Study of heat treatment of aluminium alloys

Aluminium: Abundance and Extraction

- It is the second most plentiful metallic element on Earth, estimating around 8% of the Earth's crust.
- Al has high chemical affinity, due to which it never exists in pure form.
- Al is extracted from Bauxite Ore which is a hydrated form of Aluminium oxide.
- Alumina is extracted from Bauxite by Bayer's Process patented by Karl Bayer in 1888.

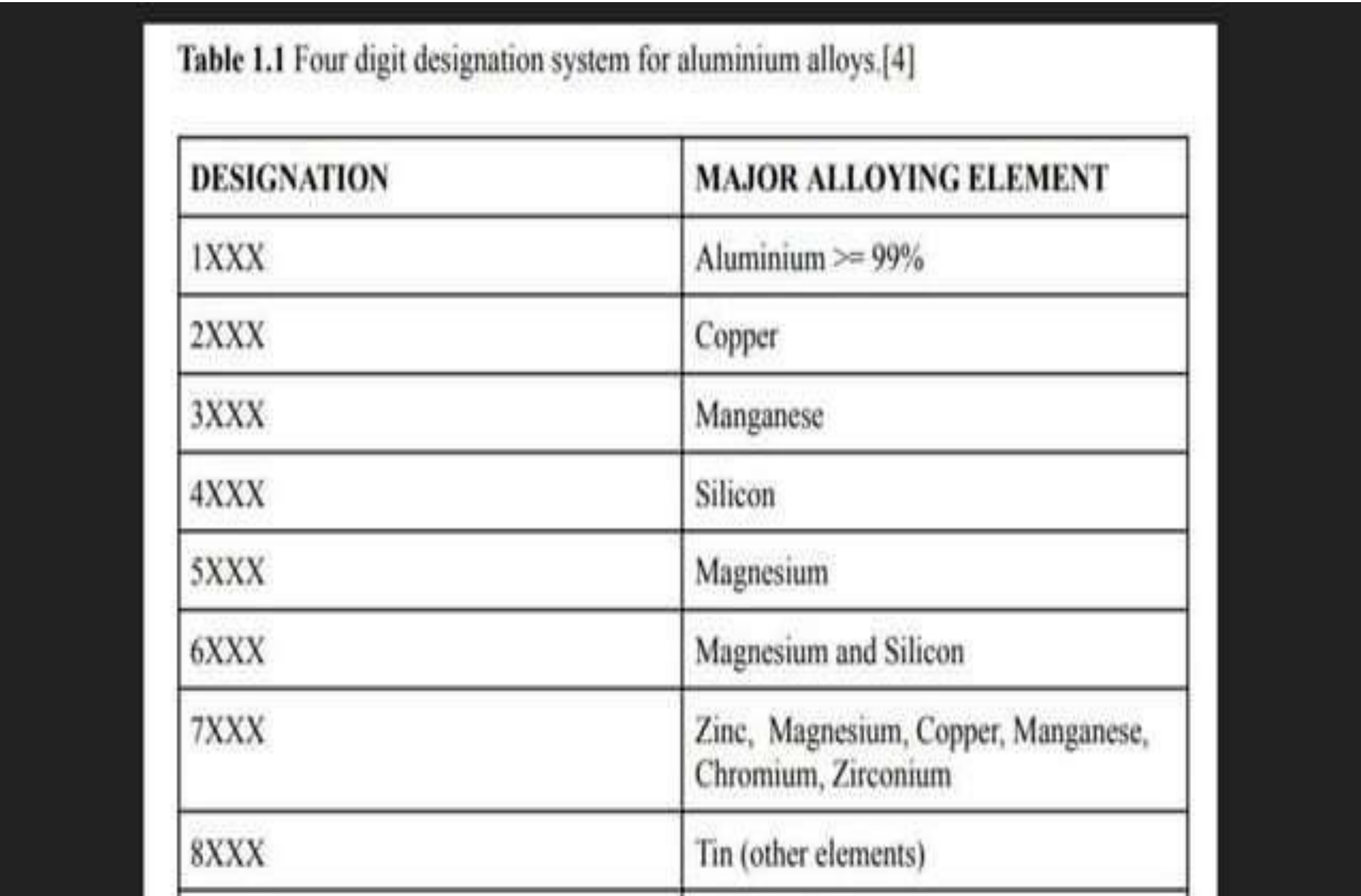


Table 1.1 Four digit designation system for aluminium alloys.[4]

DESIGNATION	MAJOR ALLOYING ELEMENT
1XXX	Aluminium >= 99%
2XXX	Copper
3XXX	Manganese
4XXX	Silicon
5XXX	Magnesium
6XXX	Magnesium and Silicon
7XXX	Zinc, Magnesium, Copper, Manganese, Chromium, Zirconium
8XXX	Tin (other elements)

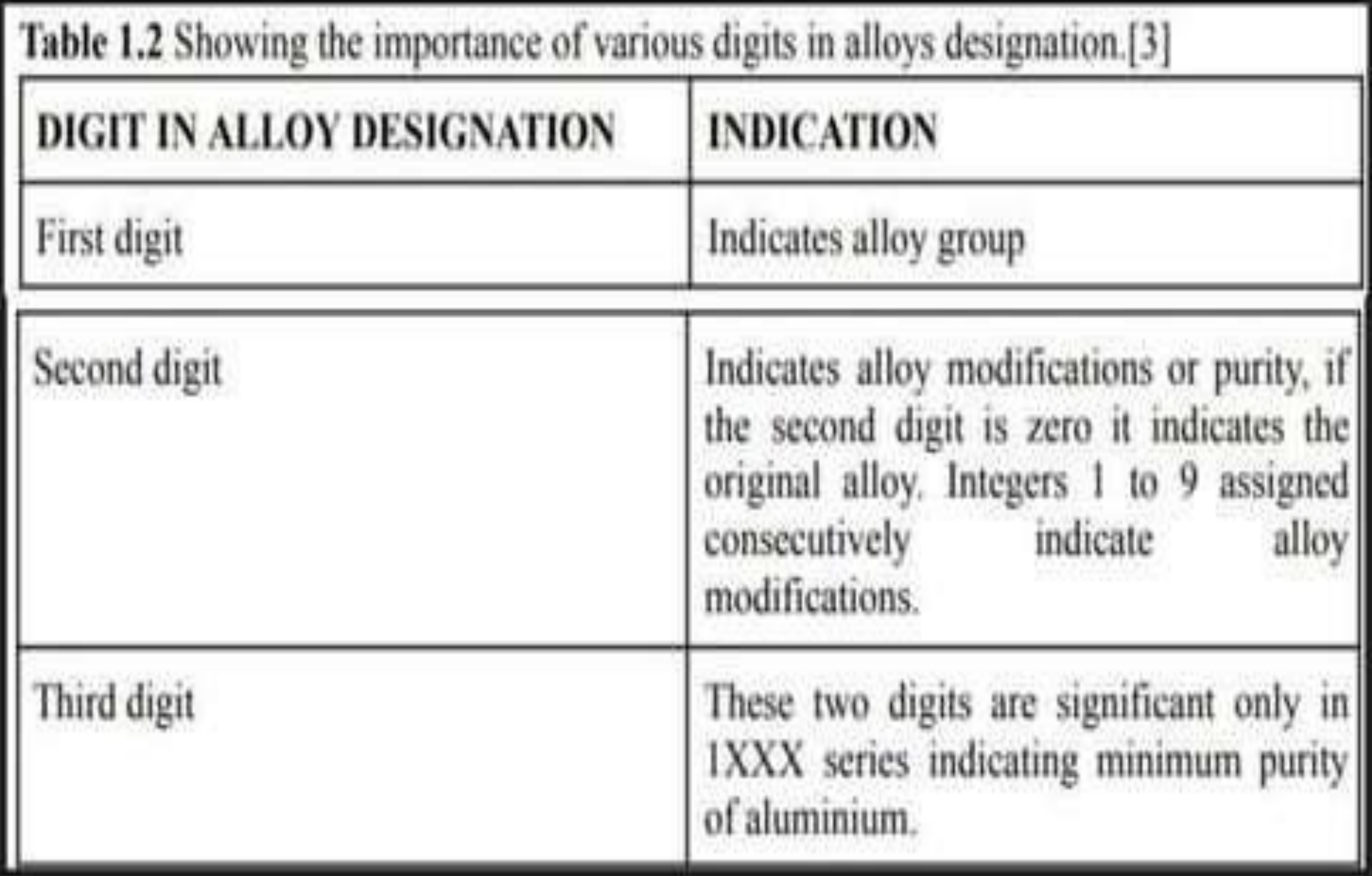


Table 1.2 Showing the importance of various digits in alloys designation.[3]

DIGIT IN ALLOY DESIGNATION	**INDICATION**
First digit	Indicates alloy group
Second digit	Indicates alloy modifications or purity, if the second digit is zero it indicates the original alloy. Integers 1 to 9 assigned consecutively indicate alloy modifications.
Third digit	These two digits are significant only in 1XXX series indicating minimum purity of aluminium.

AGE HARDENING

1. Precipitation / Age hardening used for increasing yeild strength of malleable materials .
2. This process involves controlled precipitation of fine particles or phases within the material's microstructure.
3. These precipitates hinder the movement of dislocations and improve the material's mechanical properties.

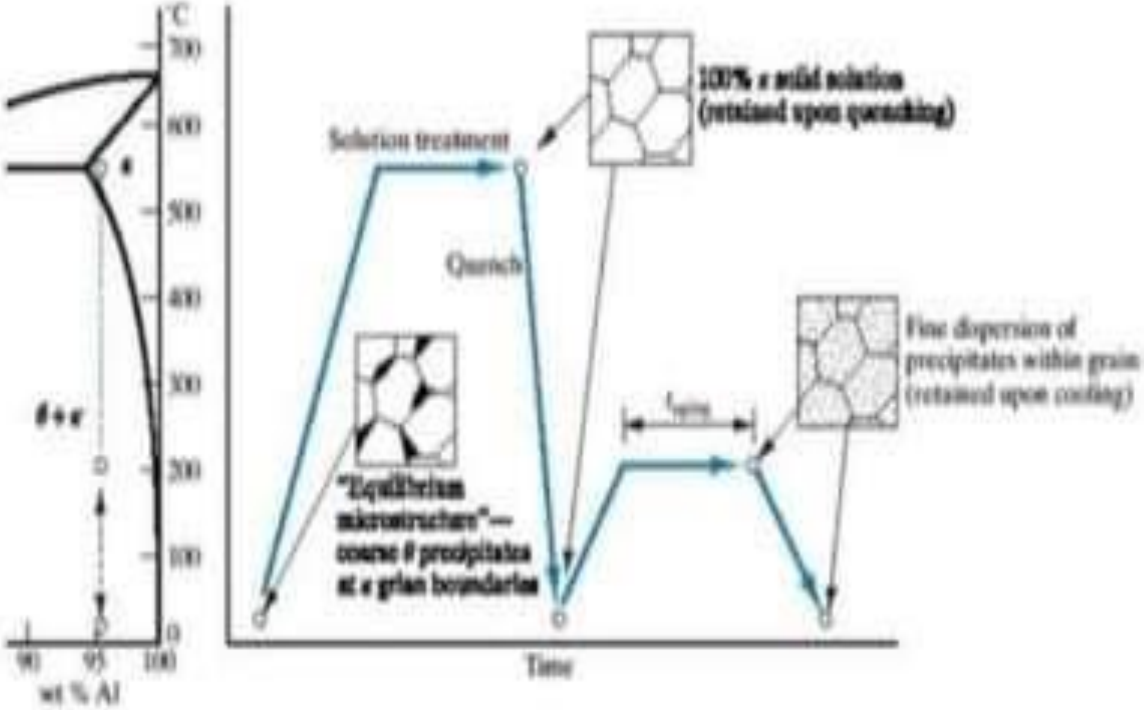
Age hardening includes the following steps:

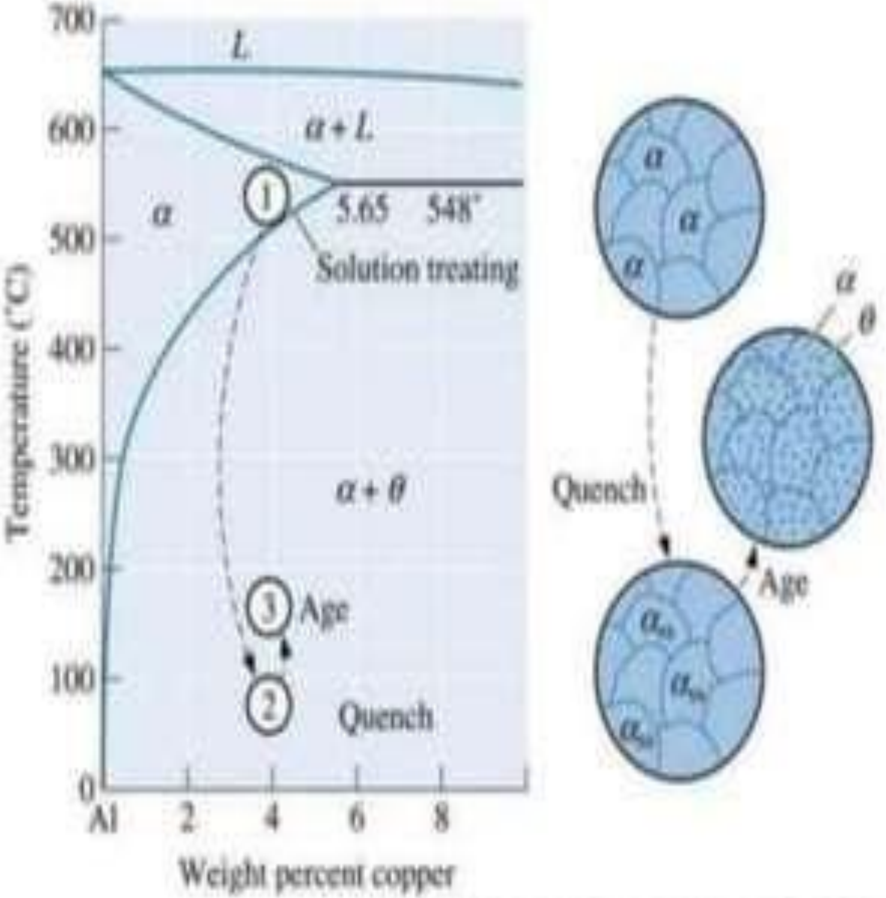
- Solutionizing
- Quenching
- Artificial Aging
- Soaking
- Cooling

During the age hardening process:

- Reheating: The material is heated again, but this time to a lower temperature than the solutionizing temperature. This temperature is known as the aging temperature or precipitation temperature. The alloy is held at this temperature for a specific period.
- Precipitation: At the aging temperature, the solute atoms begin to cluster together and precipitate out of the supersaturated solid solution. These precipitates are responsible for strengthening the material. The size, distribution, and density of these precipitates significantly impact the final mechanical properties.
- Controlled Cooling: After the specified aging time, the material is typically cooled slowly or quenched again to room temperature. The cooling rate and time at the aging temperature are crucial for achieving the desired mechanical properties.

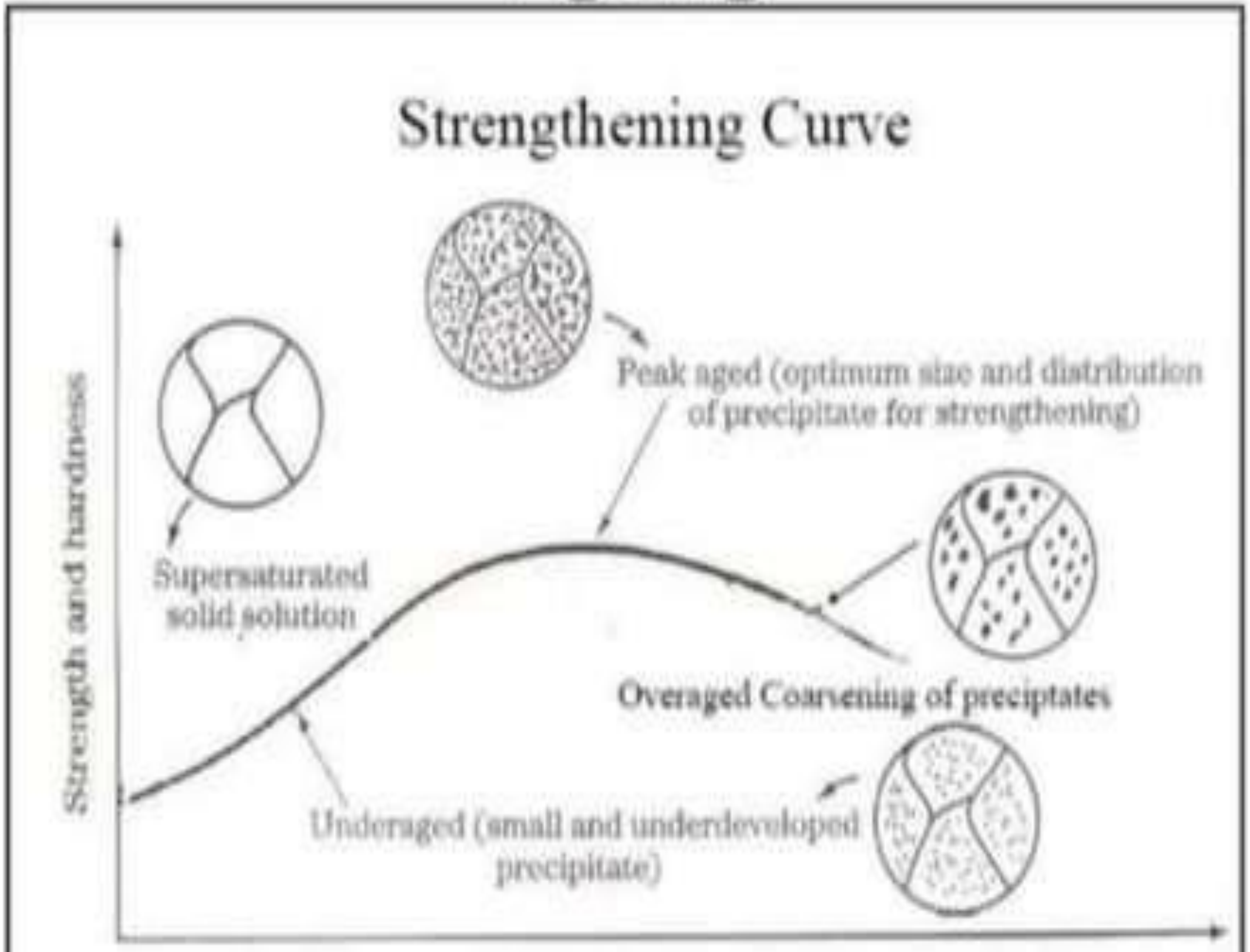
Steps in Precipitation Hardening





The aluminum-rich end of the aluminum-copper phase diagram showing the three steps in the age-hardening heat treatment and the microstructures that are produced.

Ageing


Strengthening Curve
Strength and hardness
Supersaturated solid solution
Peak aged (optimum size and distribution of precipitate for strengthening)
Overaged Coarsening of preciptates
Underaged (small and underdeveloped precipitate)

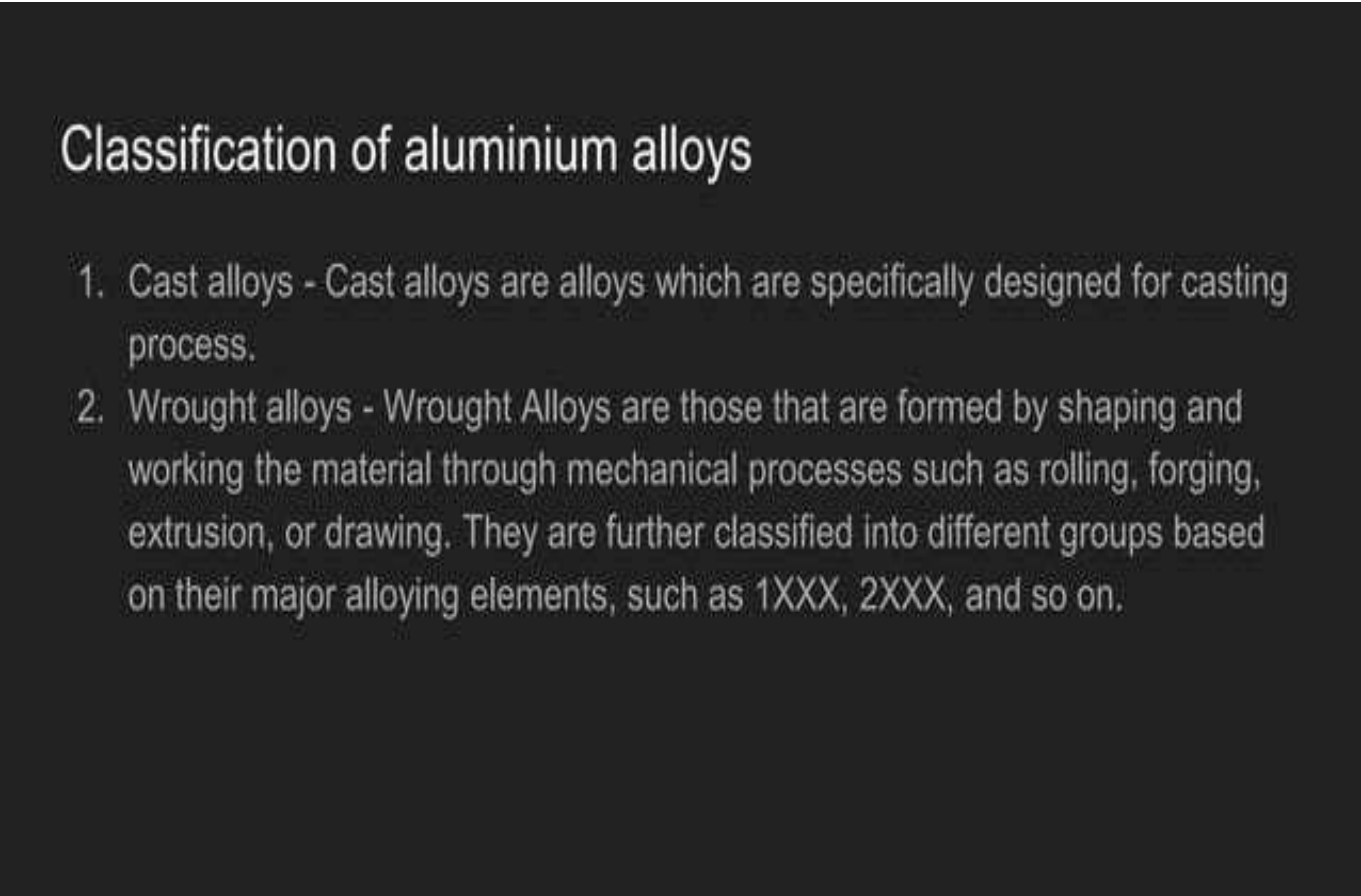
Study of heat treatment of aluminium alloys

Introduction

1. Alloy Advantages : Aluminium alloys are for their light yet strong qualities, and age hardening can enhance their properties even further.
2. Ageing process : Ageing in aluminium alloys is explored,demonstrating how different alloying elements impact properties during this phase.
3. Influence of elements : Various alloying elements react uniquely during ageing,shaping the overall characteristic of the alloy.
4. Treatment and Properties : Cryogenic treatment effects and diverse heat treatment methods,especially for 7XXX aluminium alloys,play a role in optimizing conductivity, hardness, strength and corrosion resistance.

Introduction to aluminium alloys

1. Strength and lightweight : Alloys combine low weight with strong properties,often surpassing structural steel in strength.
2. Durability and compatibility : Alloys are highly durable and don't produce harmful colored salts, making them compatible with various elements without toxic reactions.
3. Aluminium attributes : Aluminum and its alloys have excellent thermal and electrical conductivity, high reflectivity, versatile shaping capabilities, and a notably low density of 2.6gm/cc at 20 degree celsius.



Classification of aluminium alloys

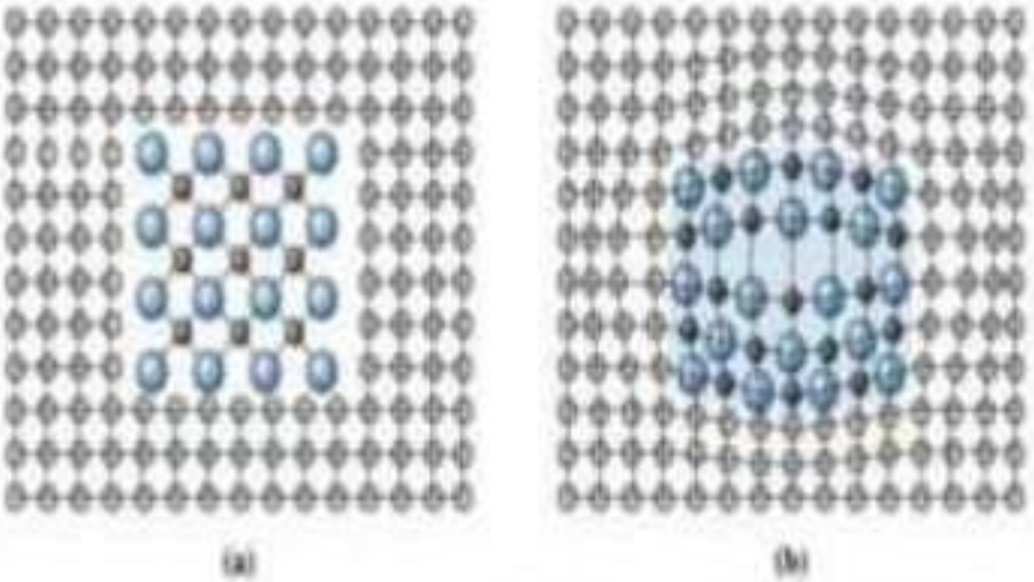
1. Cast alloys - Cast alloys are alloys which are specifically designed for casting process.
2. Wrought alloys - Wrought Alloys are those that are formed by shaping and working the material through mechanical processes such as rolling, forging, extrusion, or drawing. They are further classified into different groups based on their major alloying elements, such as 1XXX, 2XXX, and so on.

Heat Treatable and non heat treatable alloys

1. Heat treatable alloys : Heat treatable alloys are a group of materials, often including aluminum alloys, that can undergo controlled heating and cooling processes to achieve desired mechanical properties and microstructures.
2. Non heat treatable alloys : Non-heat treatable alloys are alloys, such as certain types of aluminum alloys, that do not significantly change their mechanical properties when subjected to heat treatment and are often used for their inherent characteristics without the need for additional heat-based processes.

Coherent and non coherent structures

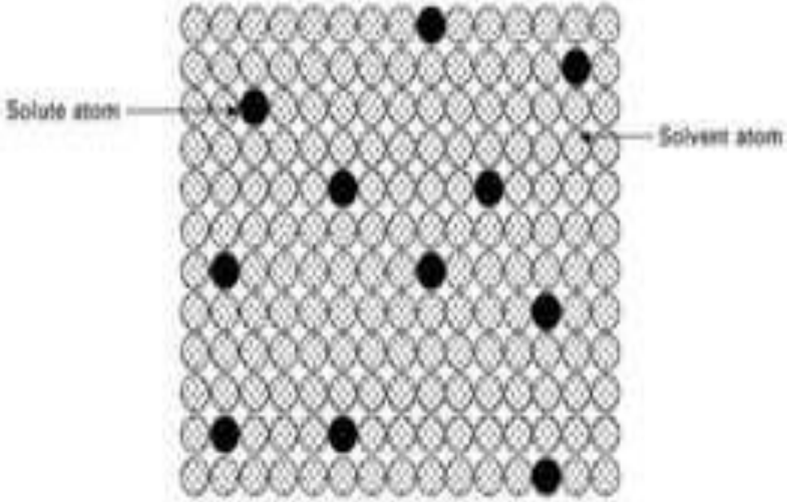
During the ageing process, precipitates in alloys can be categorized as either coherent or non-coherent. Coherent precipitates maintain the crystallographic alignment with the surrounding matrix, where the rows of atoms in the precipitate align with those in the matrix, while non-coherent precipitates disrupt this alignment, with their atomic arrangements differing from the matrix's rows of atoms.



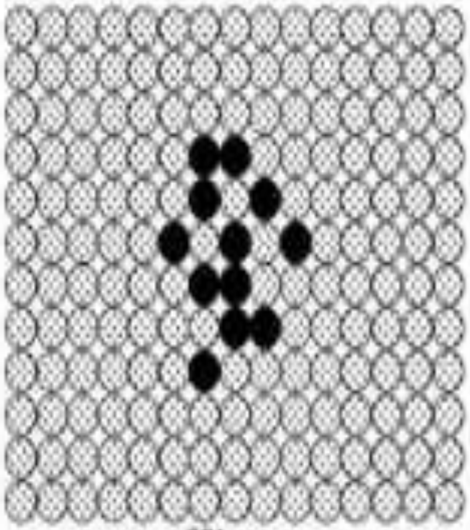
(a) A noncoherent precipitate has no relationship with the crystal structure of the surrounding matrix. (b) A coherent precipitate forms so that there is a definite relationship between the precipitate's and the matria's crystal structure.

GP zones

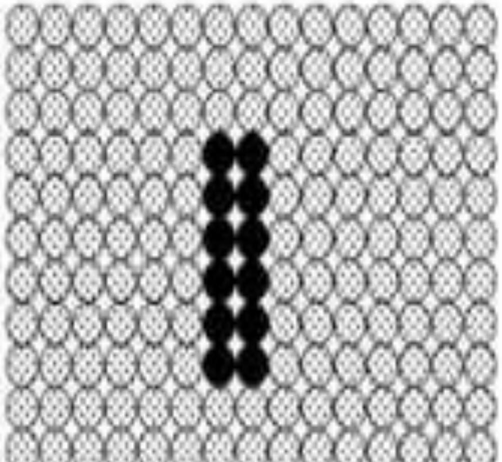
1. GP zones, short for Guinier-Preston zones, **are small clusters of solute atoms that form within a crystalline matrix of a metal alloy.**
2. These are ordered, solute-rich clusters of atoms, coherent with the matrix. The GP zones are normally finely distributed in the matrix. which contributes to the hardening.
3. These zones are typically found in certain types of age-hardening or precipitation-hardening alloys, which are materials used in engineering and metallurgy to achieve a combination of high strength and good corrosion resistance.

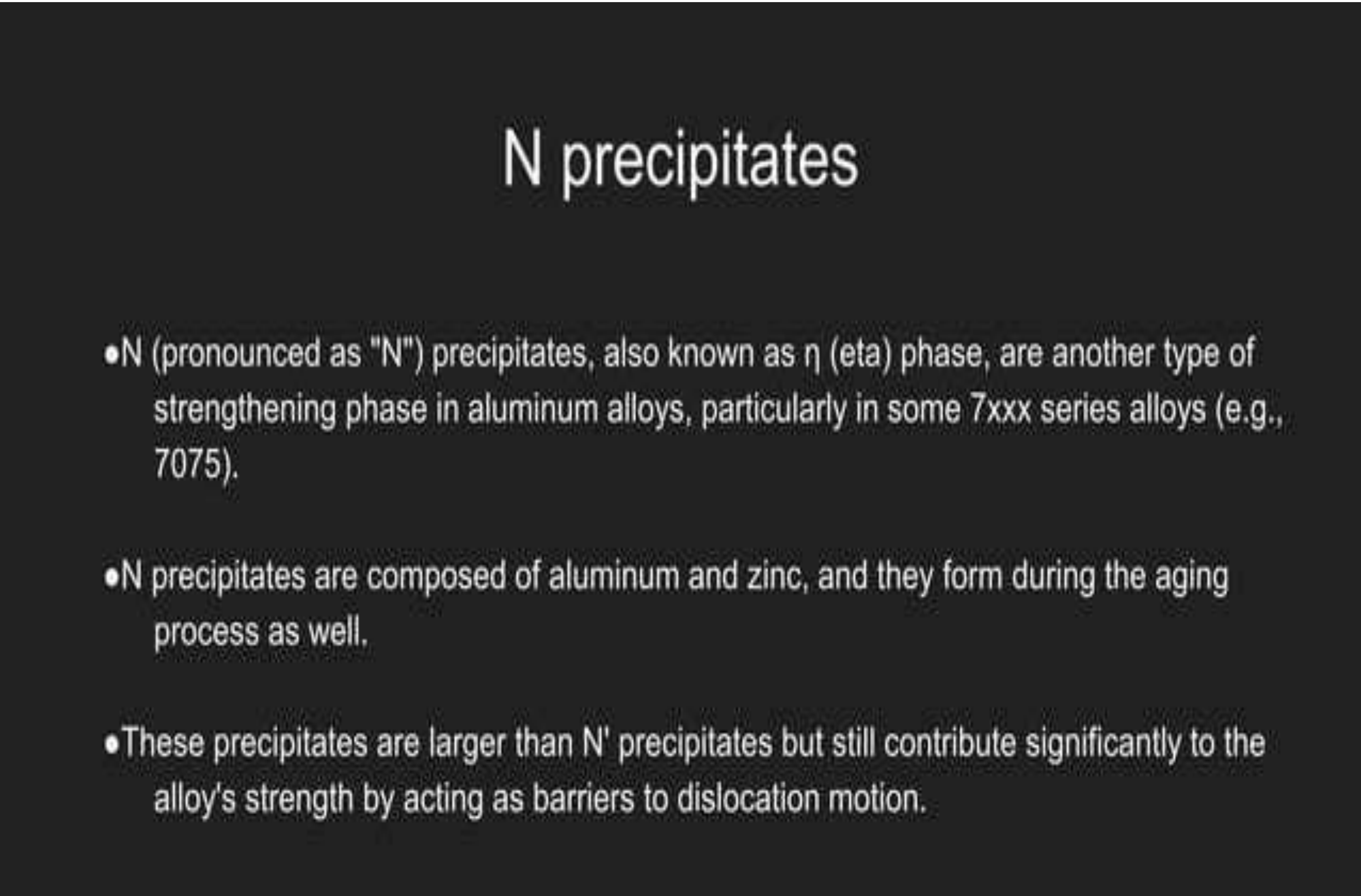


Supersaturated solid solution



GP1 zone





N precipitates

- N (pronounced as "N") precipitates, also known as η (eta) phase, are another type of strengthening phase in aluminum alloys, particularly in some 7xxx series alloys (e.g., 7075).
- N precipitates are composed of aluminum and zinc, and they form during the aging process as well.
- These precipitates are larger than N' precipitates but still contribute significantly to the alloy's strength by acting as barriers to dislocation motion.

N’ precipitates

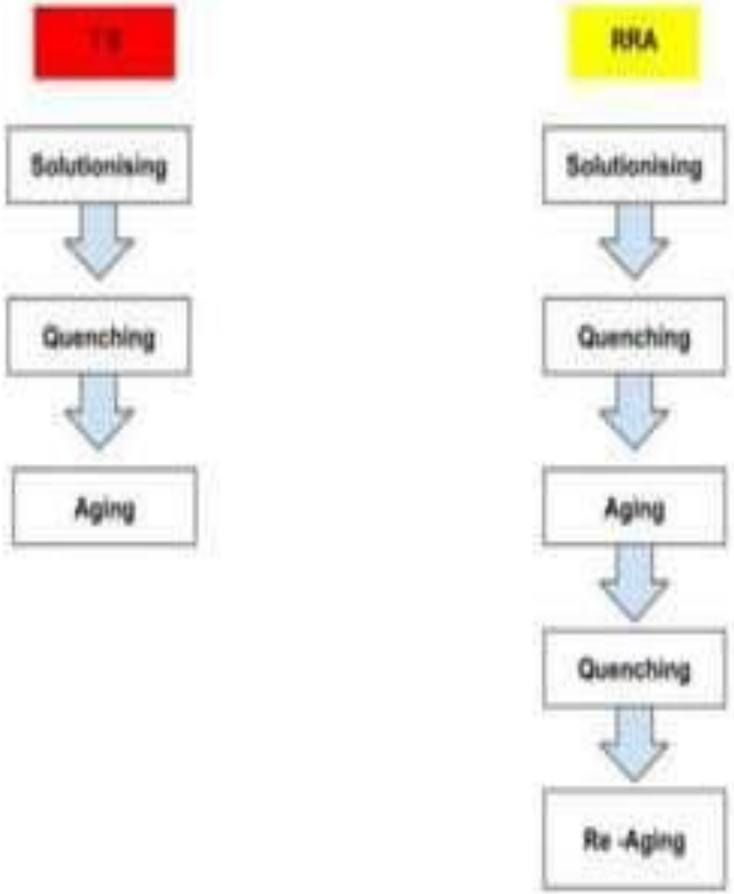
- N' (pronounced as "N prime") precipitates are one type of strengthening phase that forms in aluminum alloys, specifically in alloys like 2xxx series (e.g., 2024 and 2124) and some 7xxx series (e.g., 7050) aluminum alloys.
- N' precipitates are typically composed of aluminum, copper, and other alloying elements. They form when the alloy is subjected to a specific aging treatment.
- These precipitates are known for their small size and high number density, which makes them very effective in strengthening the alloy by impeding dislocation movement within the crystal lattice.

Precipitate free zones

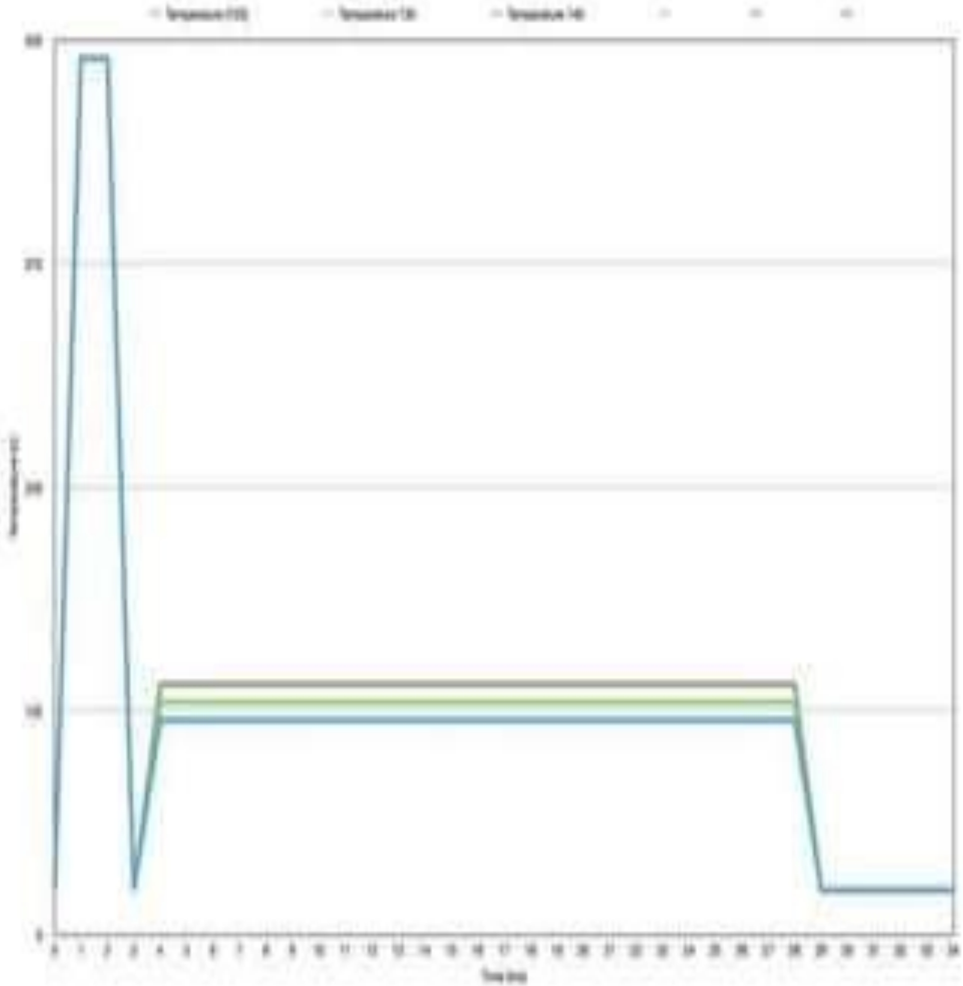
1. Precipitate Free Zones (PFZ): PFZ refers to regions along grain boundaries created after ageing, lacking precipitates due to solute atoms diffusing to form large precipitates at the grain boundary and re-dissolving on retrogression.

2. PFZ Dynamics: PFZ formation results from solute atom depletion near the grain boundary due to precipitate formation. During retrogression, solute atoms re-dissolve, and upon cooling, they diffuse to equilibrium state precipitates, impacting PFZ width.

3. Age Hardening Impact: PFZ's presence is significant in Age Hardening, influencing precipitate distribution and material mechanical properties. PFZ width can change during retrogression and re-aging processes.


T6
Solutionising
Quenching
Aging
RRA
Solutionising
Quenching
Aging
Quenching
Re -Aging

T6 Heat Treatment


Temperature
Temperature
Temperature
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
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30
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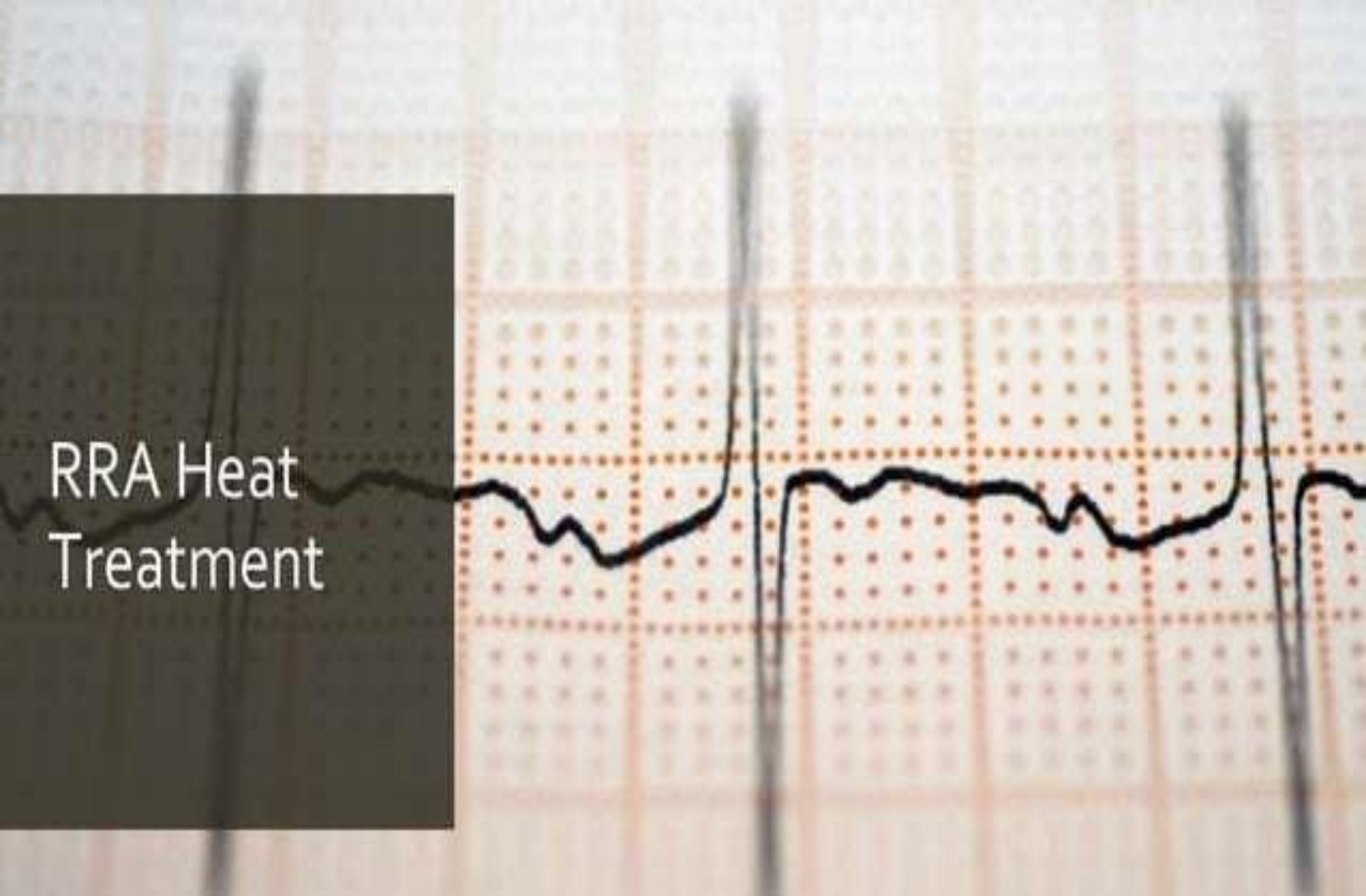
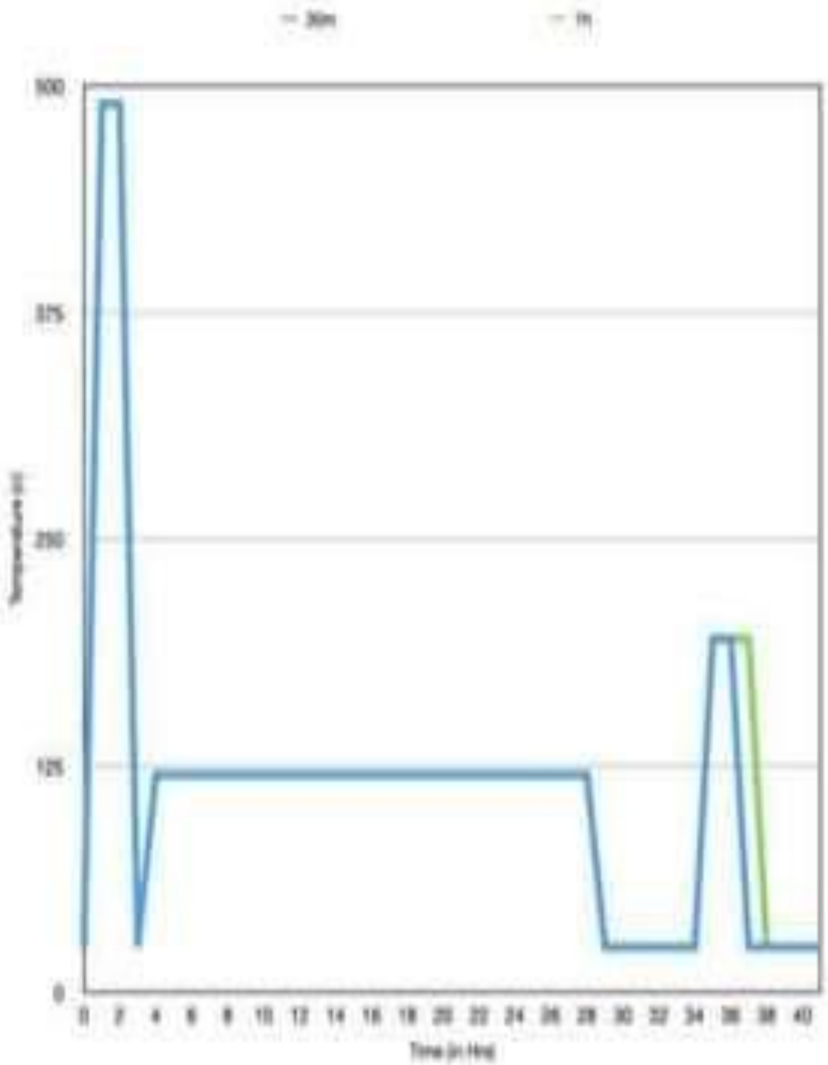
32
33
34

RRA Heat Treatment




30m
1h
500
375
250
125
0
Temperature (C)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
Time (in Hrs)

Process

1. Number of samples = 2

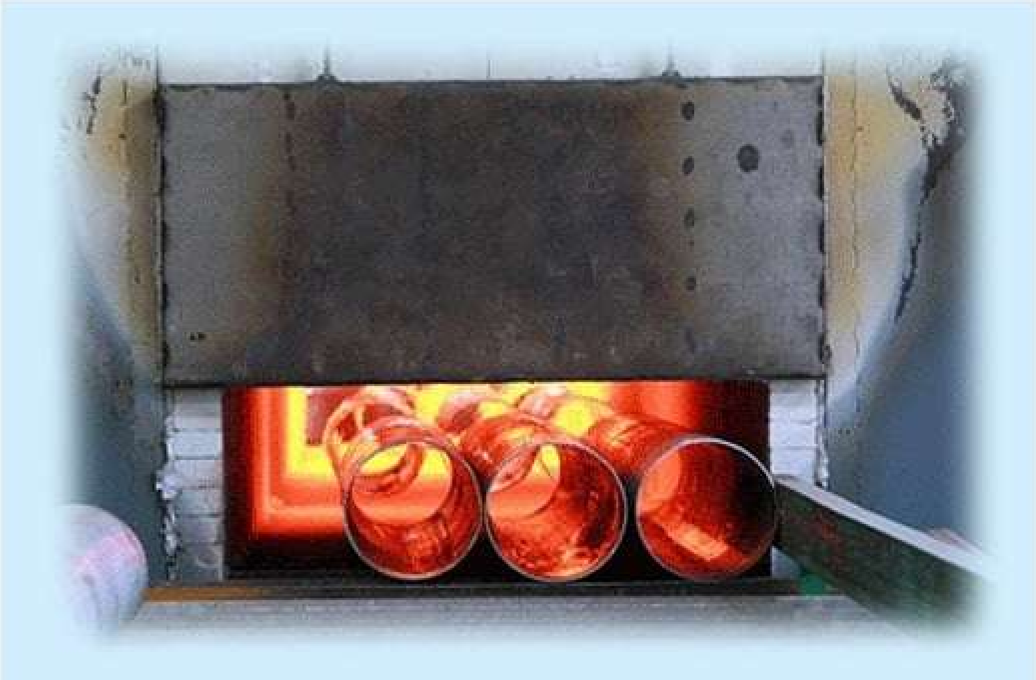
   Temperature = 490 degree celsius

   Time = 60 minutes
2. Water Quenching for 20 minutes .
3. Samples are aged at 120 degress for 24 hours .
4. Water Quenching for 20 minutes .
5. One sample aged for 30 mins at 200 degree Celsius and another for 60 mins at 200 degree Celsius(Re-aging) .
6. Water quenching for 20 mins.

Heat Treatment Process

By: Jagdish pampania

Heat Treatment



Heat Treatment

The amount of carbon present in plain carbon steel has a pronounced effect on the properties of a steel and on the selection of suitable heat treatments to attain certain desired properties.

Define

- Heat treatment may be defined as:

An operation or combination of operations

involving

Heating and cooling of a metal/alloy in solid state

to obtain desirable

Conditions, e.g., that of relieved stresses

Properties, e.g.,
- Better machinability
- Improved ductility
- Homogeneous structure, etc.

Purpose

- Cause relief of internal stresses developed during cold working, welding, casting, forging etc.
- Harden and strengthen metals.
- Improve machinability.
- Change grain size
- Soften metals for further (cold) working as in wire drawing or cold rolling.

Purpose

- Improve ductility and toughness
- Increase , heat, wear and corrosion resistance of materials.
- Improve electrical and magnetic properties.
- Homogenise the structure to remove coring .
- Spheroidize tiny particales, such as those of Fe_3C in steel, by diffusion.

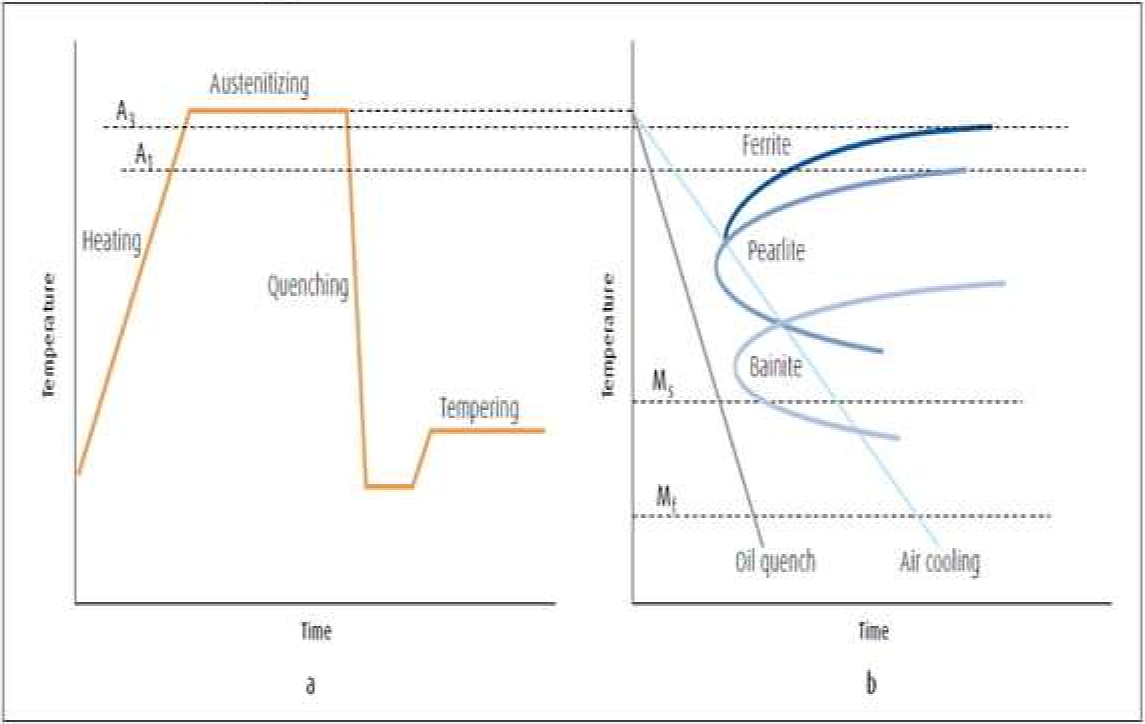
Heat Treatment Theory

- The various types of heat-treating processes are similar because they all involve the heating and cooling of metals; they differ in the heating temperatures and the cooling rates used and the final results.
- Ferrous metals (metals with iron) are annealing, normalizing, hardening, and tempering.
- Nonferrous metals can be annealed, but never tempered, normalized, or case-hardened.

Stages of Heat Treatment

- **Stage l**—Heating the metal slowly to ensure a uniform temperature.
- **Stage 2**—Soaking (holding) the metal at a given temperature for a given period of time.
- **Stage 3**—Cooling the metal to room temperature.

Stages of Heat Treatment



a) Temperature-time cycle and b) its relation to the TTT diagram

Stages of Heat Treatment

- **Soaking**

- Internal structural changes take place.
- soaking period depends on the chemical analysis of the metal and the mass of the part.

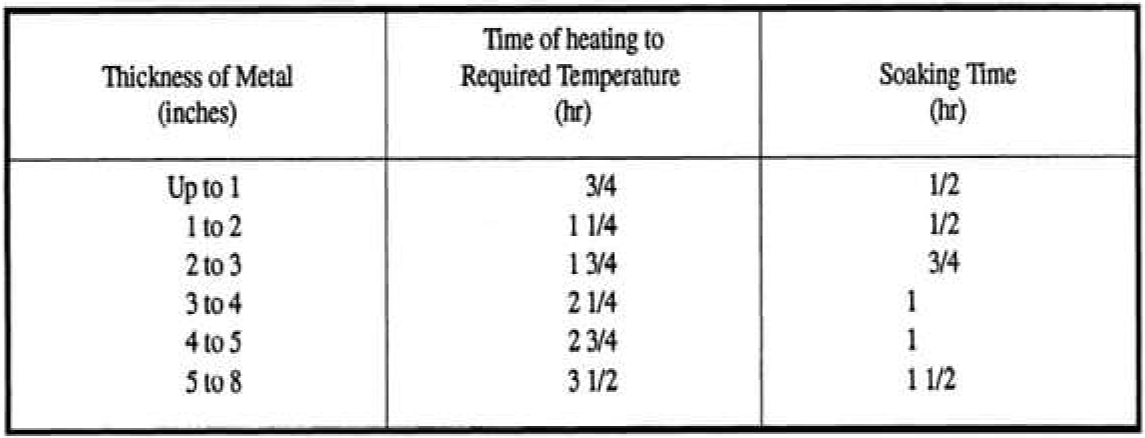
- **Cooling Stage**

- To cool the metal, you can place it in direct contact with a COOLING MEDIUM composed of a gas, liquid, solid, or combination of these.

Stages of Heat Treatment

- **Soaking Period**

Table 1: Soaking period for Hardening, Annealing and Normalizing Steel.



Thickness of Metal (inches)	Time of heating to Required Temperature (hr)	Soaking Time (hr)
Up to 1	3/4	1/2
1 to 2	1 1/4	1/2
2 to 3	1 3/4	3/4
3 to 4	2 1/4	1
4 to 5	2 3/4	1
5 to 8	3 1/2	1 1/2

Types

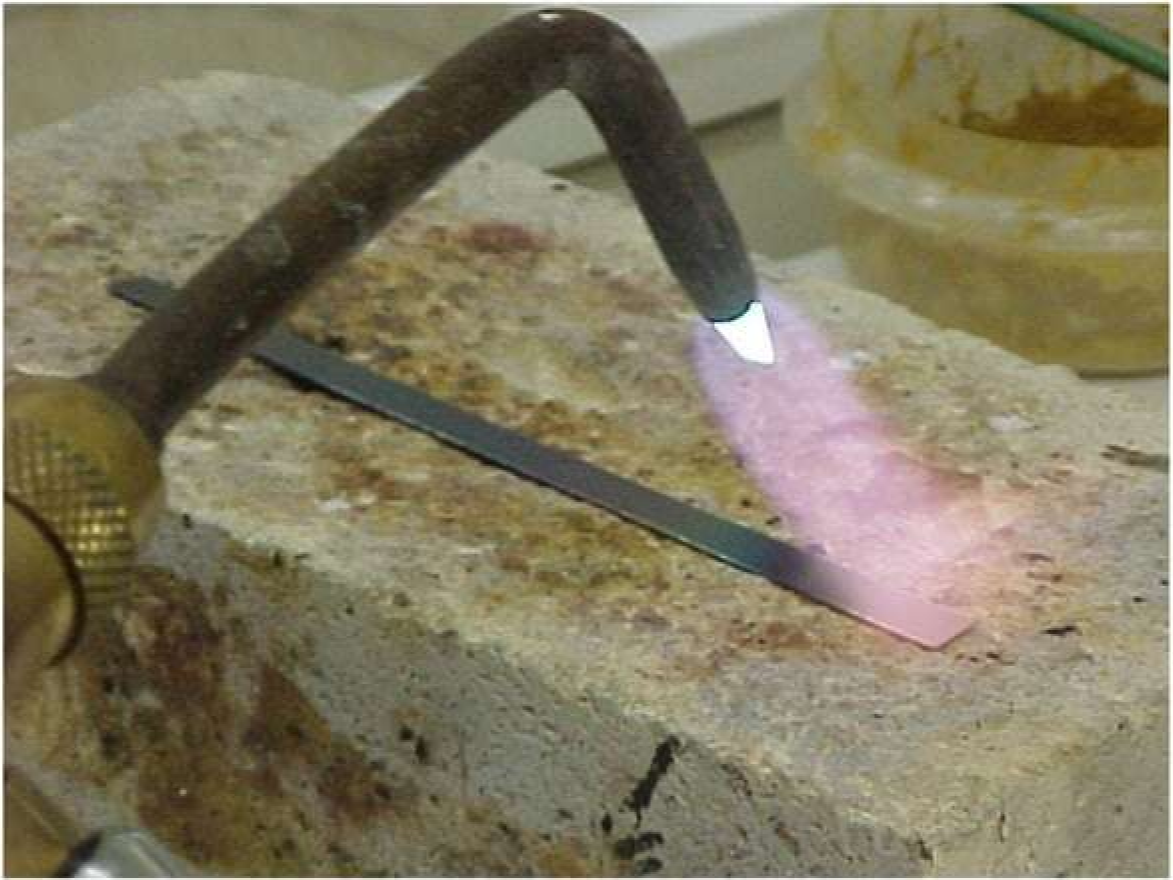
- *Annealing*
- *Normalizing*
- *Hardening*
- Carburizing
- *Tempering*

Annealing

Steel is annealed to reduce the hardness, improve machine ability, facilitate cold-working, produce a desired microstructure.

Full annealing is the process of softening steel by a heating and cooling cycle, so that it may be bent or cut easily.

In annealing, steel is heated above the transformation temperature to form austenite, and cooled very slowly, usually in the furnace.



Annealing

There are several types of annealing like

black annealing,
box annealing,
flame annealing,
isothermal annealing,
recrystallisation annealing,
finish annealing
blue annealing,
bright annealing,
intermediate annealing,
process annealing,
soft annealing,
spheroidizing annealing

These are practiced according to their different final product properties in the industry.

CLASSIFICATION

Annealing treatment can be classified into groups based on the following:

1. Heat treatment temperature

- Full annealing
- Partial annealing
- Sub-critical annealing

2. Phase transformation

- First-order annealing
- Second-order annealing

3. Specific purpose

- Full annealing
- Isothermal annealing
- Diffusion annealing
- Partial annealing
- Recrystallization annealing
- Spheroidisation annealing

1.1 In full annealing the steel is heated above the critical temperature(A_3) and then cooled very slowly.

1.2 Partial annealing, also known as incomplete annealing or intercritical annealing, involves heating of steel to a temp. lying between lower critical temperature(A_1) and upper critical temperature (A_3 or A_{cm}).

1.3 Subcritical annealing is a process in which the maximum temp. to which is heated is always less than the lower critical temperature(A_1).

Classification based on phase transformation features.

2.1 **First-order annealing** is performed on steel with the sole aim of achieving some properties. Any change in the characteristics of steel achieved by this type of annealing is not correlated to phase transformation.it can be performed at a wide range of temperatures above or below the critical temperatures.

2.2 The **second-order annealing** differs from the former in the sense that the end results in the former are essentially due to phase transformation which takes place during the treatment.

Types of annealing based on specific purpose

3.1 Full annealing

- In this, steel is heated to its 50°C above the austenitic temperature and held for sufficient time to allow the material to fully form austenite or austenite-cementite grain structure. The material is then allowed to cool slowly so that the equilibrium microstructure is obtained.
- The austenitising temp is a function of carbon content of the steel and can be generalized as:
  - For hypoeutectoid steels and eutectoid steel
    - Ac3+(20-40oC) [to obtain single phase austenite]
  - For hypereutectoid steels
    - Ac1+(20-40oC) [to obtain austenite+ cementite]

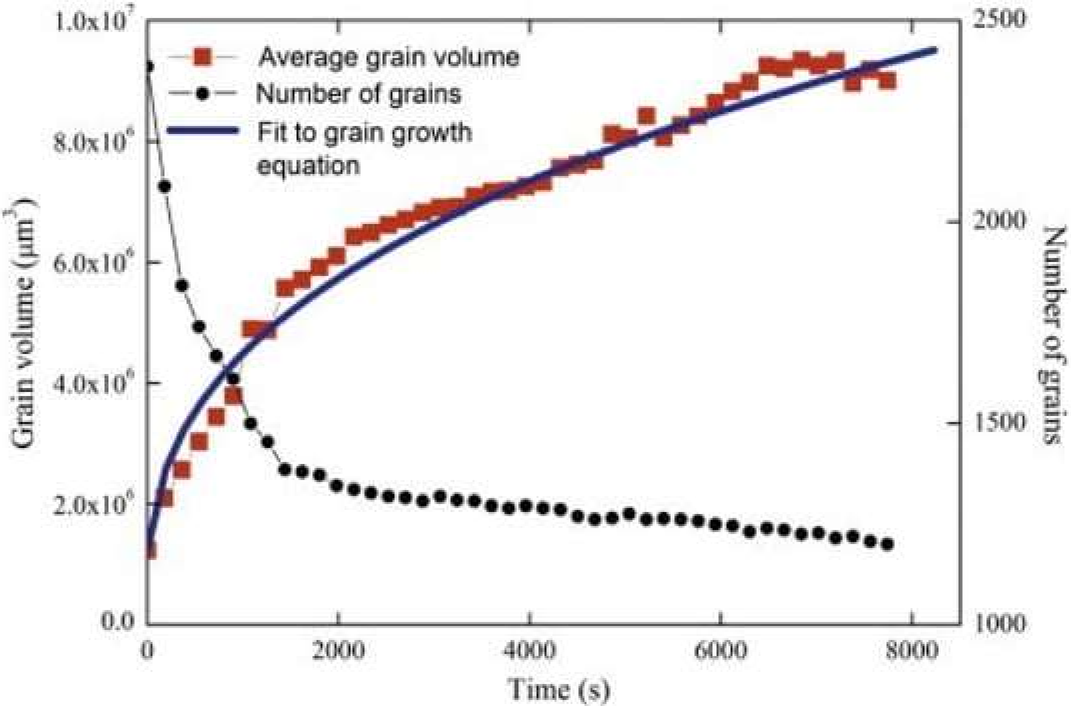
Purpose of full annealing

- To relieve internal stresses
- To reduce hardness and increase ductility
- For refining of grain size
- For making the material having homogeneous chemical composition
- For making the material suitable for high machining processes
- To make steel suitable for undergoing other heat treatment processes like hardening, normalizing etc.

3.2 Isothermal Annealing

- It is a process in which hypoeutectoid steel is heated above the upper critical temperature and this temperature is maintained for a time and then the temperature is brought down below lower critical temperature and is again maintained. Then finally it is cooled at room temperature.
- The prefix "isothermal" associated with annealing implies that transformation of austenite takes place at constant temperature.

The closer the temp of isothermal holding is to A1, coarser is the pearlite, softer is the steel, but longer is the time of isothermal transformation.



Advantages:

- Improved machinability.
- Homogeneous structure and better surface finish.
- Time required for complete cycle is comparably less.
- The process is of great use for alloy steels as the steels have to be cooled slowly.

Limitation:

It is suitable only for small-sized components. Heavy components cannot be subjected to this treatment because it is not possible to cool them rapidly and uniformly to the holding temperature at which transformation occurs. Thus structure wont be homogeneous. so mechanical properties will vary across the cross-section.

3.3 Diffusion Annealing

- This process, also known as homogenizing annealing, is employed to remove any structural non-uniformity like dendrites, columnar grains and chemical inhomogeneity which promote brittleness and reduce ductility and toughness of steel.
- Process:

➢ Steel is heated sufficiently above the upper critical temperature (say, 1000-2000°C), and held at this temperature for 10-20 hours, followed by slow cooling.

➢ Segregated zones are eliminated, and a chemically homogeneous steel is obtained by this treatment as a result of diffusion.

➢ Heating to such a high temp. results in considerable coarsening of austenitic grains & heavy scale formation. The coarse austenite thus obtained further transforms to coarse pearlite on cooling, which is not a desirable structure as mechanical properties are impaired.

- The main aim of homogenising annealing is to make the composition uniform, i.e to remove chemical heterogeneity.

- The impact energy and ductility of the steel increase as the homogenizing temperature increases and the hardness, yield strength and tensile strength decrease with an increase in the homogenizing temperature.

- Homogenizing annealing has a few shortcomings as well. It results in:
  - Grain coarsening of austenite, thereby impairing the properties
  - Thick scales on the surface of steels
  - It is an expensive process

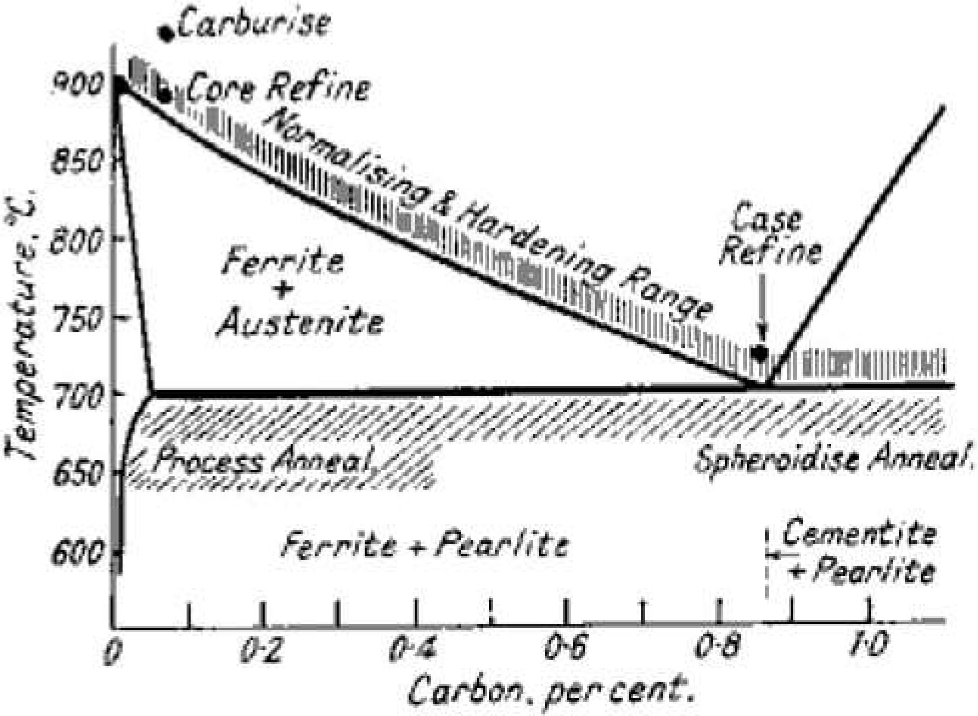
3.4 Partial Annealing

- Partial annealing, also known as inter-critical annealing or incomplete annealing, is a process in which steel is heated between A_1 and A_{cm} and is followed by slow cooling.
- Generally, hypereutectoid steels are subjected to this treatment. The resultant microstructure consists of fine pearlite and cementite instead of coarse pearlite and a network of cementite at grain boundaries.
- As low temperatures are involved in this process, it is less expensive than full annealing.

- Hupoeutectoid steels are subjected to this treatment to improve machinability.
- However, steels with coarse structure of ferrite and pearlite are not suitable for this treatment. This is because only a considerable amount of ferrite remains untransformed, and only a part of it along with pearlite transforms to austenite.
- This coarse or accicular untransformed ferrite results in poor mechanical properties.

3.5 Recrystallization Annealing

- The process consists of heating steel above the recrystallization temperature, holding at this temperature and cooling thereafter.
- It is used to treat work-hardened parts made out of low-Carbon steels (< 0.25% Carbon). This allows the parts to be soft enough to undergo further cold working without fracturing.


Carburise
Core Refine
Normalising & Hardening Range
Case Refine
Ferrite + Austenite
Process Anneal
Spheroidise Anneal.
Ferrite + Pearlite
Cementite + Pearlite
Temperature, °C.
900
850
800
750
700
650
600
0
0·2
0·4
0·6
0·8
1·0
Carbon, per cent.

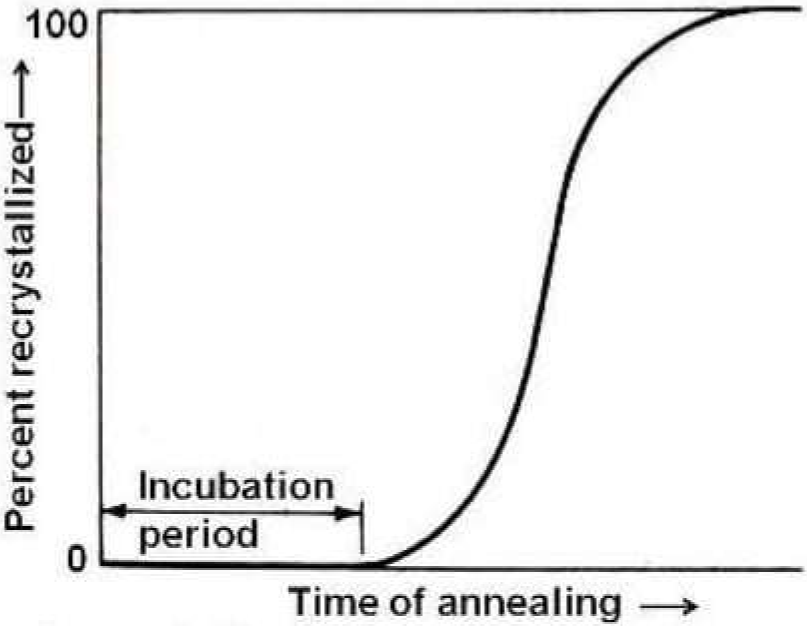
- Recrystallization temp(T_r) is given by:

$$T_r = (0.3\text{-}0.5)T_{mp}$$

- As little scaling and decarburization occurs in recrystallization annealing, it is preferred over full annealing.
- No phase change takes place and the final structure consists of strain-free, equiaxed grains of fine ferrite produced at the expense of deformed elongated ferrite grains.
- However It would produce very coarse grains if the steel has undergone critical amount of deformation. In such cases, full annealing is preferred.

Aims of Recrystallization Annealing

- To restore ductility
- To refine coarse grains
- To improve electrical and magnetic properties in grain-oriented Si steels.

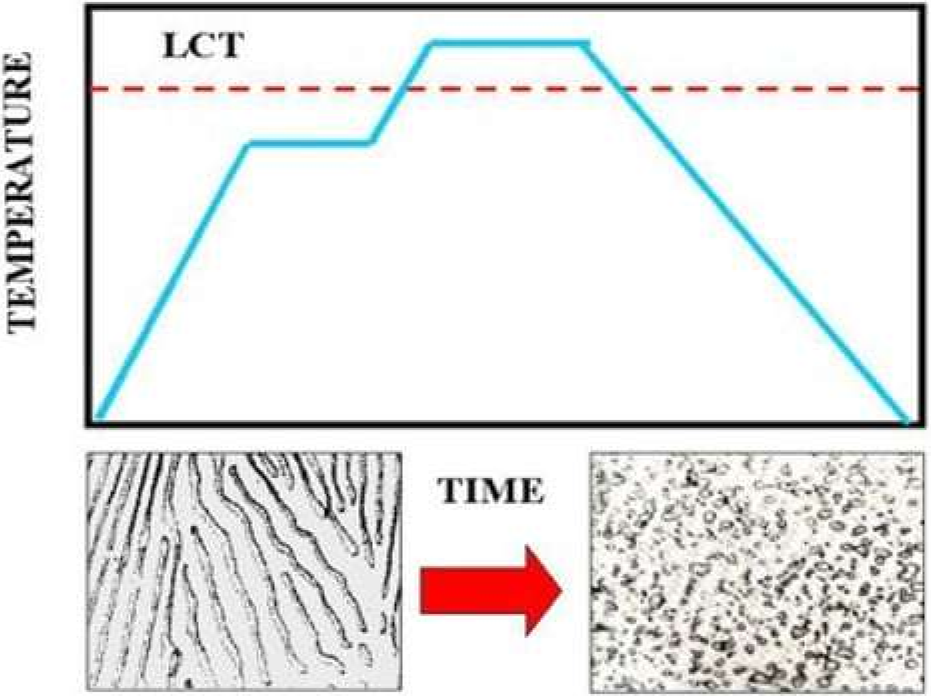


A typical recrystallization curve at constant temperature

3.5 Spheroidization annealing

- Spheroidization annealing consists of heating, soaking and cooling, invariably very slowly to produce spheroidal pearlite or globular form of carbides in steels.
- To improve the machinability of the annealed hypereutectoid steel spheroidize annealing is applied.
- Hypereutectoid steels consist of pearlite and cementite. The cementite forms a brittle network around the pearlite. This presents difficulty in machining the hypereutectoid steels.
- This process will produce a spheroidal or globular form of a carbide in a ferritic matrix which makes the machining easy.
- Prolonged time at the elevated temperature will completely break up the pearlitic structure and cementite network. The structure is called spheroidite.

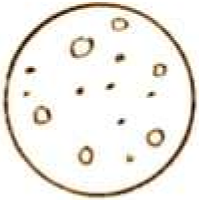
SPHEROIDIZING



Spheroidizing process applied at a temperature below and above the LCT.

Spheroidising Process:

- Heat the part to a temperature just below the Ferrite-Austenite line, line A1 or below the Austenite-Cementite line, essentially below the 727 ºC (1340 ºF) line. Hold the temperature for a prolonged time and follow by fairly slow cooling. Or
- Cycle multiple times between temperatures slightly above and slightly below the 727 ºC (1340 ºF) line, say for example between 700 and 750 ºC (1292 - 1382 ºF), and slow cool. Or
- For tool and alloy steels heat to 750 to 800 ºC (1382-1472 ºF) and hold for several hours followed by slow cooling.



SPHEROIDITE

- All these methods result in a structure in which all the Cementite is in the form of small globules (spheroids) dispersed throughout the ferrite matrix. This structure allows for improved machining in continuous cutting operations such as lathes and screw machines. Spheroidization also improves resistance to abrasion.

Aims Of Spheroidization Annealing:

- minimum hardness
- maximum ductility
- maximum machinability
- maximum softness

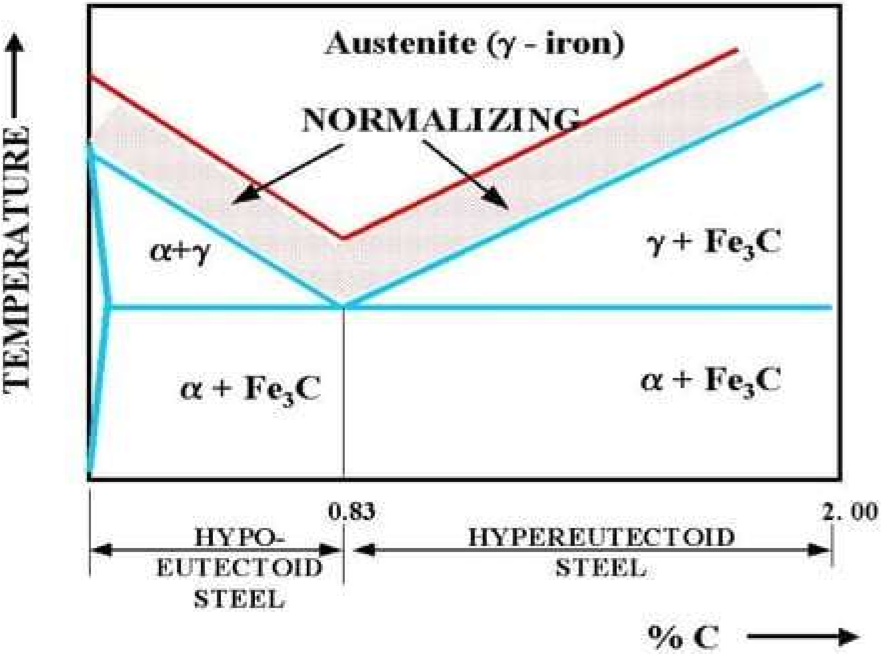
NORMALIZING

- The normalizing of steel is carried out by heating above the UCT (Upper Critical Temperature) to single phase austenitic region to get homogeneous austenite, soaking there for some time and then cooling it in air to room temperature.

- The austenitising temperature range are:
    - For hypoeutectoid steels and eutectoid steel
        - A_{c3}+ (40-60°C)
    - For hypereutectoid steels
        - A_{cm} + (30-50°C)

- During normalising we use grain refinement which is associated with allotropic transformation upon heating γ→α
- Parts that require maximum toughness and those subjected to impact are often normalized.
- When large cross sections are normalized, they are also tempered to further reduce stress and more closely control mechanical properties.
- The microstructure obtained by normalizing depends on the composition of the castings (which dictates its hardenability) and the cooling rate.

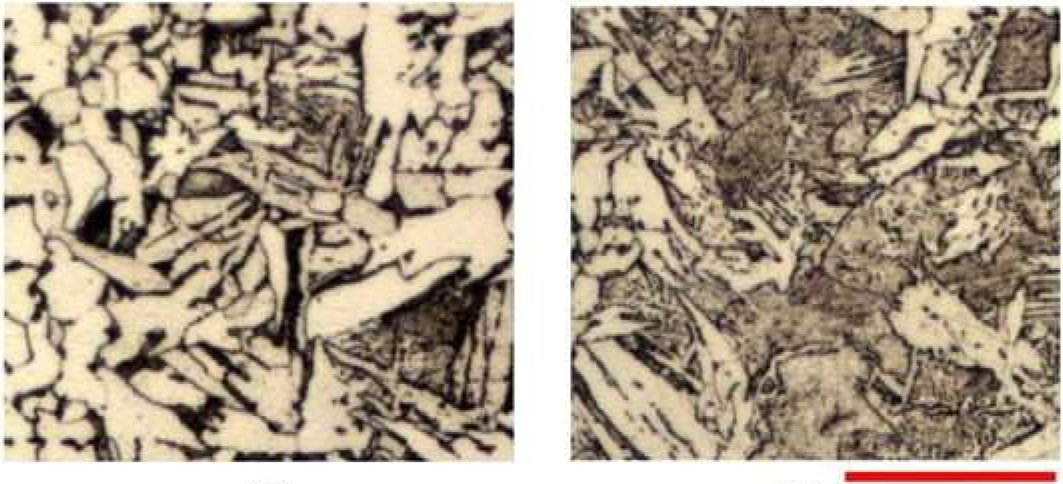
Figure below shows the normalizing temperatures for hypoeutectoid and hypereutectoid steels



AIMs OF NORMALIZING

- To produce a harder and stronger steel than full annealing
- To improve machinability
- To modify and/or refine the grain structure
- To obtain a relatively good ductility without reducing the hardness and strength
- Improve dimensional stability
- Produce a homogeneous microstructure
- Reduce banding
- Provide a more consistent response when hardening or case hardening

EFFECT OF SOAKING TIME ON THE MICROSTRUCTURE:



(a) (b)

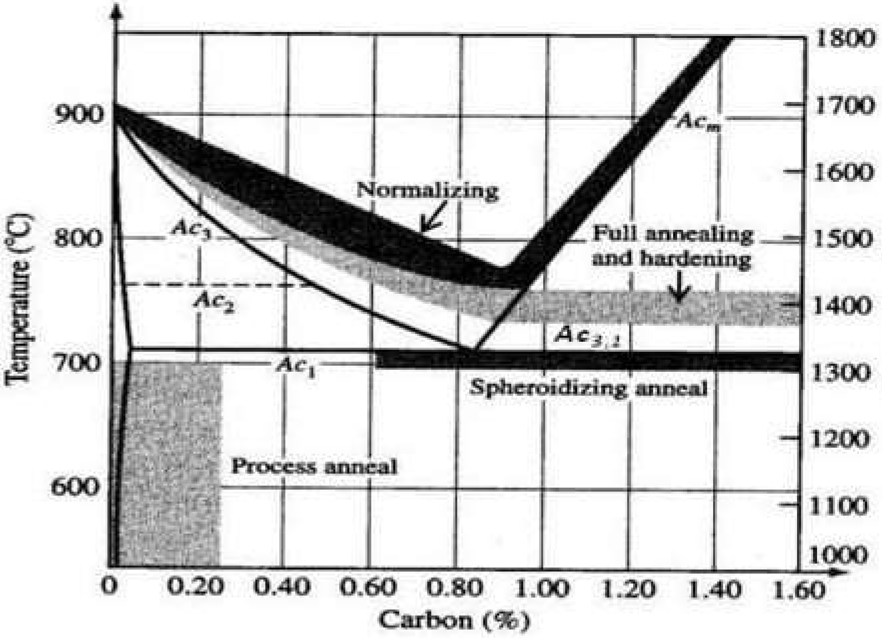
Acicular ferrite in mixture with polygonal ferrite and pearlite, normalized at (a) 960°C, 10 minutes soaking time (b) 960°C, 40 minutes soaking time.

NORMALIZING
VS
ANNEALING

COMPARISON OF ANNEALING AND NORMALIZING

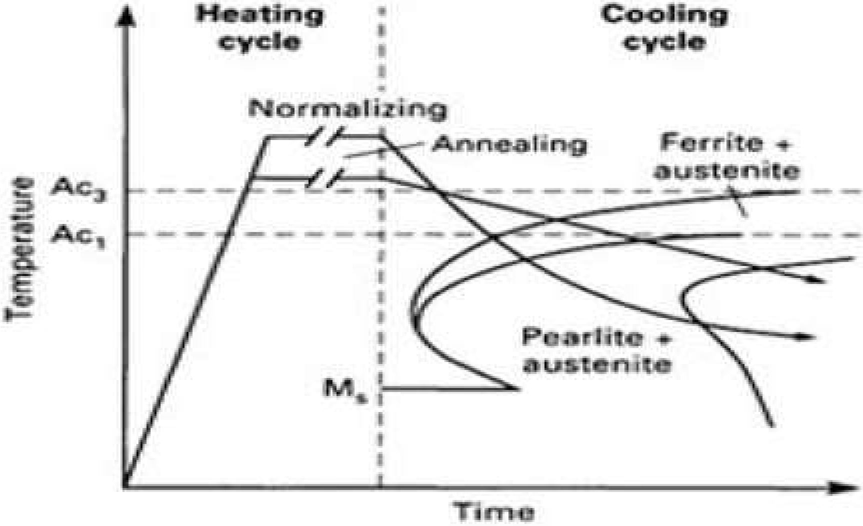
- The metal is heated to a higher temperature and then removed from the furnace for air cooling in normalizing rather than furnace cooling.
- In normalizing, the cooling rate is slower than that of a quench-and-temper operation but faster than that used in annealing.
- As a result of this intermediate cooling rate, the parts will possess a hardness and strength somewhat greater than if annealed.
- Fully annealed parts are uniform in softness (and machinability) throughout the entire part; since the entire part is exposed to the controlled furnace cooling. In the case of the normalized part, depending on the part geometry, the cooling is non-uniform resulting in non-uniform material properties across the part.
- Internal stresses are more in normalizing as compared to annealing.
- Grain size obtained in normalizing is finer than in annealing.
- Normalizing is a cheaper and less time-consuming process.

Comparison of temperature ranges in annealing and normalizing



Temperature Range for Heat Treatment of Carbon Steels

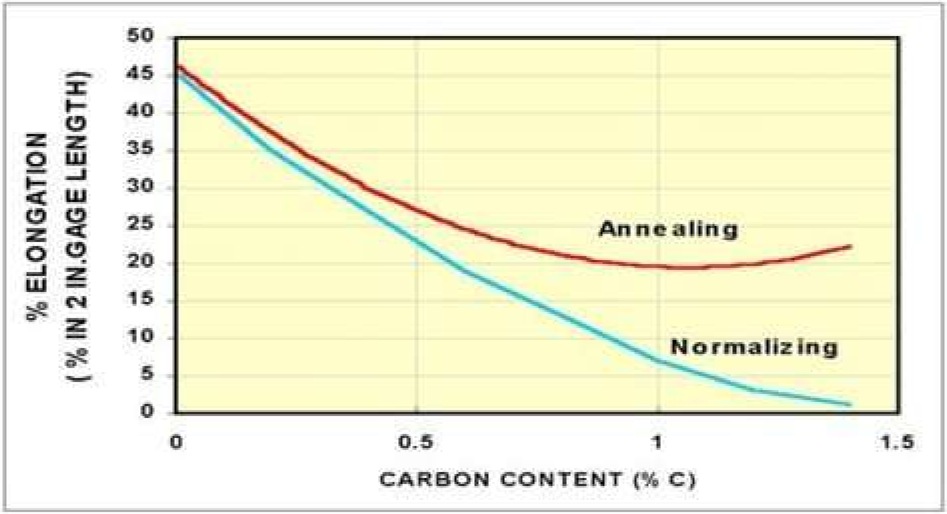
Comparison of time-temperature cycles for normalizing and full annealing



The slower cooling of annealing results in higher temperature transformation to ferrite and pearlite and coarser microstructures than does normalizing.

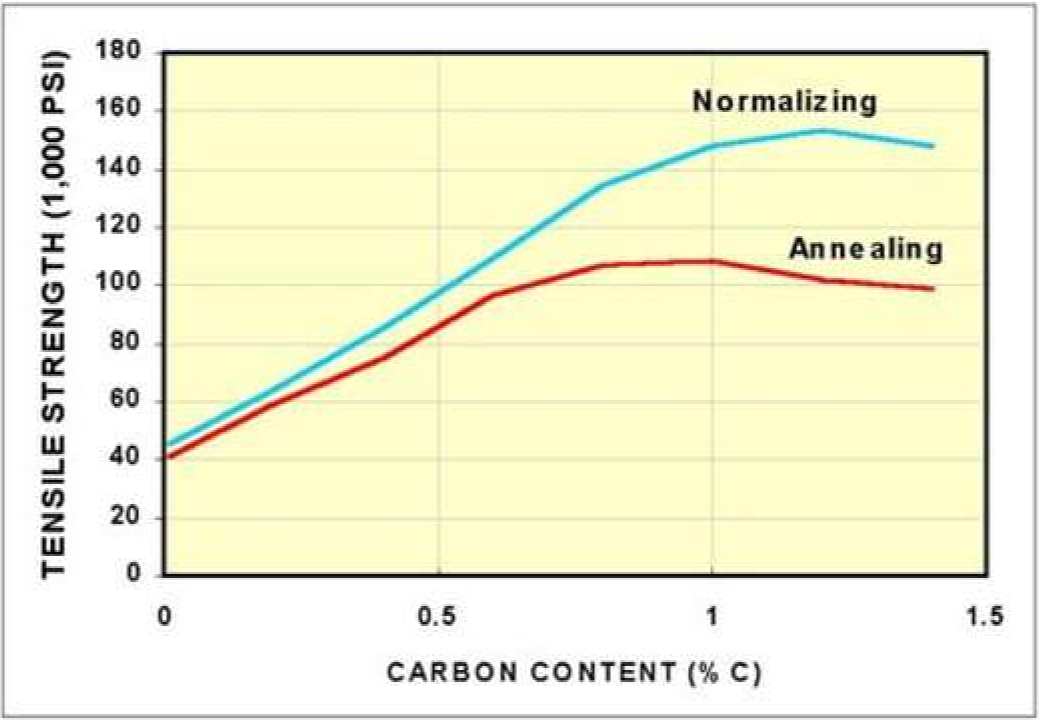
effect of annealing and normalizing on ductility of steels

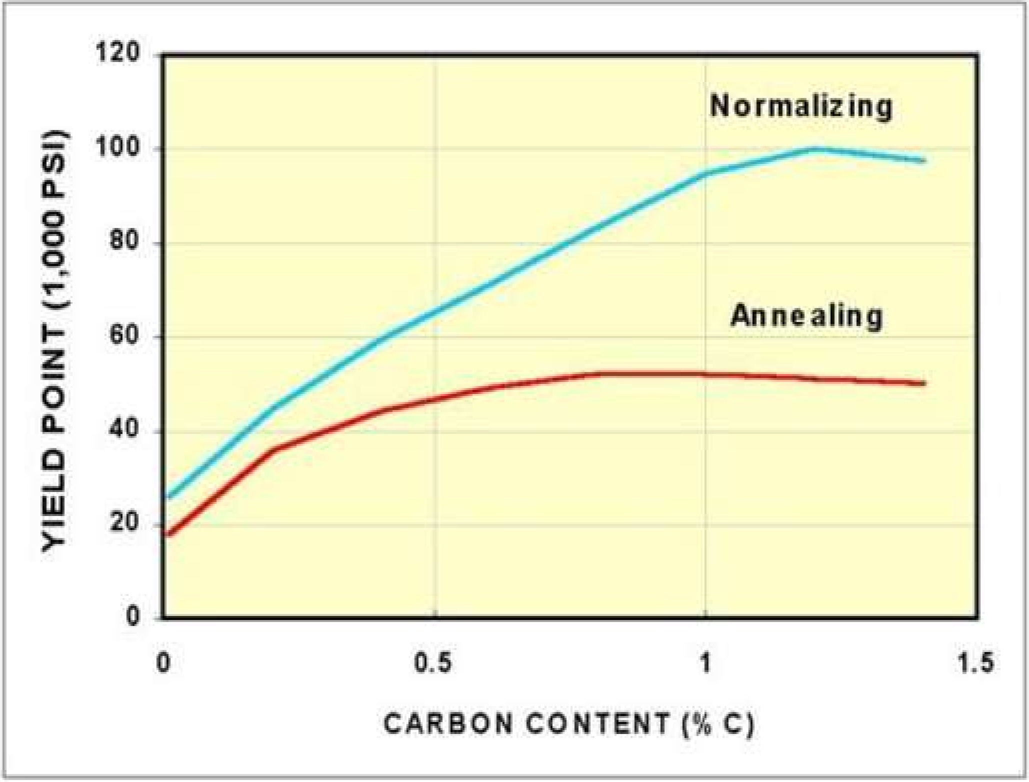
Annealing and normalizing do not present a significant difference on the ductility of low carbon steels. As the carbon content increases, annealing maintains the % elongation around 20%. On the other hand, the ductility of the normalized high carbon steels drop to 1 to 2 % level.



effect of annealing and normalizing on the tensile strength AND YIELD POINT of steels

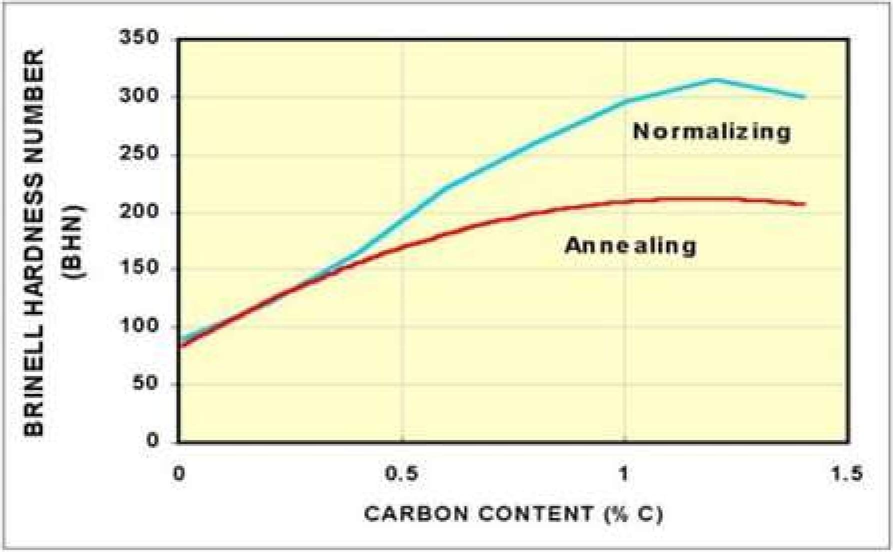
- **The tensile strength and the yield point of the normalized steels are higher than the annealed steels.**
- **Normalizing and annealing do not show a significant difference on the tensile strength and yield point of the low carbon steels.**
- **However, normalized high carbon steels present much higher tensile strength and yield point than those that are annealed. This can be illustrated from the figures.**


TENSILE STRENGTH (1,000 PSI)
180
160
140
120
100
80
60
40
20
0
Normalizing
Annealing
0
0.5
1
1.5
CARBON CONTENT (% C)


Normalizing
Annealing
YIELD POINT (1,000 PSI)
120
100
80
60
40
20
0
0
0.5
1
1.5
CARBON CONTENT (% C)

effect of annealing and normalizing on the hardness of steels

Low and medium carbon steels can maintain similar hardness levels when normalized or annealed. However, when high carbon steels are normalized they maintain higher levels of hardness than those that are annealed.



ADVANTAGES OF NORMALIZING OVER ANNEALING

- Better mechanical properties
- Lesser time-consuming
- Lower cost of fuel and operation

ADVANTAGES OF ANNEALING OVER NORMALIZING

- Greater softness
- Complete absence of internal stresses which is a necessity in complex and intricate parts

HARDENING

- It is the process of heating the steel to proper austenitizing temperature , soaking at this temperature to get a fine grained and homogeneous austenite , and then cooling the steel at a rate faster than its critical cooling rate.

OBJECTIVES OF HARDENING

The aims of hardening are:

1. Main aim of hardening is to induce high hardness. The cutting ability of a tool is proportional to its hardness.
2. Many machine parts and all tools are hardened to induce high wear resistance higher is the hardness , higher is the wear and the abrasion resistance .For example ,gears, shaft.
3. The main objective of hardening machine components made of structural steel sis to develop high yield strength with good toughness and ductility to bear high working stresses.

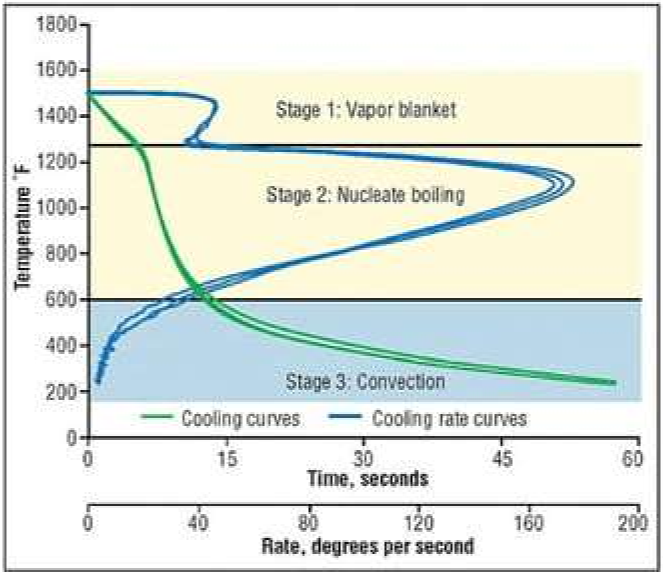
PROCESS OF QUENCHING

- When a heated steel object (say at 840°C) is plunged into a stationary bath of cold it has three stages as:

Stage A -vapour-blanket stage:

- Immediately on quenching, coolant gets vapourized as the steel part is at high temperature, and thus, a continuous vapour- blanket envelopes the steel part.
- Heat escapes from the hot surface very slowly by radiation and conduction through the blanket of water vapour.
- Since the vapour-film is a poor heat conductor, the cooling rate is relatively low (stage A in fig). This long stage is undesirable in most quenching operations.

PROCESS OF QUENCHING



PROCESS OF QUENCHING

Stage B-Intermittent contact stage (Liquid-boiling stage):

- Heat is removed in the form of heat of vaporization in this stage as is indicated by the steep slope of the cooling curve.
- During this stage, the vapour-blanket is broken intermittently allowing the coolant to come in contact with the hot surface at one instant, but soon being pushed away by violent boiling action of vapour bubble.
- The rapid cooling in this stage soon brings the metal surface below the boiling point of the coolant.

PROCESS OF QUENCHING

- The vaporization then stops. Second stage corresponds to temperature range of 500 ° to 100 ° c , and this refers to nose of the CCT curve of the steel , when the steel transforms very rapidly (to non martensite product).
- Thus, the rate of cooling in this stage is of great importance in hardening of steels.

Stage C-Direct-Contact stage (Liquid-cooling stage):

- This stage begins when the temperature of steel surface Is below the boiling point of coolant.
- Vapours do not form. The cooling is due to convection and conduction through the liquid. Cooling is slowest here.

WATER

- The oldest and still the most popular quenching medium, water meets the requirements of low cost ,general easy availability, easy handling and safety.
- The cooling characteristics change more than oil with the rise of temperature, specially there is a rapid fall in cooling capacity as the temperature rises above 60°C, because of easy formation of vapour-blanket.
- The optimum cooling pover is when water is 2O-4O°C.
- Thc cooling power of water is between brine and oils.
- Water provides high cooling power to avoid the transformation of austenite to pearlite/bainite, but the major draw back is that it also provides high cooling rate in the the temperature range of martensite formation.
- At this stage, the steel is simultaneously under the influence of structural stresses (non-uniform change in structure) and thermal stresses which increase the risk of crack formation.

BRINE

- Sodium chloride aqueous solutions of about 10% by weight are widely used and are called brines.
- The cooling power is between 10% NaOH aqueous solution and water.
- These are corrosive to appliances.
- The greater cooling efficiency of brines, or other aqueous solutions is based as :
- In brine heating of the solution at the steel surface causes the deposition of crystal of the salt on hot steel surface .
- This layer of solid crystals disrupts with mild explosive violence, und throws off a cloud of crystals. This action destroys the vapour-film from the surface, and thus permits direct contact of the coolant with the steel surface with an accompanying rapid removal of heat.
- Brines are used where cooling rates faster than water arc requited.

OILS

- Oils have cooling power between water at 40°C to water at 90°C.
- In oil-quench, considerable variation can be obtained by the use of animal, vegetable, or mineral oil, or their blends.
- Oils should be used at 50- 80°C when these are more fluid, i.e less VISCOUS, which increases the cooling power.
- As the oils used generally have high boiling points, moderate increase of temperature of oil does not very much increase the vapour blanket stage. However, oils in contrast to water, or brine, have much lower quenching power .
- Its this relatively slow cooling rate in the range of martensitic formation is atlvantageous as it helps in minimsing the danger to crack formation.
- Oils with high viscosity are less volatile, and thus have decreased vapour-blanket stage (increase thecooling rate). As lesser volatile matter is lost, their cooling power is not affected much with use.

POLYMER QUENCHANTS

- polymer quenchants cool rapidly the heated steel to Ms temperature, and then rather slowly when martensite is forming .
- Polymer quenchants are water-soluble organic chemicals of high ,molecular weights, and are generally polyalkylene glycol-based, or polyvinyl pyrolidene-based.
- Widely different cooling rates can be obtained by varying the concentration of Organic additives in water; higher the additions, slower is the cooling rate of solution.
- There are little dangers of distortions and cracks.

SALT BATHS

- It is an ideal quenching medium for a steel of not very large section but with good hardenabilty.
- Addition of O.3-O.5'% water almost doubles the cooling capacity. Normally holding time is 2-4 minutes/cm of section thickness.
- Salt baths used for austenitising keep the steel clean.

Tempering

Tempering (formerly called drawing), consists of reheating a quenched steel to a suitable temperature below the transformation temperature for an appropriate time and cooling back to room temperature. Freshly quenched marten site is hard but not ductile. Tempering is needed to impart ductility to marten site usually at a small sacrifice in strength.

Tempering

The effect of tempering may be illustrated as follows. If the head of a hammer were quenched to a fully marten-sitic structure, it probably would crack after the first few blows. Tempering during manufacture of the hammer im-parts shock resistance with only a slight decrease in hard-ness. Tempering is accomplished by heating a quenched part to some point below the transformation temperature, and holding it at this temperature for an hour or more, depending on its size.

Tempering

The micro structural changes accompanying tempering include loss of acicular marten site pattern and the precipitation of tiny carbide particles. This micro structural is referred to as tempered marten site.