Product Knowledge Document

HEAT TREATMENT

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AGENDA : HEAT TEATMENT

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1. INTRODUCTION TO HEAT TREATMENT
2. PURPOSE OF HEAT TREATMNET
3. APPLICATION OF HEAT TREATMENT
4. BASIC STEPS IN HEAT TREATMENT

CHAPTER 2

1. TYPES OF HEAT TREATMENT
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4. HARDEING & TEMPERING
5. CASE HARDENING

CHAPTER 3

1. DEFECTS AND CAUSES IN HEAT TREATMENT

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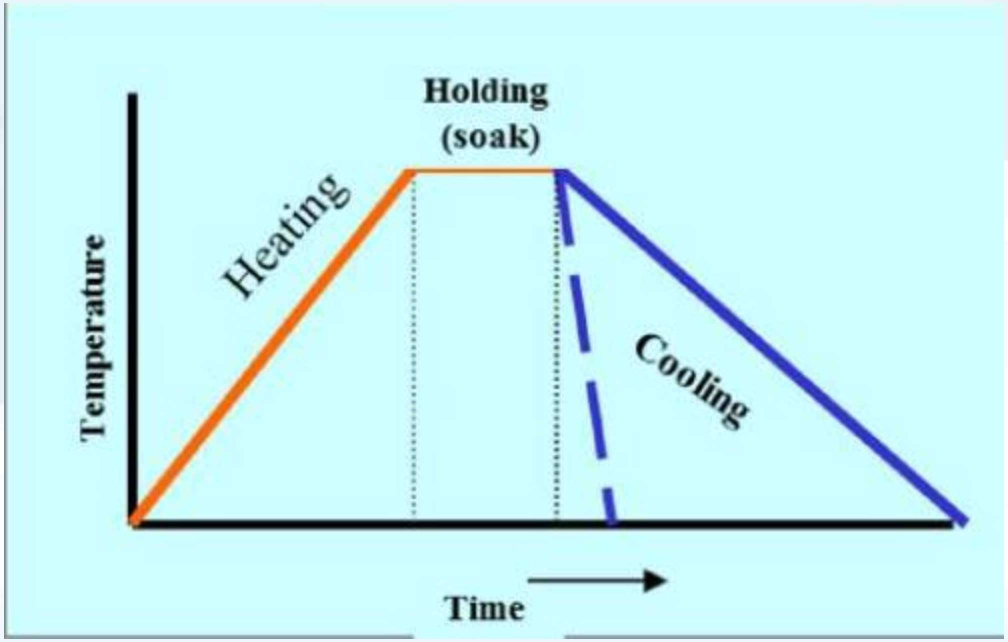
CHAPTER 1 : INTRODUCTION TO HEAT TEATMENT

1.1 - INTRODUCTION TO HEAT TEATMENT

Heat treatment is heating and cooling of metal at controlled rate to get desired Outcomes in mechanical properties (Improving or altering their properties like strength, ductility, hardness, toughness, machinability etc.)



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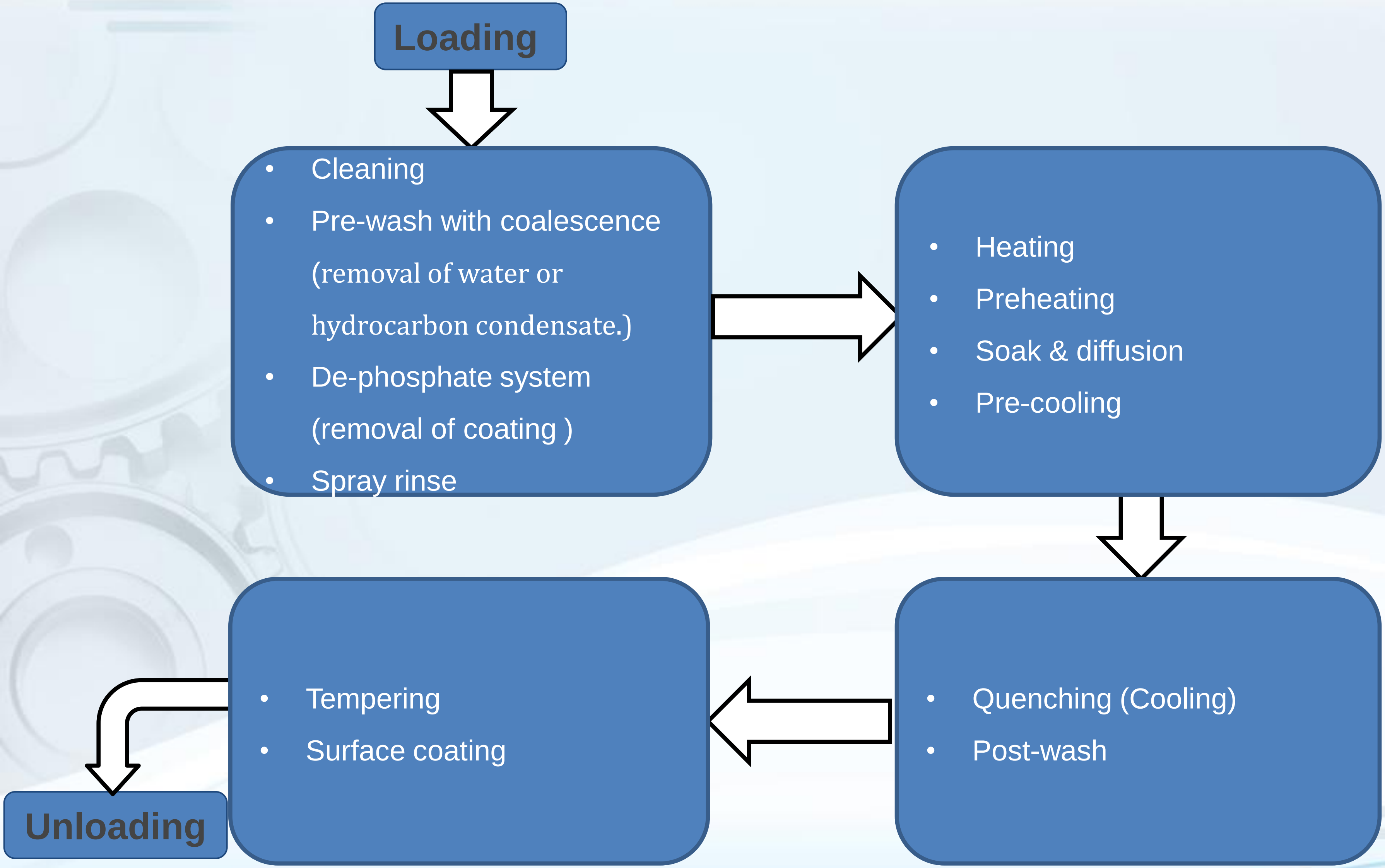
1.2 - PURPOSE OF HEAT TREATMENT

- To relieve internal stress
- To improve machinability
- To refine grain size
- To soften the metal
- To improve the hardness
- To improve mechanical properties
- To increase resistance to wear, heat and corrosion.
- To improve ductility and toughness
- To change the chemical composition.

1.3 - APPLICATION OF HEAT TEATMENT

- Aircraft Industry
- Automobile Manufacturing
- Defense Sector
- Forging
- Foundry
- Heavy Machinery
- Manufacturing
- Powder Metal Industries

1.4 – BASIC STEPS IN HEAT TEATMENT



1.4 – BASIC STEPS IN HEAT TEATMENT

Requires three basic steps:

1. Heating to a specific temperature
2. Holding (soaking) at that temperature for the appropriate time
3. Cooling according to a prescribed method

Note

- heating temperature range to 2400 °F (1316 °C)
- soaking times vary from a few seconds to 3 to 4 days
- cooling may be slowly in the furnace or quickly (quenched) into water, brine, oil, Air, polymer solutions, molten salts, molten metals or gases
- 90% of metal parts are quenched in water, oil, polymers, or gases

CHAPTER 2 : TYPES OF HEAT TEATMENT

2.1 – TYPES OF HEAT TEATMENT

- ANNEALING
  - FULL ANNELING
  - STRESS RELIEF ANNEALING
  - SPHEROIDISE ANNEALING
- NORMALIZING
- HARDENING & TEMPERING
  - CONVENTIONAL HARDENING & TEMPERING
  - AUSTEMPERING
  - MARTEMPERING
- CASE HARDENING
  - CARBURIZING CYANIDING NITRIDING CARBONITRIDING
  - FLAME HARDENING
  - INDUCTION HARDENING
  - ELECTRON BEAM HARDENING
  - LASER BEAM HARDENING

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2.2 – ANNEALING

It refers to a heat treatment in which the material is exposed to an elevated temperature for an extended time period and then slowly cooled.

When an annealed part is allowed to cool in the furnace, it is called a "full anneal" heat treatment.

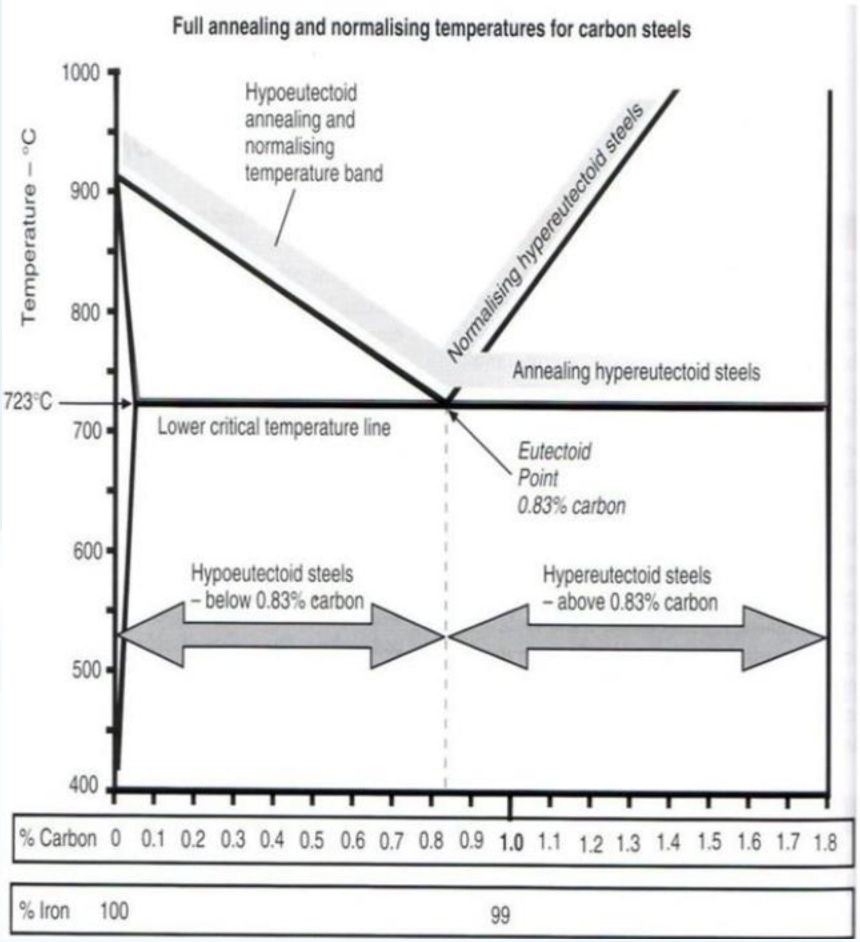
Types of Annealing

- Full Annealing
- Process Annealing
- Stress Relief Annealing
- Recrystallization Annealing
- Spheroidise Annealing

2.2 – ANNEALING - FULL

Main Objective: Soften the metal, Relieve the stress, Refine the structure.

- **Temp is 30 – 50 ° C above the upper critical temp for hypo eutectoid steel.**
- **30 – 50 ° C above the lower critical temp for hyper eutectoid steel.**
- **Cooling is done at the furnace at the rate of 10-30°C per hour.**
- **For hypoeutectoid steel the resulting microstructure is coarse pearlite and ferrite.**



Note : Hypoeutectoid steels are those steels with less than ~0.80 wt. % carbon

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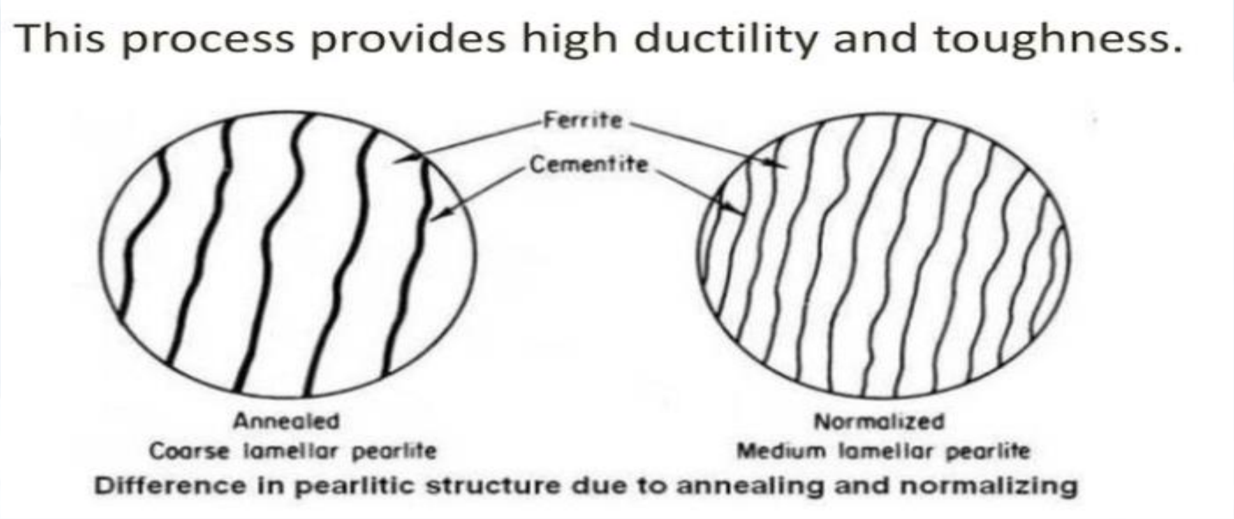
2.2 – ANNEALING – FULL

For hypereutectoid steel annealing temp is 30-50°C above the lower critical temp.

For hyper eutectoid steel the resulting microstructure is coarse pearlite and cementite.

This process provides high ductility and toughness.



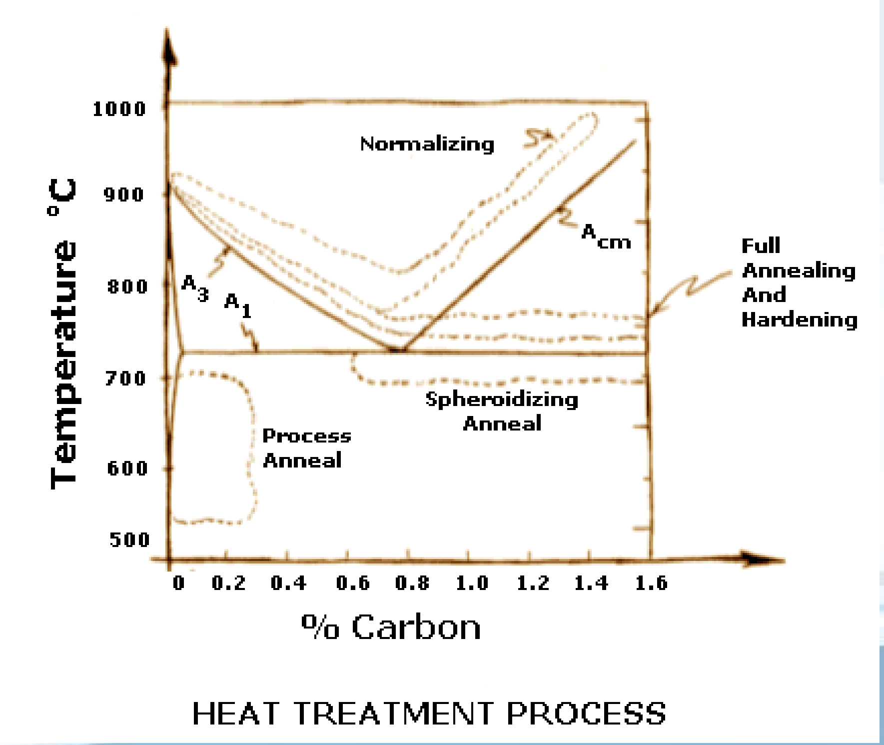
2.2 – ANNEALING – PROCESS

This process is done above its recrystallization temp.

This process is similar to that of recrystallization process and both the process involves crystallization and formation of new stress free grains.

Applicable for low carbon steel.

Due to this process ferrite recrystallizes and cementite tries to speroidise.



2.2 – ANNEALING – STRESS RELIF ANNEALING

Stress relief or recovery annealing.
Annealing temp is at the range of °C.
Uniform cooling is mandatory.
It eliminates the stress formed during welding, cold working, casting, quenching, machining.

Need for Stress Relief Annealing

Causes for stress:

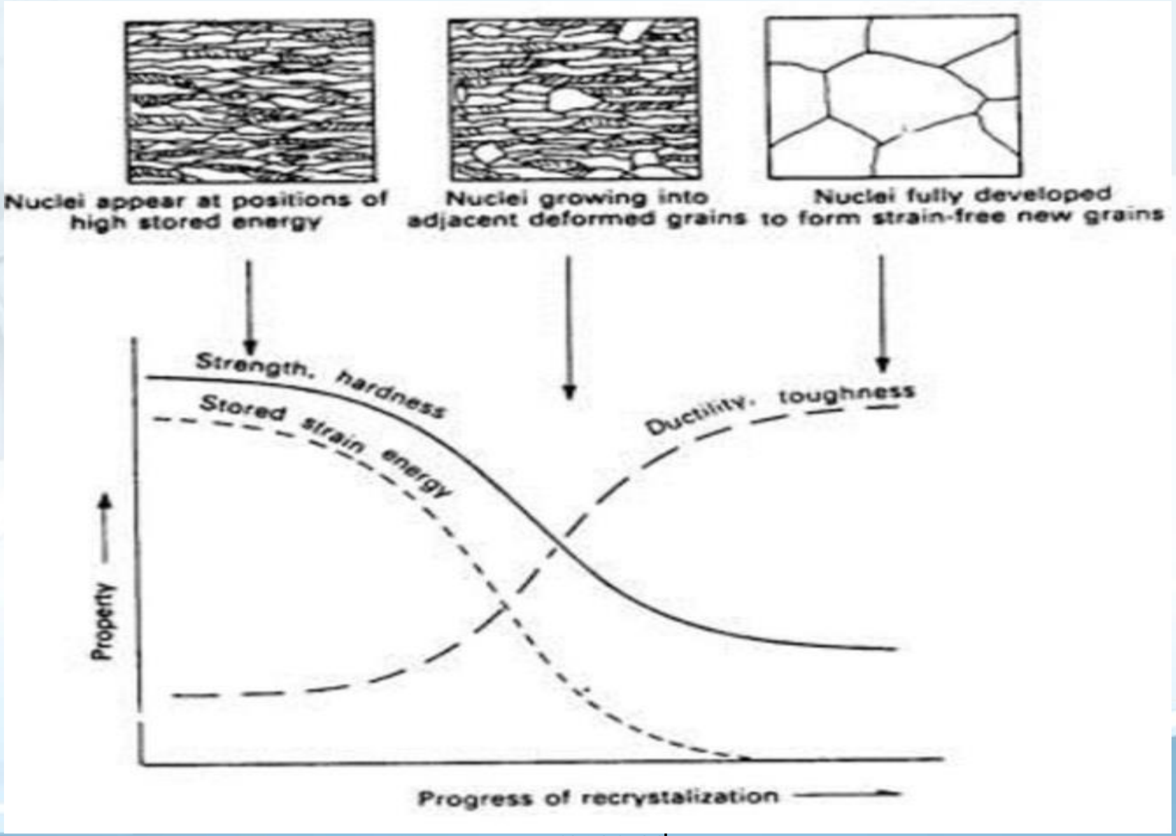
Plastic deformation during machining
Non-uniform cooling
Phase transformations between phases with different densities.

Effect of Stress

War page
Crack
Distortion

2.2 – ANNEALING – RECRYSTALLIZATION

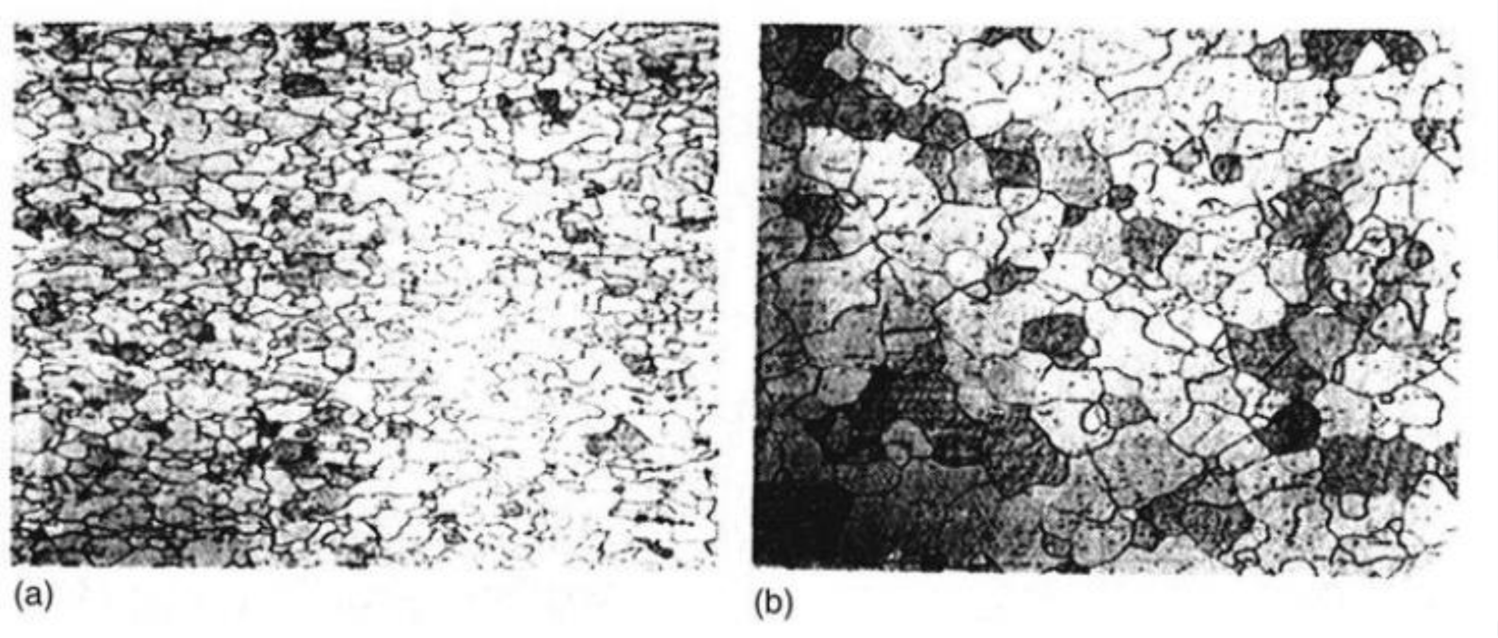
It is a process in which distorted grains of cool worked material are replaced by strain free new grains.
Recrystallization annealing is an annealing process at temperatures above the recrystallization temperature of the cold-worked material, without phase transformation.
The recrystallization temperature is not a constant for a material but depends on the amount of cold work, the annealing time, and other factors.



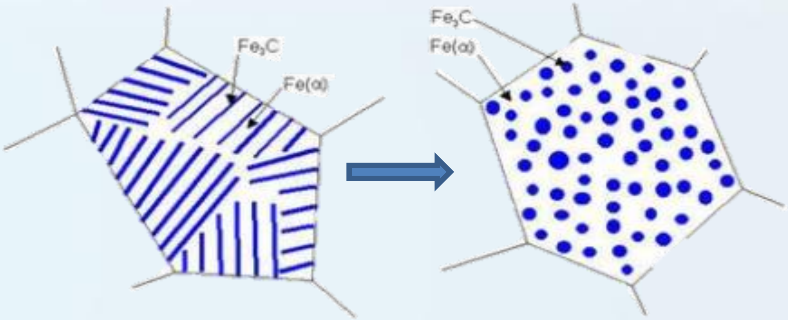
2.2 – ANNEALING – RECRYSTALLIZATION

It reduces the Dislocation density and converts elongated grains to equ axied .

(a) after cold worked
(b) after recrystallization annealing

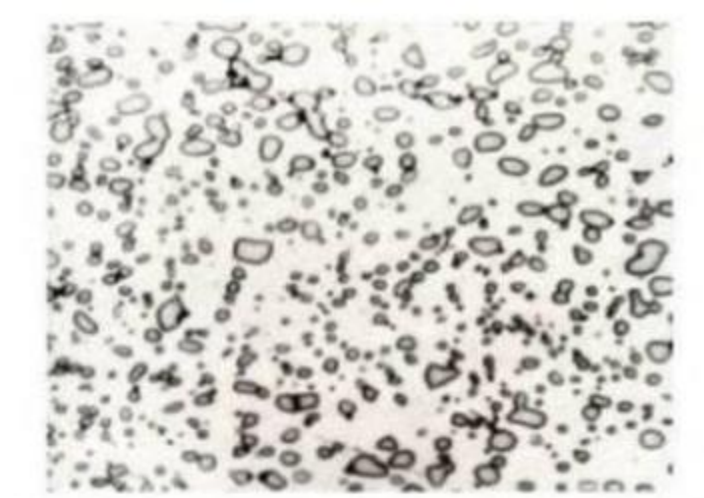


2.2 – ANNEALING – SPHEROIDIZING



CONVERTS -

- Lamellar Pearlite to Globular Pearlite
  Plates of Cementite to Spheroids of Cementite



Spheroidized cementite in a ferrite matrix

Main objectives of Spheriodising:

To soften the steel
Increase ductility and toughness
Improves machinability and formability
Reduces hardness, strength and wear resistance.

Materials mainly concentrated

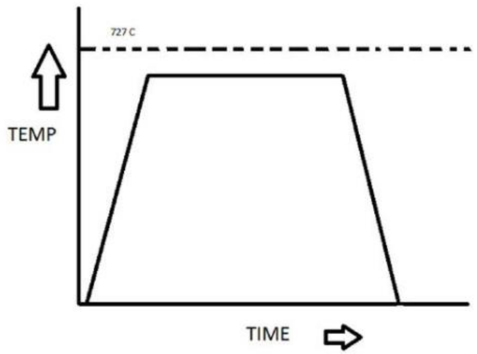
Medium carbon steel
High carbon (tool steel)

Spheriodising is not used for Low carbon Steel

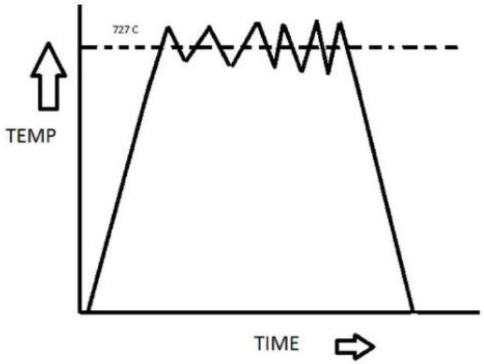
2.2 – ANNEALING – SPHEROIDIZING

Three ways of Spheriodising

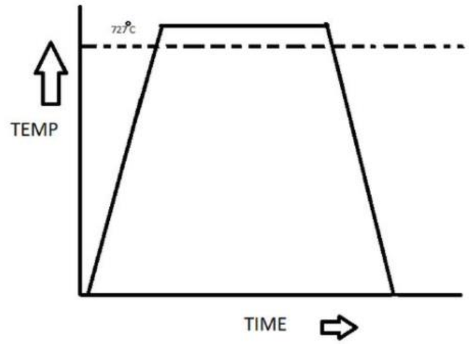
Prolong heating below Lower critical temperature and slow cooling.



Cycling between temperature and then relatively slow cooling.



For tool and high speed steel heating at the temperature range between 750° - 800°C then hold at this temperature and then slow cooling.



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2.2 – ANNEALING – PURPOSE AND APPLICATION

PURPOSE

- To relive internal stresses that are developed from welding and cold rolling.
- To reduce hardness
- To refine the grain size
- To make material homogeneous in respect of chemical composition
- To increase machinability
- To make steel suitable to subsequent heat treatment like hardening

APPLICATIONS

- In steel used in sheet and wire drawing
- High carbon steel
- Ball bearing steel
- Casting of carbon and alloy steel.

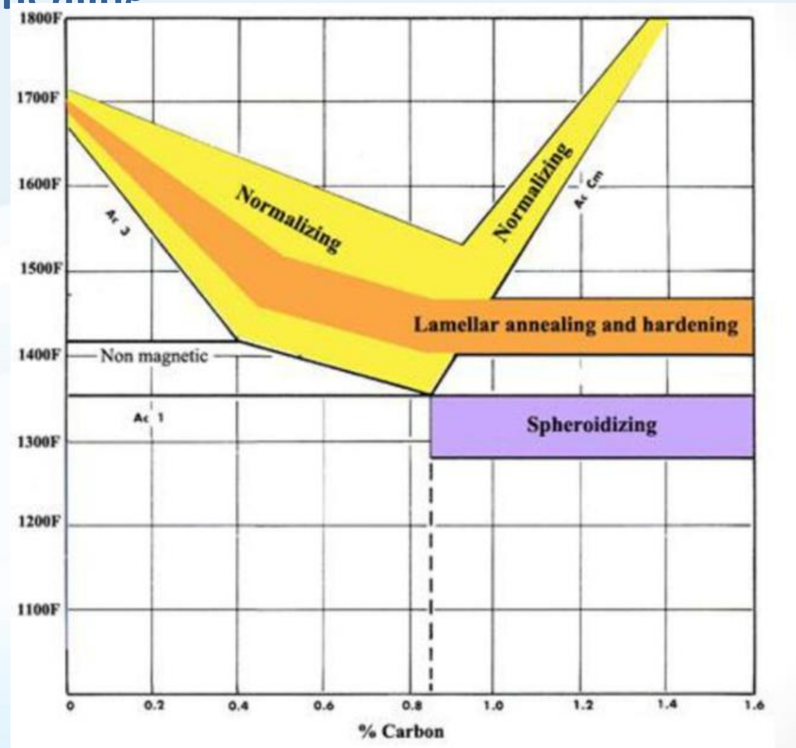
2.3 – NORMALIZING

When an annealed part is removed from the furnace and allowed to cool in air, it is called a "normalizing"

Material is heated 40 to 50c above its critical temp then it is hold at that temp for around 15 min and then it is cooled slowly in air

Normalizing is done on cold work parts to remove internal stresses and restructure the material grain

Normalizing is done at higher temperature than Annealing



Main Objectives:

To refine grain structure.
To remove strains
To remove internal stress
To remove dislocations
To improve mechanical properties(strength, hardness
and toughness)
To improve machinability of low carbon steels.

Note - Normalizing is done on cold worked parts

2.3 – ANNEALING VS.NORMALIZING

The process of annealing is same as that of normalizing but differ in following manner

Annealing	Normalizing
Less Hardness, Tensile, Strength and Toughness	Slightly more Hardness, Tensile, Strength and Toughness
Internal stresses are least	Internal stresses are more
Grain size distribution is more more uniform	Grain size distribution is less uniform
Pearlite is coarse	Pearlite is fine

2.3 – NORMALIZING – PURPOSE AND APPLICATION

PURPOSE

- The purpose of process is same as that of annealing . to eliminate cementite network in hypereutectoid steel ,formed due to slow cooling in the temp range from acm to a1.
- Produce uniform structure
- Produce harder and stronger steel
- Increase strength and ductility
- To refine grain size.

APPLICATION

- Used to improve microstructure in steel
- It is applied on welded structure to improve uniformity.
- It is mostly applied on low and medium carbon steels
- To refine grain structure in rolled and cast steel.

2.3 – HARDENING

Material is heated above its critical temp then it is hold at that temp for specific time and then quenching it

Quenching is dipping the material directly in to the bath of oil/water/polymer

Objective :

To improve hardness

To improve wear resistance

Hardening Steps:

Heating

Soaking → Complete γ

Cooling

FACTORS AFFECTING HARDNESS

Carbon Content

Increasing Carbon → Increasing Hardness

Specimen Size

Increase the specimen size → Decreases the hardness.

Quenching Medium

Faster the cooling → Greater the hardness.

Other Factors

Geometry

Quenching medium

Degree of agitation

Surface conditions

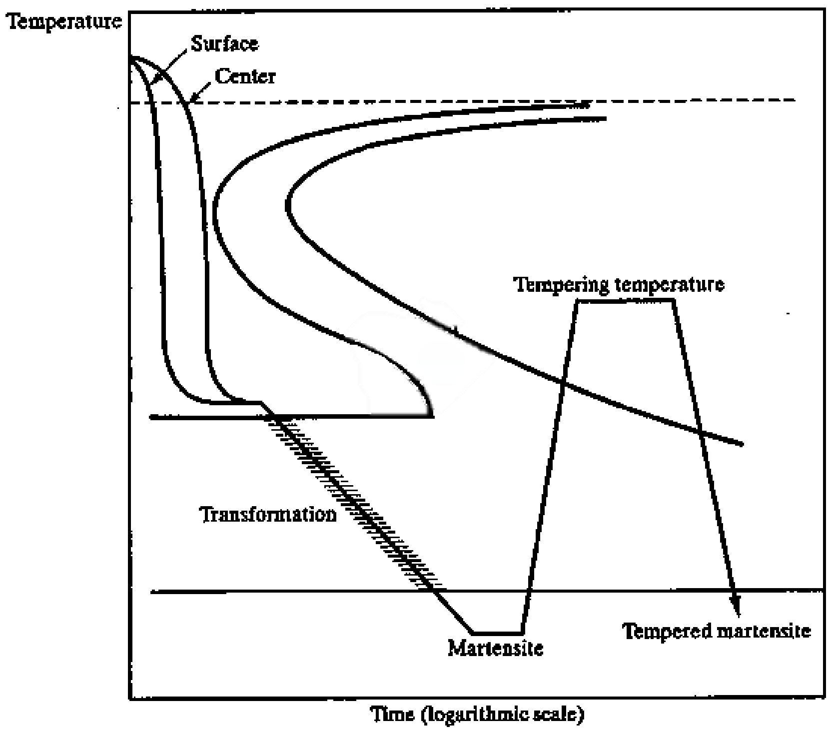
Alloy elements

2.4 – TEMPERING

Martensite formed in the hardening process is converted to TEMPERED MARTENSITE
To improve ductility and toughness.

Objective

- To improve ductility
- To improve toughness
- To reduce hardness
- To remove internal stress (rapid cooling)
- To impart wear resistance.

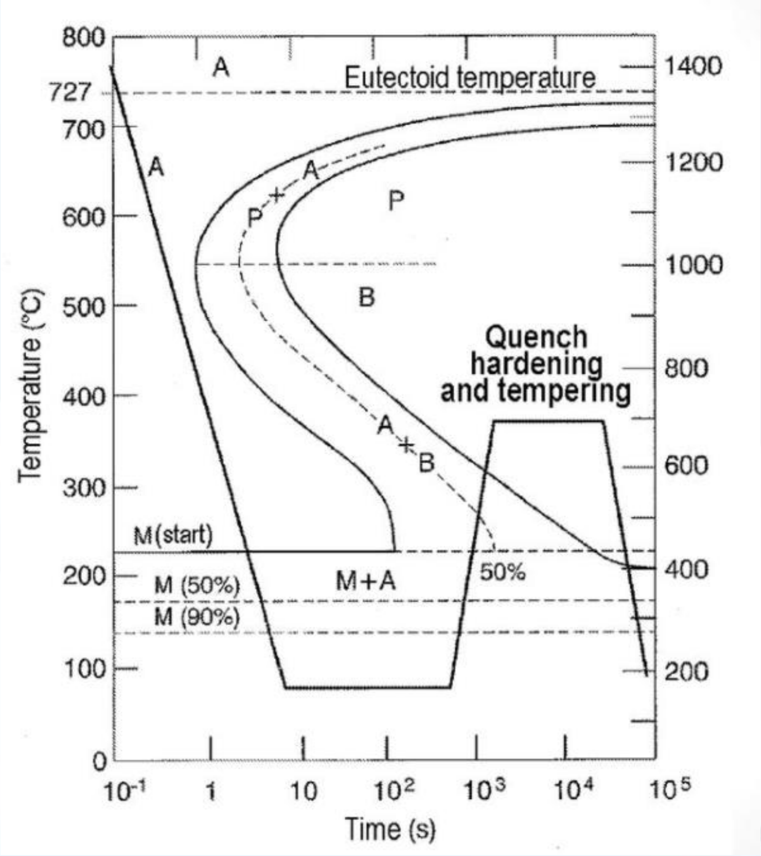


2.4 – TEMPERING

In Tempering

- Tempering Heated to 250˚ - 650˚C and cooled slowly to room temp
- This is also done to relieve internal stress.
- Martensite →Tempered Martensite
- BCT → supersaturated carbon
- Stable ferrite and cementite
- Hardness decreases with increasing in tempering

time.



Body-centered tetragonal (BCT) crystal structure. Martensite

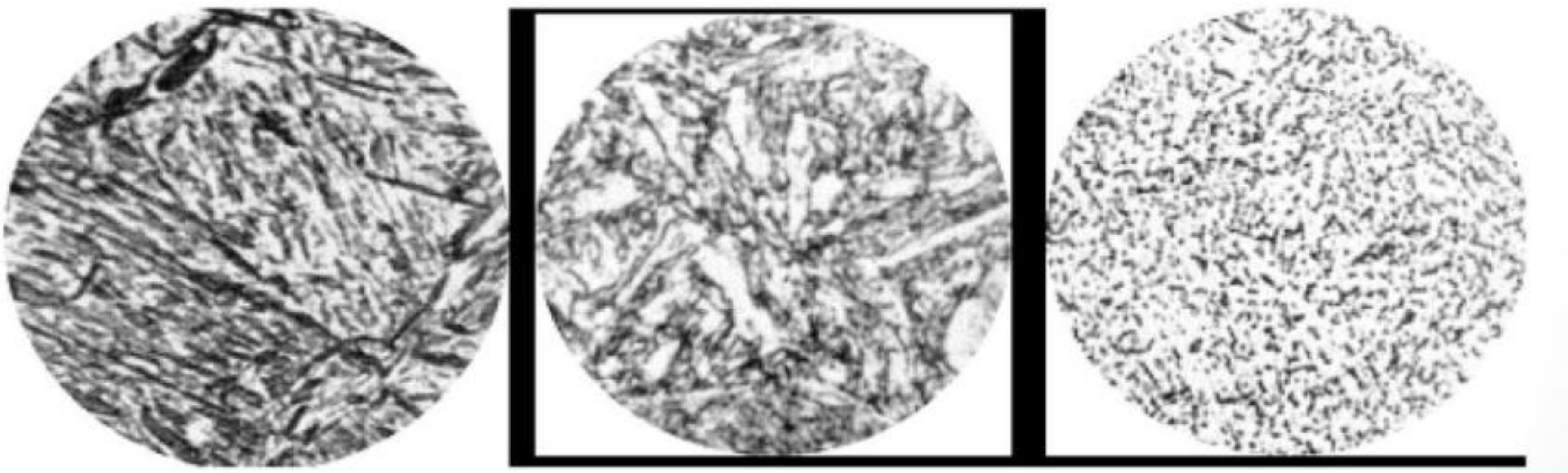
2.4 – TEMPERING

Types of tempering

Low temp
T 150-250˚C
Retain hard martensite
Relieve internal stress

Med TEMP
T 350 – 450 ˚C
Increases endurance limit
Increases elastic limit
for spring steel

High temp
T 500 – 650 ˚C
On structural steel



Martensite Tempered Martensite Heavily Tempered Martensite

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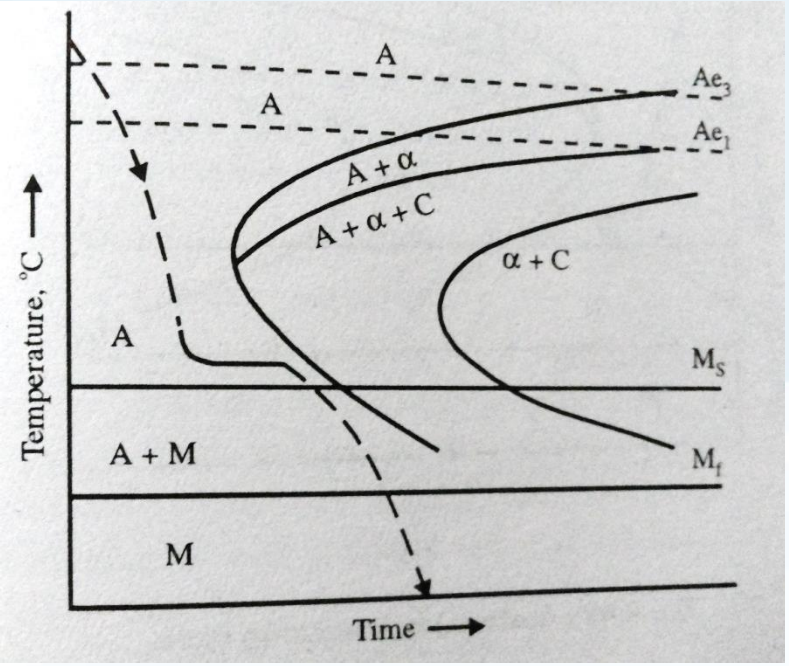
2.4 – MARTEMPERING

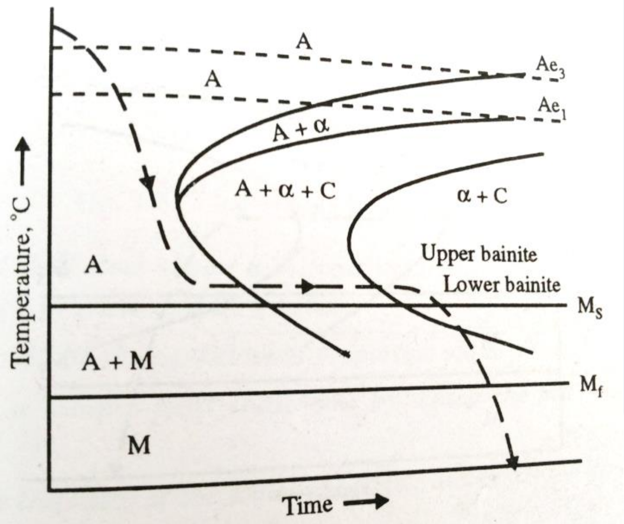
In this process austenised steel is cooled rapidly avoiding the nose of the i.t. diagram to temp between nose and soaked at this temp. for some time but not enough to permit the formation of bainite and then cooled to room temp.in air or oil.



Process is applicable for high carbon steel and Low alloy steel.
It is less warping and less possibility of quenching cracks

2.4 – AUSTEMPERING

In this process Austenised steel is cooled with rate Exceeding the critical cooling rate in a molten. Bath held at some constant temp. Between the nose Of ttt diagram and ms temp i.E. In bainite region, holding at this temp. For a sufficient period for the Completion of bainitic transformation and cooling To room temp at any desired rate.



THE ADVANTAGE OF THIS AUSTEMPERING IS THAT IT

- Produces structure and properties much similar to tempered martensite without involving in Martensitic transformation.
- Depending upon temp of transformation , the product may be upper bainite or lower bainite .
- Properties of bainite are intermediate to those of martensite and pearlte are very much similar to that of tempered martensite.

2.5 – CASE HARDENING

- Case hardening is also called as surface hardening
- Case hardening is used to harden the surface
- Case hardening is required to reduce surface wear of part without loosing core toughness

Types of Case Hardening

- CARBURIZING
- CYANIDING
- NITRIDING
- CARBONITRIDING
- FLAME HARDENING
- INDUCTION HARDENING
- ELECTRON BEAM HARDENING
- LASER BEAM HARDENING

2.5 – CASE/SURFACE HARDENING

NEED OF SURFACE TREATMENT:

In many application such as crankshaft ,camshafts, gears etc., hard and wear resistance is required with tough core(at center) to withstand impact loads .

Such a requirement is difficult to achieve by using a steel of uniform composition .

Low carbon steel are tough but cant hardened, high carbon steels can be hardened but are not tough also they are very much likely to crack during hardening .

Medium carbon steel are intermediate in properties to those of low and high carbon steel and do not satisfy requirement to optimum level.

Such problem are solved by :

- **Increasing the carbon on the surface of a low carbon or low carbon low alloy steel .**
- **Introducing nitrogen in surface of a tough steel.**
- **Introducing carbon and nitrogen in the surface of tough steel.**
- **Hardening the surface without change of composition of surface.**

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2.5 – CASE HARDENING - CARBURIZING

- In Case Carburizing mild steel is heated its near critical temperature with charcoal or carbon around it surface
- At this high temp carbon form metal solution in iron and surface becomes high carbon steel
- High carbon steel is hard and there is tough core of mild steel inside

Three types of Carburizing

1. Solid/Pack
2. Gas
3. Liquid

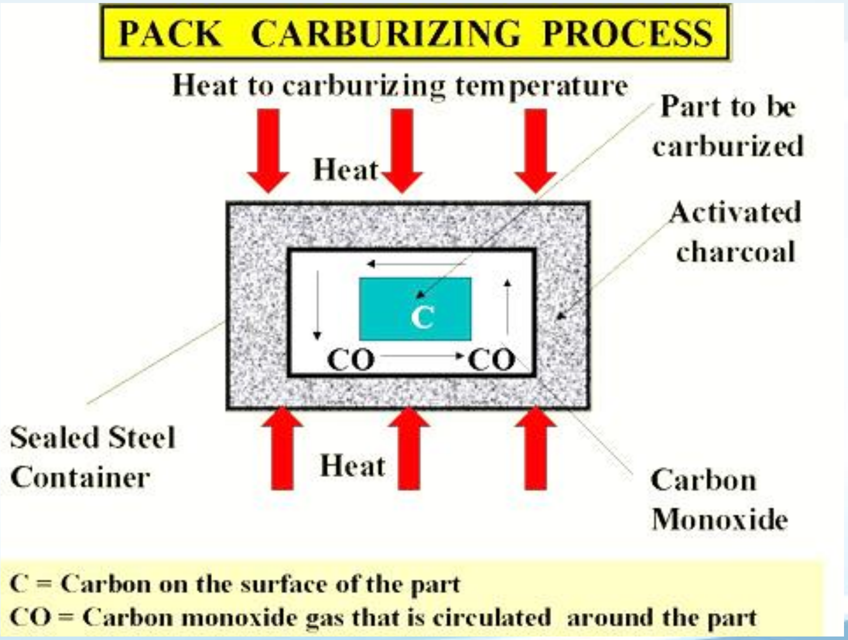
2.5 – CASE HARDENING – SOLID/PACK CARBURIZING

The component to be carburized are packed with a carbonaceous material in the steel or cast iron boxes clay.

If the boxes are not properly sealed, air comes in contact with the carbonaceous medium and medium simply burns without any carburising .

The usual carbonaceous medium consist of hard wood charcoal ,coke and an energirizer or accerlator such as barium carbonate or other sodium or calcium carbonate.

These boxes are heated to some temp. In austenetic region and kept at this temp until the desired degree of penetration is obtained.



2.5 – CASE HARDENING – SOLID/PACK CARBURIZING

Maximum carbon at surface and case depth depend On the temp of carburizing and the time of holding. Higher the temp., Higher is the carbon at the surface and more is case depth.

At the usual temp. Of carburising (925-950 c) the case depth varies from 1 mm to 2.5 mm for total carburizing time 6 to 15 hours.

2.5 – CASE HARDENING – GAS CARBURIZING

Here the components are heated in the austenitic region in the presence of a carbonaceous gas such as methane, ethane propane or butane diluted with a carrier gas such as flue gas.

These gases decomposes and the carbon diffuses in to steel . to maintain a constant and uniform rate of carbon diffusion ,gas composition must be properly controlled along with proper circulation of gas in the furnace chamber.

This process require less time as compare to solid Carburizing because of no boxes. Process is carried out lowere temp.(900-925 c) than those normally used for pack carburizing.

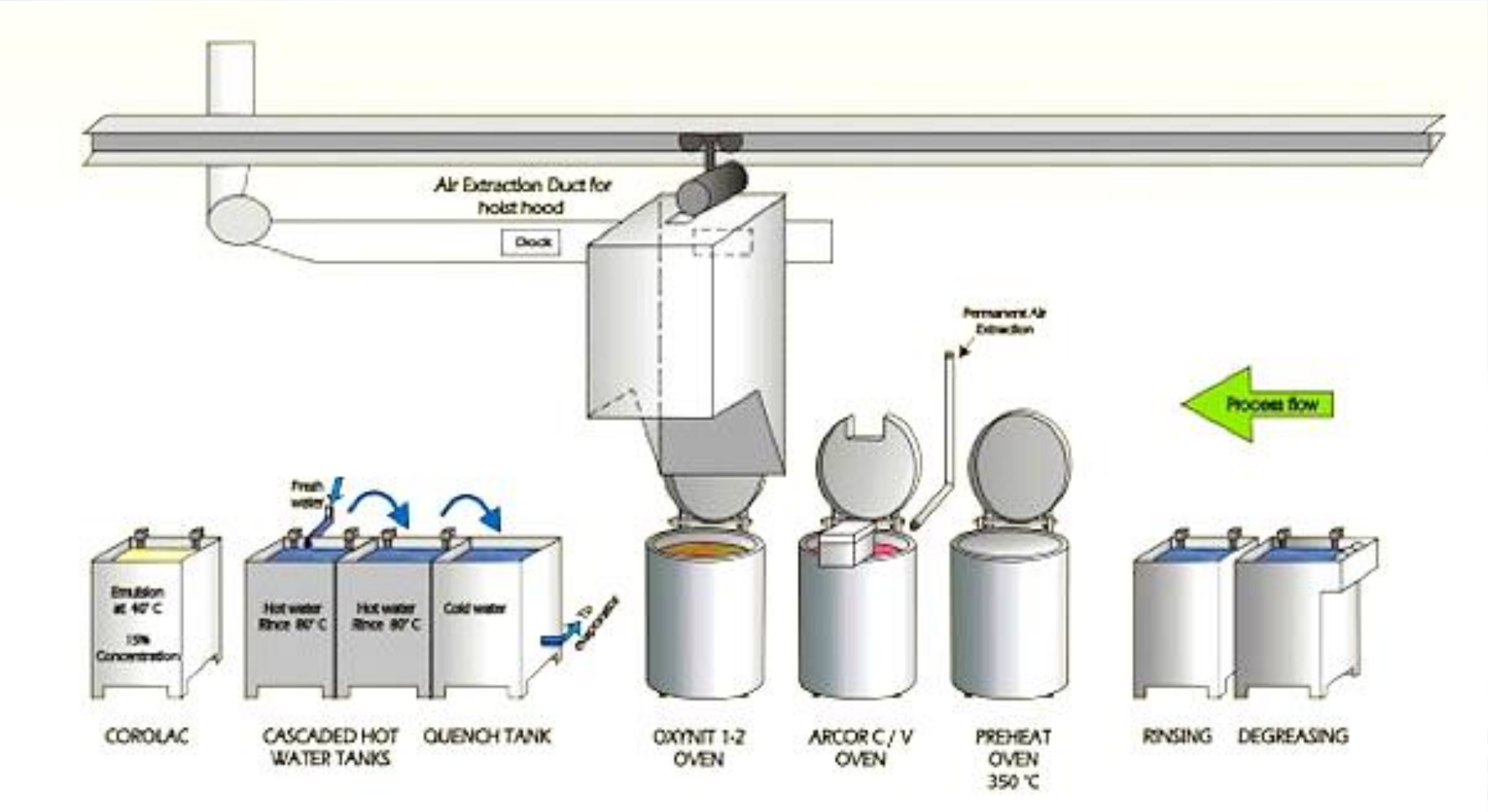
Gas carburizing is commonly used to obtain relatively thin cases of high uniformity. Case depths from 0.2 to 0.5 mm can be obtained in 1 to 2 hours at a temp. of 900 c.

The process has less labor cost as compared to pack carburizing but the skilled persons are required to maintain necessary control.

2.5 – CASE HARDENING – LIQUID CARBURIZING

In this method carburizing is done by immersing the sSteel component in a carbonaceous fused salt bath medium at a temp in the austenitic region .

This bath is composed of sodium cyanide ,sodium carbonate and sodium chloride .



2.5 – CASE HARDENING – LIQUID CARBURIZING

The atomic nitrogen thus produced diffuses in to the steel and results in nitriding along with carburizing.
Case depth of 0.1 to 0.5 mm can be obtained in a period of ½ to 1 hours at the usual carburizing temp.

ADVANTAGES

- Rapid and uniform heat transfer
- Low distortion
- Negligible surface oxidation
- Rapid absorption of carbon

DISADVANTAGES

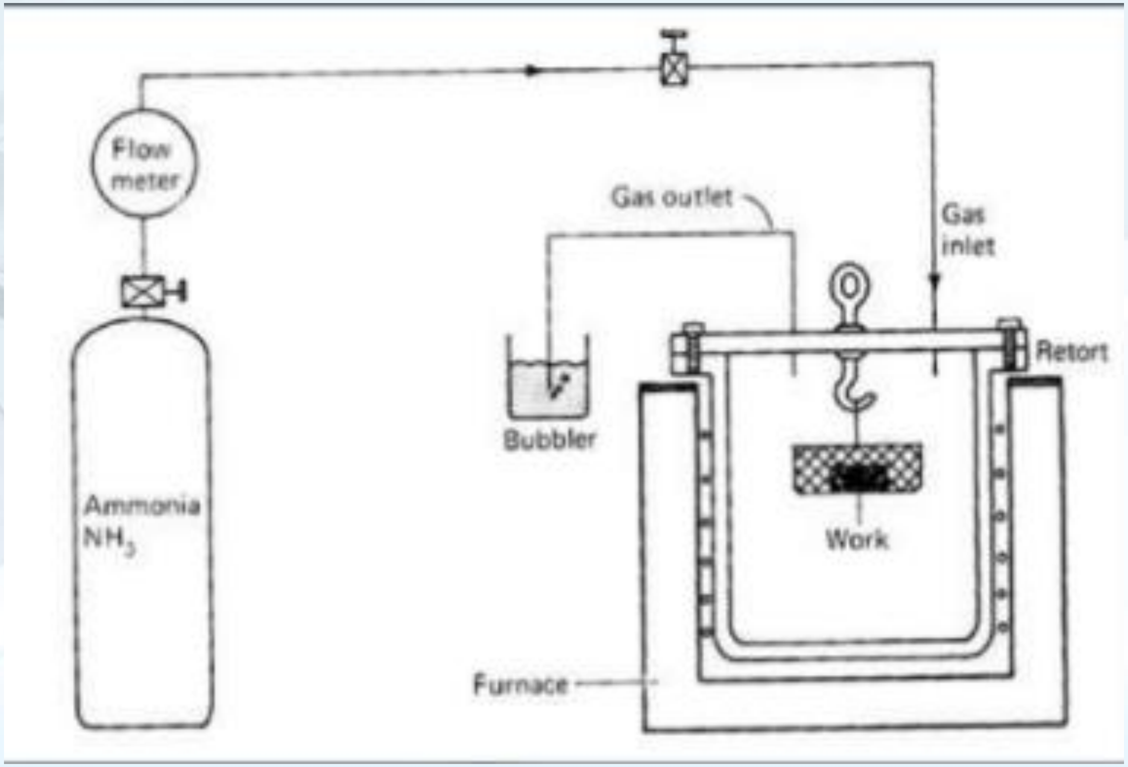
- Sodium cyanide is highly poisonous
- Salt sticks to components, must be removed by washing

2.5 – CASE HARDENING - CYANIDING

- **In this process steel is immersed in bath of sodium chloride + Sodium carbonate + Sodium cyanide at a temp of 80 to 90 C and then it is dipped in cold bath for quenching**
- **The case hardening in this process is uniform and we can get great surface finish**

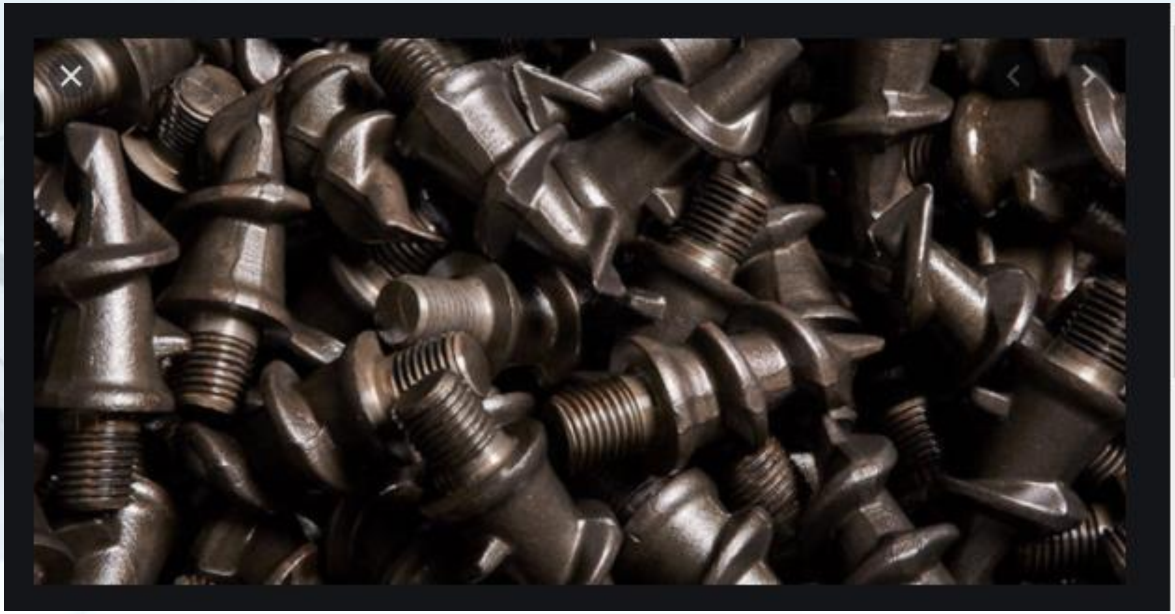
2.5 – CASE HARDENING - NITRIDING

- In this process steel is heated above 500 C in presence of Ammonia
- This forms the nitride on surface of metal
- Nitride are hard in nature which increase the hardiness of surface



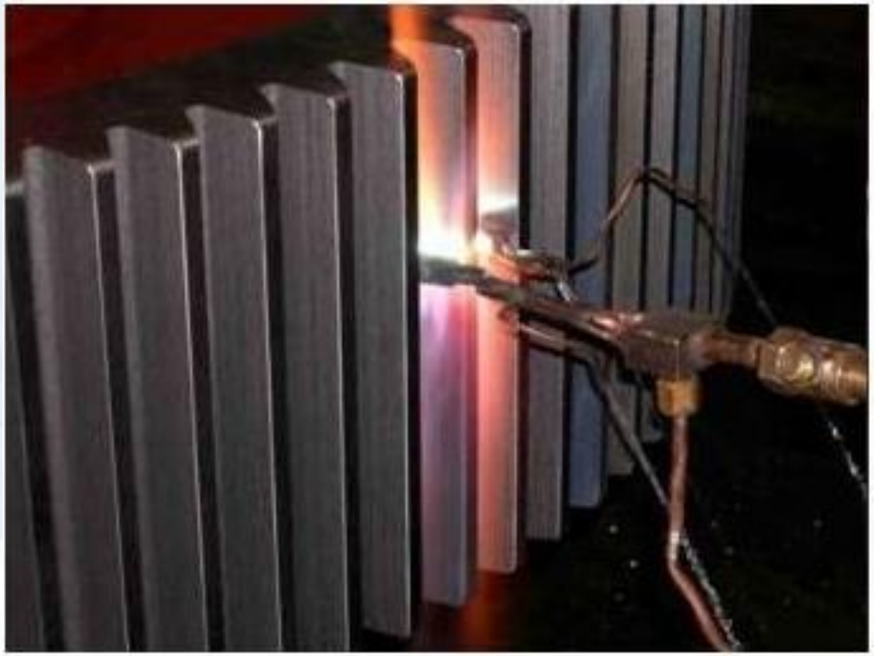
2.5 – CASE HARDENING - CARBONITRIDING

- **During carbonitriding, parts are heated in a sealed chamber well into the austenitic range—around 1600 degrees Fahrenheit—before nitrogen and carbon are added. Because the part is heated into the austenitic range, a phase change occurs and carbon and nitrogen atoms can diffuse into the part.**



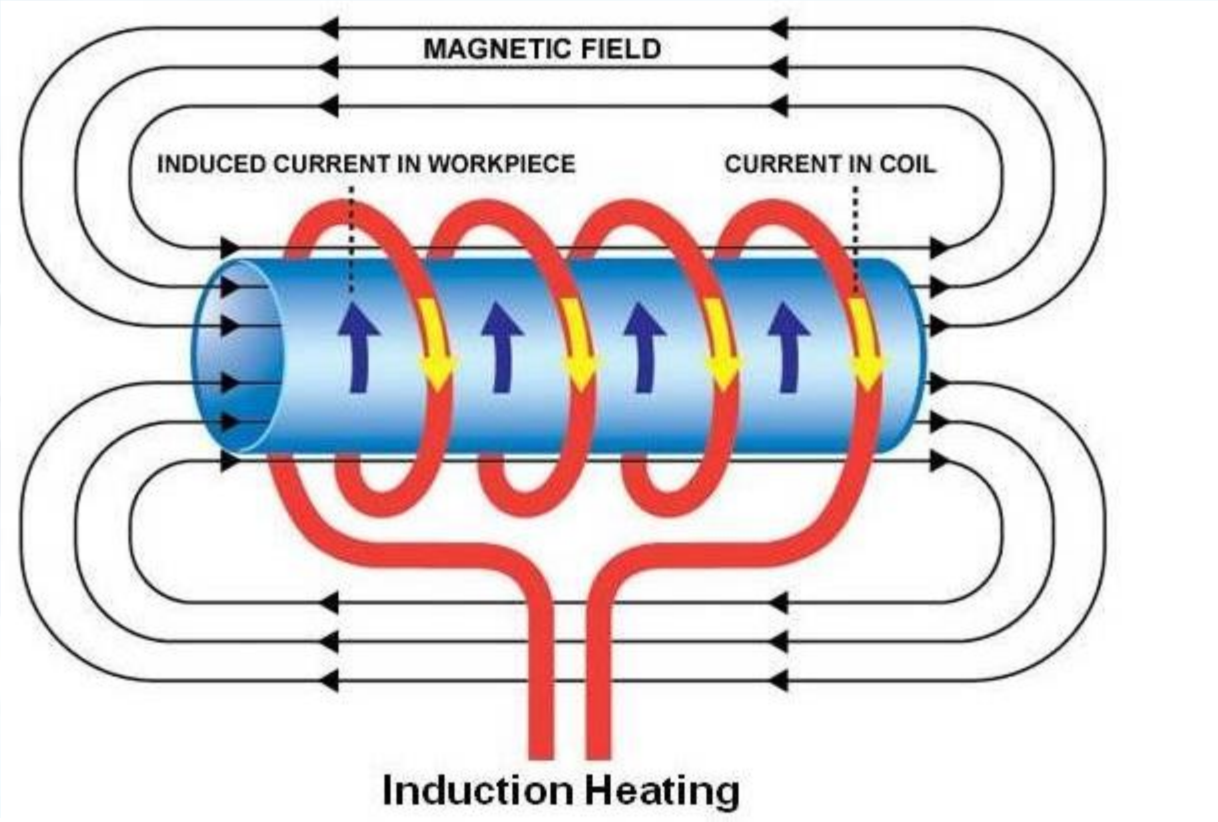
2.5 – CASE HARDENING – FLAME HARDENING

- **In this process metal surface which require to be harden is heated by oxyacetylene flame and then it is quenched**
- **This is quick process and only specific part of metal heated by flame is hardened**



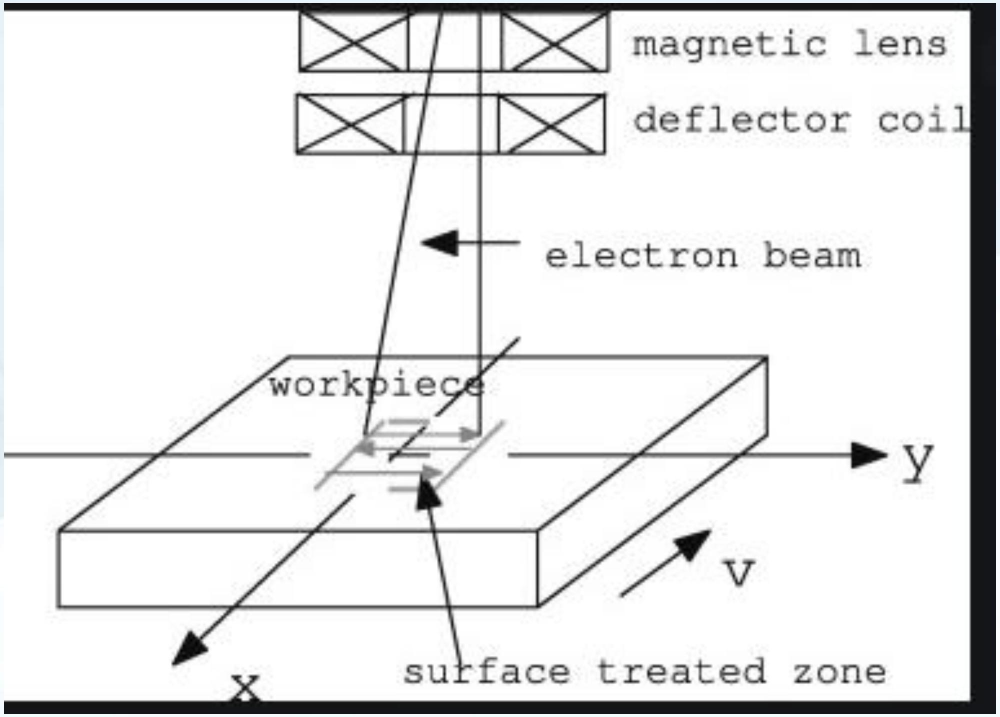
2.5 – CASE HARDENING – INDUCTION HARDENING

- **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 copper coil and then heated above their transformation temperature by applying an alternating current to the coil.**



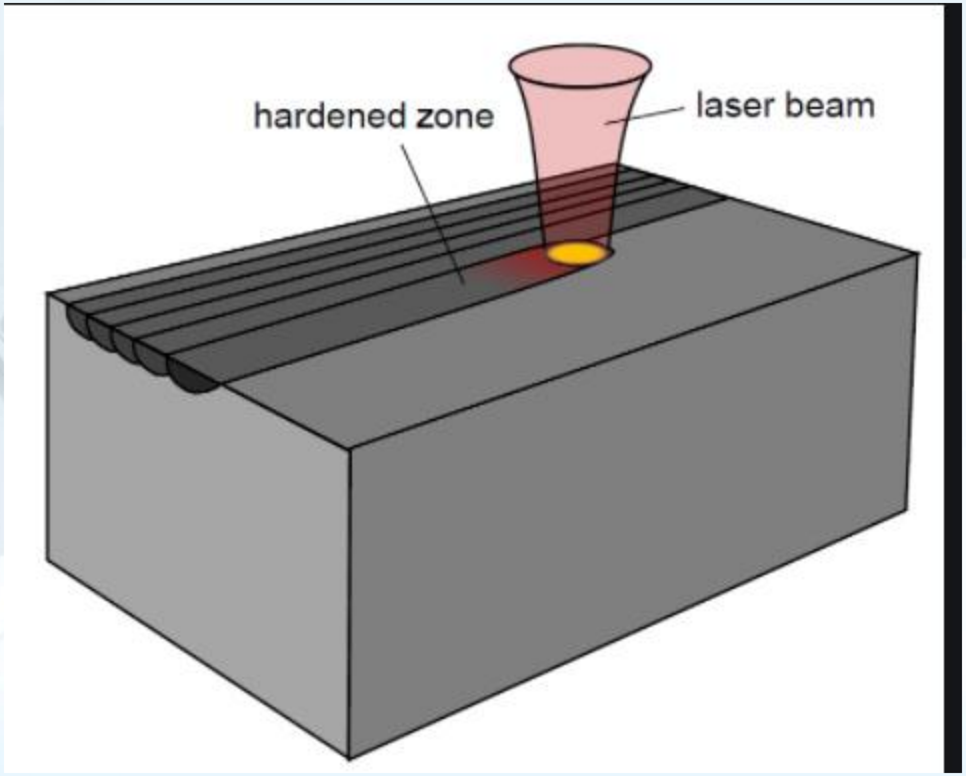
2.5 – CASE HARDENING – ELECTROBEAM

- **Electron beam hardening is typically used to harden a very thin surface layer of an object by raising it to a specific temperature and then allowing it to cool rapidly. ... This focusing gives the electron beam hardening process the energy density required to heat the material on which the work is being performed**



2.5 – CASE HARDENING – LASER BEAM

- **Laser hardening is a method aimed at improving component wear behaviour. During laser hardening, also known as surface layer hardening, the energy from the laser beam is applied directly to the component surface. ... Self-quenching is produced as a martensitic structure is formed and the hardening layer is 'cooled.**



CHAPTER 3 : DEFECTS AND CAUSES IN HEAT TREATMENT

3.1 – DEFECT AND CAUSES IN HEAT TREATMENT

- Soft Spots
- Lower hardness and strength
- Oxidation and Decarburization
- Formation of Cracks
- Overheating and burning
- Distortion and wrapping
- Temper Embrittlement

3.1 – DEFECT AND CAUSES IN HEAT TREATMENT

- **SOFT SPOT**

Sometimes, after the steel is quenched from austenitizing temperature, surface hardness varies from region to region. This variation of hardness in quenched steel from point to point is termed as Soft Spots.

REASONS FOR SOFT SOPT

1. **Problem with Quenching media - the temperature of quenching media is high or agitation is improper, this, also, results in the generation of soft spots in steel.**
2. **Localized Decarburization of Steel - steel part is not properly packed in carburizing**
3. **Inhomogeneous Microstructures**
4. **Improper handling during Quenching**
5. **Uneven heating and Improper Cleaning of Steel part**

3.1 – DEFECT AND CAUSES IN HEAT TREATMENT

- **REMIDES FOR SOFT SOPT**

1. **The packing mixture should be properly mixed and packed around the steel part.**
2. **Continuously replace quenching media after set intervals.**
3. **Use coolant during grinding.**
4. **Quenching media should have a properly controlled temperature.**

3.1 – DEFECT AND CAUSES IN HEAT TREATMENT

➢ **LOWER HARDNESS AND STRENGTH AFTER QUENCHING**

For achieving desired hardness and strength Steel requires **martensitic formation After heat treatment, not getting desired hardness or strength can become a cause of stress.**

REASONS FOR LOWER HARDNESS AND STRENGTH AFTER QUENCHING

1. **Lower hardening temperature**
2. **Insufficient Soaking Time**
3. **Delayed Quenching/Slower Cooling Rate**
4. **Presence of large amount of retained austenite**
5. **Low Hardness in Surface Hardening Treatment**

3.1 – DEFECT AND CAUSES IN HEAT TREATMENT

- **OXIDATION AND DECARBURIZING**

During the heat treatment of steel in an open atmosphere, steel may get exposed to environmental gases like oxygen, carbon dioxide, and water vapours. They may react with steel at high temperature and given rise to oxidation and decarburizing

REASONS FOR OXIDATION AND DECARBURIZING

1. **Oxidation of steel takes place in the presence of gases like carbon dioxide, air, and water vapours.**
2. **when steel is heated above 650o C, decarburizing or loss of carbon from the surface of steel takes place resulting in loss of mechanical properties like fatigue strength. The defect of this nature is termed as Decarburizing of steel.**

3.1 – DEFECT AND CAUSES IN HEAT TREATMENT

3. If the presence of oxygen and water vapours, the tendency of carbon towards oxygen and vapours increases above 650oC and carbon from the steel surface starts reacting with environmental gases resulting in depletion of carbon from the steel surface

- **REMIDES FOR OXIDATION AND DECARBURIZING**

1. Perform heat treatment of steel in Vacuum or molten salts or a protective atmosphere
2. If the steel product is not a finished product, then the steel decarburized surface can be removed by grinding.
3. Copper plating with a thickness of 0.013 to 0.025 mm can be used for preventing deoxidation and decarburizing of steel.
4. Ceramic coatings can be also used for the protective surface of the steel.
5. Special surface coatings like borax can also be used for protection.

3.1 – DEFECT AND CAUSES IN HEAT TREATMENT

- **QUENCH CRACK**

Quenching process is always accompanied by several tensile and compressive stresses associated with austenite to Martensite transformation. These stresses, in severe cases, result in cracks during heat treatment. Cracks of these nature are a matter of concern as these cracks make steel render useless and of scrap value.

- **REASONS FOR QUENCH CRACK**

1. **compressive stresses associated with austenite to Martensite transformation**
2. **Cracks nucleated due to thermal stresses within** steel during the **quenching process**

3.1 – DEFECT AND CAUSES IN HEAT TREATMENT

- **REMIDES FOR QUENCH CRACK**

1. Use of Alloying elements
2. Relieving of Thermal Stresses
3. Tempering steel at a low-temperature range of 250oC can easily remove 80-85% thermal stresses

3.1 – DEFECT AND CAUSES IN HEAT TREATMENT

- **DISTORTION AND WARPING**

Symmetrical change in shape or size of a component is termed as Distortion e.g. contraction in steel component during cooling.

If change is asymmetrical then it termed as warping e.g. thin steel sheets get deformed or lose their straightness during cooling which termed as warping of steel.

REASONS FOR DISTORTION AND WARPING

1. Development of internal stresses. These distortions can be either residual stresses due to martensitic formation in steel or internal stresses developed due to differential temperature between core and case of Steel
2. Size distortion -This type of distortion takes place due to stages of expansion and contraction in steel during heat treatment.
3. Shape distortion-This type of distortion is manifested due to the bending and twisting of steel commonly termed as warping of steel

3.1 – DEFECT AND CAUSES IN HEAT TREATMENT

REMIDES FOR DISTORTION AND WARPING

1. Stress Relieving
2. Heating Rate
3. Quenching Media
4. Press Quenching
5. Trays, Fixtures and Support

3.1 – DEFECT AND CAUSES IN HEAT TREATMENT

- **OVER HEATING AND BURNING OF STEEL**

Hot work products of low alloy steel are used widely in the form of fasteners, and machine tools because of properties like high strength, fatigue strength, and good toughness. Improper hot working of low alloy steel imparts a reduction in ductile properties of materials with faceted fracture surfaces making it unsuitable for practical applications. These conditions are normally caused by Overheating or burning of steel.

REASONS FOR DISTORTION AND WARPING

1. High Temperature
2. Composition of low alloy steel
3. Cooling rate
4. Methods of Manufacture

3.1 – DEFECT AND CAUSES IN HEAT TREATMENT

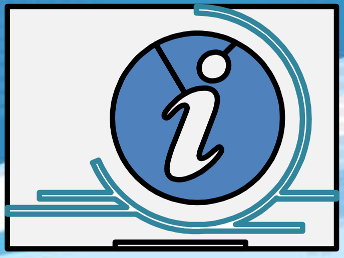
- **TEMPER EMBRITTLEMENT**

Tempering of steel is carried out to relieve internal stresses in steel and also to bring toughness within a material. Since the process is a sub-critical heating process, so cooling in any manner will not bring any change. Certain compositions of steel if tempered at a temperature of 400oC – 600oC lose a considerable amount of hardness. This loss in hardness during tempering is termed as Tempe embrittlement.

- **REASONS FOR TEMPER EMBRITTLEMENT**

1. **Arsenic**
2. **Phosphorus**
3. **Antimony**

THANK YOU



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Are there any Questions?