, new equiaxed, strain-free grains nucleate at high-stress regions in the cold-worked microstructure, and hence hardness and strength decrease whereas ductility increases.

d) Process Annealing

Annealed crystal (grain) —— Cold work ——→ Deformed or Strained crystal (high energy state)

- When a metal is cold worked, most of energy goes into plastic deformation to change the shape and heat generation. However, a small portion of the energy, up to ~5 %, remains stored in the material. The stored energy is mainly in the form of elastic energy in the strain fields surrounding dislocations and point defects generated during the cold work.
- Cold worked grains are quite unstable due to the strain energy. By heating the cold worked material to high temperatures where sufficient atomic mobility is available, the material can be softened and a new microstructure can emerge. This heat treatment is called process annealing where recovery and recrystallization take place.

Equiaxed crystals are crystals that have axes of approximately the same length. **Equiaxed grains** can in some cases be an indication for recrystallization. **Equiaxed** crystals can be achieved by heat treatment, namely annealing and normalizing.



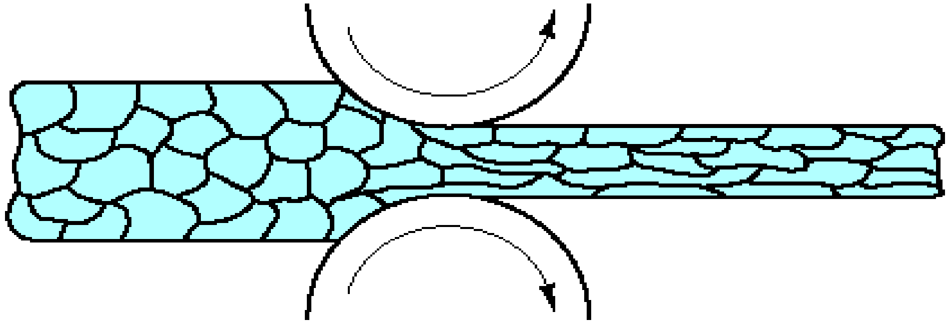
d) Process Annealing

Cont..)

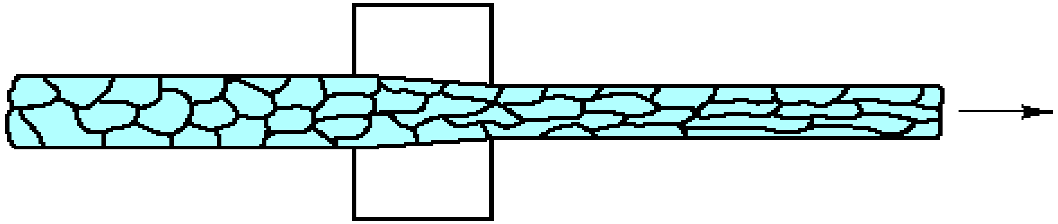
- **Cold work** : mechanical deformation of a metal at relatively low temperatures. Thus, cold working of a metal increases significantly dislocation density from 10^8 (annealed state) to 10^{12} cm/cm^3, which causes hardness and the strength of the metal.

Example --- rolling, forging, and drawing etc.

- % cold work = $(A_0 - A_f)/A_0 \times 100\%$,
  where A_0 is the original cross- sectional area and A_f is the final cross-sectional area after cold working.
- With increasing % cold work, the hardness and strength of alloys are increased whereas the ductility of the alloys are decreased.
- For further deformation, the ductility has to be restored by process annealing.



Cold-rolling



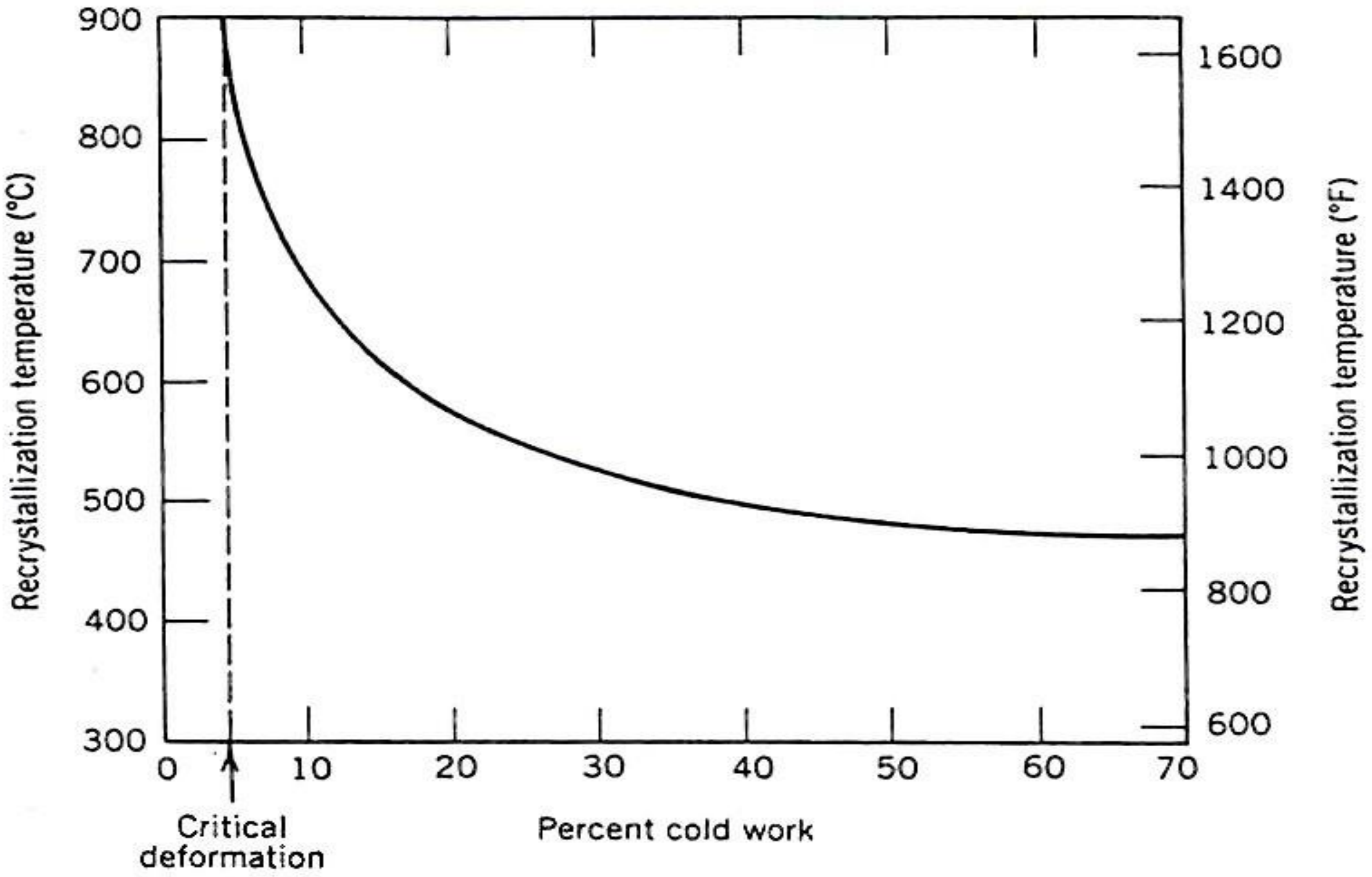
Cold-drawing

Recrystallization : occurs at 1/3 to 1/2 Tm(Melting Temp.)

Recrystallization temp. is that at which recrystallization just reaches completion in 1 hour.

d) Process Annealing

Variation of recrystallization temperature with percent cold work for iron



d) Process Annealing

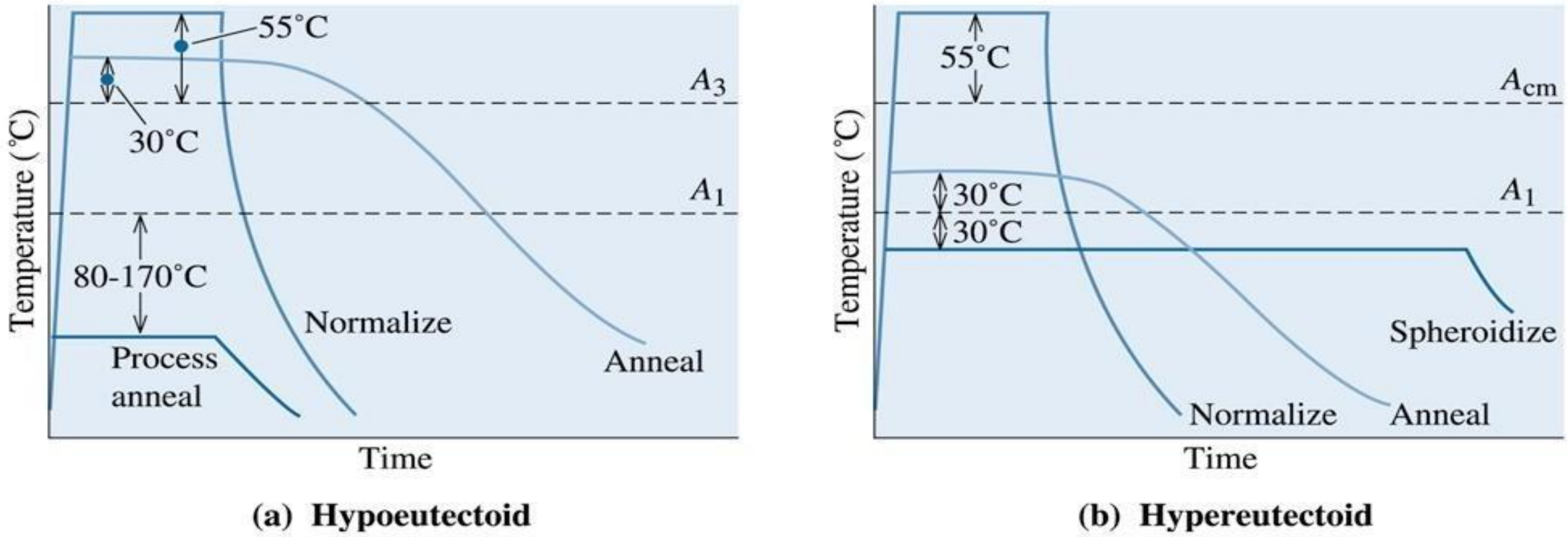


Figure :Schematic summary of the simple heat treatments for (a) hypoeutectoid steels and (b) hypereutectoid steels.

Stages of Annealing

There are three stages of annealing
1. Recovery
2. Recrystallization
3. Grain Growth

Recovery

- The relief of some of the internal strain energy of a previously cold-worked material.
- Relieves the stresses from cold working.
- Recovery involves annihilation of point defects.
- Driving force for recovery is decrease in stored energy from cold work.
- During recovery, physical properties of the cold worked material are restored without any observable change in microstructure.
- Recovery is first stage of annealing which takes place at low temperatures of annealing.

- There is some reduction, though not substantial, in dislocation density as well apart from formation of dislocation configurations with low strain energies.

Recrystallization

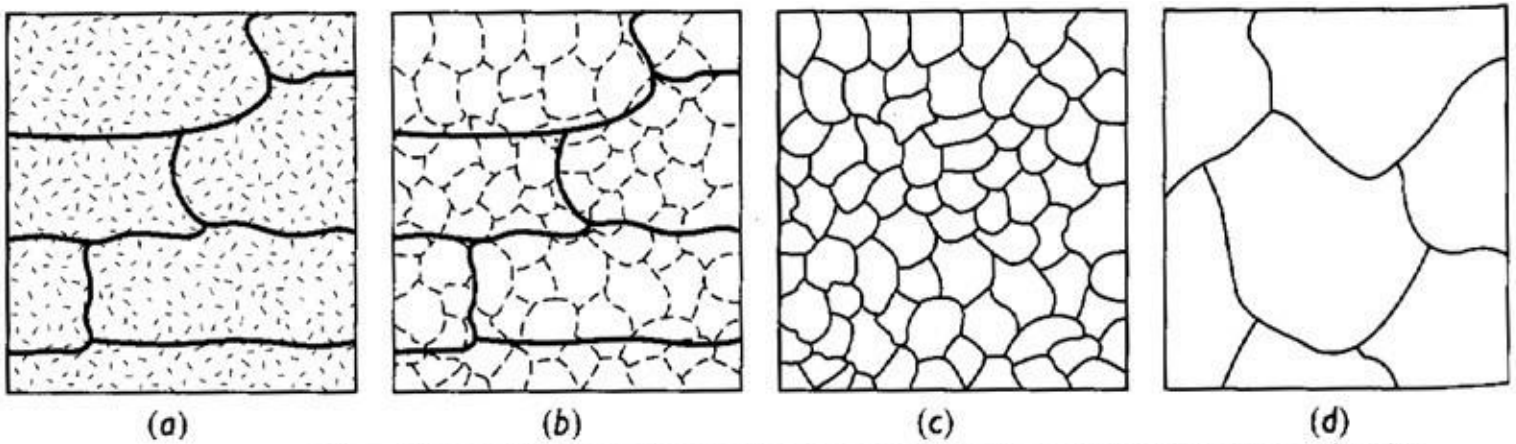
- This process occurs above recrystallization temperature which is defined as the temperature at which 50% of material recrystallizes in one hour time.

- The recrystallization temperature is strongly dependent on the purity of a material.
- Pure materials may recrystallize around 0.3Tm, while impure materials may recrystallize around 0.4Tm, where Tm is absolute melting temperature of the material.
- The formation of a new set of strain-free grains within a previously cold-worked material.
- It involves replacement of cold-worked structure by a new set of strain-free, approximately equi-axed grains to replace all the deformed crystals.

Grain Growth

- The increase in average grain size of a polycrystalline material.
- Grain growth follows complete crystallization if the material is left at elevated temperatures.
- Grain growth does not need to be preceded by recovery and recrystallization; it may occur in all polycrystalline materials.
- In contrary to recovery and recrystallization, driving force for this process is reduction in grain boundary energy.
- Tendency for larger grains to grow at the expense of smaller grains is based on physics.
- In practical applications, grain growth is not desirable.
- Incorporation of impurity atoms and insoluble second phase particles are effective in retarding grain growth and it is very strongly dependent on temperature.

Changes in Microstructure during different stages of Annealing



The effect of annealing temperature on the microstructure of cold-worked metals: (a) cold worked, (b) after recovery, (c) after recrystallization, and (d) after grain growth.

2. Hardening

- The purpose of hardening is not only to harden steel as the name implies, but also to increase its strength. While a hardening heat treatment does increase the hardness and strength of the steel, it also makes it less ductile, and brittleness increases as hardness increases.
- To remove some of the brittleness, temper the steel after hardening. Many nonferrous metals can also be hardened and their strength increased by controlled heating and rapid cooling, but for nonferrous metals, the same process is called heat treatment rather than hardening.
- For most steels, hardening consists of employing the typical first two stages of heat treatment (slowly heat to temperature and soak to time and temperature), but the third stage is dissimilar. With hardening, you rapidly cool the metal by plunging it into oil, water, or brine. (Note: Most steels require rapid cooling [quenching] for hardening, but a few can be air cooled with the same results.)
- The cooling rate required to produce hardness decreases when alloys are added to steel; this is advantageous since a slower cooling rate also lessens the danger of cracking and warping.

- The follow provides hardening characteristics for a few irons and low-carbon steel.
  - Pure iron, wrought iron, and extremely low-carbon steels — very little hardening properties; difficult to harden by heat treatment.
  - Cast iron — limited capabilities for hardening
    - ✓Cooled rapidly, it forms white iron; hard and brittle
    - ✓Cooled slowly, it forms gray iron; soft but brittle under impact
  - Plain carbon steel — maximum hardness depends almost entirely on carbon content
    - ✓Hardening ability increases as carbon content increases to a maximum of 0.80 % carbon
    - ✓Increased carbon content beyond 0.80 % increases wear resistance but not hardness
    - ✓Increased wear resistance is due to the formation of hard cementite
- Adding an alloy to steel to increase its hardness also increases the carbon's effectiveness to harden and strengthen. Consequently, the carbon content required to produce maximum hardness is lower in alloyed steels than it is for plain carbon steels with the result that alloy steels are usually superior to carbon steels.

The following presents different commercially used methods of hardening.

TYPES OF HARDENING

a. CASE HARDENING
b. FLAME HARDENING
c. INDUCTION HARDENING
d. AGE HARDENING

a) Case Hardening

- The object of case hardening is to produce a hard, wear-resistant surface (case) over a strong, tough core.
- In case hardening, the surface of the metal is chemically changed by the introduction of a high carbide or nitride content, but the core remains chemically unaffected. When the metal is heat treated, the high-carbon surface responds to hardening and the core toughens. Case hardening applies only to ferrous metals.
- It is ideal for parts that must have a wear-resistant surface yet be internally tough enough to withstand heavy loading. Low-carbon and low-alloy series steels are best suited for case hardening. When high-carbon steels are case hardened, the hardness penetrates beyond the surface resulting in brittleness.

- There are three principal processes for case hardening: carburizing, cyaniding, and nitriding.

Carburizing

- A case hardening process by which carbon is added to the surface of low-carbon steel.

When the carburized steel is heat treated, the case becomes hardened and the core remains soft and tough--in other words, it has a high-carbon surface and a low-carbon interior.

- There are two methods for carburizing steel:
  - Heat the steel in a furnace containing a carbon monoxide atmosphere.
  - Place the steel in a container packed with charcoal (or some other carbon-rich material) and heat in a furnace.
- The parts can be left in the container and furnace to cool, or they can be removed and air-cooled. In either case, the parts become annealed during the slow cooling. The depth of the carbon penetration depends on the length of the soaking period during heat treatment. Modern methods dictate that carburizing is almost exclusively done by gas atmospheres.

Cyaniding

Cyaniding — a case hardening process by which preheated steel is dipped into a heated cyanide bath and allowed to soak.

The part is then removed, quenched, and rinsed to remove any residual cyanide. This process is fast and efficient. It produces a thin, hard shell, harder than the shell produced by carburizing, and can be completed in 20 to 30 minutes vice several hours. The major drawback is the use of cyanide; cyanide salts are a deadly poison.

Nitriding

Nitriding — a case hardening process by which individual parts have been heat treated and tempered before being heated in a furnace that has an ammonia gas atmosphere. This case hardening method produces the hardest surface of any of the hardening processes, and it differs from the other methods in that no quenching is required so there is no worry about warping or other types of distortion. The nitriding process is used to case harden items such as gears, cylinder sleeves, camshafts, and other engine parts that need to be wear-resistant and operate in high-heat areas.

b) Flame Hardening

- Flame hardening is another process available for hardening the surface of metal parts. In flame hardening, you use an oxyacetylene flame to heat a thin layer of the surface to its critical temperature and then immediately quench it with a water spray. In this case, the cold base metal assists in the quenching since it is not preheated. Similar to case hardening, this process produces a thin, hardened surface while the internal parts retain their original properties. The process can be manual or mechanical, but in either case, maintain a close watch since an oxyacetylene flame can heat the metal rapidly and temperatures in this method are usually determined visually. Flame hardening may also be done with automatic equipment.
- Typically, for the best flame-hardening heating results, we should hold the torch with the tip of the inner cone about an eighth of an inch from the surface and direct the flame at right angles to the metal. Occasionally, we may need to change the angle for better results, but rarely use a deviation of more than 30°. The speed of torch travel will depend on the type of metal, the mass, the shape of the part, and the depth of hardness desired.

Typical flame hardening.

- For hardening localized areas, you can flame harden with a standard hand-held welding torch and the torch flame adjusted to neutral for normal heating.
- In corners and grooves, however, you should use a slightly oxidizing flame to keep the torch from sputtering, and exercise particular care against overheating.
- If dark streaks appear on the metal surface, this is a sign of overheating, and you need to increase the distance between flame and metal.

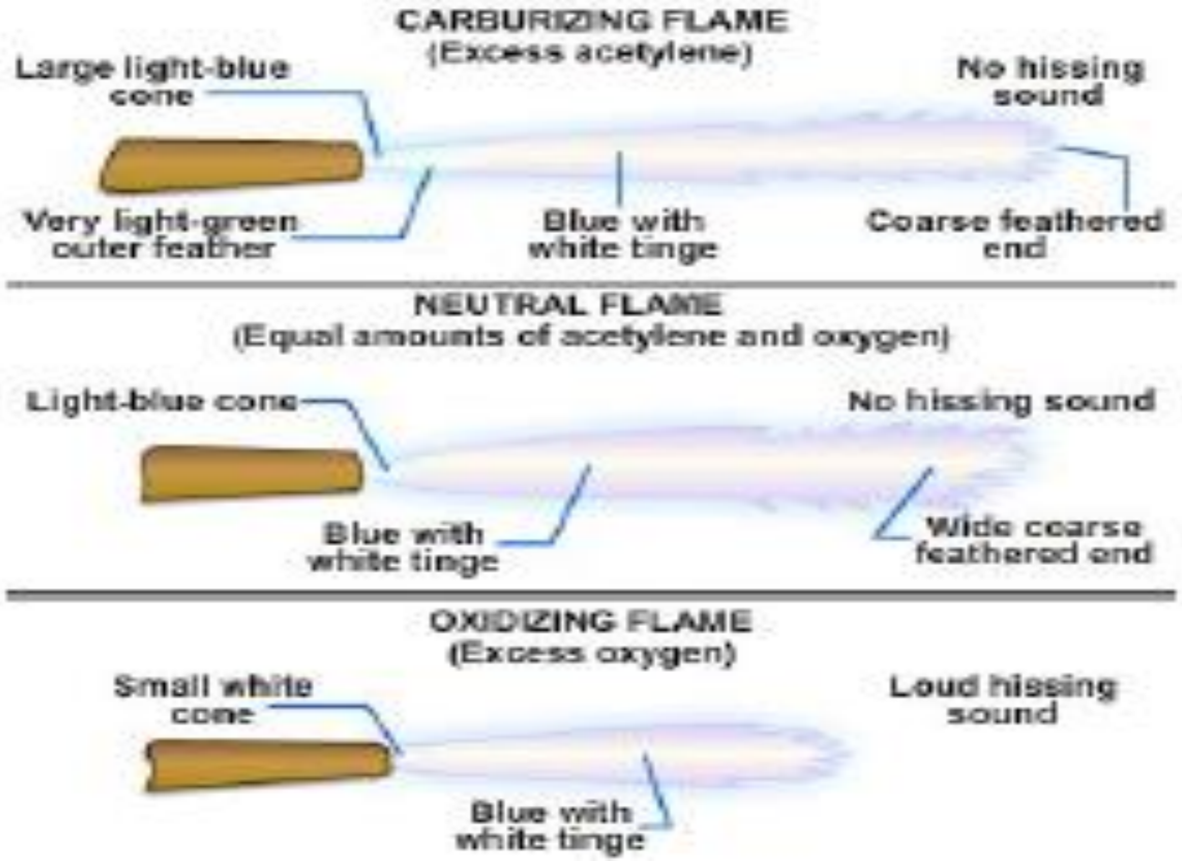


Fig: Example of carburizing, neutral, and oxidizing flames.

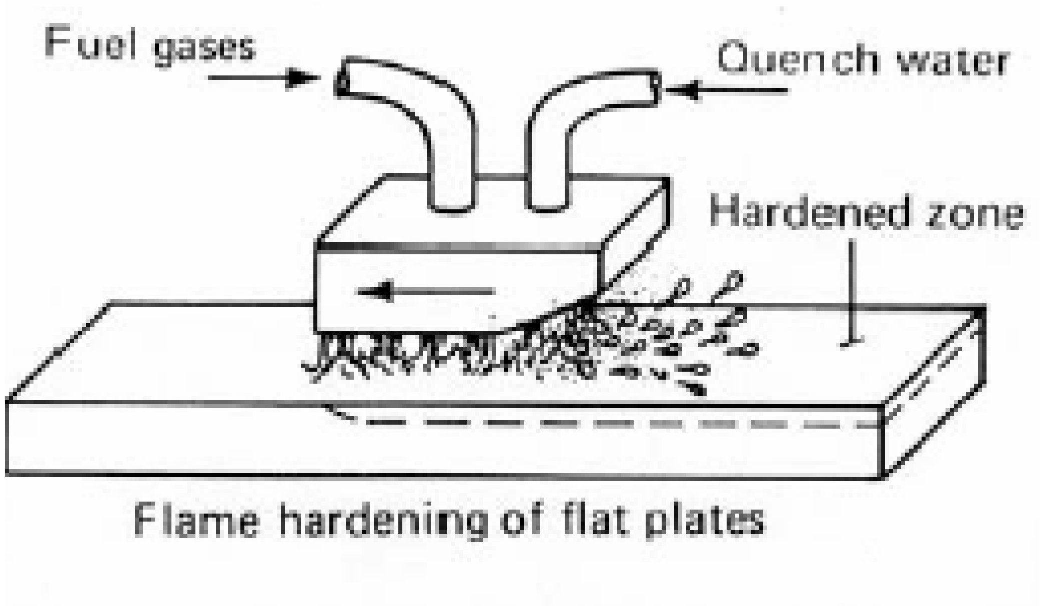
- There are three methods of flame hardening are:

(1) SPOT Flame Hardening: Flame is directed to the spot that needs to be heated and hardened.

(2) SPIN Flame Hardening: The workpiece is rotated while in contact with the flame

(3) PROGRESSIVE Flame Hardening: The torch and the quenching medium move across the surface of the workpiece.

- Flame hardening is the process of selective hardening with a combustible gas flame as the source of heat for austenitizing. (The material should have at least 0.40 % Carbon content to allow hardening.)
- Water quenching is applied as soon as the transformation temperature is reached. The heating media can be oxygen acetylene, propane, or any other combination of fuel gases that will allow reasonable heating rates. This procedure is applied to the gear teeth, shear blades, cams, ways on the lathes, etc.
- Flame hardening temperatures are around 1500oF. Up to HRC 65 hardness can be achieved. For best results the hardness depth is 3/16 inch.



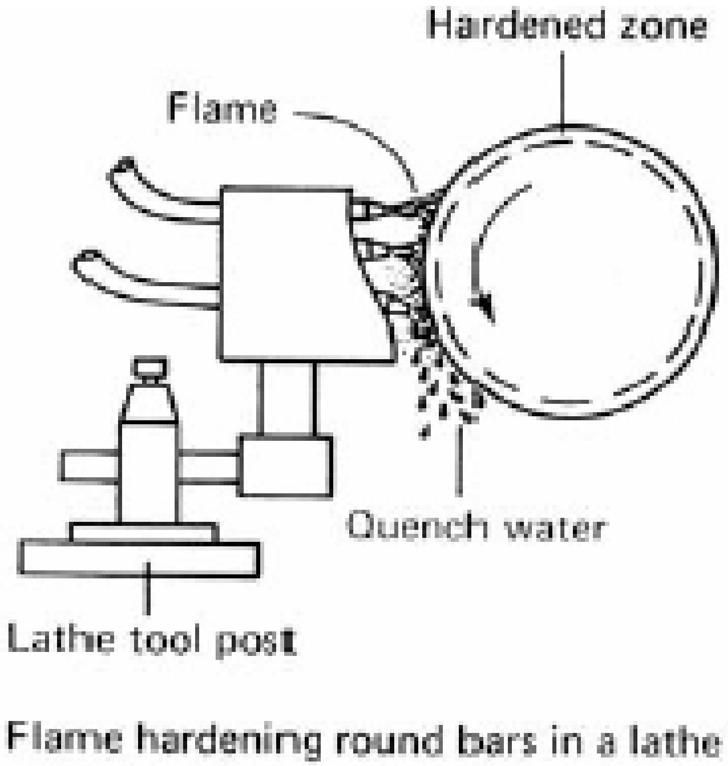


Fig: Flame hardening

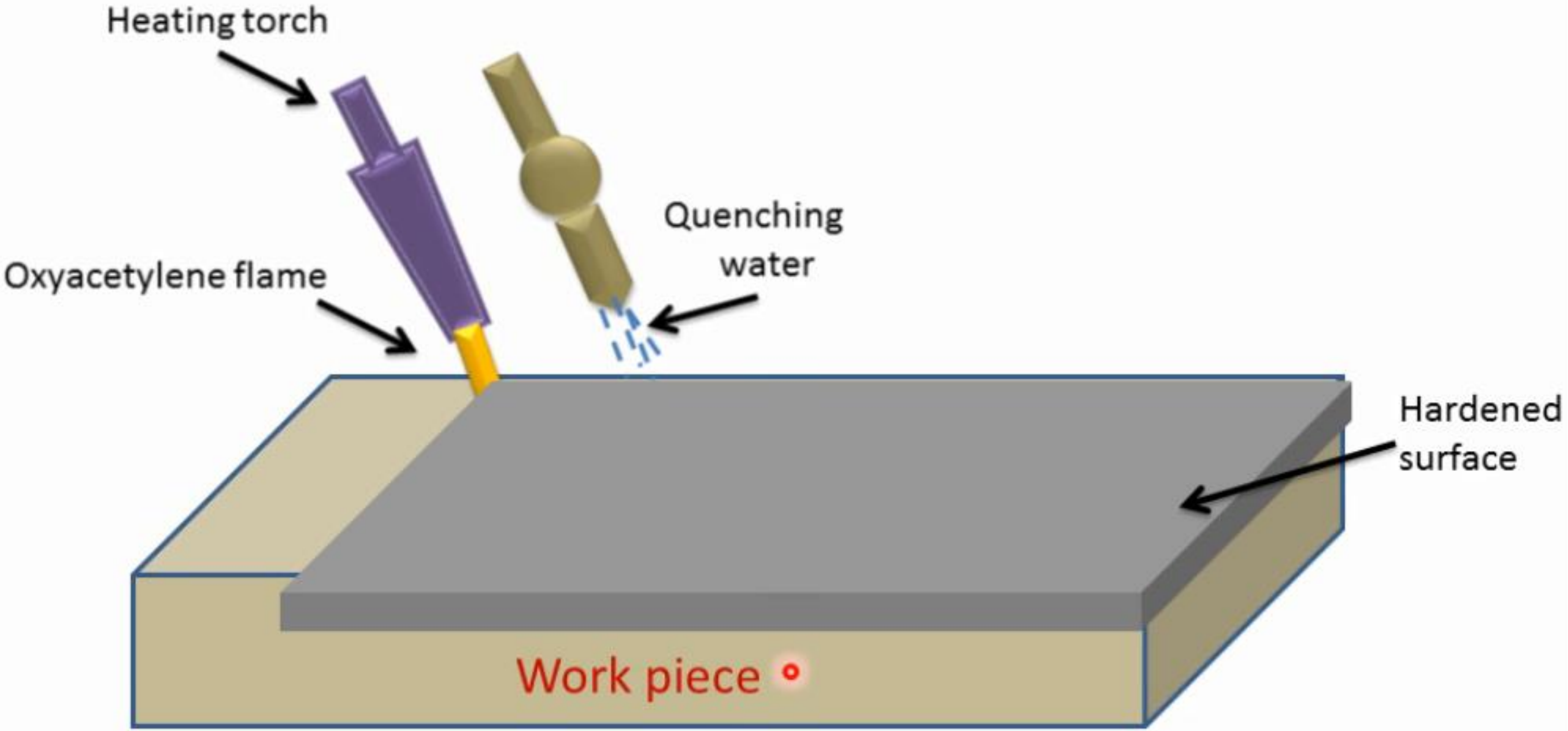


Fig: Flame hardening

c) Induction Hardening

- Induction hardening is a process used for the surface hardening of steel and other alloy components. The parts to be heat treated are placed inside a water cooled copper coil and then heated above their transformation temperature by applying an alternating current to the coil. The alternating current in the coil induces an alternating magnetic field within the work piece, which if made from steel, caused the outer surface of the part to heat to a temperature above the transformation range. Parts are held at that temperature until the appropriate depth of hardening has been achieved, and then quenched in oil, or another media, depending upon the steel type and hardness desired.
- The core of the component remains unaffected by the treatment and its physical properties are those of the bar from which it was machined or preheat treated. The hardness of the case can be HRC 37 - 58. Carbon and alloy steels with a carbon content in the range 0.40 - 0.45% are most suitable for this process. In some cases, parts made from alloy steels such as 4320, 8620 or 9310, like steel and paper mill rolls, are first carburized to a required case depth and slow cooled, and then induction hardened. This is to realize the benefit of relatively high core mechanical properties, and surface hardness greater than HRC 60, which provides excellent protection.

- In this process an electric current flow is induced in the work piece to produce a heating action. Every electrical conductor carrying a current has a magnetic field surrounding the conductor. Since the core wire is a dead-end circuit, the induced current cannot flow anyplace, so the net effect is heating of the wire. The induced current in the core conductor alternates at frequencies from 60 cycles per second (60 Hz) to millions of Hertz.
- The resistance to current flow causes very rapid heating of the core material. Heating occurs from the outside inward. Induction hardening process includes water quench after the heating process. The big advantage of this system is its speed and ability to confine heating on small parts. The major disadvantage is the cost.

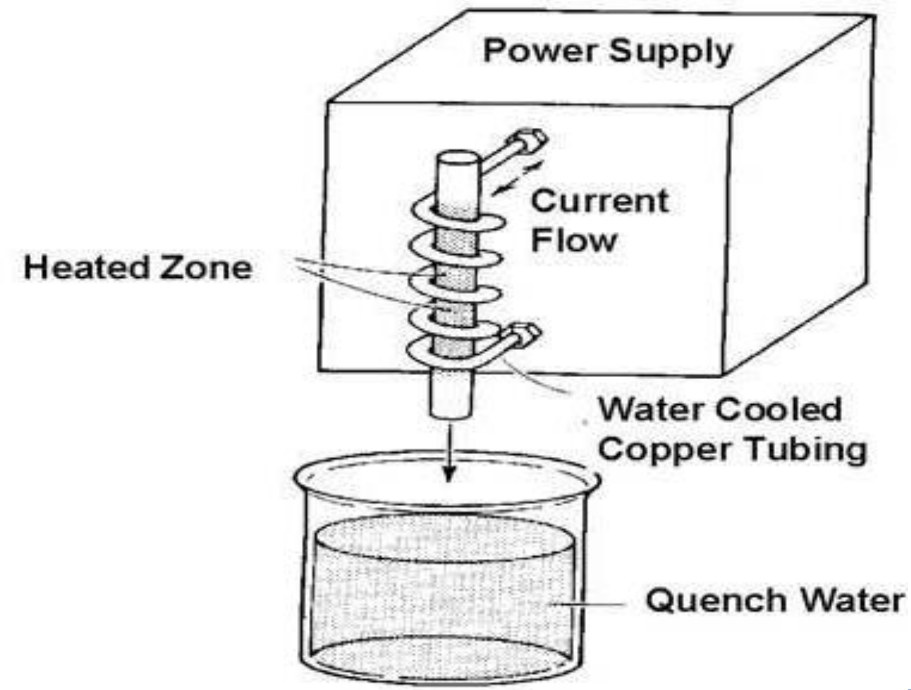
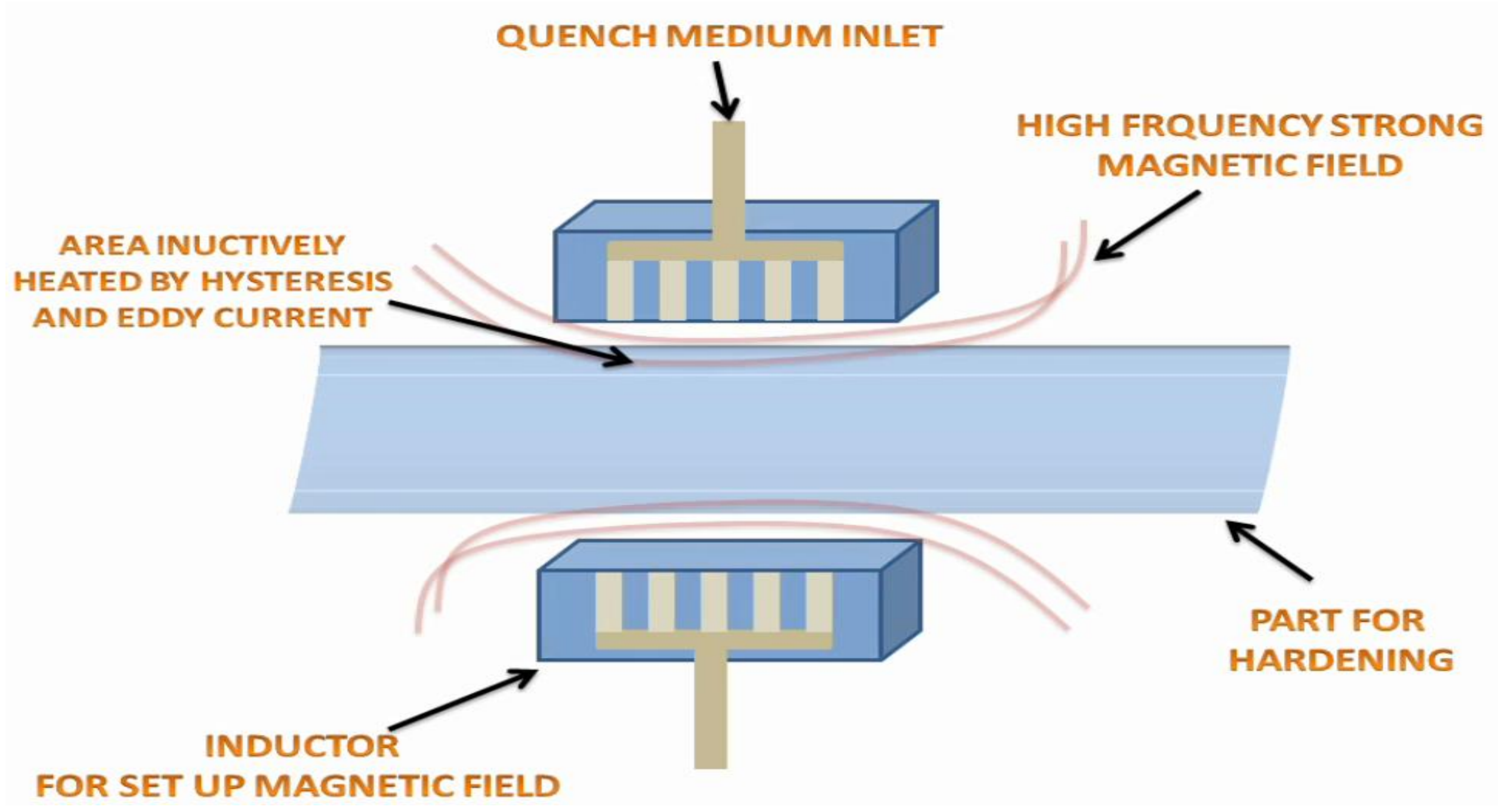


Fig: Induction hardening

- Induction Hardening can be split into two steps. The first one is induction heating, in which electrically conducting metals are heated with an electromagnet. The quenching phase follows directly after to alter the surface structure of the material.
- **Induction Heating:** Materials such as steel are typically placed inside a water cooled copper coil where they are subject to an alternating magnetic field. They undergo electromagnetic induction by means of an electromagnet and an electronic oscillator. This oscillator sends alternating currents through the electromagnet, causing alternating magnetic fields that penetrate the material. The results are eddy currents (loops of electrical current) which heat the object within the coil. Induction hardening is a form of surface hardening in which the depth can be up to 8mm.
- **Quenching**: Directly after the induction heating process, the object has to be quenched, meaning that it has the be cooled down extremely quickly. To do that, the workpiece is typically placed in a tank of oil or water, although sometimes cold air is used. Quenching ensures that only the surface is hardened and that heat doesn’t spread into the core of the material, avoiding phase transformations from arising. Furthermore, the rapid cooling down creates a martensitic or ferritic-martensitic structure on the surface layer. These structure display higher tensile strength and low initial yielding stress than a purely ferritic structure. Quenching also reduced grain size which is a key factor to increasing hardness of materials.


QUENCH MEDIUM INLET
HIGH FRQUENCY STRONG MAGNETIC FIELD
AREA INUCTIVELY HEATED BY HYSTERESIS AND EDDY CURRENT
PART FOR HARDENING
INDUCTOR FOR SET UP MAGNETIC FIELD

d) Age hardening

- Age hardening, also known as precipitation hardening, is a type of heat treatment that is used to impart strength to metals and their alloys. It is called precipitation hardening as it makes use of solid impurities or precipitates for the strengthening process. The metal is aged by either heating it or keeping it stored at lower temperatures so that precipitates are formed.
- Malleable metals and alloys of nickel, magnesium and titanium are suitable for age hardening process. Through the age hardening process the tensile and yield strength are increased. The precipitates that are formed inhibit movement of dislocations or defects in the metals crystal lattice. The metals and alloys need to be maintained at high temperatures for many hours for the precipitation to occur; hence this process is called age hardening.

Techniques of Age Hardening

- The process of age hardening is executed in a sequence of three steps.
- First the metal is treated with a solution at high temperatures. All the solute atoms are dissolved to form a single phase solution. A large number of microscopic nuclei, called zones, are formed on the metal. This formation is accelerated further by elevated temperatures.
- The next step is the rapid cooling across the solvus line so that the solubility limit is exceeded. The result is a super saturated solid solution that remains in a metastable state. The lowering of temperatures prevents the diffusion.
- Finally, the supersaturated solution is heated to an intermediate temperature in order to induce precipitation. The metal is maintained in this state for some time
- Age hardening requires certain parameters for the process to be successfully completed. These requirements are listed below:
  - Appreciable maximum solubility
  - Solubility must decrease with fall of temperature
  - Alloy composition must be less than the maximum solubility.

Advantages of Age Hardening

- Some of the advantages that age hardening offers are listed below:
  - Imparts high tensile and yield strength to the metal.
  - Enhances wear resistance.
  - Age hardening facilitates easy machinability.
  - Does not cause distortion to the part.

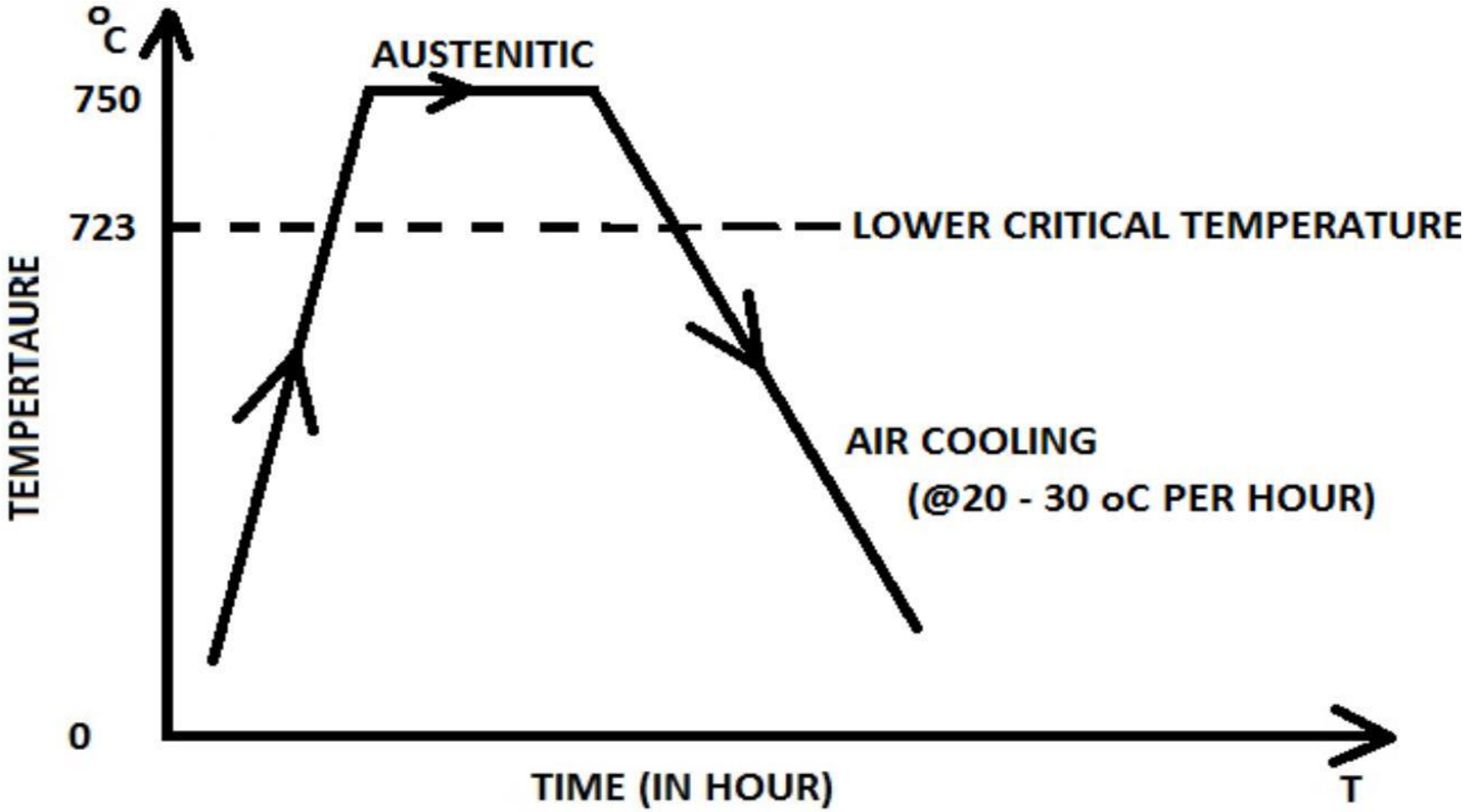
Industrial Applications

- Some of the industrial applications of age hardening are listed below:
  - Strengthening of metals like aluminium, nickel, stainless steel and titanium.
  - Hardening gate valves, engine parts, shafts, gears and plungers.
  - Strengthening balls, bushings, turbine blades, fasteners, moulding dies and nuclear waste cracks.
  - Treating aircraft parts, processing equipment and valve stems.

3. Normalizing

- The intent of normalizing is to remove internal stresses that may have been induced by heat treating, welding, casting, forging, forming, or machining. Uncontrolled stress leads to metal failure; therefore, you should normalize steel before hardening it to ensure maximum results.
- Normalizing applies to ferrous metals only, and it differs from annealing; the metal is heated to a higher temperature, but then it is removed from the furnace for air cooling.
- Low-carbon steels do not usually require normalizing, but if they are normalized, no harmful effects result.
- Note the approximate soaking periods for normalizing steel, which varies with the thickness.
- Normalized steel has a higher strength than annealed steel; it has a relatively high strength and ductility, much tougher than in any other structural condition.
- Metal parts that will be subjected to impact and those requiring maximum toughness with resistance to external stress are usually normalized.
- In normalizing, since the metal is air cooled, the mass of a metal has a significant influence on the cooling rate and hence on the resulting piece’s hardness. With normalizing, thin pieces cool faster in the air and are harder than thick ones, whereas with annealing and its associated furnace cooling, the hardness of the thin and thick pieces is about the same.

- Normalizing is a process of heating steel 40 to 50 ºC above the lower critical temperature.

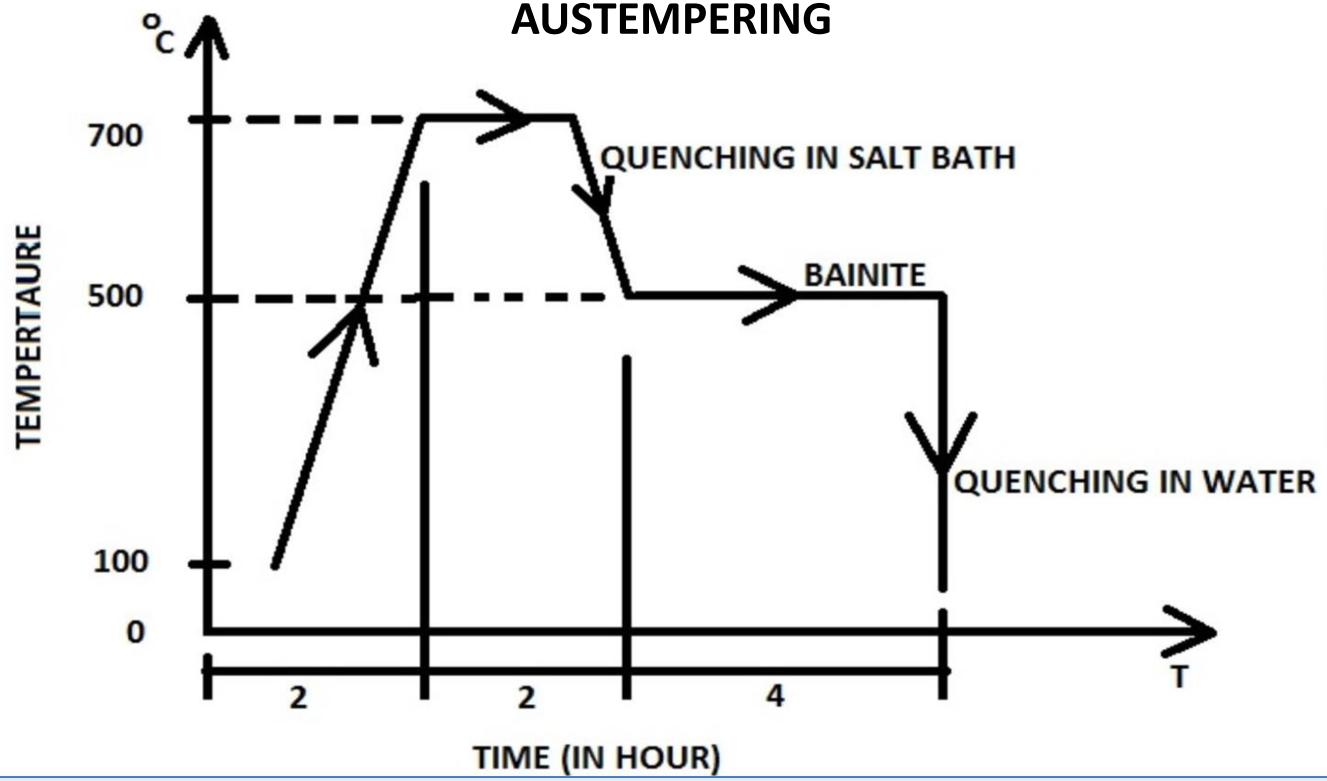


4. TEMPERING

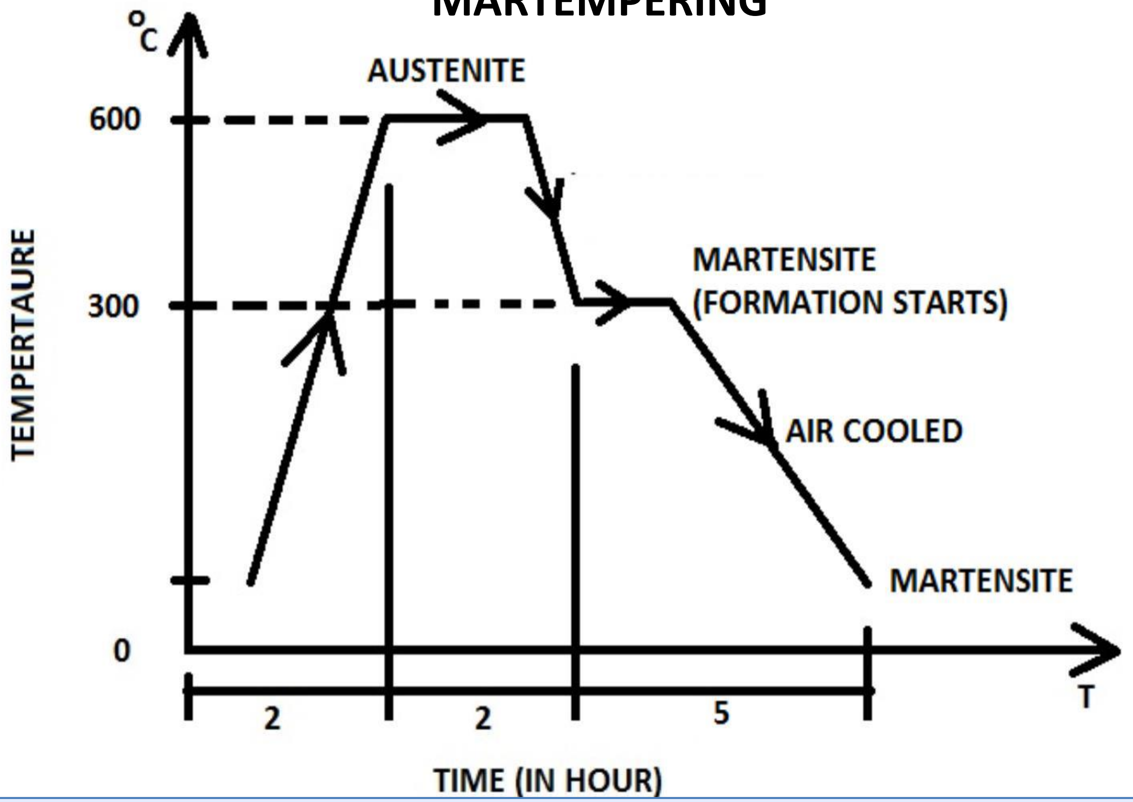
- Steel after hardening becomes brittle, develops non-visible micro-cracks and its strained due to internal stress. These undesired symptoms are reduced by tempering the steel.
- Tempering is an essential operation that has to be performed after hardening.
- After hardening, we need to temper the steel to relieve the internal stresses and reduce brittleness.
- After hardening by either case or flame, steel is often harder than needed and too brittle for most practical uses, containing severe internal stresses that were set during the rapid cooling of the process.
- Tempering consists of:
  - Heating the steel to a specific temperature (below its hardening temperature).
  - Holding it at that temperature for the required length of time.
  - Cooling it, usually in still air.
- Tempering relieves internal stresses from quenching, reduces hardness and brittleness, and may actually increase the tensile strength of hardened steel as it is tempered up to a temperature of about 450°F; above 450°F, tensile strength starts to decrease.
- Typically, tempering increases softness, ductility, malleability, and impact resistance, but again, high-speed steel is an exception to the rule. High-speed steel increases in hardness on tempering, provided you temper it at a high temperature (about 1150°F).

- Remember, to temper a part properly, we need to remove it from the quenching bath before it is completely cold and proceed with the tempering process. Failure to temper correctly can result in a quick failure of the hardened part.
- This process involves reheating of the hardened steel to a certain temperature below lower critical temperature.
- Low Temperature Tempering: heated about 200 ºC.
- Medium Temperature Tempering: heated about 200 to 275 ºC.
- High Temperature Tempering: heated about 275 to 375 ºC.

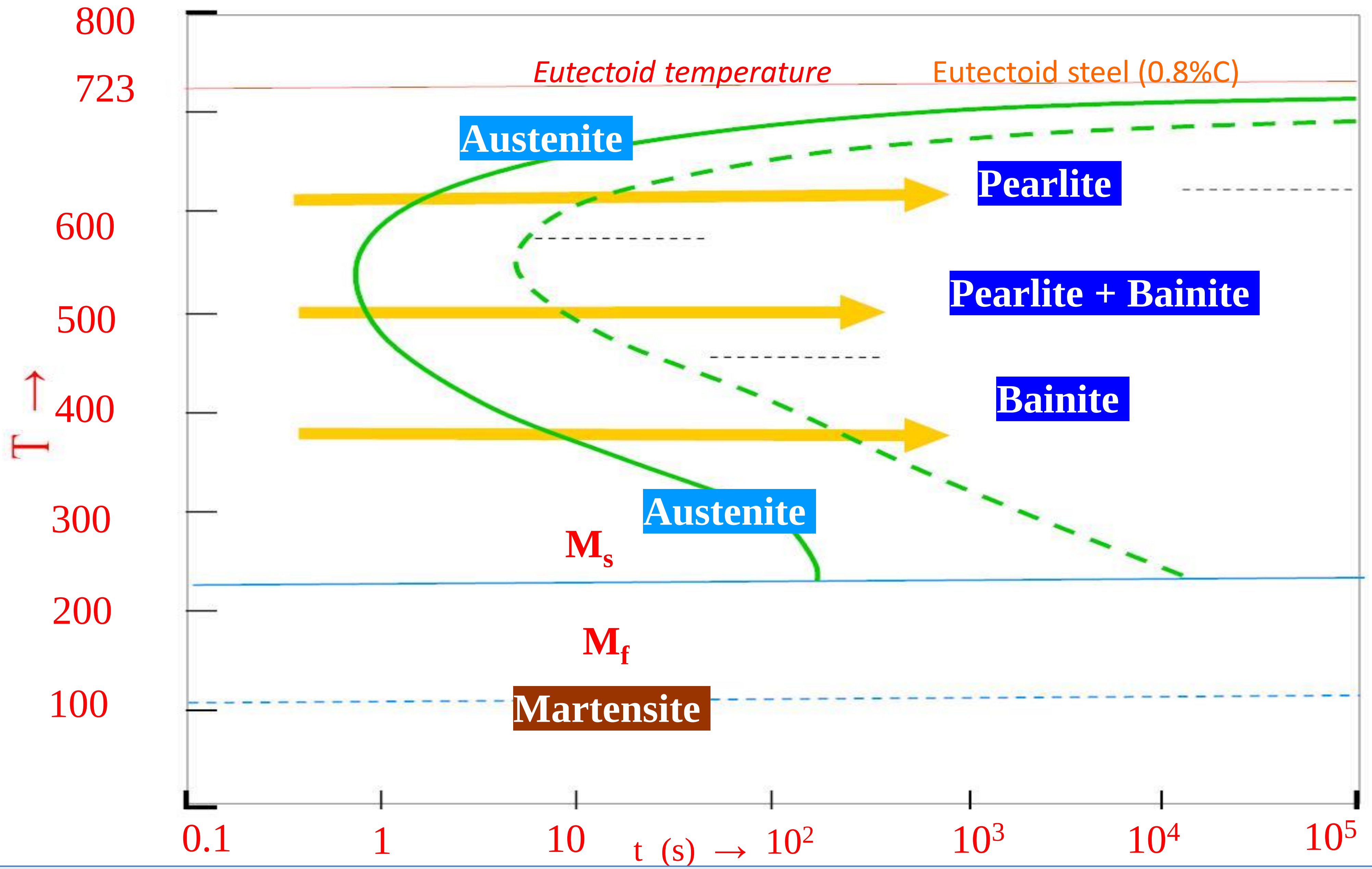
AUSTEMPERING



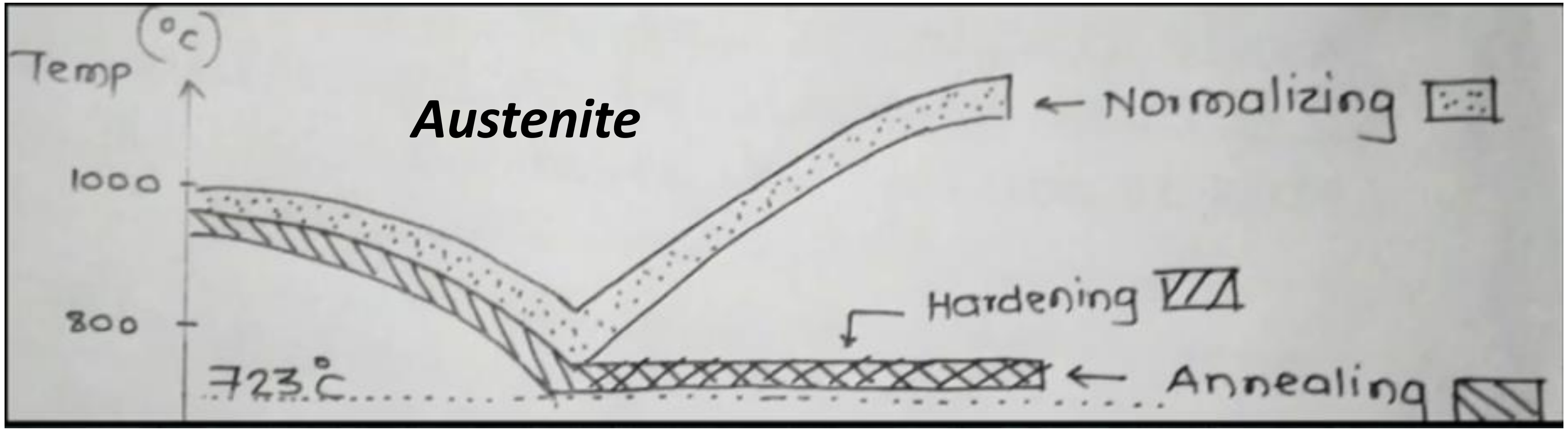
MARTEMPERING



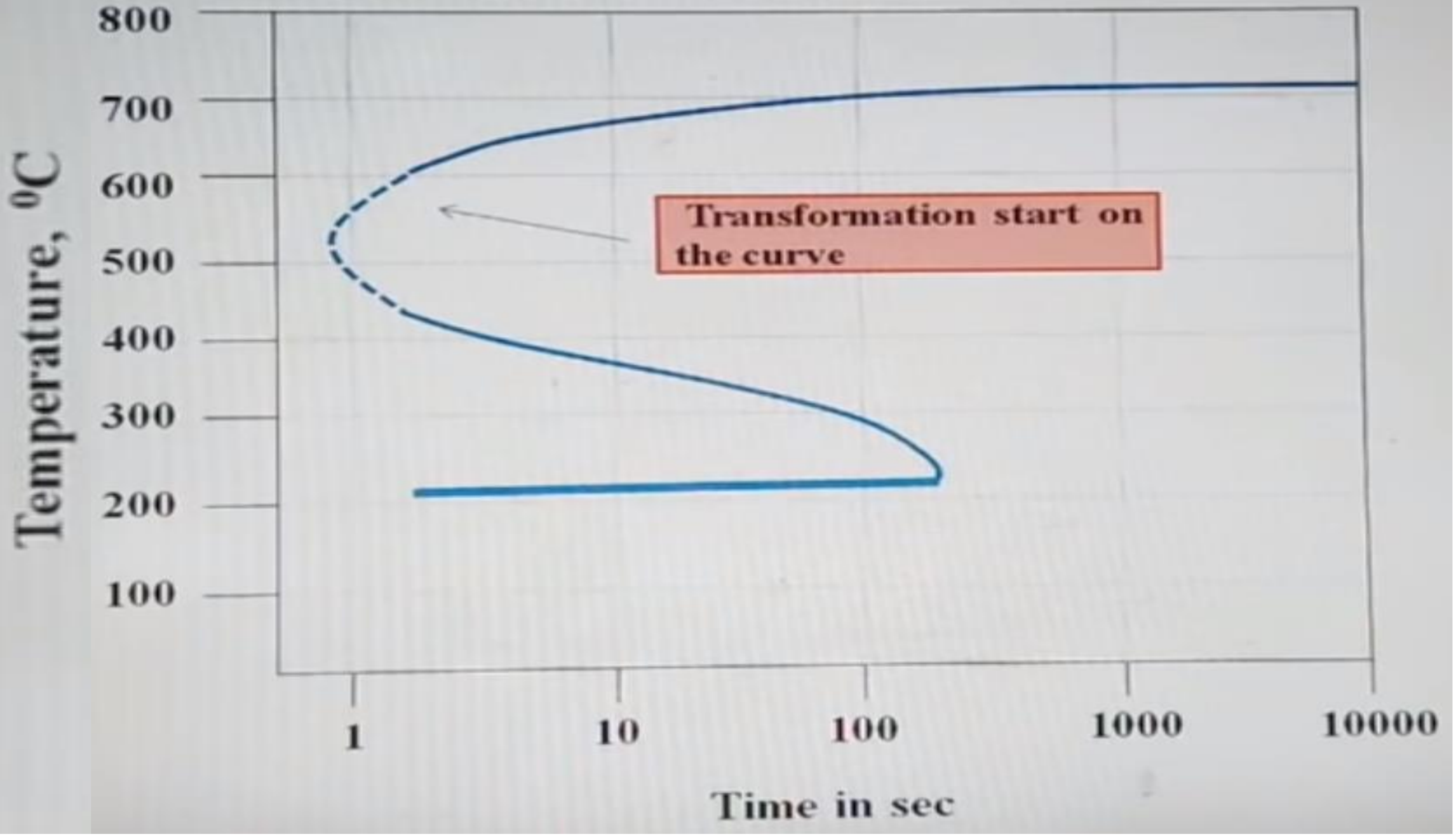
Time- Temperature-Transformation (TTT) Curves – *Isothermal Transformation*



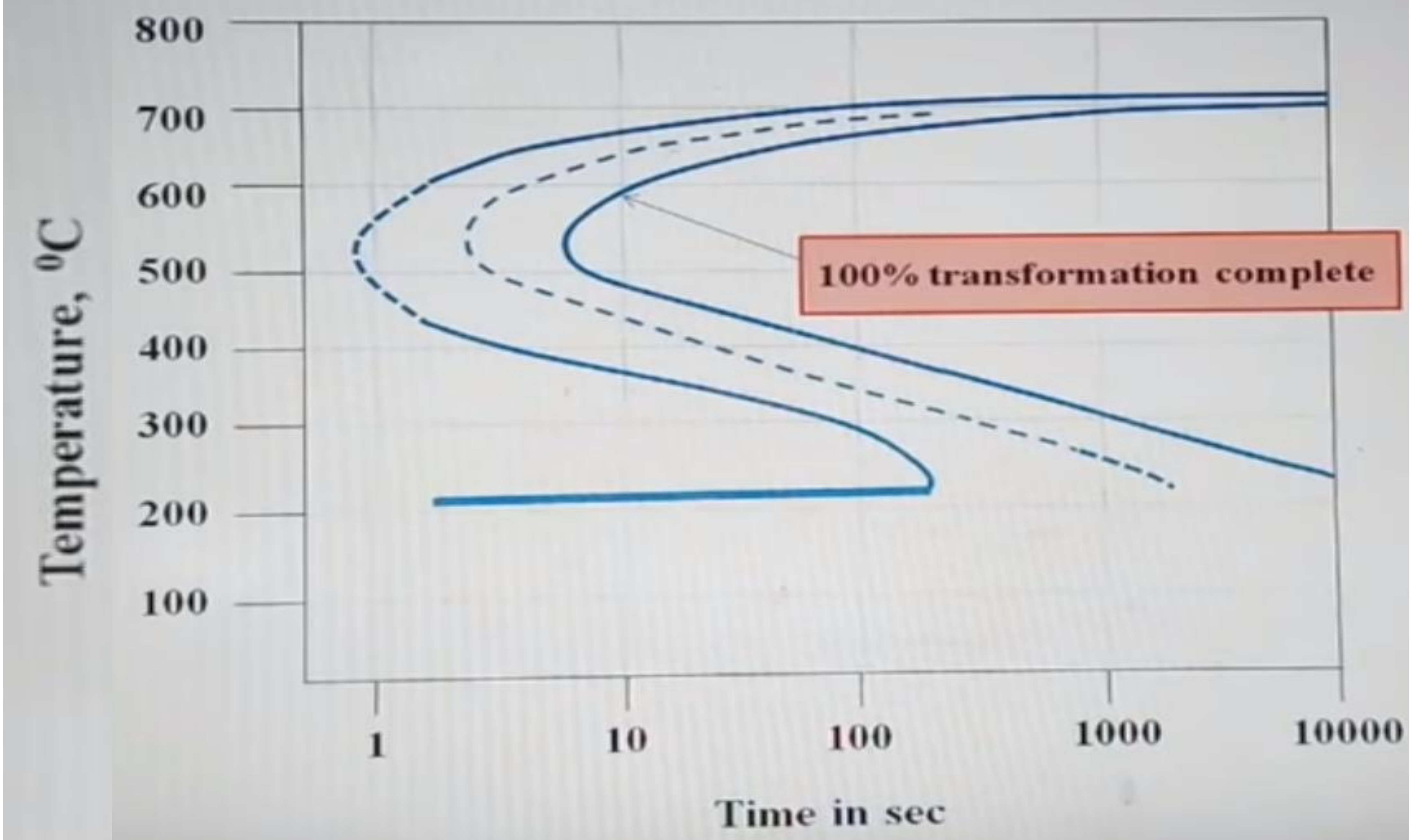
- This diagram deals with the conversion of Austenite into Pearlite/ Bainite/ Martensite.
- In Iron – carbon diagram we assumed that the equilibrium established at any moment. Time factor was excluded there.

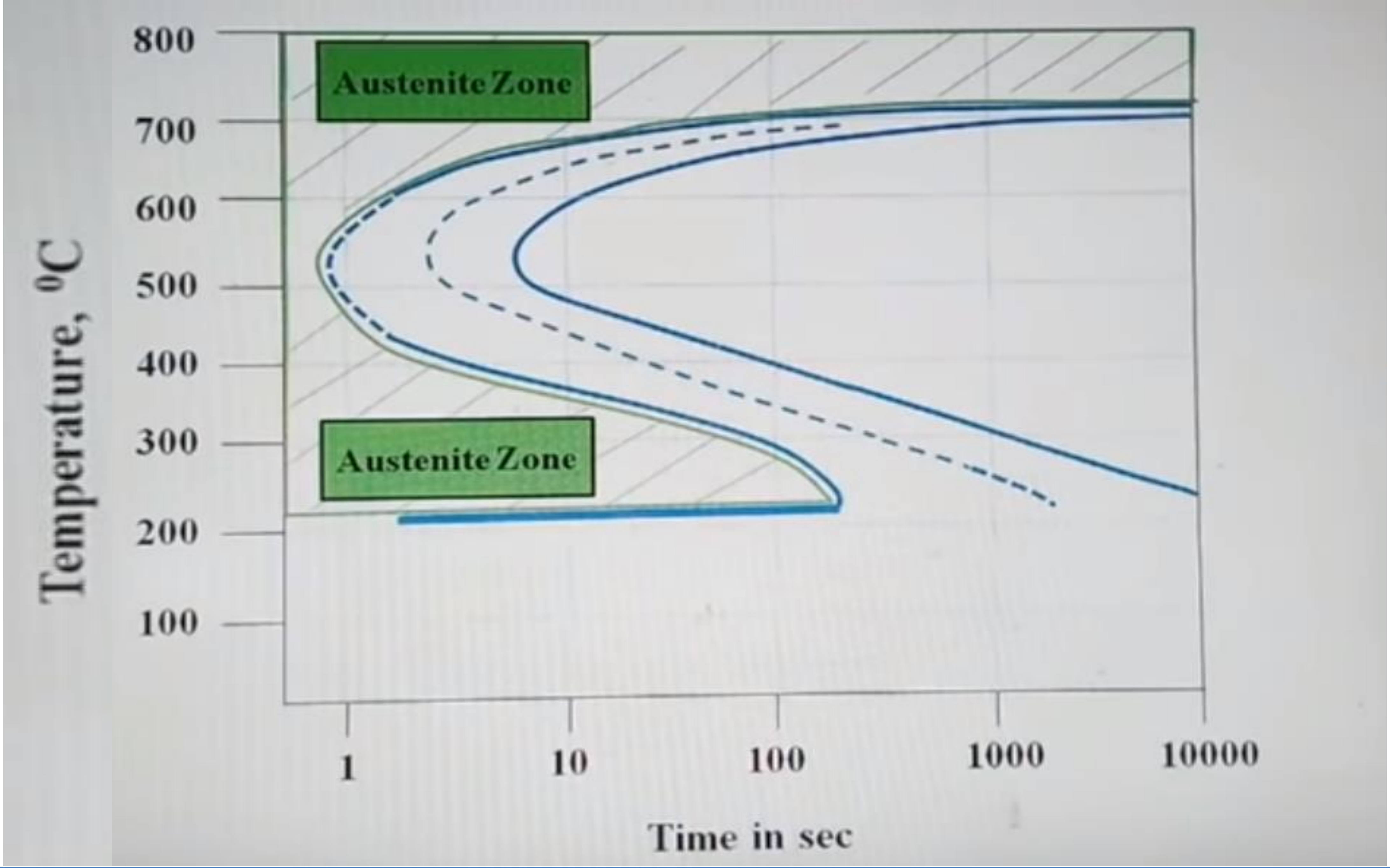


Time- Temperature Transformation Graph

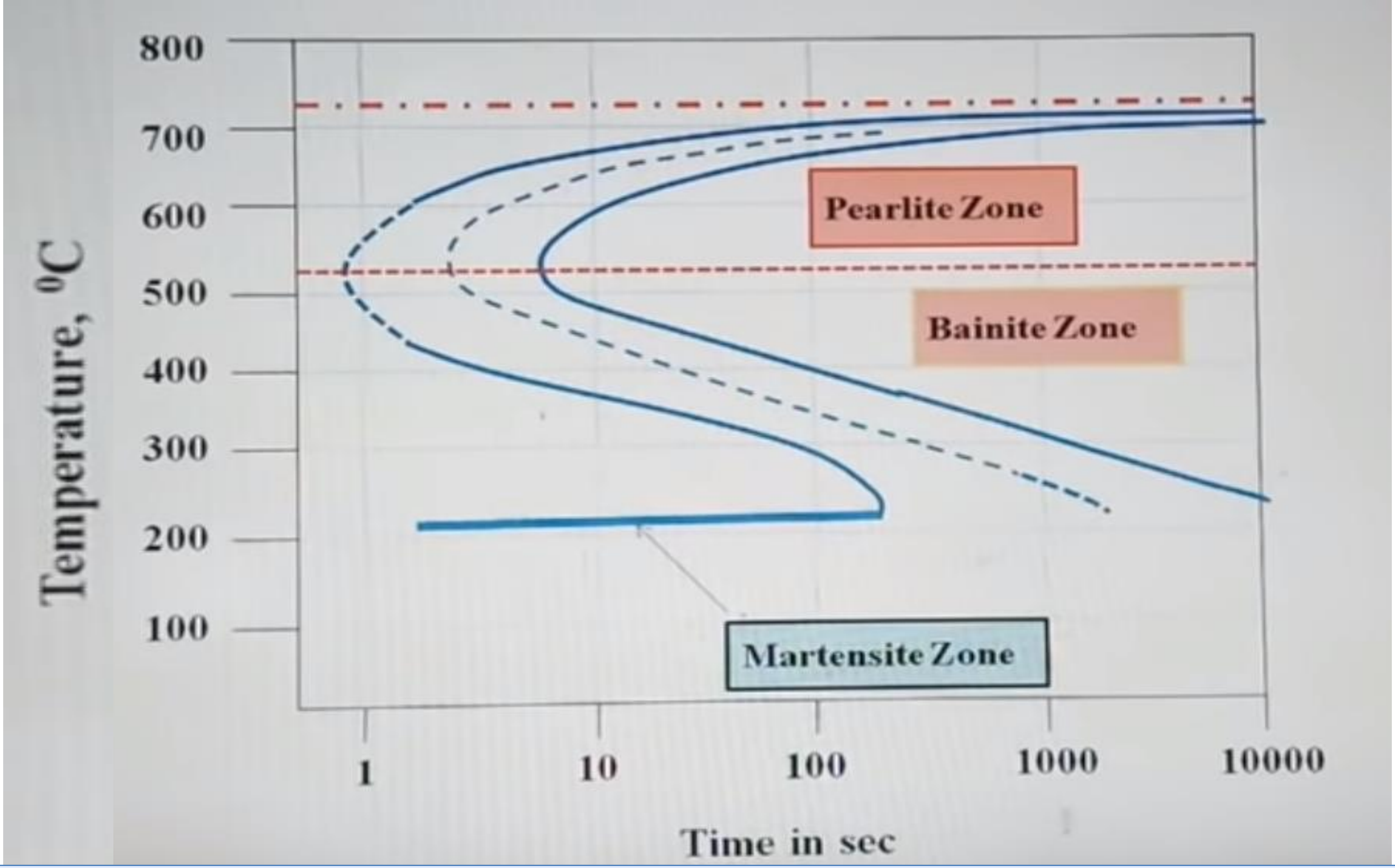



800
700
600
500
400
300
200
100
Temperature, ^{0}C
50% transformation complete
1
10
100
1000
10000
Time in sec

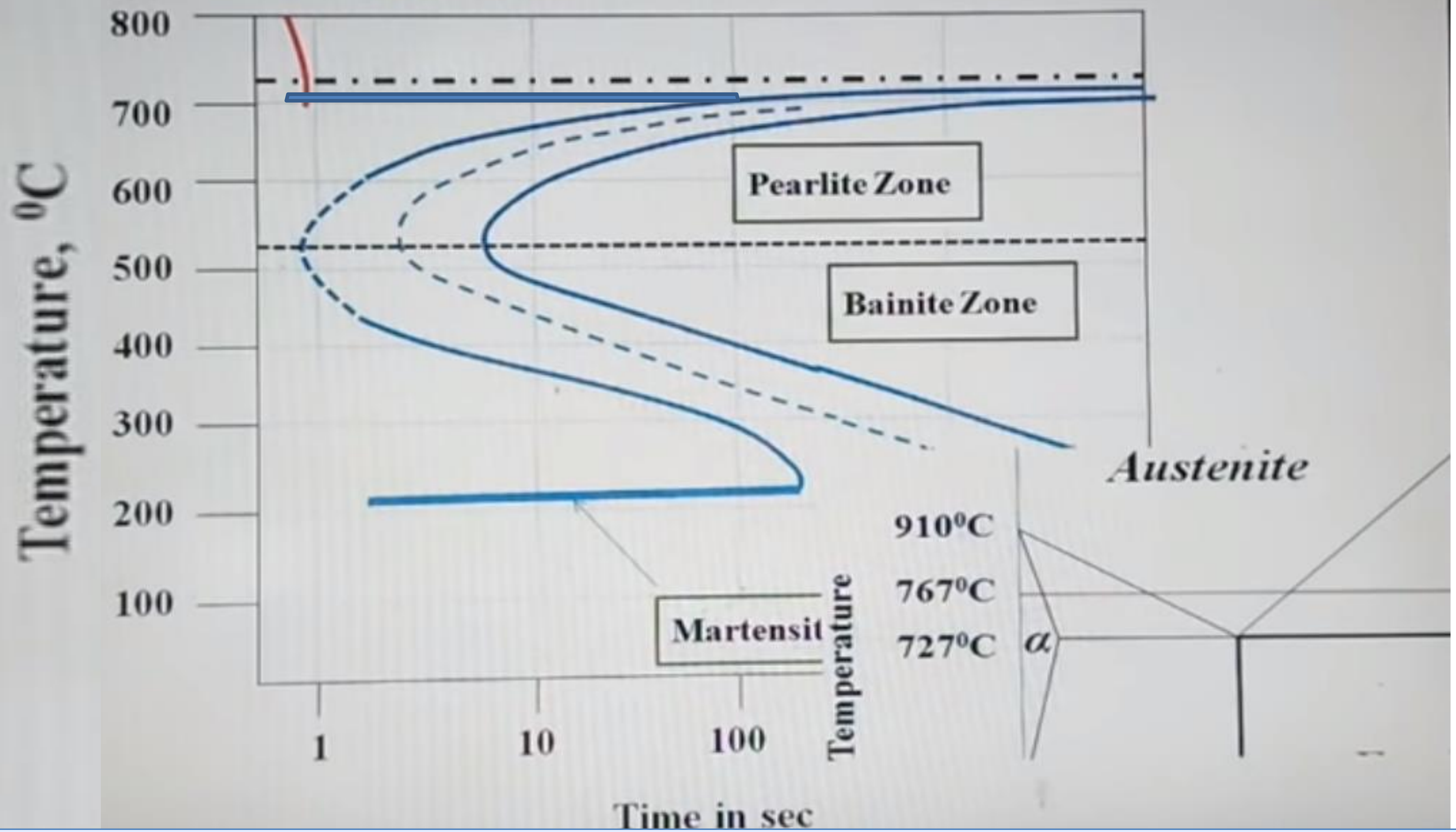

800
700
600
500
400
300
200
100
Temperature, ^{0}C
100% transformation complete
1
10
100
1000
10000
Time in sec

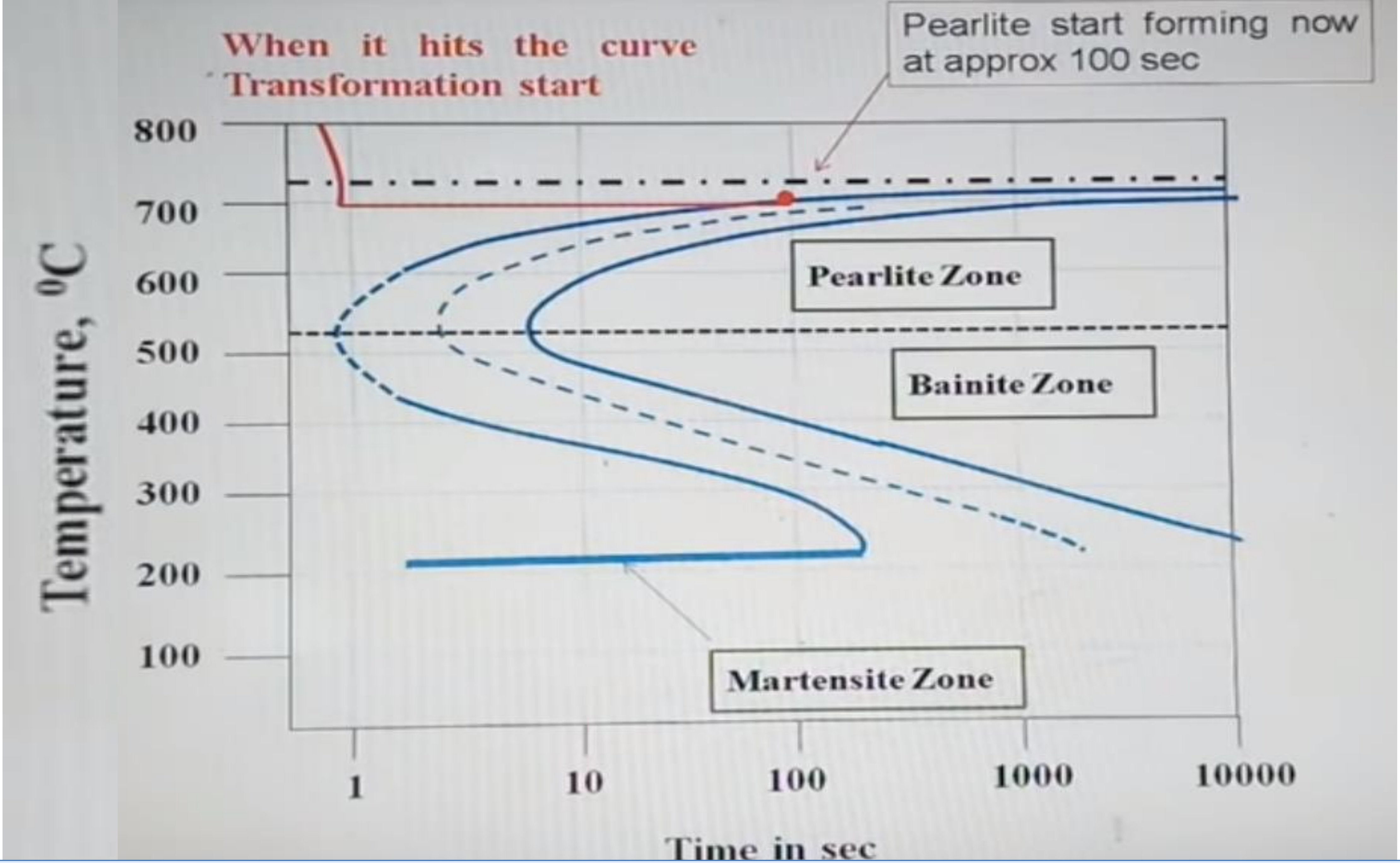


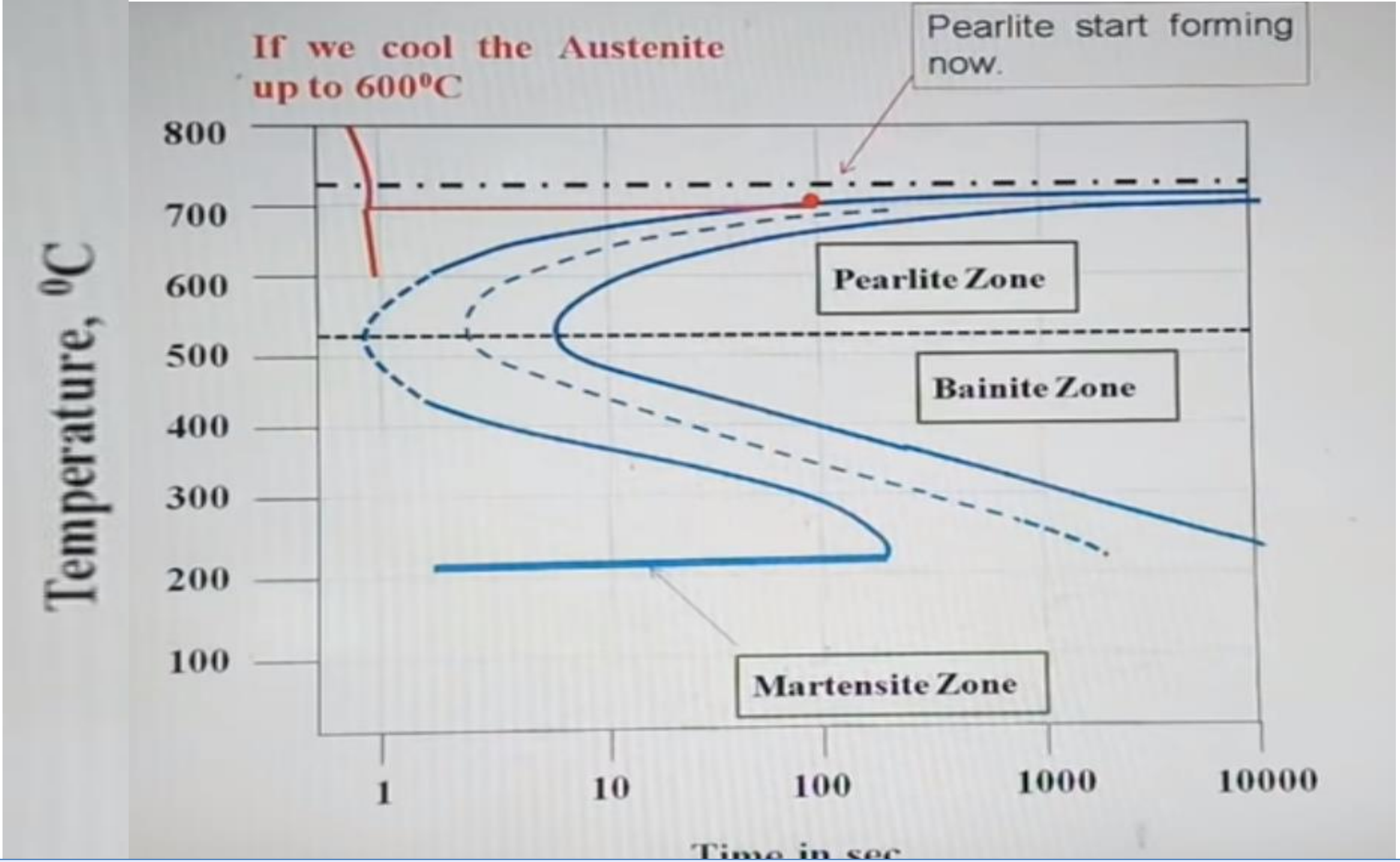
Austenite Zone
Austenite Zone
Temperature, ⁰C
800
700
600
500
400
300
200
100
1
10
100
1000
10000
Time in sec

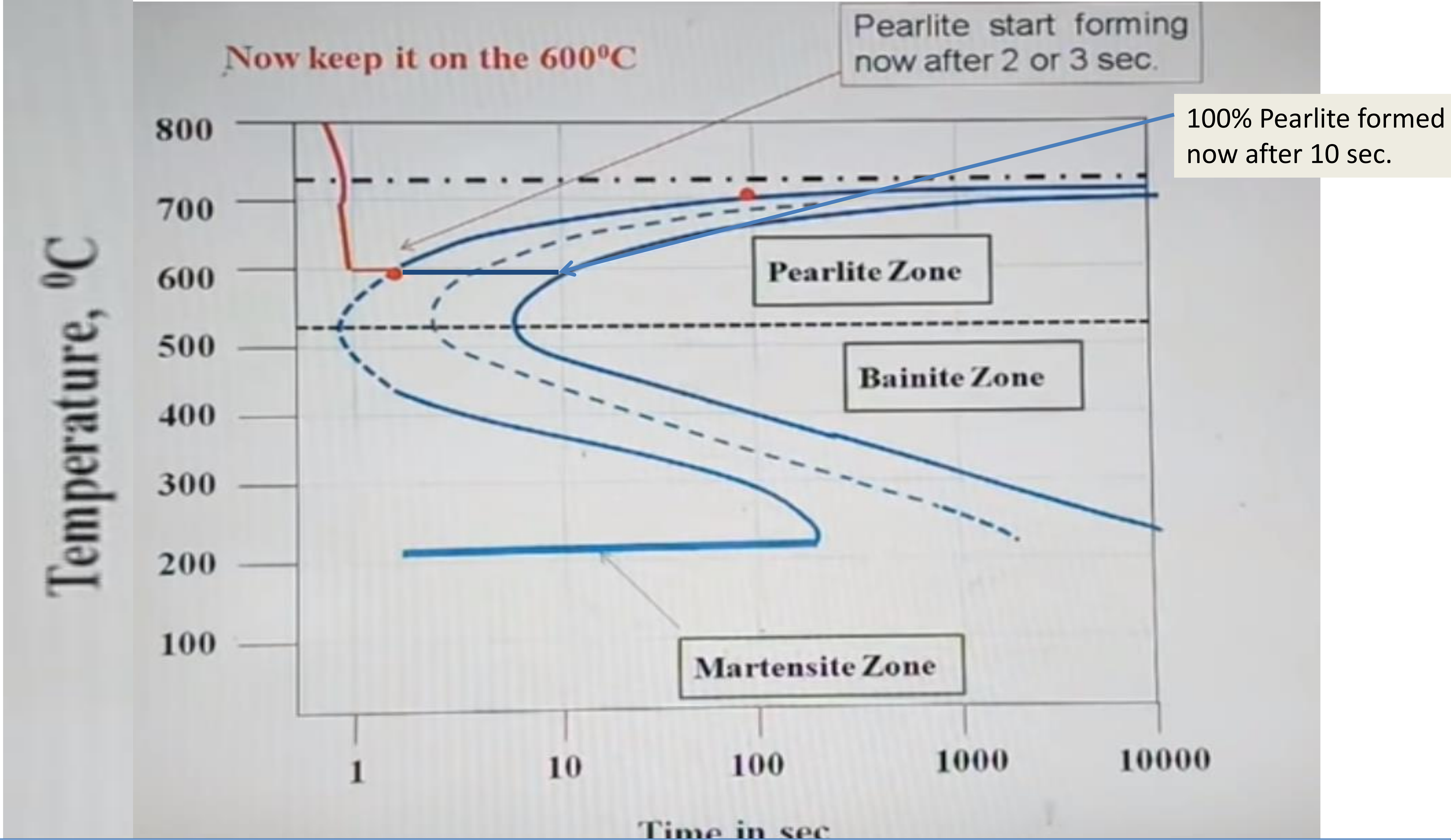

800
700
600
500
400
300
200
100
Temperature, ^0C
Pearlite Zone
Bainite Zone
Martensite Zone
1
10
100
1000
10000
Time in sec

Let us cool the Austenite up to 700⁰C




When it hits the curve
Transformation start
Pearlite start forming now at approx 100 sec
Temperature, ⁰C
800
700
600
500
400
300
200
100
Pearlite Zone
Bainite Zone
Martensite Zone
1
10
100
1000
10000
Time in sec


If we cool the Austenite up to 600⁰C
Pearlite start forming now.
800
700
600
500
400
300
200
100
Temperature, ⁰C
Pearlite Zone
Bainite Zone
Martensite Zone
1
10
100
1000
10000


Now keep it on the 600°C
Pearlite start forming now after 2 or 3 sec.
100% Pearlite formed now after 10 sec.
Temperature, °C
800
700
600
500
400
300
200
100
Pearlite Zone
Bainite Zone
Martensite Zone
1
10
100
1000
10000
Time in sec

At higher temperature, the nucleus formation is very low but transformation takes place due to high diffusion rates.

At lower temperature the nucleus formation is very large diffusion is almost same, therefore at lower temperature the transformation of Austenite in to Pearlite is very fast.

Due to above reason, at higher temperature coarse Pearlite is formed, while at lower temperature fine Pearlite is formed.

Machining Process

- Machining is an operation that changes the shape, surface finish, mechanical properties of a material by the application of special tools and equipment.

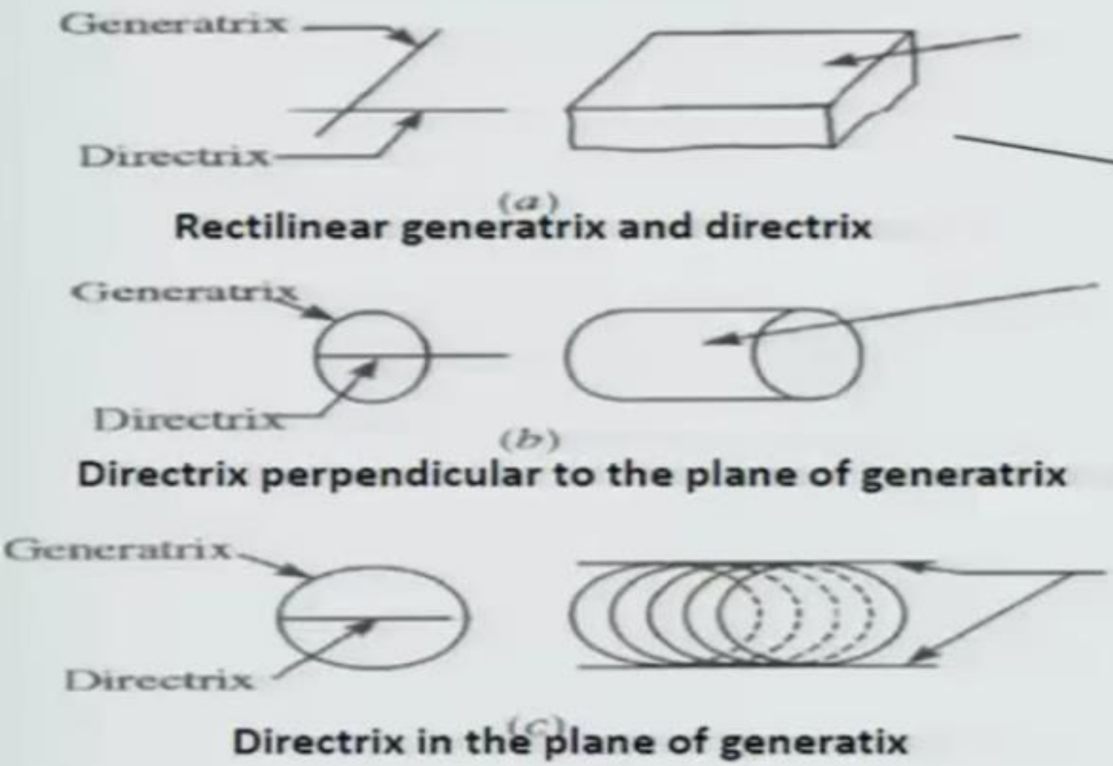
- This is typically carried out by machines where a cutting tool removes material to effect the required change to the work piece.

- A material removal process in which a sharp cutting tool is used to mechanically cut away material so that the desired part geometry remains

- Most common application: to shape metal parts
- Machining is the most versatile and accurate of all manufacturing processes in its capability to produce a diversity of part geometries and geometric features
  - Casting can also produce a variety of shapes, but it lacks the precision and accuracy of machining

Concept of generatrix and directrix

❖*Basics of common machining processes*



Surface obtained	Generatrix	Directrix	process
Plain	Straight line	Straight line	Tracing
Cylindrical	Circular	Straight line	Tracing
Surface of revolution	Plain curve	circular	Tracing
Straight line (plain surface in practice)	Circular	Straight line	generatio n

2

Common machining processes

*Cutting processes remove material from the surface of a work piece by producing **chips***

- **Common cutting processes:**

1. <u>Turning</u>

(work piece rotates; tool moves left, removes layer of material)

2. <u>Cutting off</u>

(cutting tool moves radially inward)

3. <u>Milling</u>

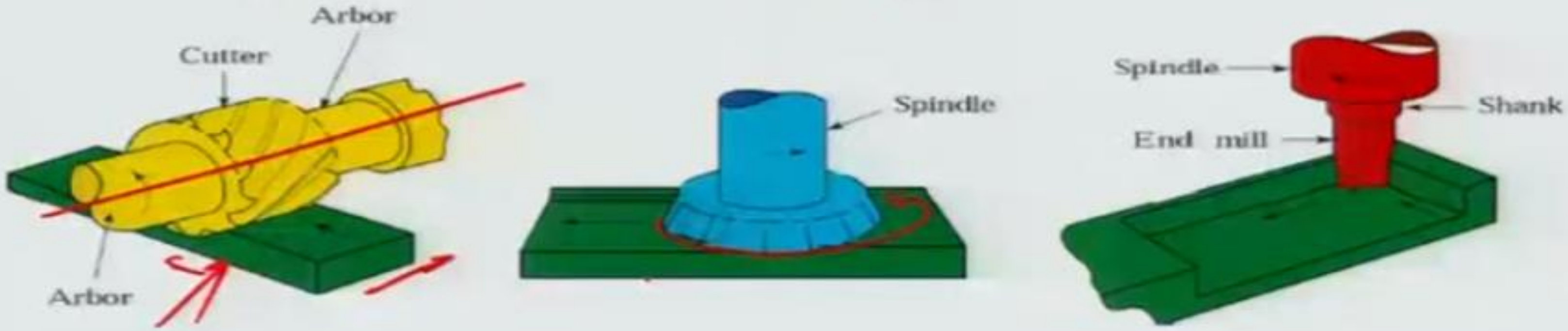
****Slab milling**

(rotating cutting tool removes material from work piece)

****End milling** (rotating cutter; produces cavity)

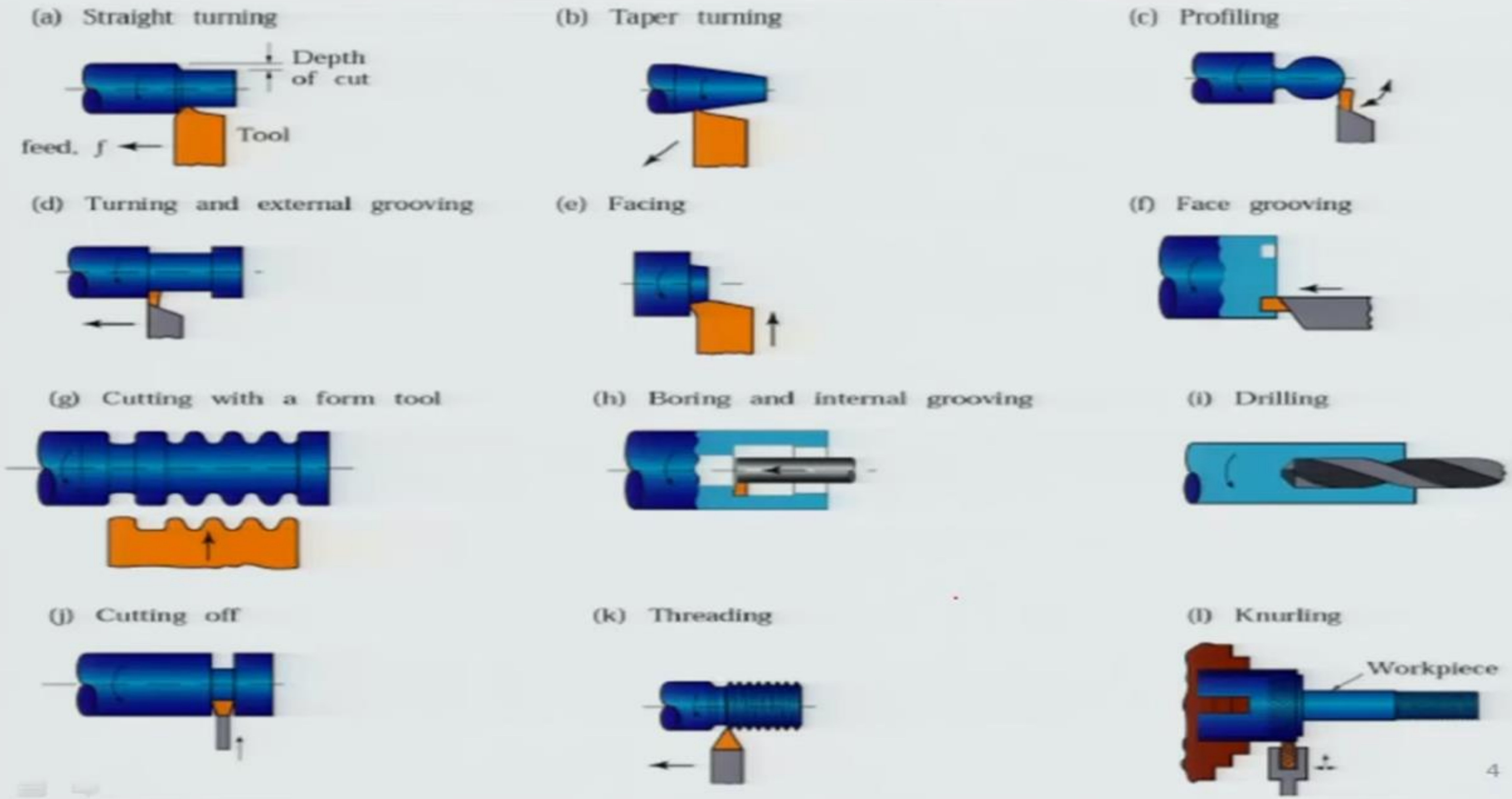
(a) Straight turning (b) Cutting off

Milling

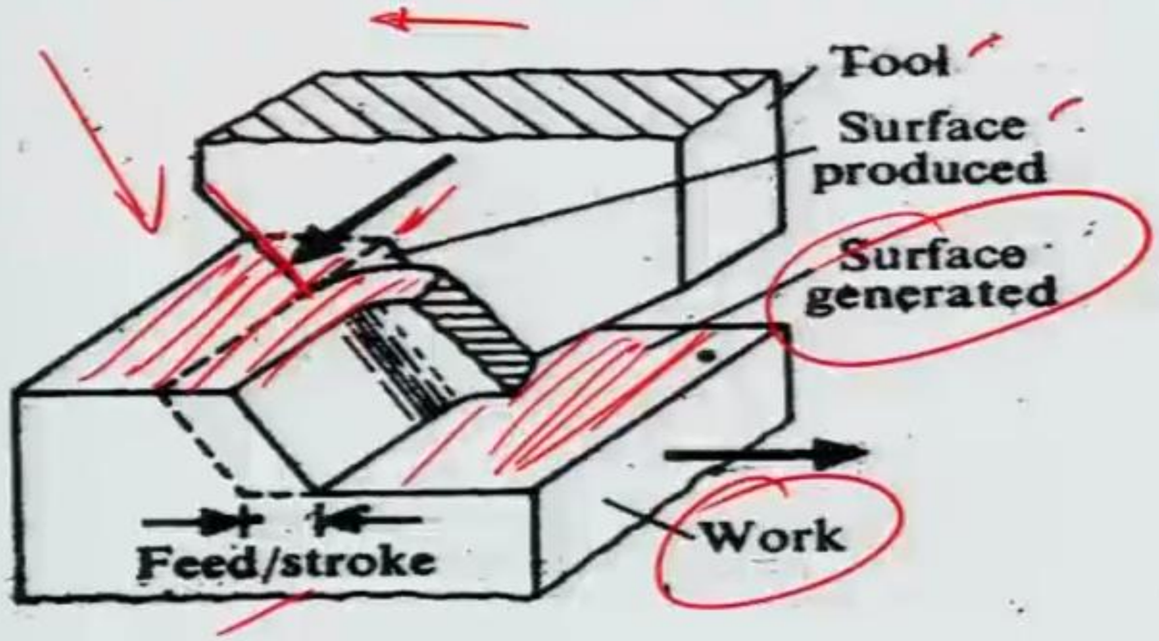


(a) Slab milling (b) Face milling (c) End milling

Schematic of other Machining Processes



Detailed Basic Processes (Shaping and Planning Process)

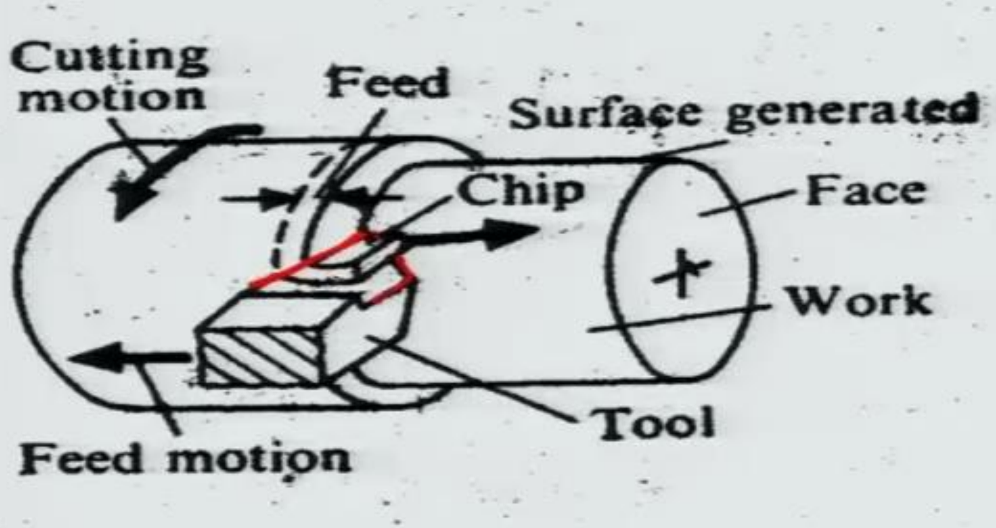


1. Surface obtained in both these processes are planar.
2. In shaping process, the cutting tool is provided with reciprocating motion and after every cutting stroke, the work is fed perpendicularly to the cutting direction
3. Since the cutting is not continuous it is known as intermittent cutting.

4. When the job is long, it is very difficult to provide a long cutting stroke with the mechanism used in a shaping machine.

5. In such a case the work provides the cutting motion and the tool merely gives the feed. This is known as planning.

Detailed Basic Processes (Turning Process)



1. Surface obtained in turning process is generally cylindrical.
2. In face turning , a flat surface can be obtained.
3. The machine tool for this operation is a lathe.

4. The tool is provided with a feed motion as the workpiece is rotated and the tool path is helical.

5. Here the machining operation is continuous

Machining processes

Milling

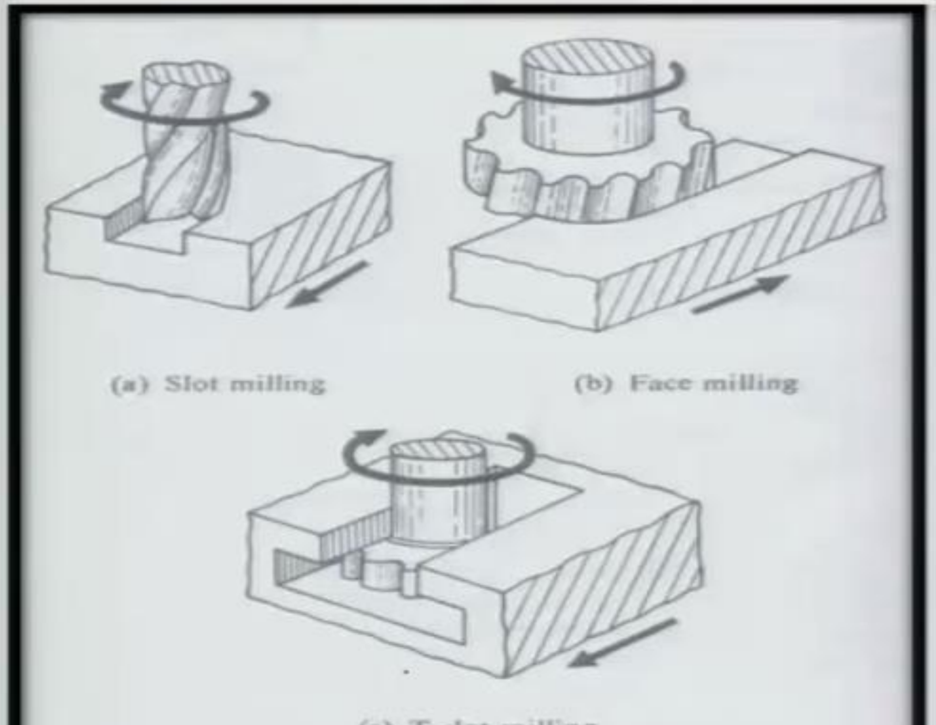
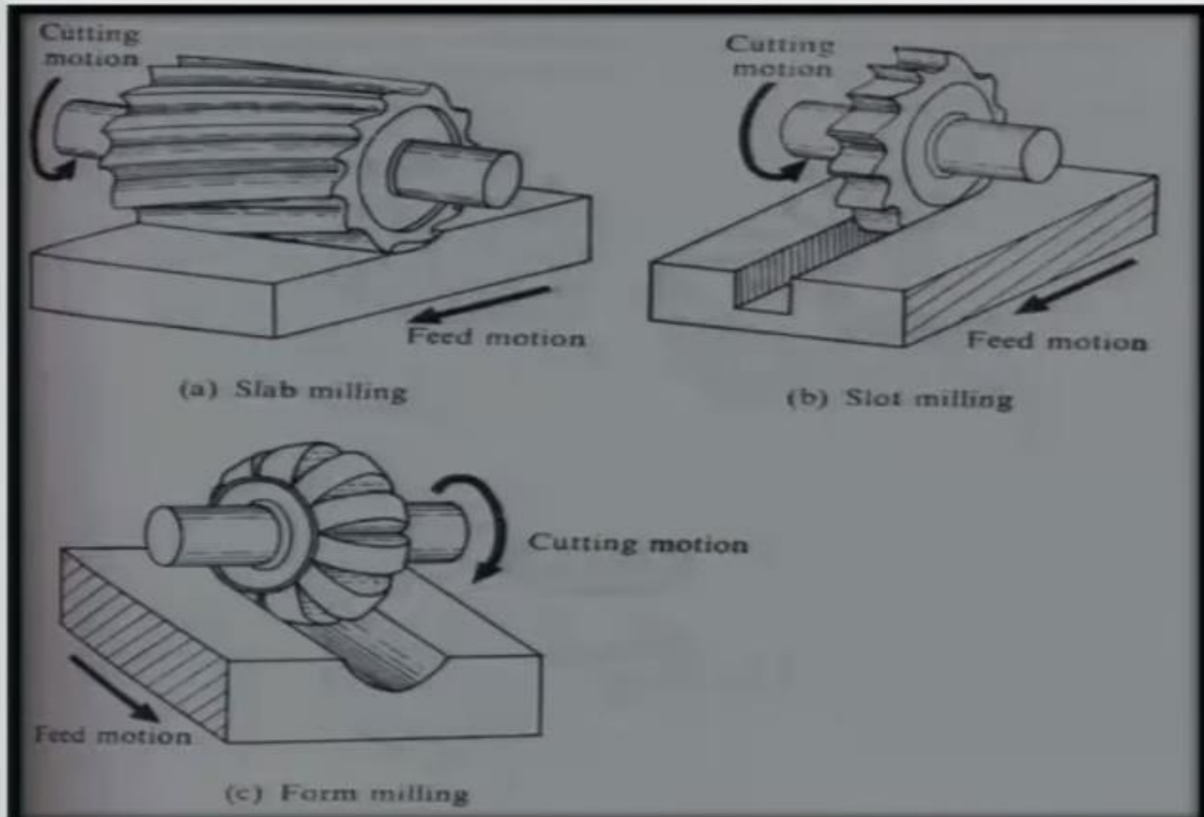


Fig. 4.46 Types of vertical milling operations.

Types of milling operations

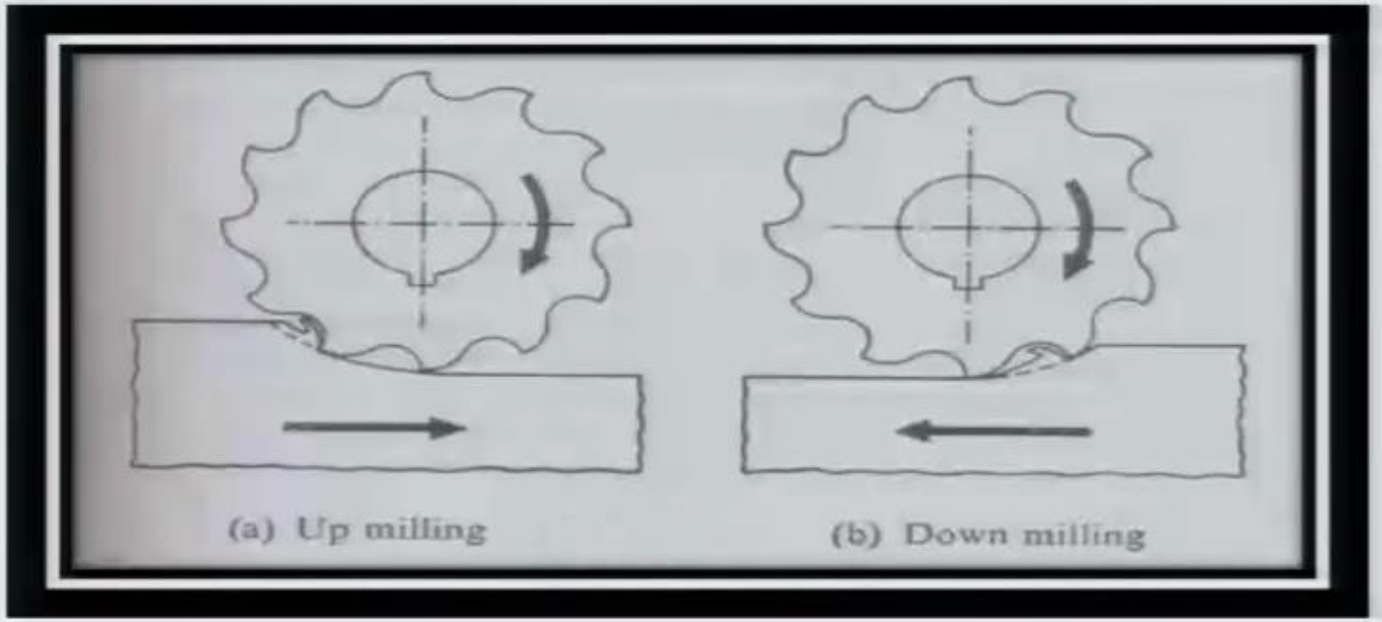


1. In milling the tool possesses a no. of cutting edges and is provided with rotary motion.

2. The work is gradually fed due to which small chips are removed by each cutting edge finally producing a flat surface.

When the cutting and feed motion are in the same direction operation is called down milling

When the cutting and feed direction are in opposite direction, operation is called up milling



CONVENTIONAL MILLING – "UP" MILLING
(Feed movement opposite to tool rotation)

- Width of chip starts from zero and increases.
- Tooth meets the workpiece at the bottom of cut.
- Upward force tends to lift up workpiece.
- More power required - rubbing provoked by chip beginning at minimum width.
- Surface finish marred (spoiled) due to the chips being carried upward by tooth.
- Chips fall in front of cutter - chip disposal difficult.
- Faster wear on tool than climb milling.

Climb milling – "Down" milling
(Feed movement and tool rotation same direction.)

- Width of chip starts at maximum and decreases.
- Tooth meets workpiece at top of cut.
- Easier chip disposal - chips removed behind cutter.
- Less wear - increases tool life up to 50%.
- Improved surface finish - chips less like to be carried by the tooth.
- Less power required - cutter with high rake angle can be used.
- Climb milling exerts a downward force on workpiece - fixtures simple and less costly.

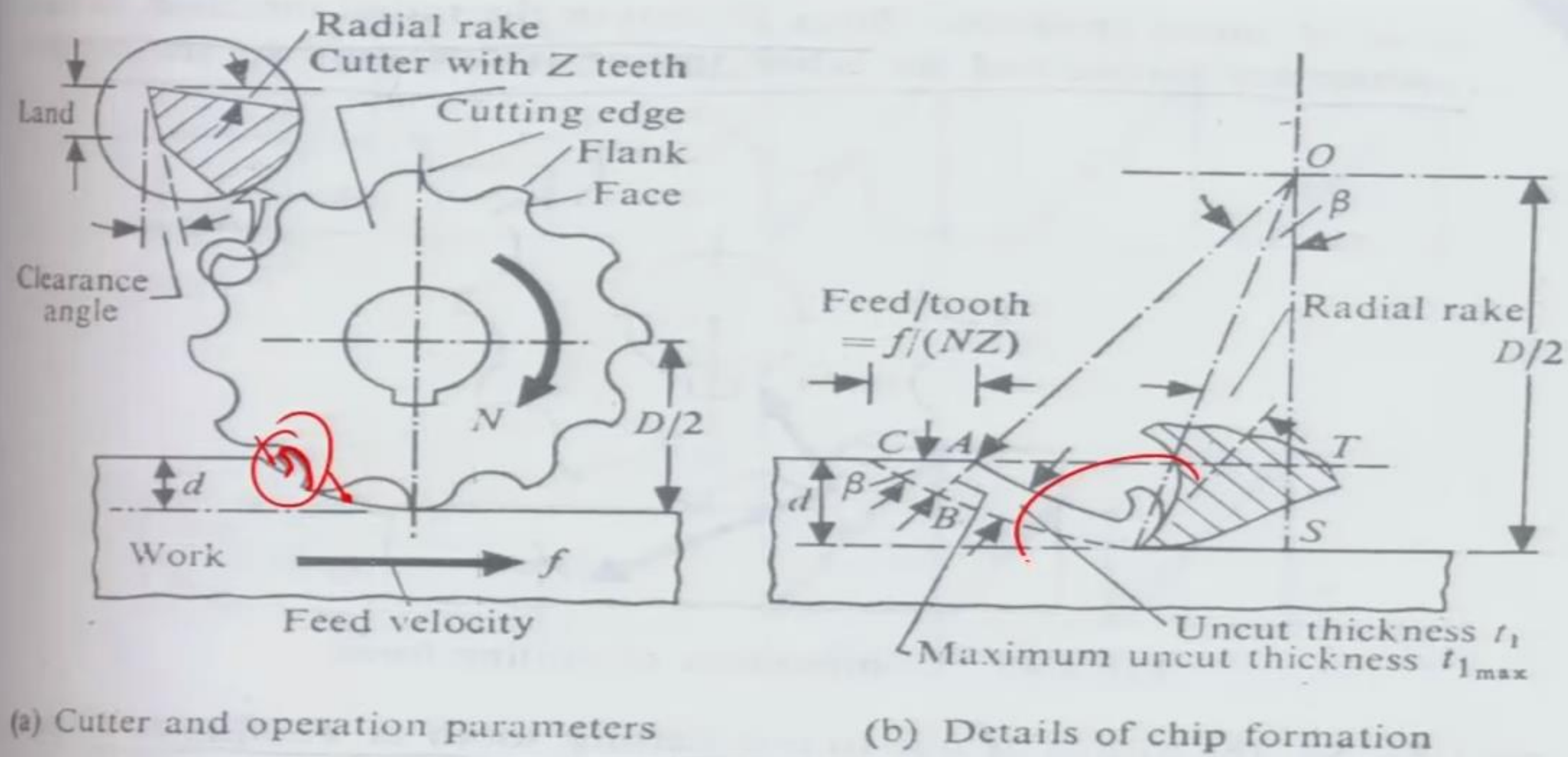


Fig. 4.47 Details of milling operation.

Classification of Machined Parts

1. *Rotational* - cylindrical or disk-like shape
2. *Nonrotational* (also called *prismatic*) - block-like or plate-like

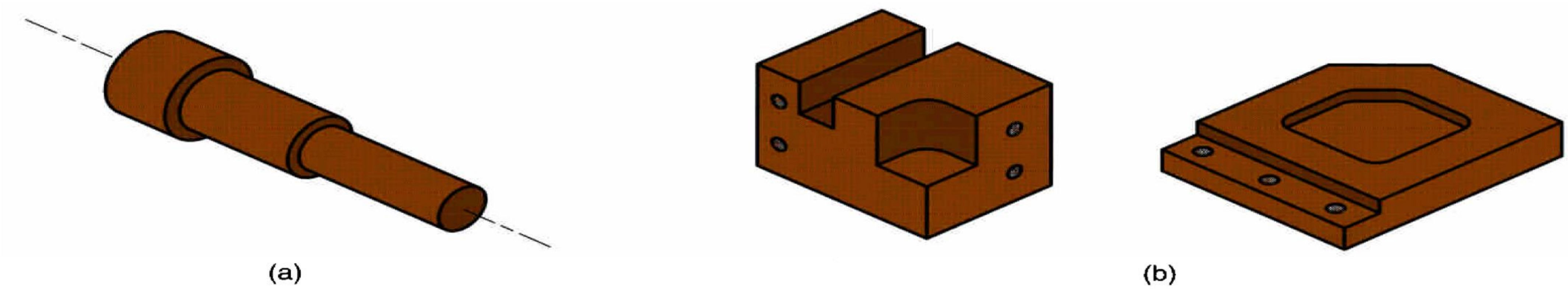


Figure 22.1 - Machined parts are classified as: (a) rotational, or (b) nonrotational, shown here by block and flat parts

Machining Operations and Part Geometry

- Each machining operation produces a characteristic part geometry due to two factors:
  1. Relative motions between the tool and the workpart
     - *Generating* – part geometry is determined by the feed trajectory of the cutting tool
  2. Shape of the cutting tool
     - *Forming* – part geometry is created by the shape of the cutting tool

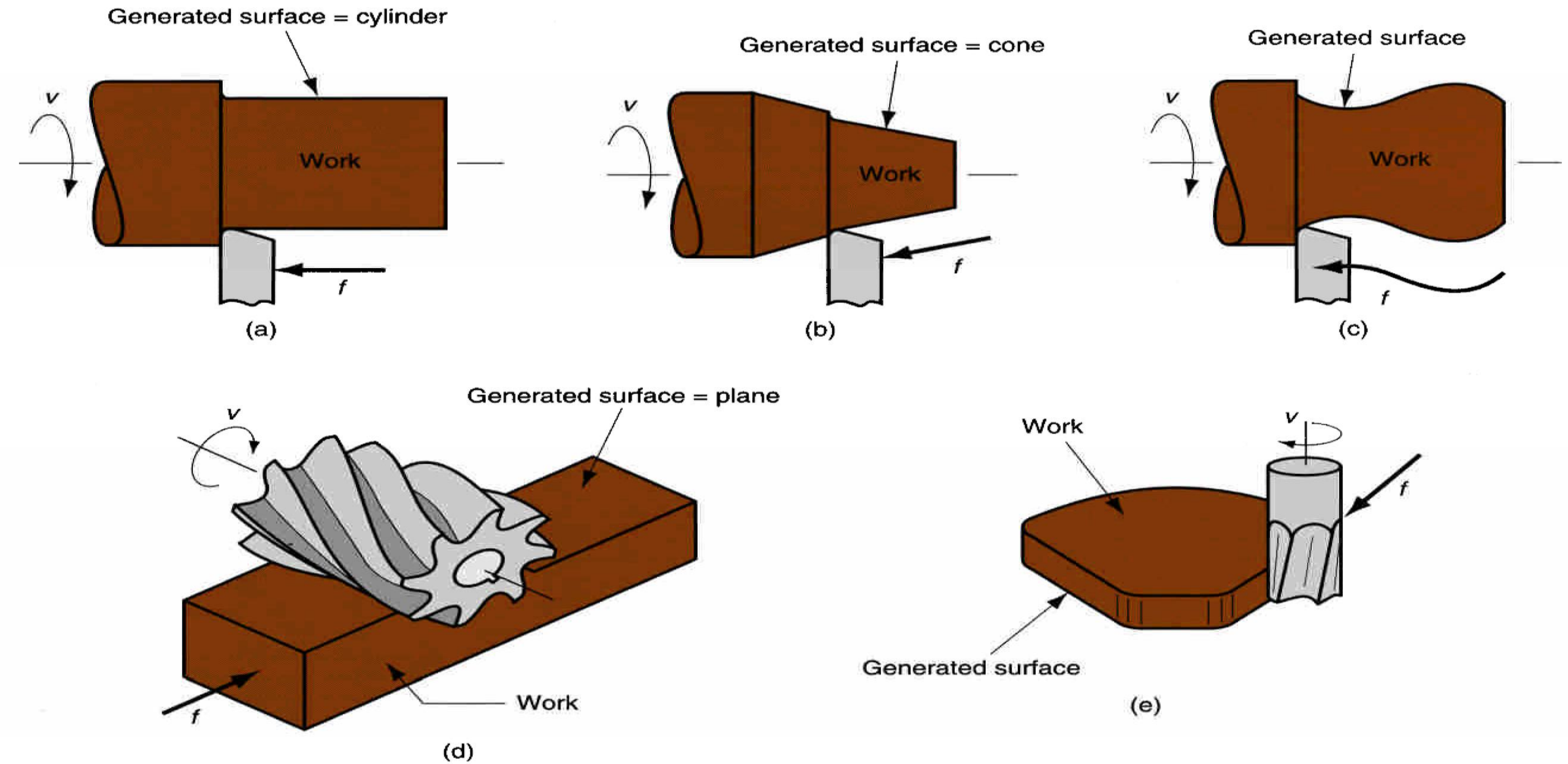


Figure :- Generating shape: (a) straight turning, (b) taper turning, (c) contour turning, (d) plain milling, (e) profile milling

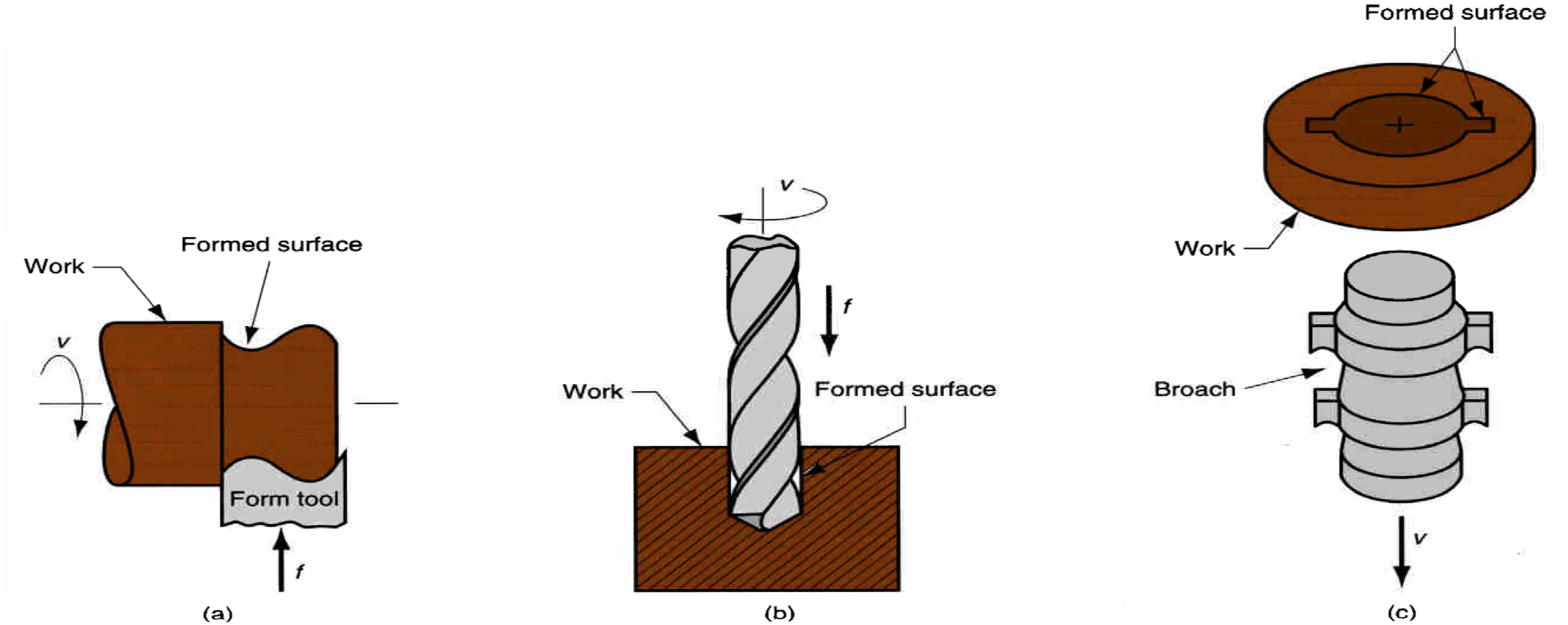


Figure :- Forming to create shape: (a) form turning, (b) drilling, and (c) broaching

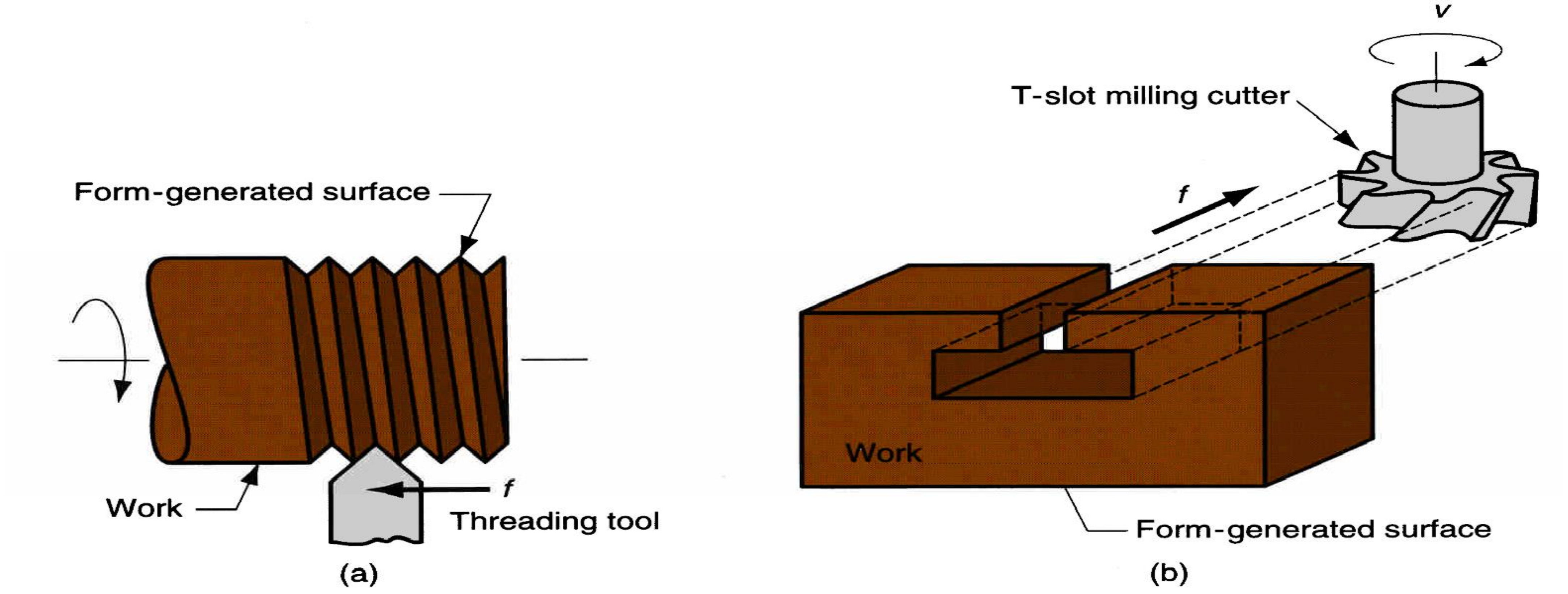


Figure :- Combination of forming and generating to create shape: (a) thread cutting on a lathe, and (b) slot milling

Turning

- Turning operation is a machining process and is used to produce round parts in shape by a single point cutting tool. Materials are removed by traversing in a direction parallel to the axis of rotation of axis or along a specified path to form a complex rotational shape.

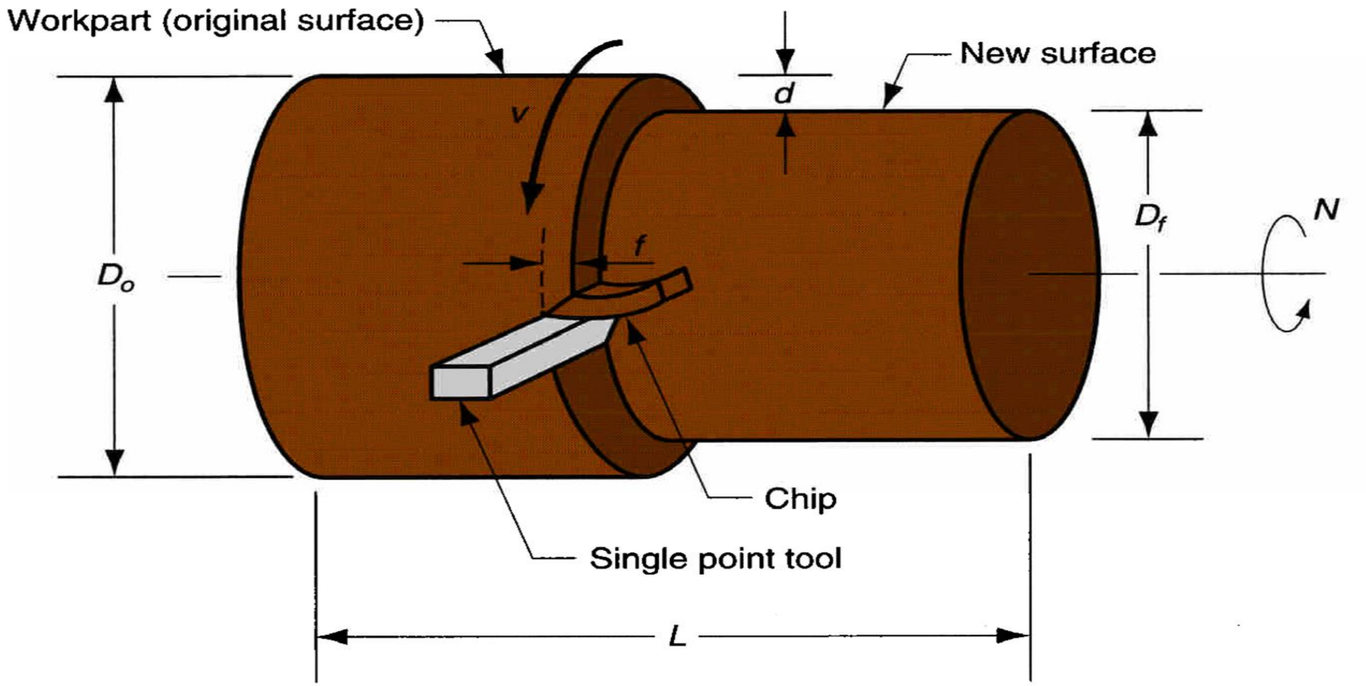


Figure :- Turning operation

- The tool is fed either linearly in a direction parallel or perpendicular to the axis of rotation.
- A single point cutting tool removes material from a rotating workpiece to generate a cylindrical shape
  - Performed on a machine tool called a *lathe*

- Variations of turning that are performed on a lathe:
  - Facing
  - Contour turning
  - Chamfering
  - Cutoff
  - Threading

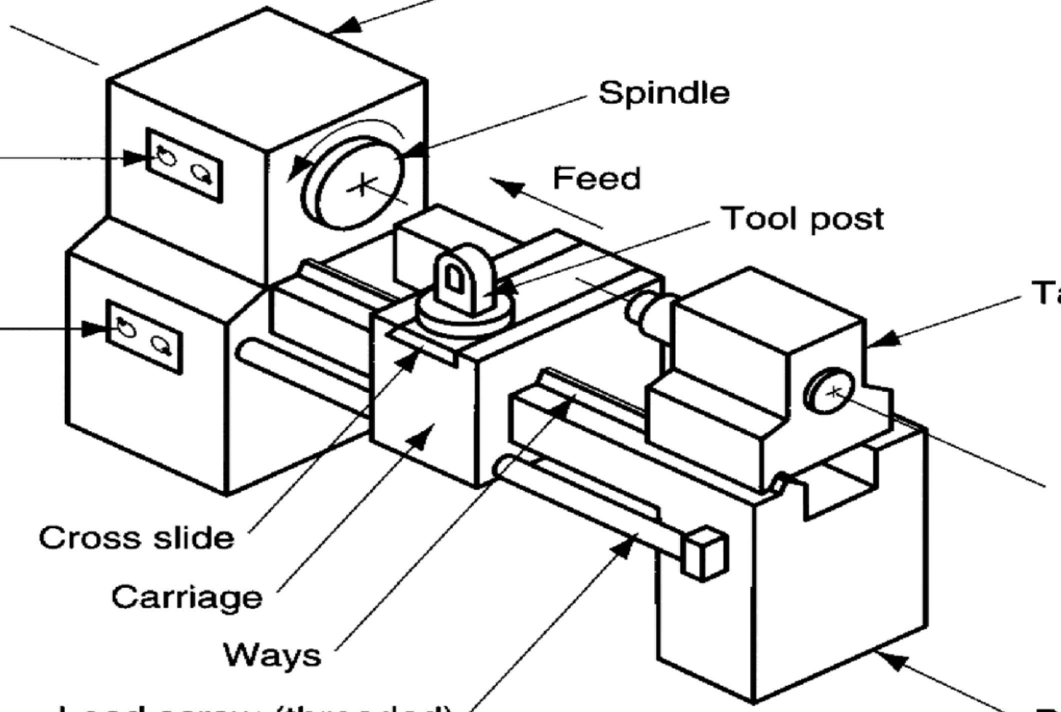
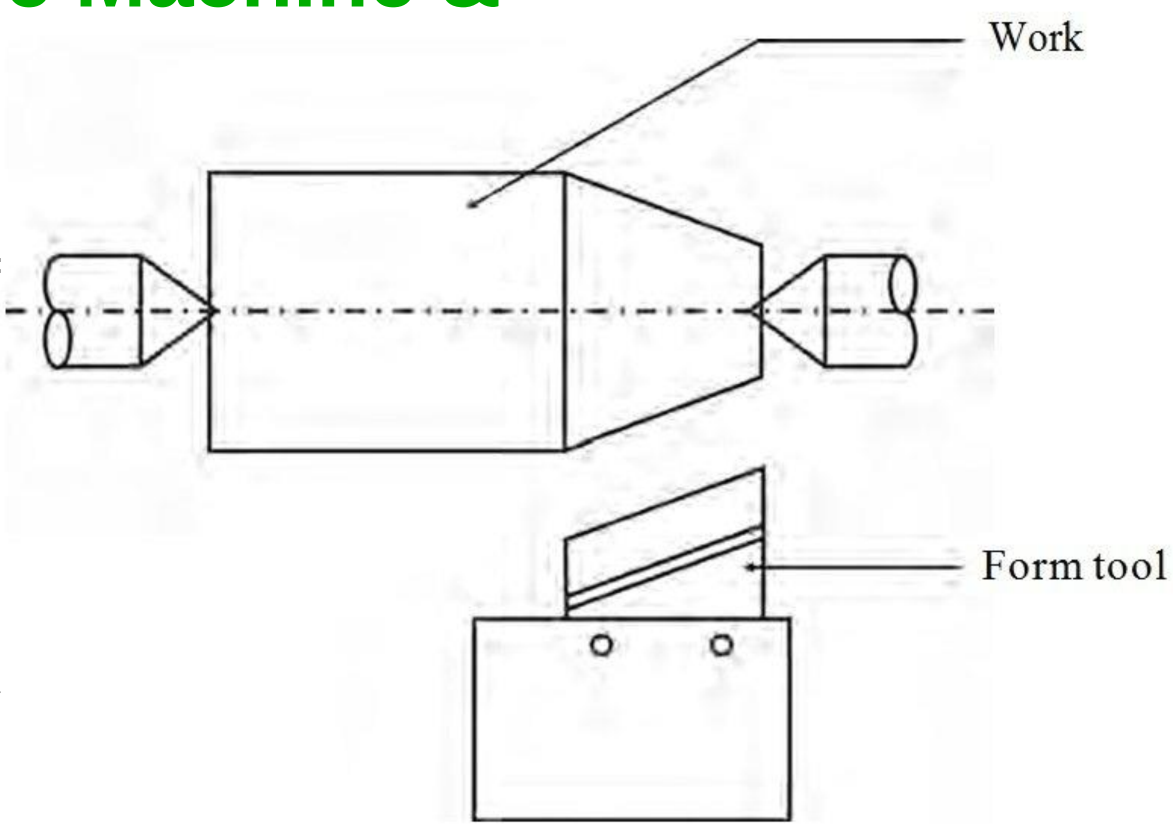


Figure:-

Diagram of an engine lathe, showing its principal components

Taper Turning Methods in Lathe Machine & Types of Taper Turning

- Taper turning process is the process used in lathe to provide a taper cut on the surface of workpiece.
- It consists of guide box, connecting link. Guide box contain guide way which is connected to carriage by connecting link



Taper turning by form tool method

- Taper turning attachment consists essentially of a bracket or frame which is attached to the rear end of the lathe bed and supports a guide plate pivoted at the centre.
- The plate having graduations in degrees may be swiveled on either side of the zero graduation and is set at the desired angle with the lathe axis. When the taper turning attachment is used, the cross slide is first made free from the lead screw by removing the binder screw

- The rear end of the cross slide is then tightened with the guide block by means of a bolt. When the longitudinal feed is engaged, the tool mounted on the cross slide will follow the angular path, as the guide block will slide on the guide plate set at an angle to the lathe axis.
- The required depth of cut is given by the compound slide which is placed at right angles to the lathe axis. The guide plate must be set at half taper angle and the taper on the work must be converted in degrees. The maximum angle through which the guide plate may be swiveled is 10º.
- There are four methods
    1. Form tool method
    2. Tailstock set over method
    3. Compound rest method
    4. Taper turning attachment method

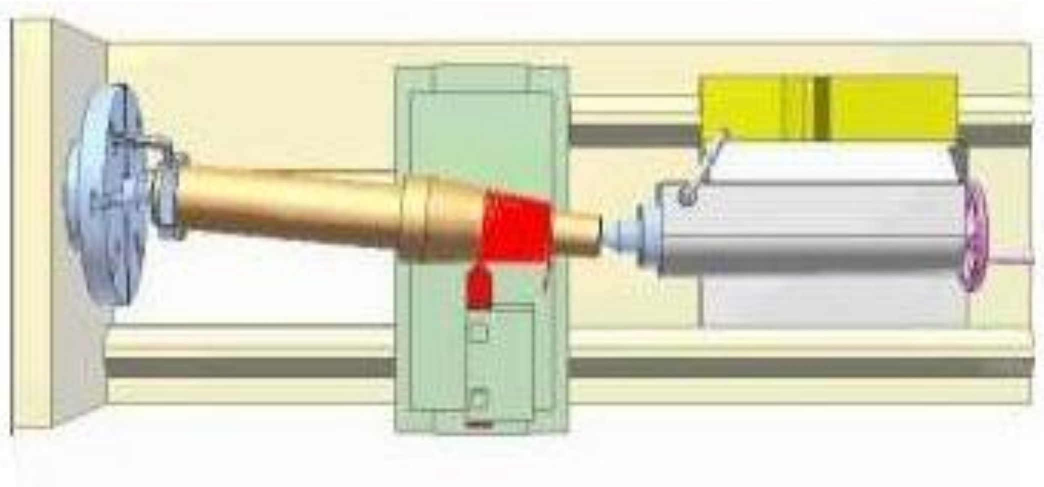
1) Form tool method

- This is one of the simplest methods to produce short taper. This method is shown in the above figure. To the required angle the form is grounded. The tool is fed perpendicular to the lathe axis, when the work piece rotates.

- The tool cutting edge length must be greater than the taper length. Since the entire cutting edge removes the metal, it will produce a lot of vibration and hence a large force is required. It is done in slow speed.

2) Tailstock set over method

- Generally, when the angle of taper is very small this method will be employed. The work piece be placed in the live center and live center. Now, the tailstock will be moved in a cross wise, that is perpendicular to the lathe axis by turning the set over method. This process is known as tail stock set over method.


TAIL STOCK SET OVER METHOD

- Hence here the job is inclined to the required angle. When the work piece rotates the tool is moved parallel to the lathe axis. So that the taper will be generated on the work piece.

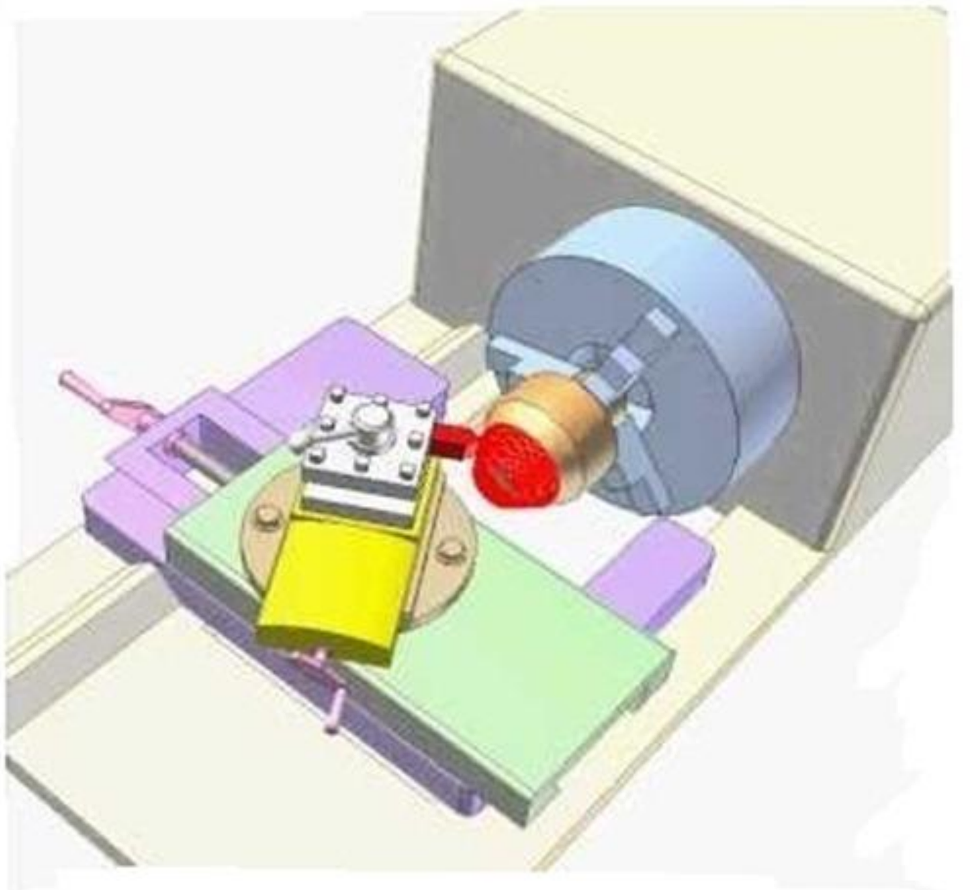
3) Compound rest method

Generally short and steep taper will be produced will be produced using this method. In this method the work piece will be held in the chuck and it will be rotated about the lathe axis.

- The compound rest is swivelled to the required angle and then it will be clamped in position.
- The angle is determined using the formula,

$$\tan\alpha = (D-d)/2l)$$

- Then by using the compound rest hand wheel the tool will be fed. Both the internal and external taper can be done using this method. The important feature is that the compound rest can be swivelled up to 45° on both sides. Only with the help of the hand the tool should be moved.



Taper turning by compound rest method

4) Taper turning attachment method

- In this method by using bottom plate or bracket, a taper turning attachment is attached to the rear end of the bed. It has a guide bar which is usually pivoted as its center.
- The guide bar has the ability to swing and it can be set in any required angle. It has graduations in degrees. On either side, the guide bar can be swivelled to a maximum angle of 10°. It has a guide block which connects to the rear end of the cross slide and it moves on the guide bar. The binder screw is removed, before connecting the cross slide, hence the cross slide is free from the cross slide screw.

Threading/ Thread Cutting

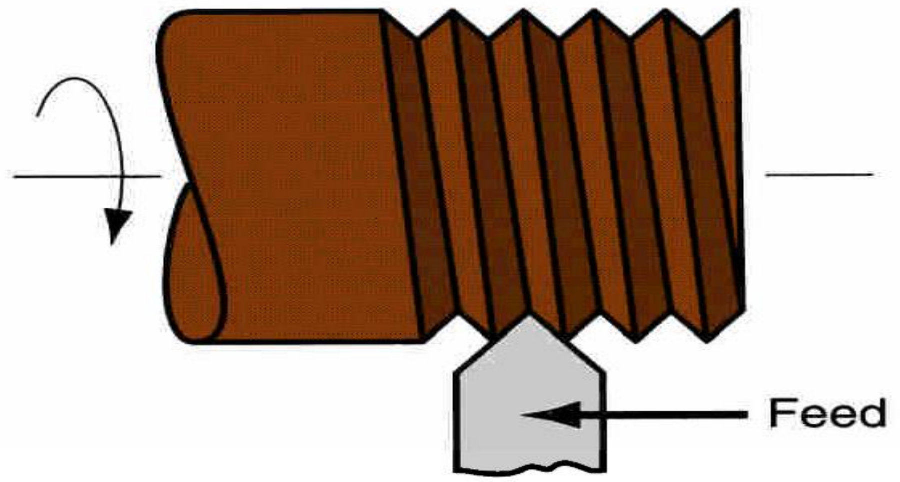


Figure :- Threading

- Thread cutting on the lathe is a process that produces a helical ridge of uniform section on the workpiece. This is performed by taking successive cuts with a threading tool bit the same shape as the thread form required.
- Pointed form tool is fed linearly across surface of rotating work part parallel to axis of rotation at a large feed rate, thus creating threads.
- It is the process of creating screw threads for fastening things together. Threaded parts are incredibly common, and for good reason: threads allow parts to be joined together easily and at a low cost.
- A common method of creating threads is to cut them with a tap or die. Taps are used to cut internal threads, like those in a nut, while dies are used to cut external threads, like those on a bolt. Cutting threads with a tap is called “tapping” and cutting threads with a die is called “threading”. Both of these processes can be done by hand with a tap or die handle.

Grinding Process

Grinding process carried out with a grinding wheel which is made up of abrasive grains (its mean a hard material) for removing very fine quantities of material from a work piece surface.

Applications

1. Machining materials which are too hard for other machining process.
2. Close dimensional accuracy of the order of micro....
3. For the high degree of surface smoothness.

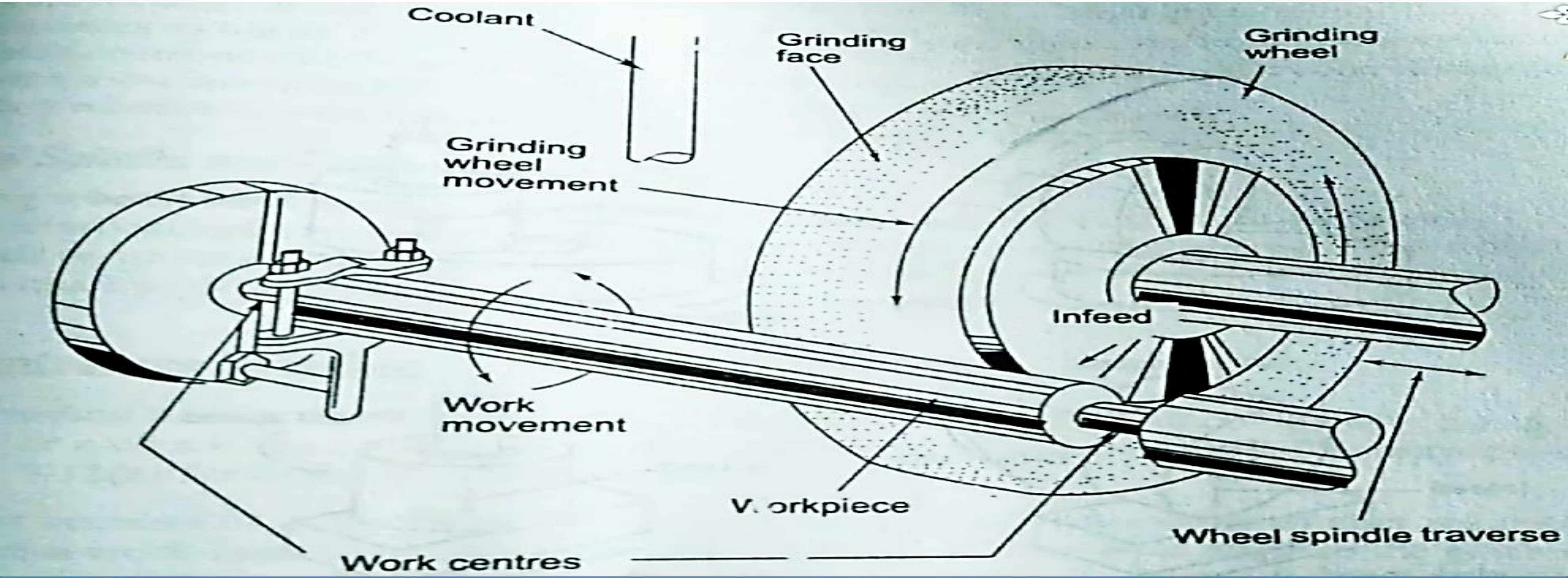
Different types of Grinding machines or grinding process.

Basically three grinding process or grinding machines are their .....

1. *Cylindrical grinding*
2. *Surface grinding*
3. *Centerless grinding*

1. Cylindrical grinding.

- Cylindrical grinding generally used for generating external cylindrical surface.
- The machine used for cylindrical grinding is very similar to a centre lathe m/c.



Operation;-

The **grinding wheel** is located similar to the toolpost ,with an motor which rotate wheel at very high speed.

The **work piece** are normaly held between the center with the help of spindle.

Both the wheel and work piece are in contact and both rotates counter clock wise. The abrasive particle remove the material from the work piece.

2. Surface Grinding Process

Surface grinding machines are generally used for generating flat surface.

Expand panel to show vide

These machines are similar to milling machines in construction as well as motion

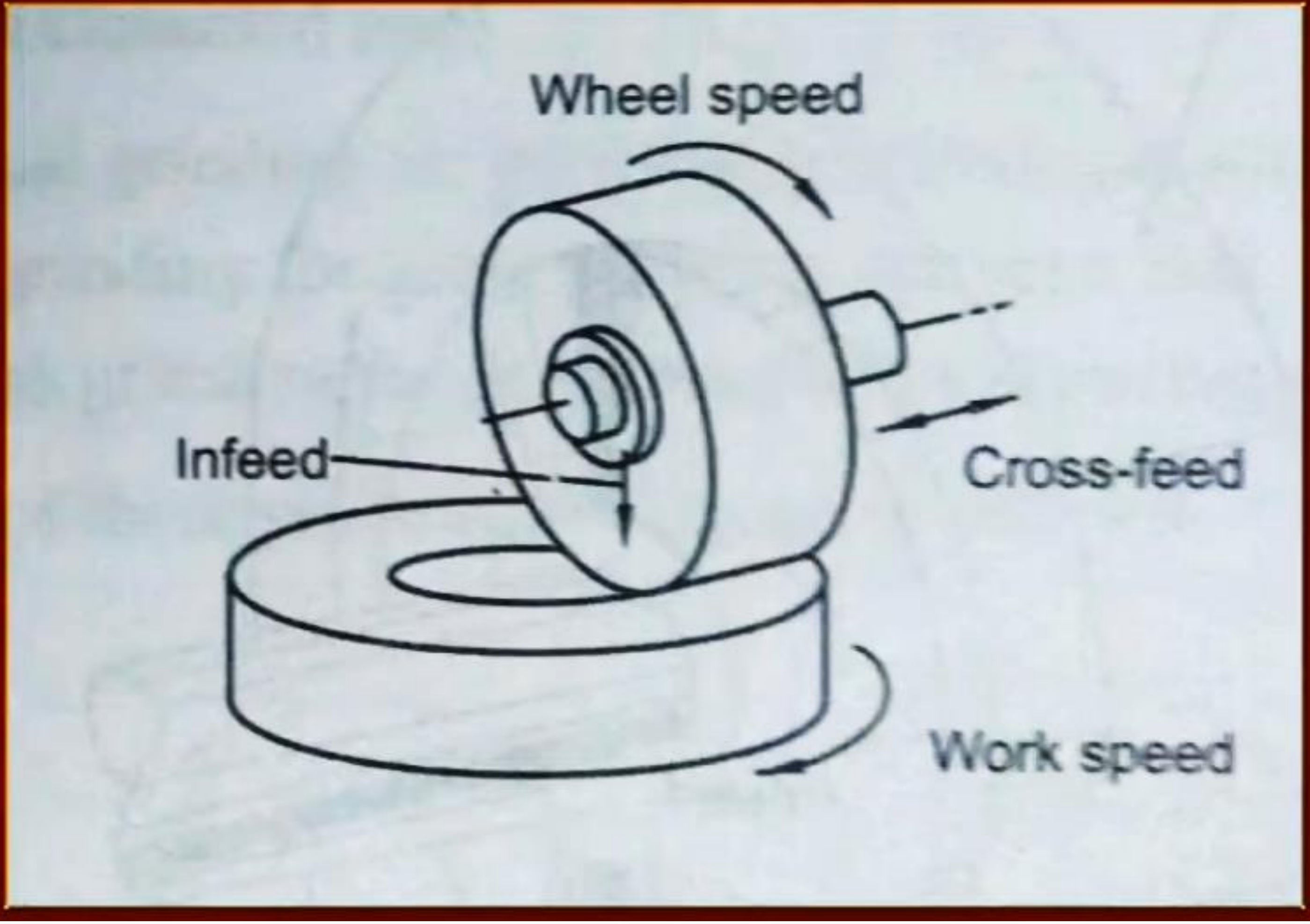
Types of surface grinding :-

Based on direction of spindle and the motion of table,

1. Horizontal spindle and rotating table
2. Vertical spindle and rotating table
3. Horizontal spindle and reciprocating table
4. Vertical spindle and reciprocating table

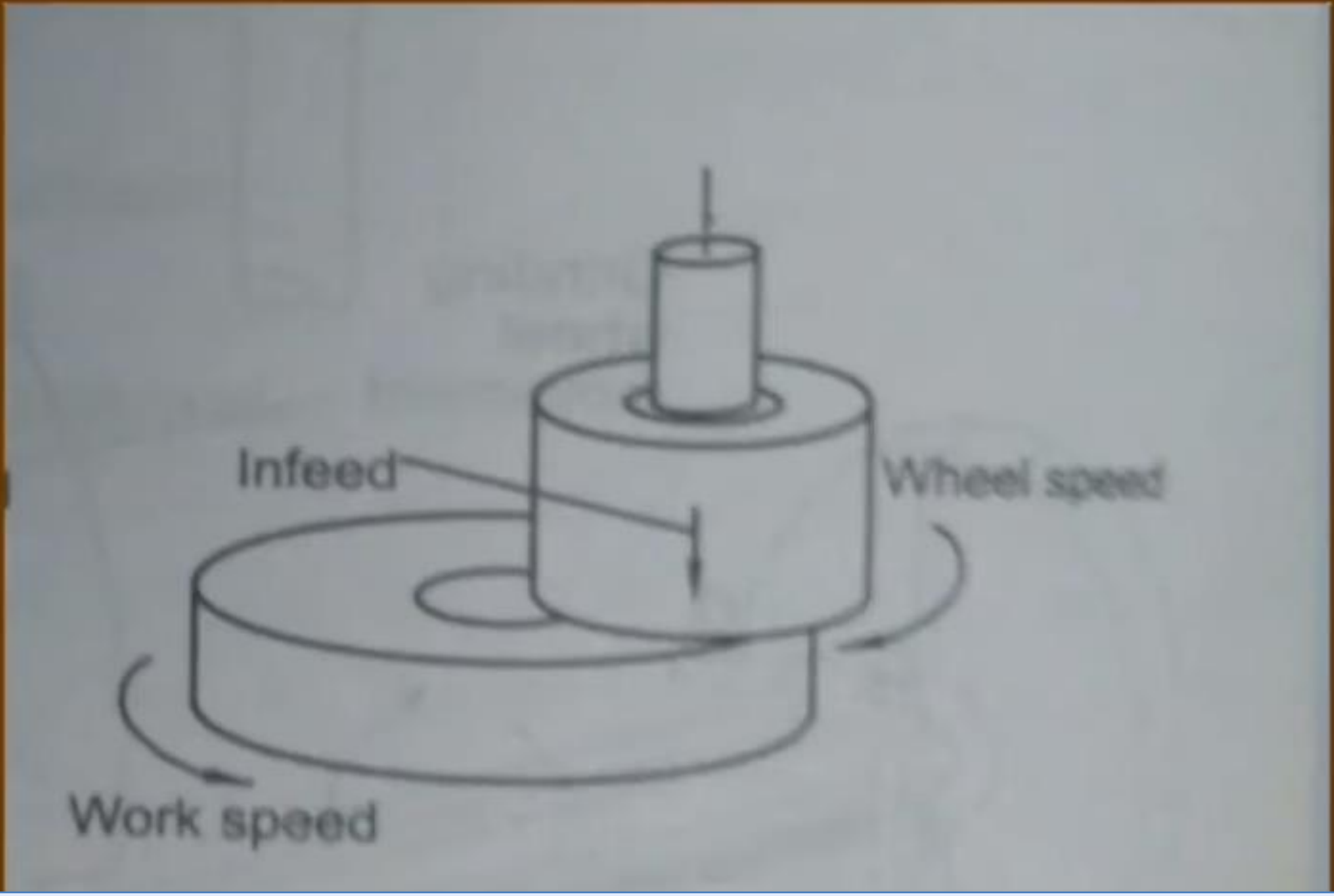
1.Horizontal spindle and rotating table

spindle

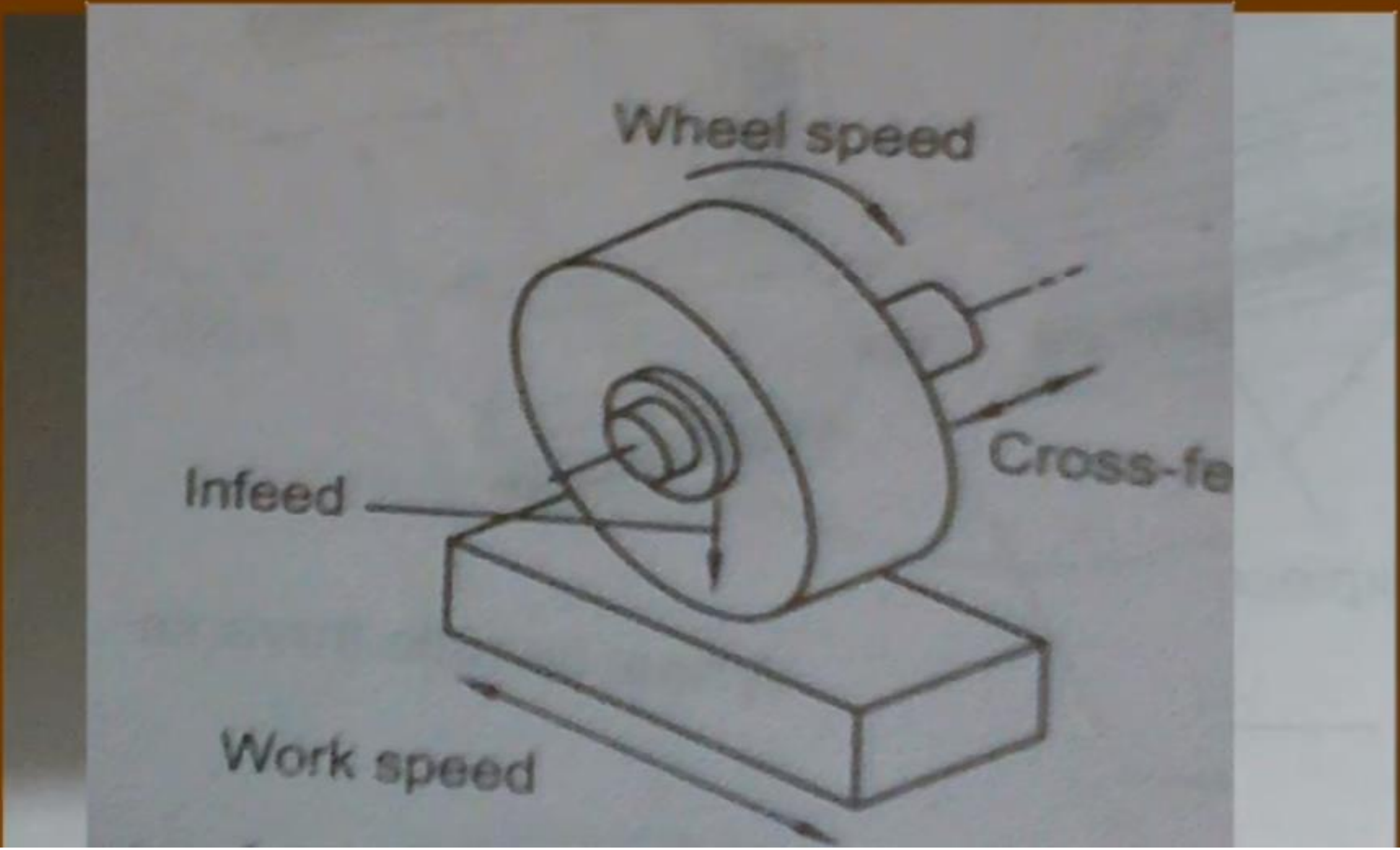


Table

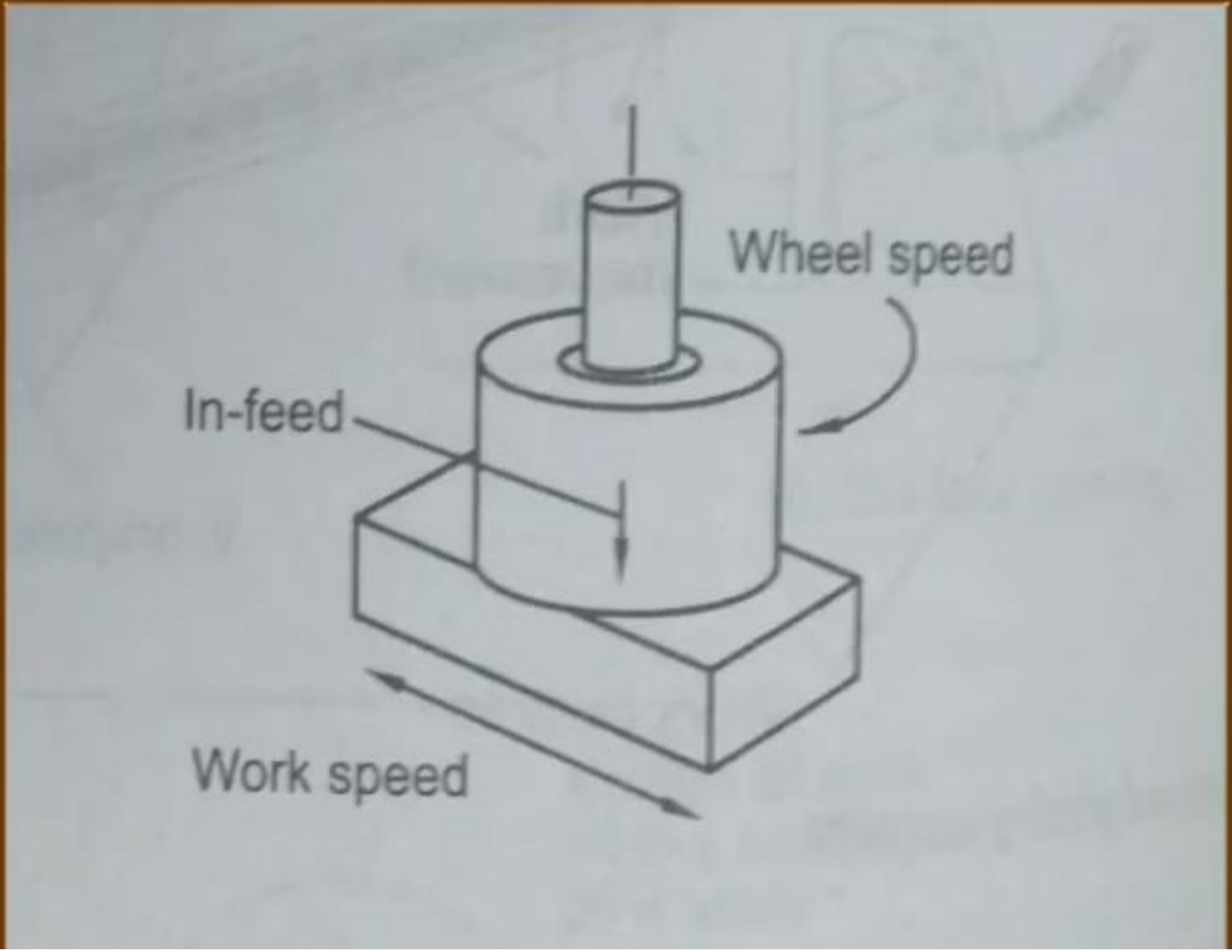
2.Vertical spindle and rotating table



3.Horizontal spindle and reciprocating table



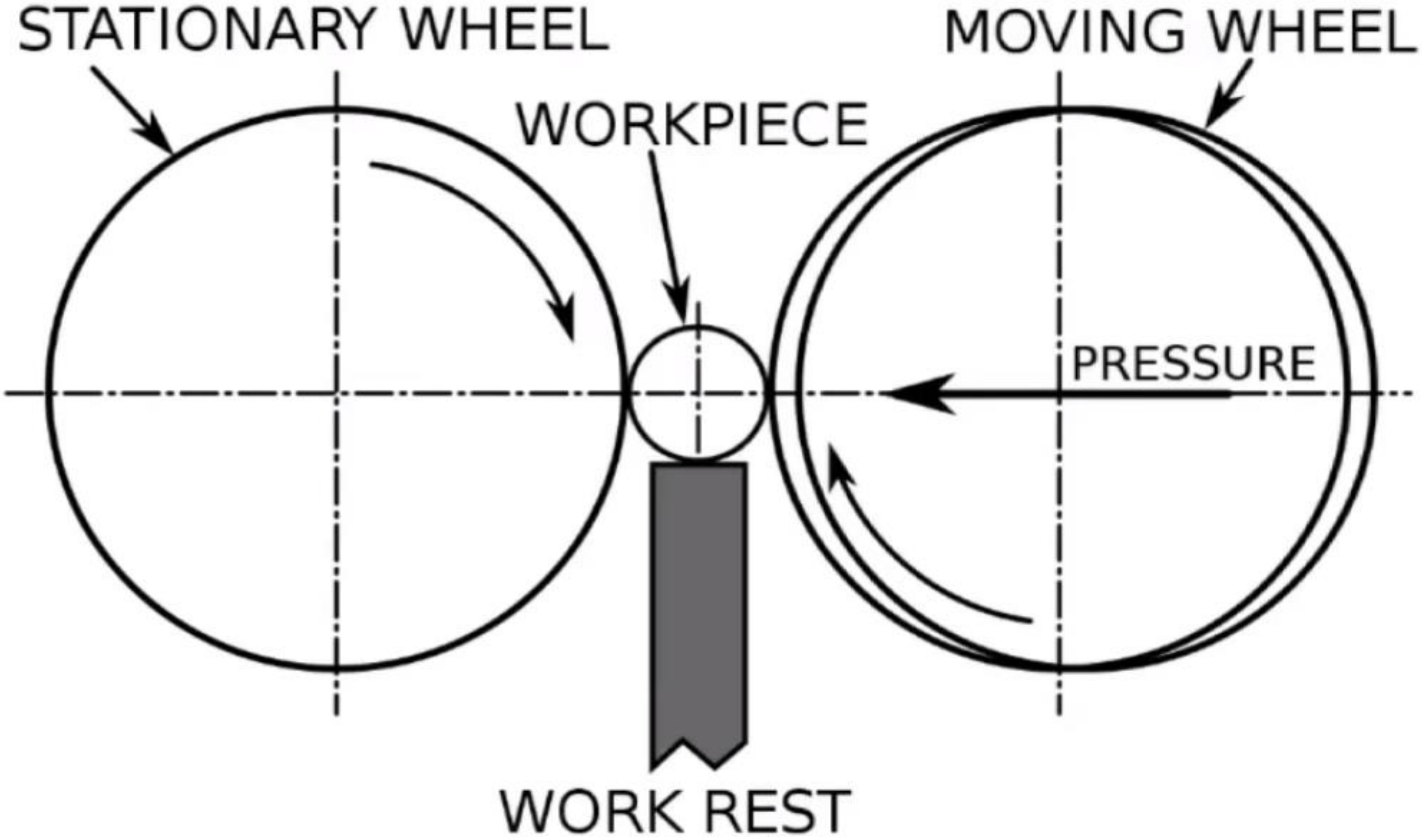
4.Vertical spindle and reciprocating table



Centerless grinding

Centerless grinding is a machining process that uses abrasive cutting to remove material from a workpiece in different way.

Centerless Grinding



Advantage

1. *The grinding process is essentially continuous, because the loading time, when compared to grinding between centers, is exceedingly small.*
2. *The work is rigidly supported directly under the grinding cut as well as for the full length of the cut. This means that no deflection takes place during the grinding operation, permitting heavier passes than grinding between centers.*
3. *No axial thrust is imposed on the work while grinding. The absence of end pressure makes it possible to grind long pieces of brittle materials and to grind easily distorted parts.*

- Less grinding allowance may be required, because the out of roundness is corrected across the diameter rather than the radius.

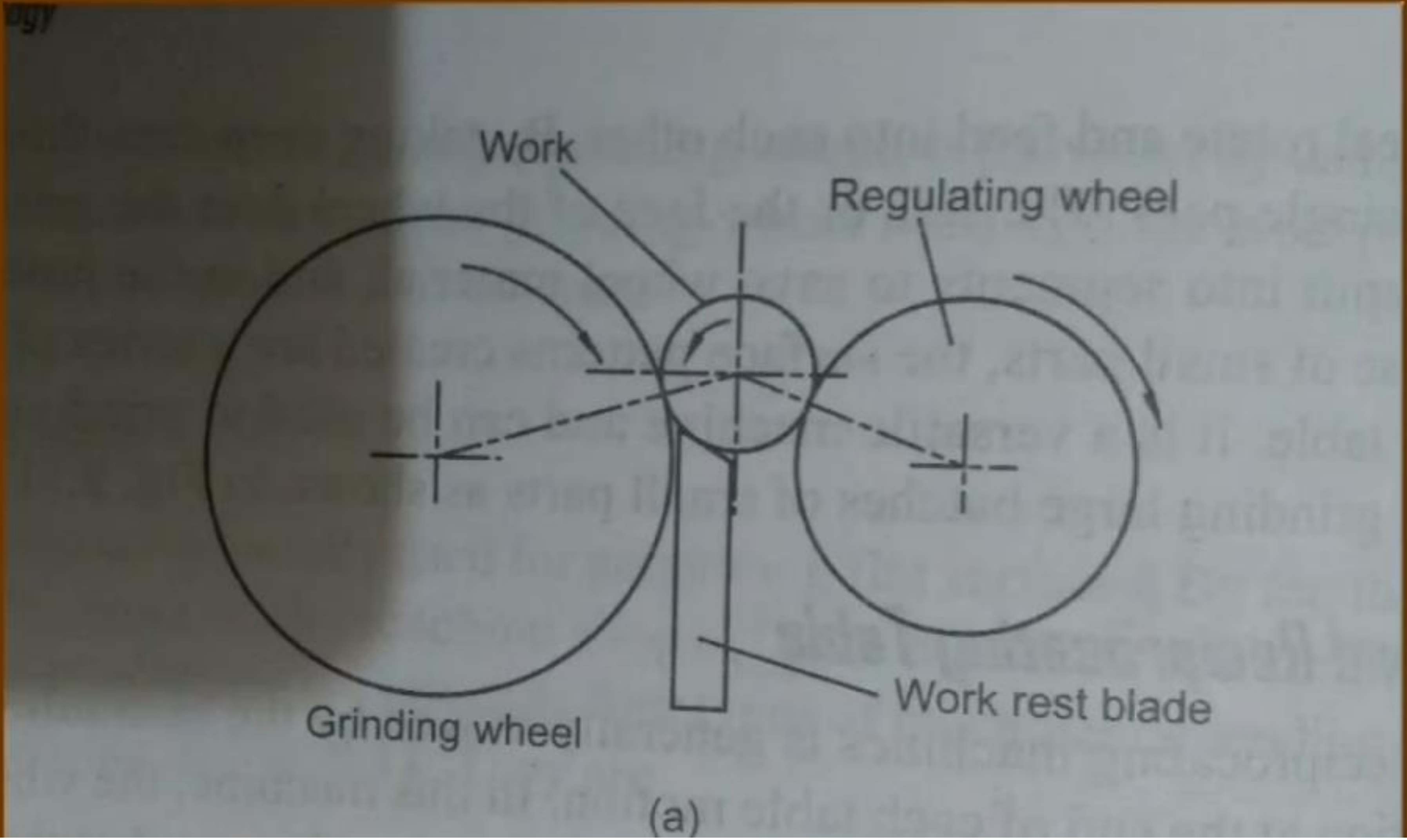
- workpieces may often be loaded into the machine by automatic feeding devices.

Types of centerless grinding Operation

There are 3 types of centerless grinding

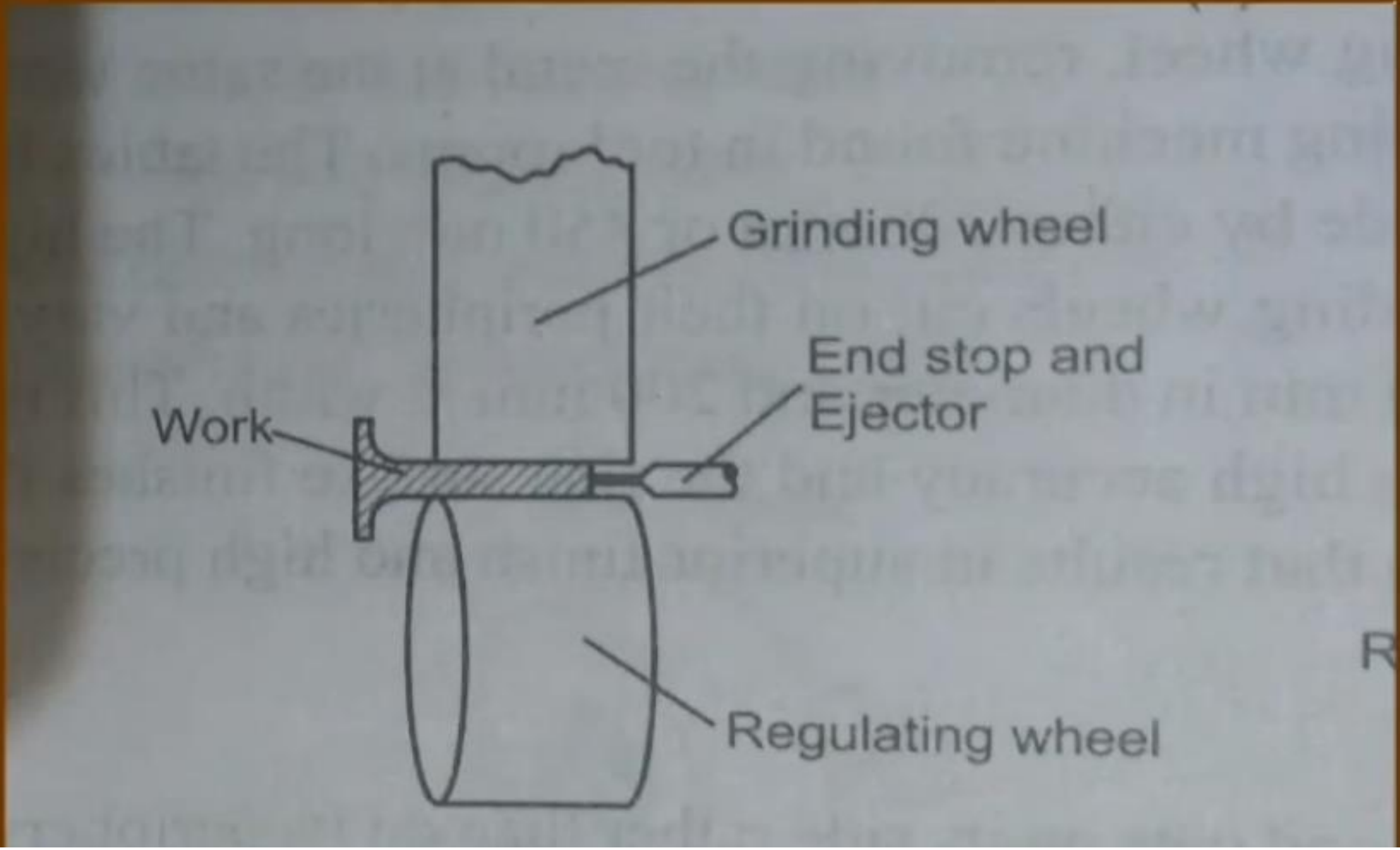
1. Through feed
2. In feed
3. End feed

1. Through feed



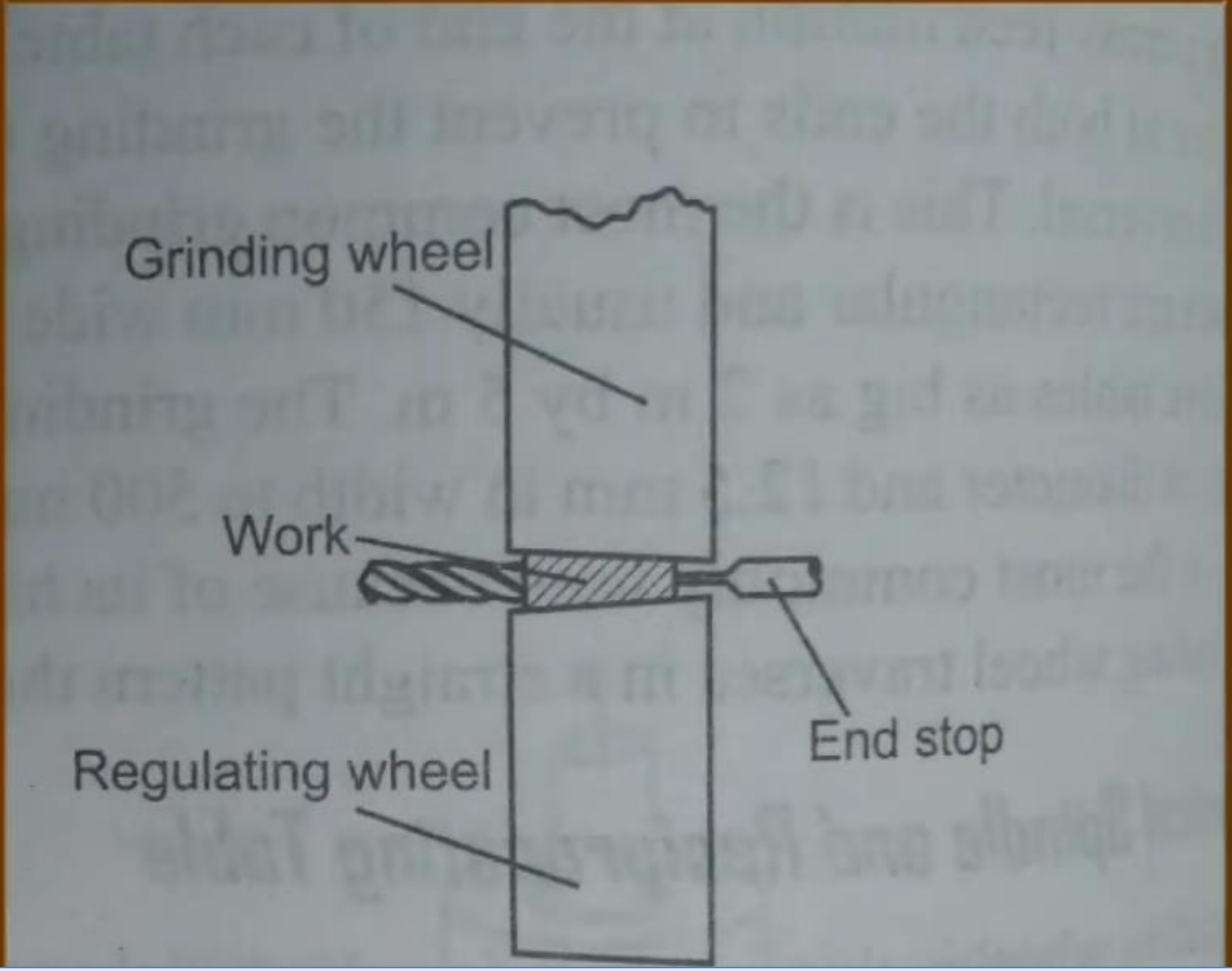
A circular work piece are used

2.In feed



Workpiece are used with an obstacles on piece

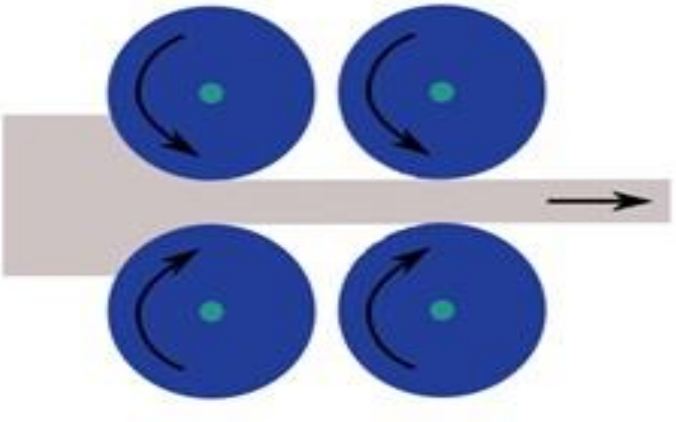
3. End feed:-



Used for tapped workpiece

Sheet Metal Rolling

- Sheet Metal is a metal being formed by a manufacturing process into thin, flat pieces. The sheet metal rolling process consists of passing metal stock through one or more pairs of rolls to reduce the thickness and to make the thickness uniform.
- To determine the designation of sheet vs. plate in general terms we can say that anything 1/8″ and thicker is a plate and anything less than 1/8″ is a sheet. The thickness of sheet metal is normally designated by a non-linear measure known as gauge. The larger the gauge number, the thinner the metal. Commonly used steel sheet metal ranges from 30 gauge to about 6 gauge.



Sheet Metal Forming Between Rolls

- Sheet metal can be available in flat pieces or coiled strips. It is one of the essential shapes used in metalworking. Innumerable everyday objects are fabricated from sheet metal. Sheet metal can be cut and bent into an unlimited number of applications like ductwork, machine guards, other machine components, architectural column covers, wall coverings and downspouts, tank bodies, just to name a few.
- There are multiple manufacturing processes that sheet metal can be formed by bending, curling, incremental sheet forming, laser cutting, perforating, press brake forming, punching, roll forming, rolling, spinning, stamping, water jet cutting.

Fig:-10' Promecam Press Brake

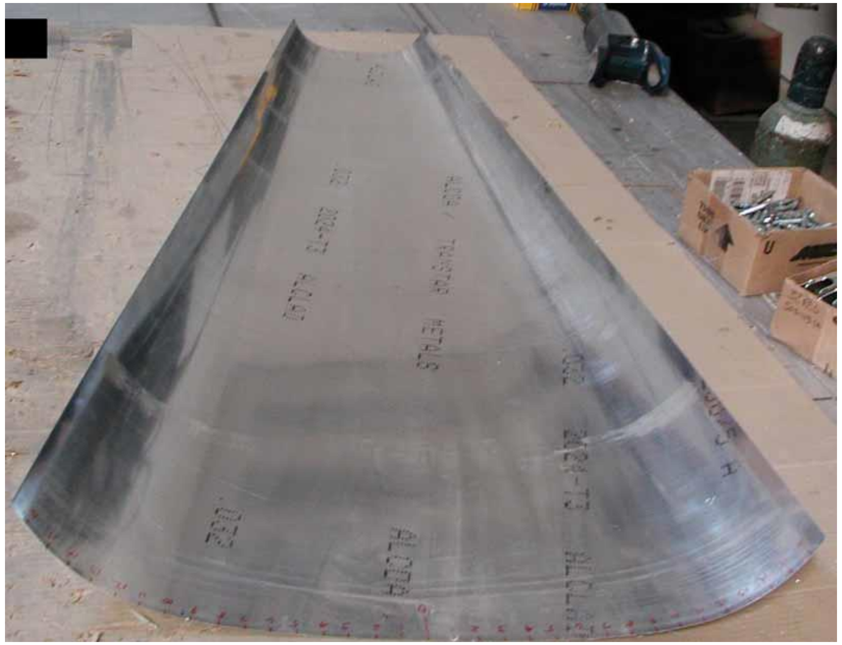
Fig:-Rolled Shapes from Sheet Metal

FARNHAM ROLL

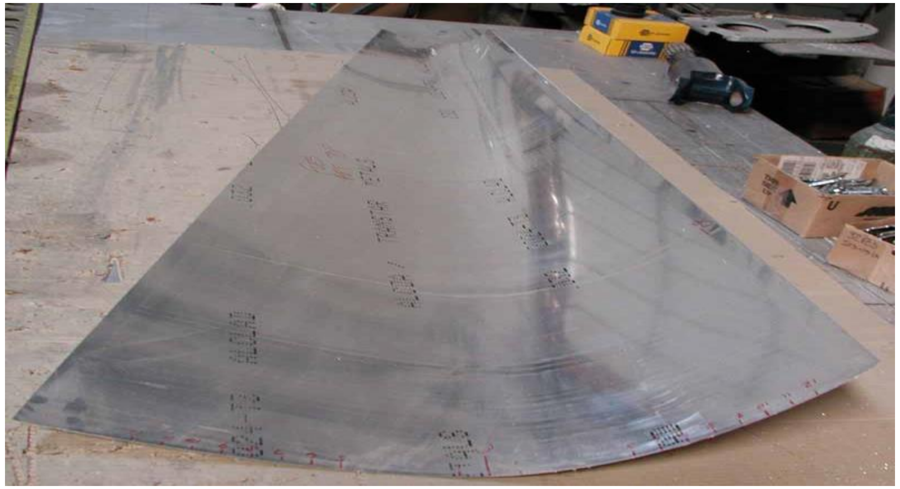
- This is technically a pyramid rolling machine. It is sometimes referred to as a contour roll or a leading edge roll. It was designed to roll aircraft wing leading edges but it can do more than just that one job. The Farnham Roll is a manual machine with no "set rules" for it's operation. The lower rolls can be moved closer or farther apart to adjust the radius of the bend. The upper roller moves up and down, though not necessarily parallel to the lower rolls. There are indicator wheels on each end that provide the height of the roller at the end of the machine.
- Each shape must be individually established and can be a time-consuming operation. Once the position of the rolls is established to produce the desired shape, a part can be easily duplicated. Records of the setting required to produce each part are kept so that future set-up time is reduced. The Farnham Roll can also produce tapered parts.
- The Aeroplane Factory has had several contracts for non-Swift parts which have required the use of our Farnham Roll. Some examples include wing, slot and flap leading edges for the Lockheed C-5. These C-5 parts required outer and inner skins with bonded honeycomb between the surfaces. We have also formed rolled sheet metal parts for companies who provide the patterns and specifications for the parts.

12' Farnham Counter Roll

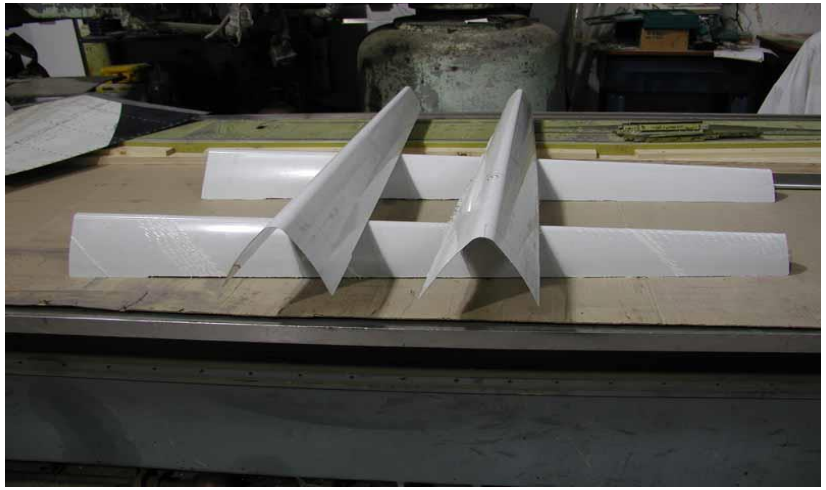
Rolling a Leading Edge Skin



Swift Bottom, Aft Fuselage Skin



Swift Top, Aft Fuselage Skin



Horizontal Stabilizer Leading Edges

One-Piece of Leading Edge Skin