HEAT TREATMENT OF MATERIALS

LAB 6

FOR THE LAB

- 1 group, 4 samples
- Bigger group
- Week 2: hardness testing

9	October 28 Exam II Heat Treatment	October 28, November 1 Heat Treatment Part I
10	November 4 No Lecture	November 4, 8 Heat Treatment Part I
11	November 11 Fracture Mechanics Fluid Mechanics	November 11, 15 Heat Treatment Part II/Fracture Mechanics Fluid Mechanics
12	November 18 No Lecture	November 18, 22 Heat Treatment Part II/Fracture Mechanics Fluid Mechanics

Laboratory times: Mon 8:30 AM– 10:00 AM
Mon 10:00 AM– 11:30 AM
Mon 1:30 PM – 3:00 PM
Mon 3:00 PM – 4:30 PM
Thu 1:30 PM – 3:00 PM
Thu 3:00 PM – 4:30 PM

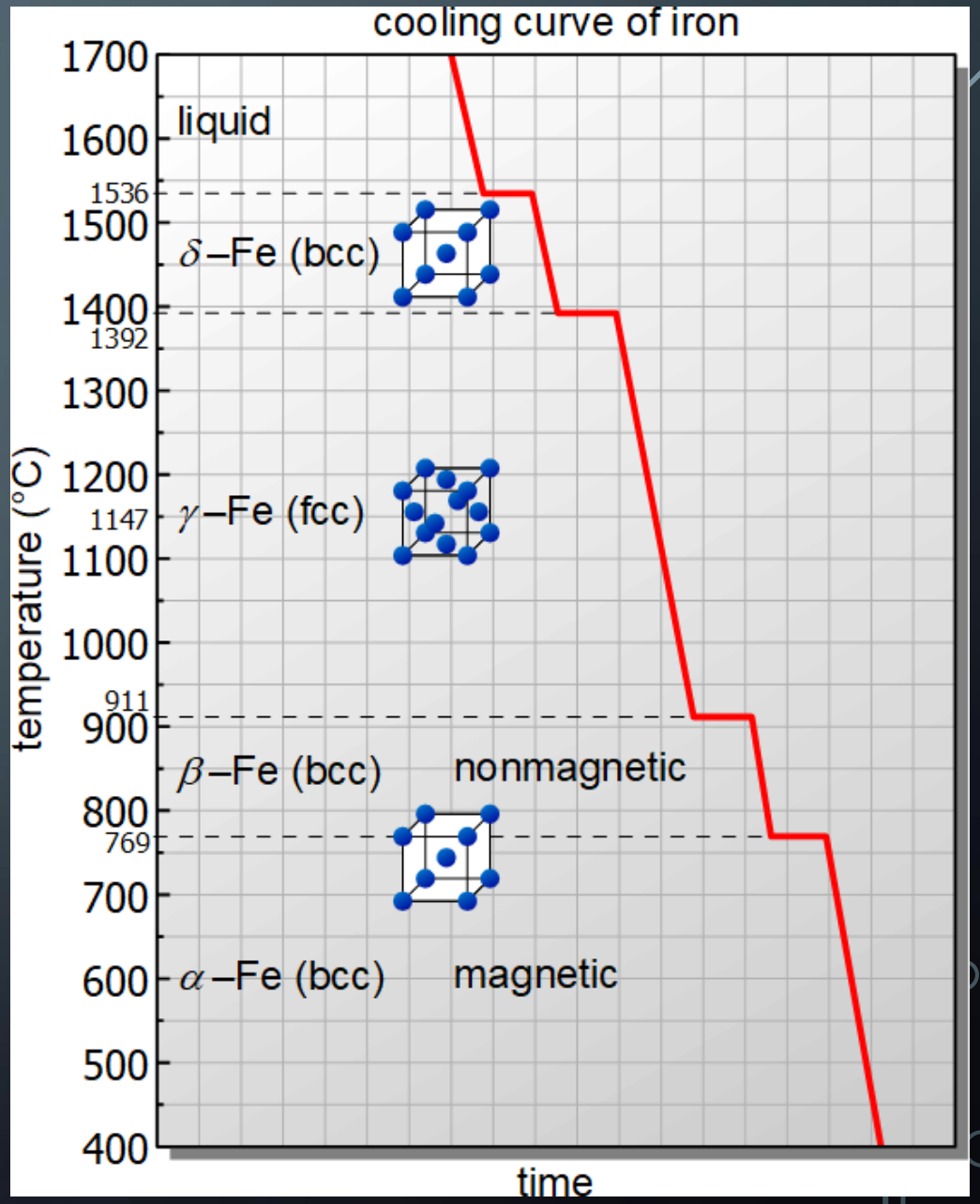
HEAT TREATMENT OF MATERIALS

- Polymorphous metal
- Heat treatment
- Hardness testing
- Goal: To observe the heat treatment process for steel and the effect it has on mechanical properties.

POLYMORPHOUS METAL

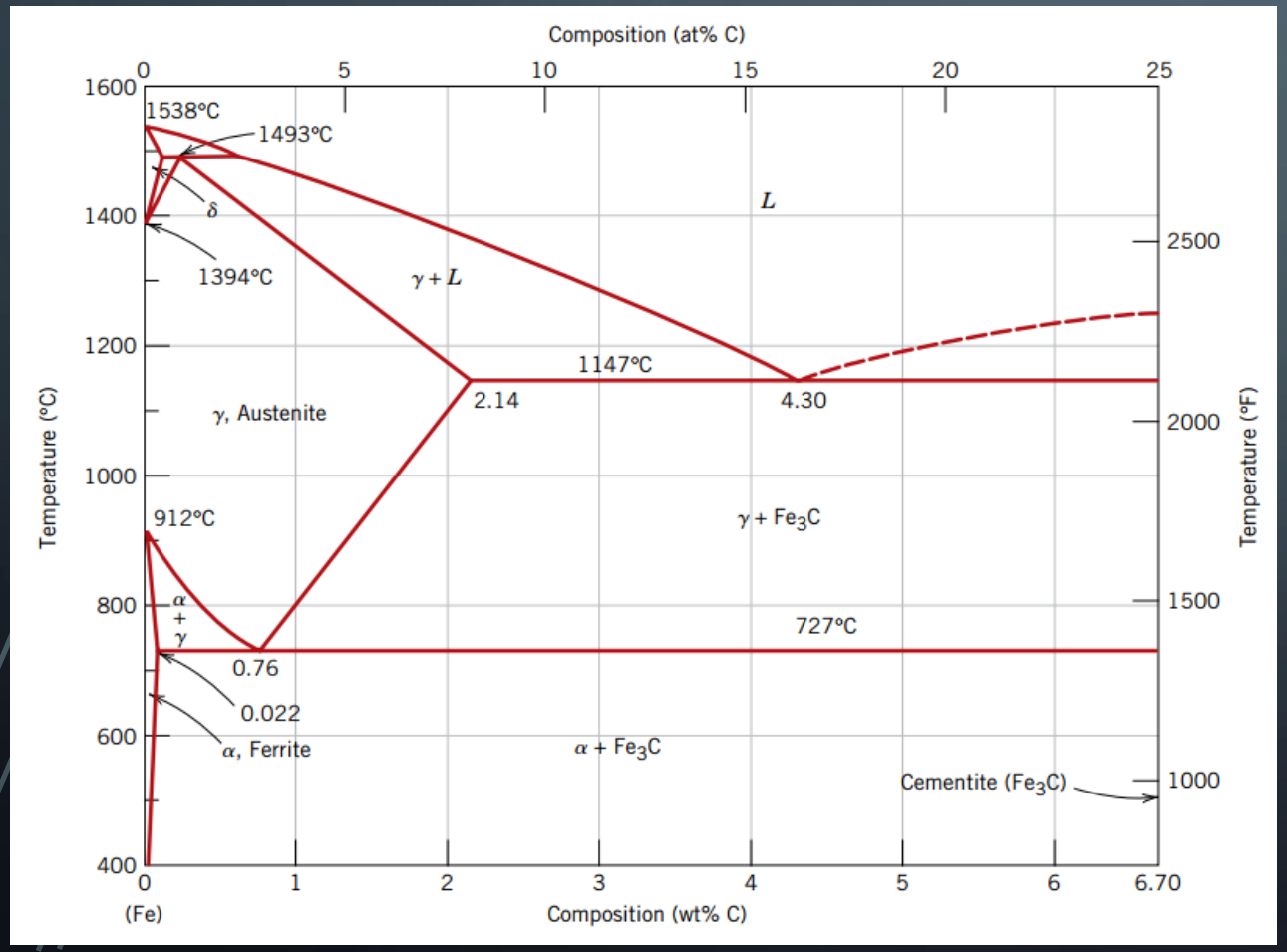
- Polymorphism
  - existence of a solid material in more than one form or crystal structure.
- Polymorphic transition
  - A reversible transition of a solid crystalline phase at a certain temperature and pressure (the inversion point) to another phase of the same chemical composition with a different crystal structure

$$L \xrightarrow{1536^\circ C} \underset{bcc}{\delta-Fe} \xrightarrow{1392^\circ C} \underset{fcc}{\gamma-Fe} \xrightarrow{911^\circ C} \underset{bcc}{\alpha-Fe}$$

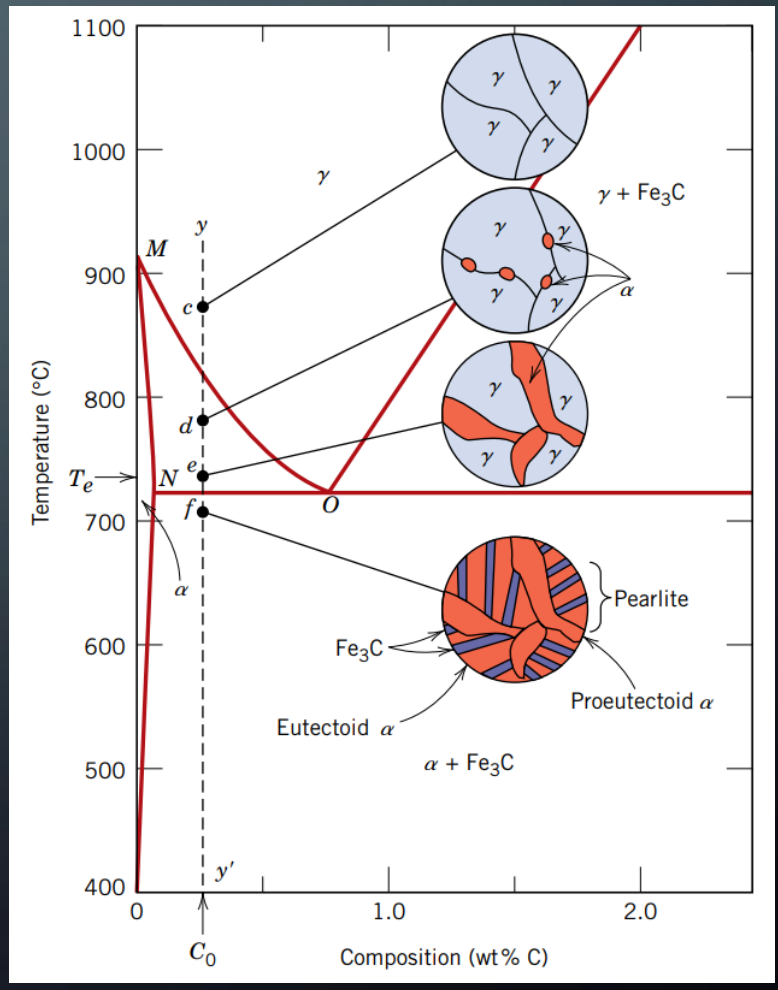


IRON–IRON CARBIDE PHASE DIAGRAM

- Maximum solubility
  - BCC: 0.022 wt% (727 °C)
  - FCC: 2.14 wt% (1147 °C)



- Hypoeutectoid alloys
  - containing less than 0.76 wt% C



THERMAL PROCESSING OF METALS

THERMAL PROCESSING OF METALS

- Heat treating is a group of industrial and metalworking processes used to alter the physical, and sometimes chemical, properties of a material.
- Heat treatment involves the use of heating or chilling, normally to extreme temperatures, to achieve a desired result such as hardening or softening of a material.
- Heat treatment techniques include
  - Annealing
  - Normalizing
  - Quenching
  - Tempering
  - …

ANNEALING

Annealing involves heating the material to a predetermined temperature and hold the material at the temperature and cool the material to the room temperature slowly. The process involves:

- Heating of the material at the elevated or predetermined temperature
- Holding the material (Soaking) at the temperature for longer time.
- Very slowly cooling the material to the room temperature.

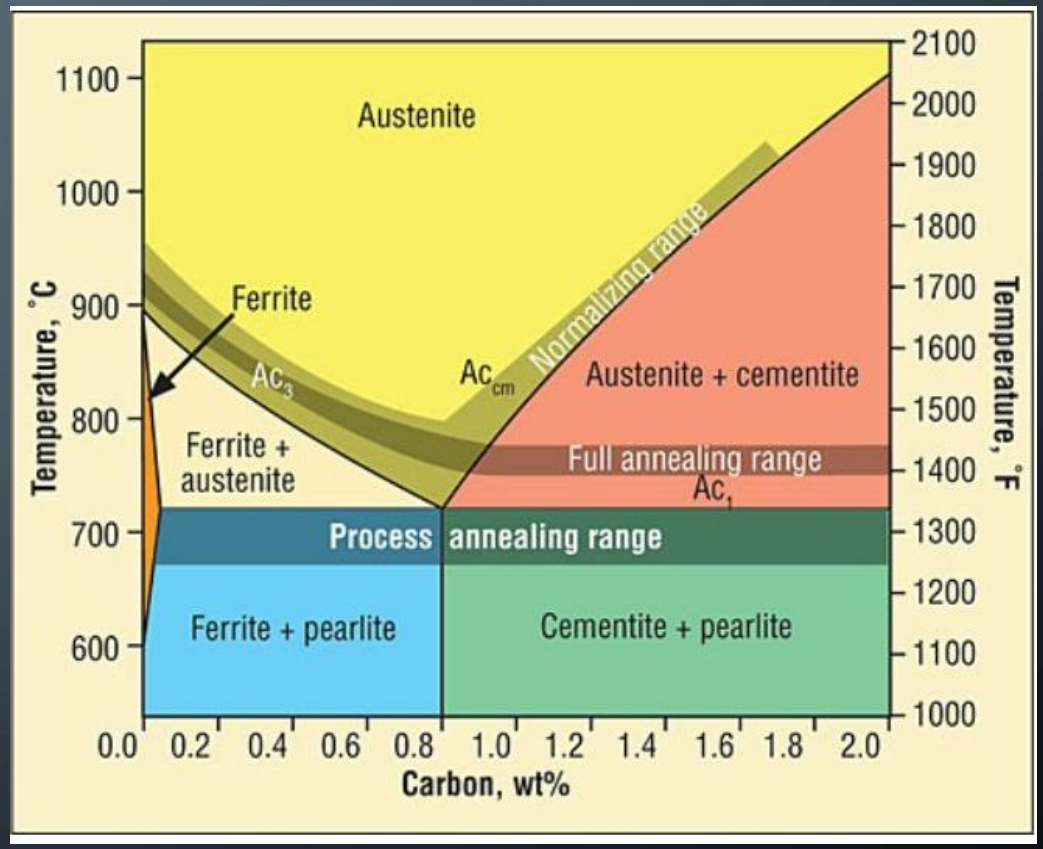
ANNEALING

Purpose

- Relieve internal stresses developed during solidification, machining, forging, rolling or welding
- Improve or restore ductility and toughness
- Enhance machinability
- Refrain grain size & reduce the gaseous contents in steel

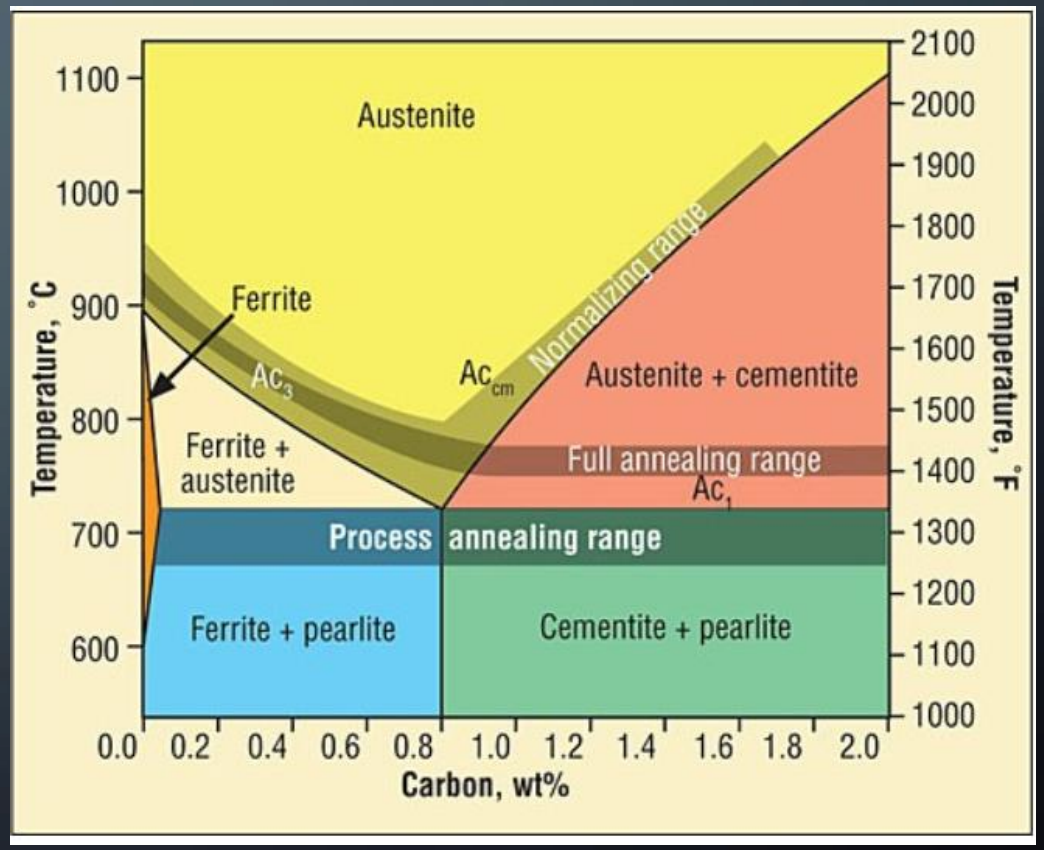
NORMALIZING

- The normalizing consists of heating steel to about 40-55 ℃ above critical temperature (Ac_3 or Ac_{cm}), and holding for proper item and then cooling in still air or slightly agitated air to room temperature

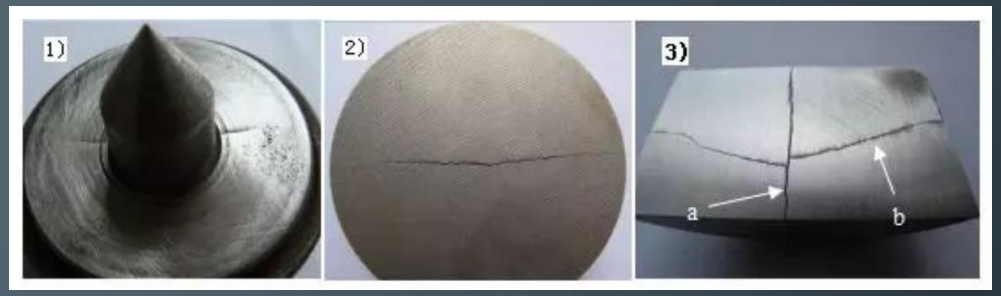


NORMALIZING

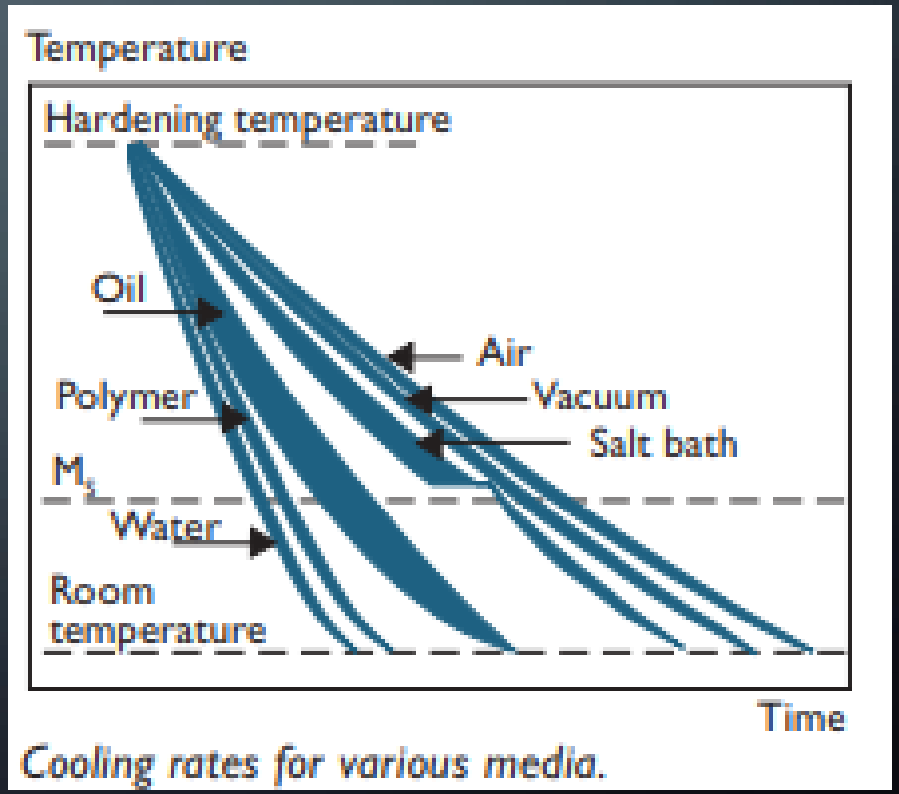
- Normalized treatment is frequently applied to steel in order to achieve any one or more of the objectives, namely:
  - To refine the grain structure
  - To obtain uniform structure
  - To decrease residual stresses
  - To improve machinability



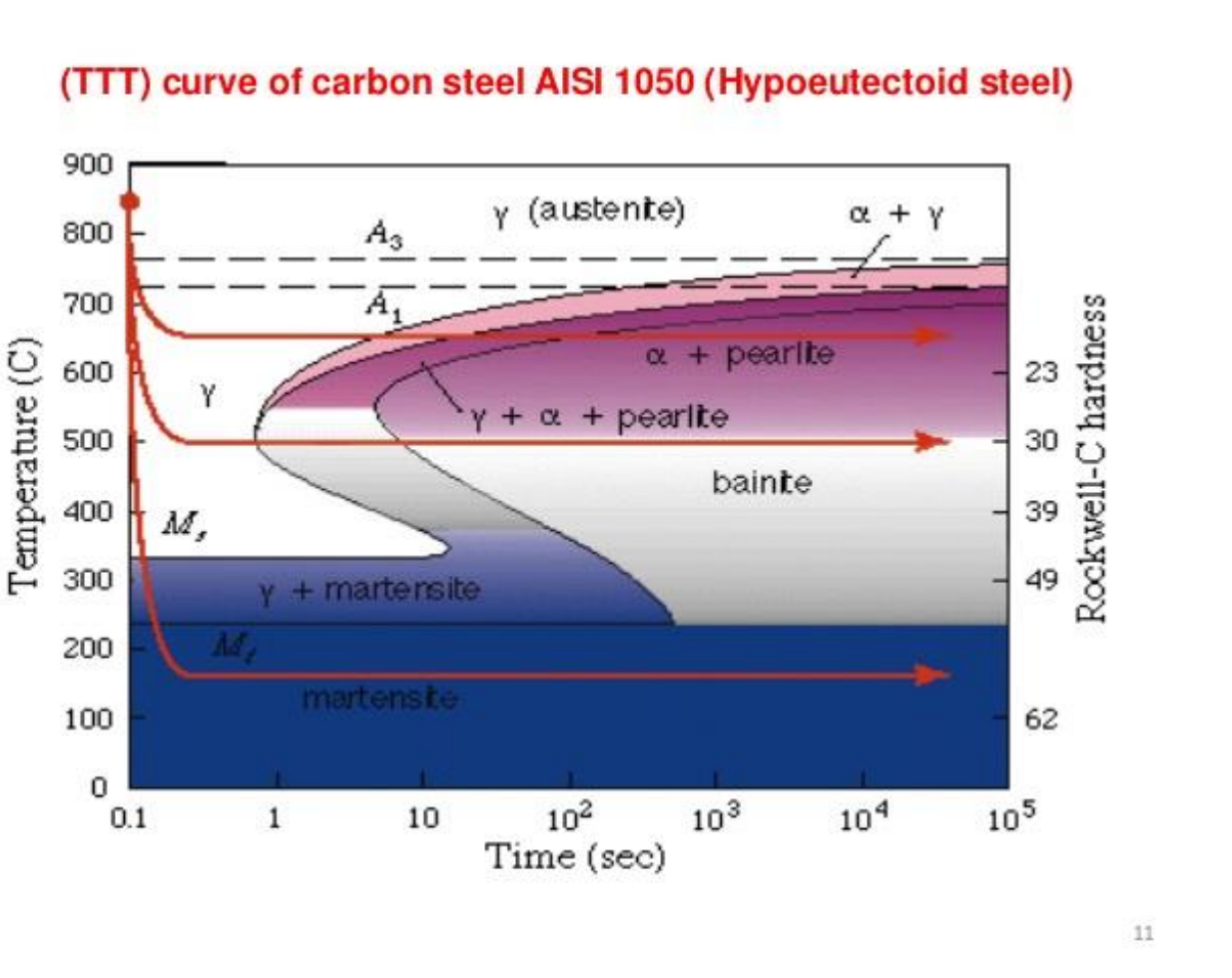
QUENCHING

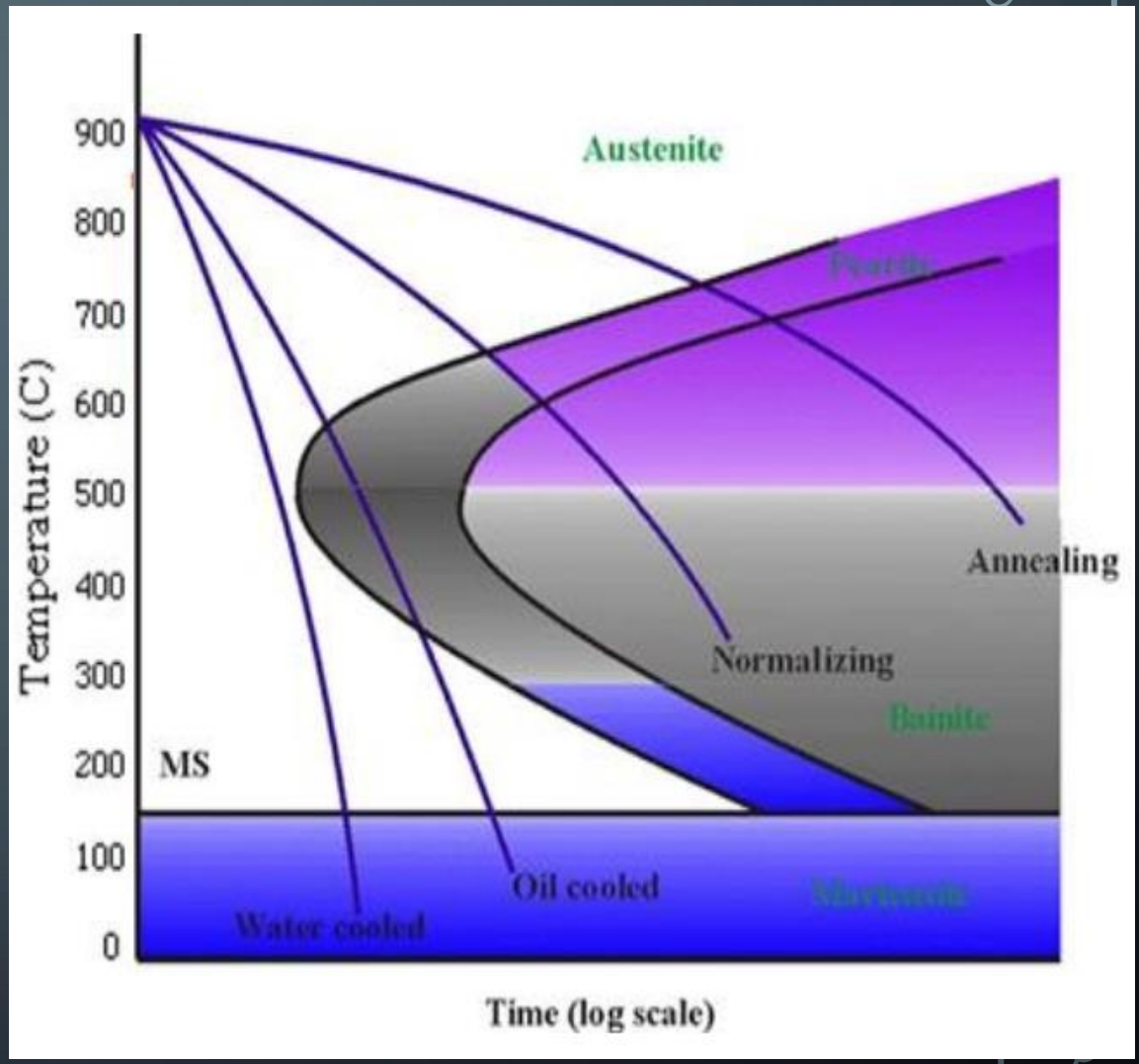


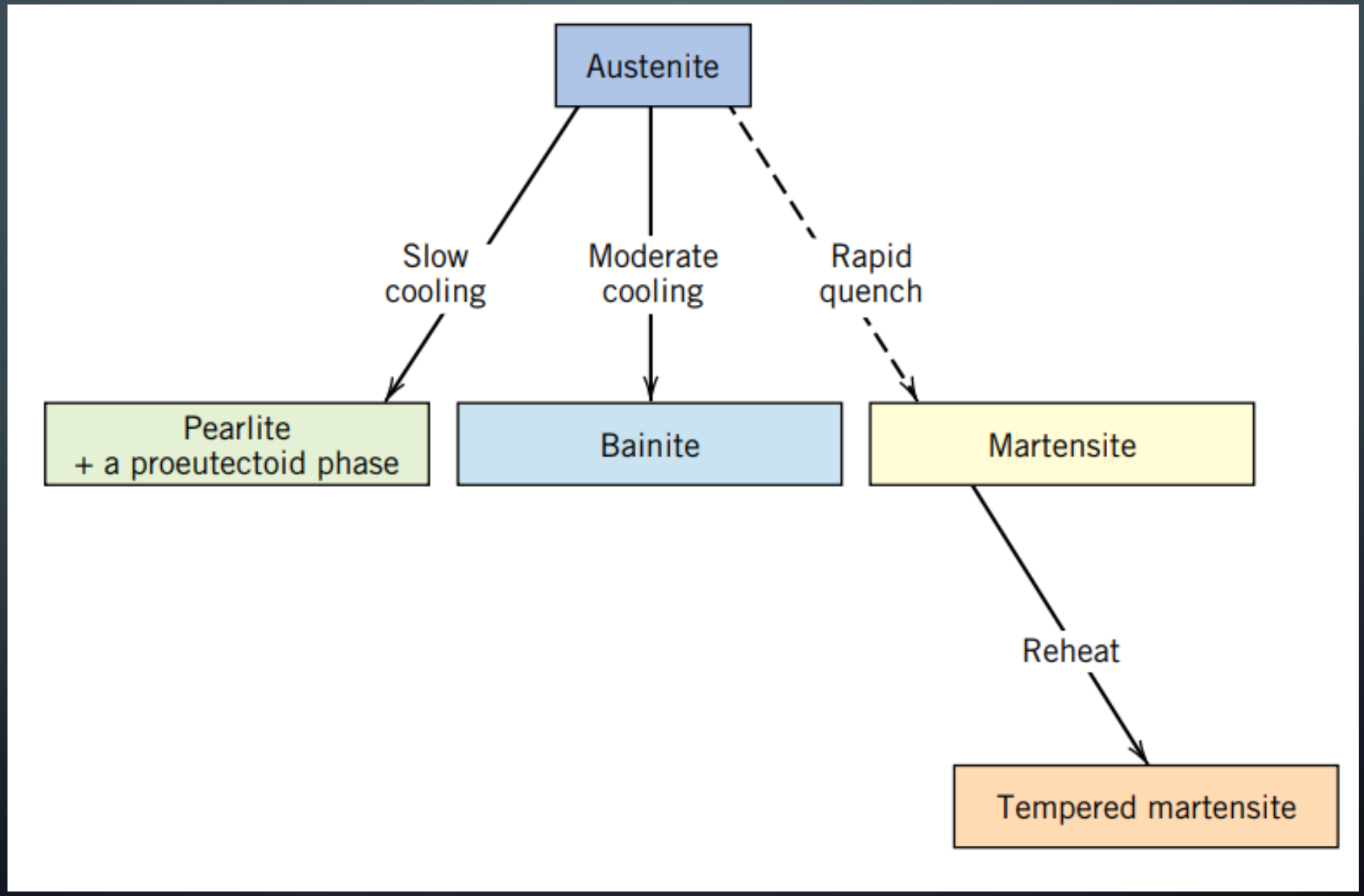
- Quenching is a heat treatment process in which steel is rapidly cooled from austenitising temperature. As a result, the hardness and wear resistance of steel are improved
- Quenching treatment generally consists of heating to hardening temperature, holding at that temperature, followed by rapid cooling such as quenching in oil or water or salt baths



Cooling rates for various media.

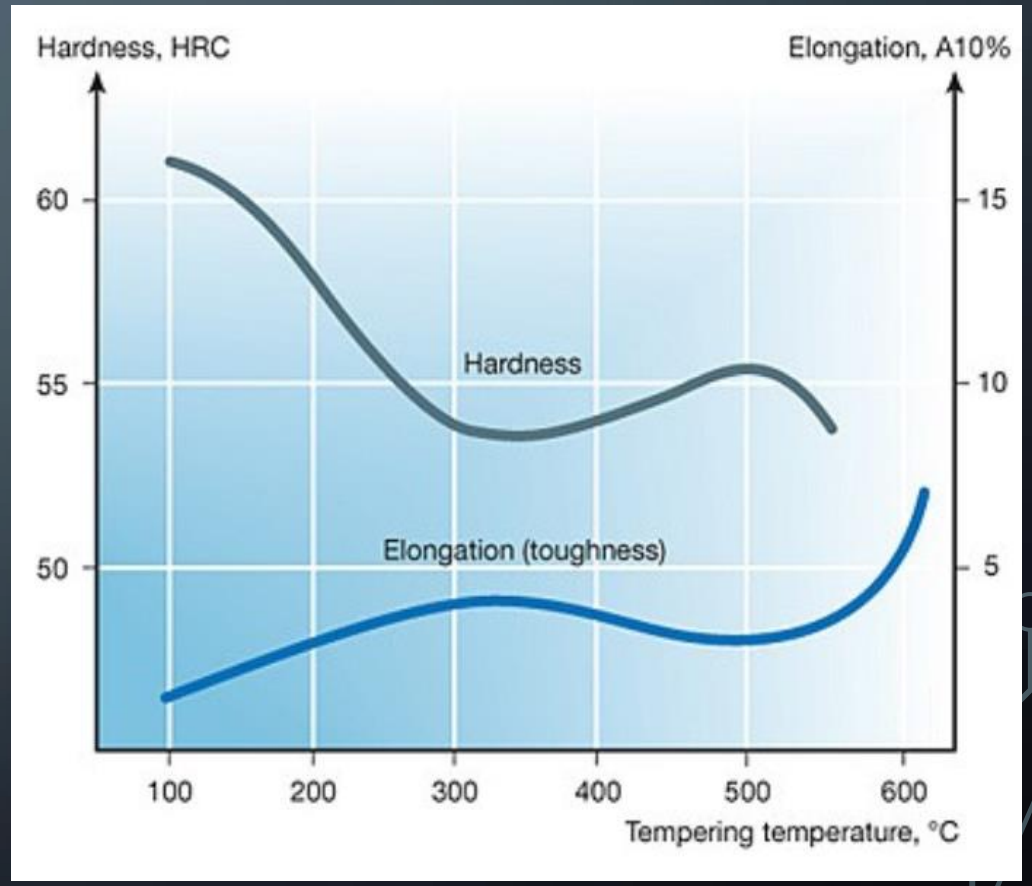

(TTT) curve of carbon steel AISI 1050 (Hypoeutectoid steel)
Temperature (C)
900
800
700
600
500
400
300
200
100
0
γ (austenite)
α + γ
A_3
A_1
α + pearlite
γ
γ + α + pearlite
bainite
M_s
γ + martensite
M_f
martensite
0.1
1
10
10^2
10^3
10^4
10^5
Time (sec)
Rockwell-C hardness
23
30
39
49
62


Temperature (C)
900
800
700
600
500
400
300
200
100
0
Austenite
Pearlite
Annealing
Normalizing
Bainite
MS
Martensite
Oil cooled
Water cooled
Time (log scale)


Austenite
Slow cooling
Moderate cooling
Rapid quench
Pearlite + a proeutectoid phase
Bainite
Martensite
Reheat
Tempered martensite

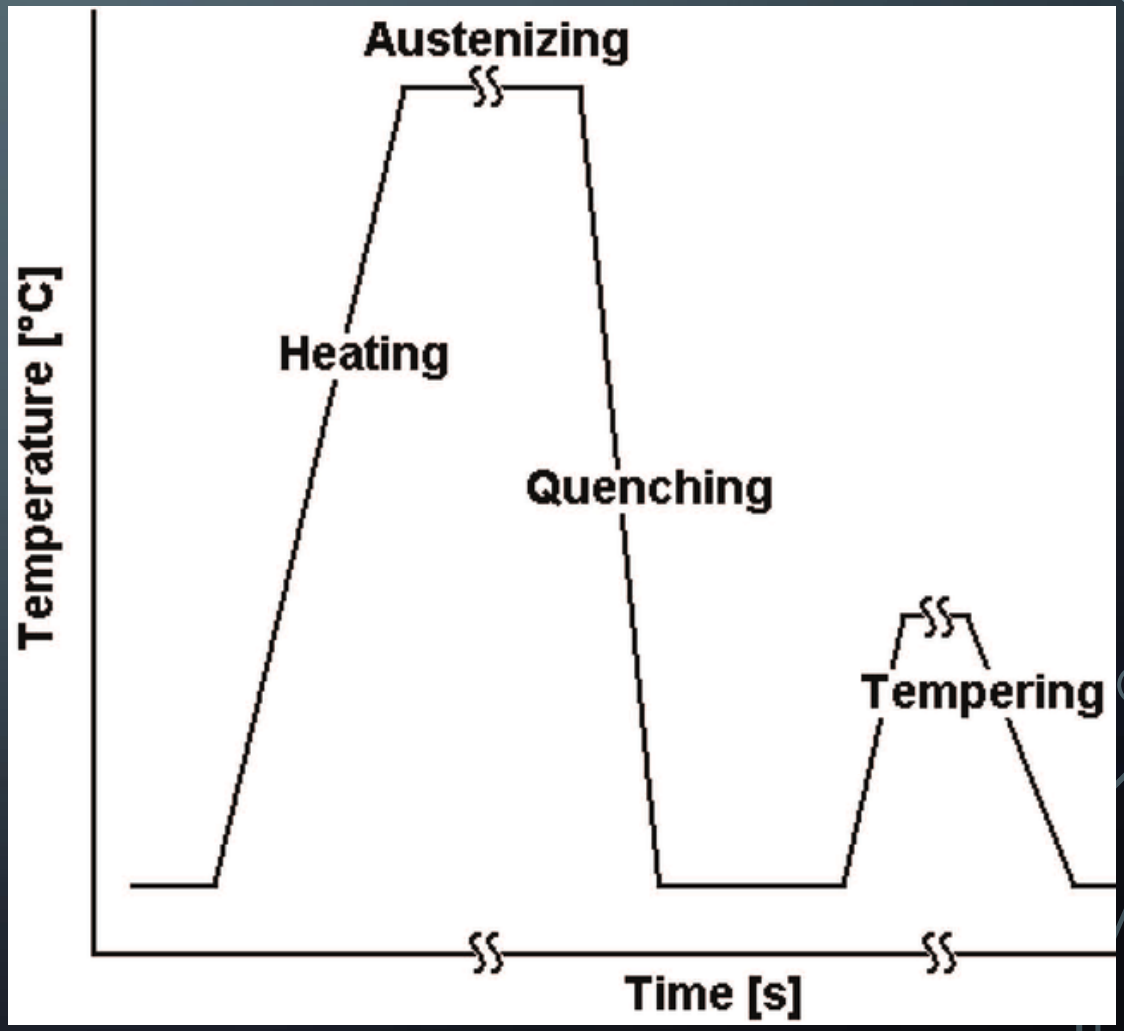
TEMPERING

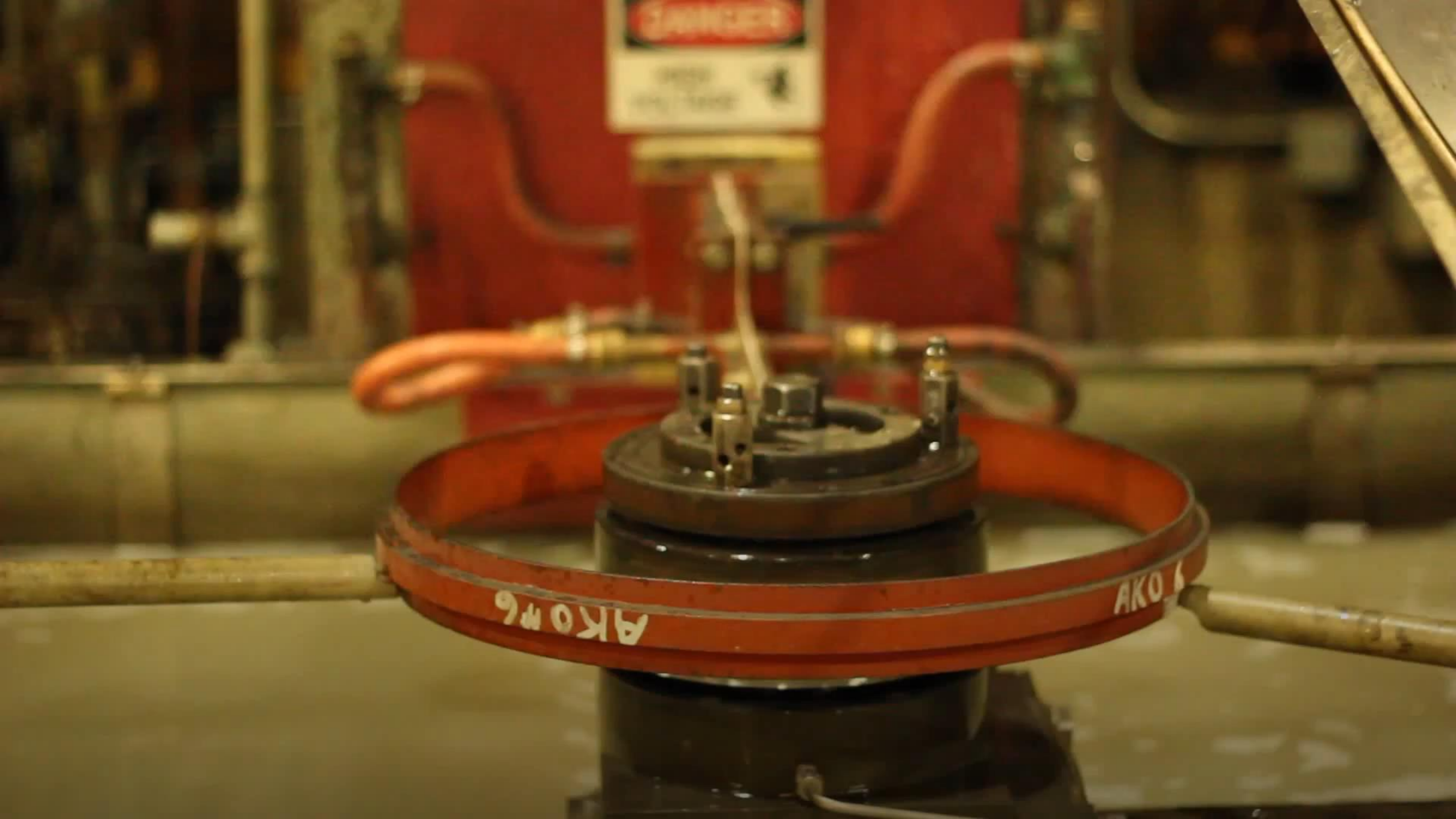
- Tempering
  - Quenched steels are so brittle that even a small impact will cause fracture. Toughness of such a steel can be improved by tempering. However there is small reduction in strength and hardness.
  - Tempering is a sub-critical heat treatment process used to improve the toughness of hardened steel
  - Tempering consists of reheating of hardened steel to a temperature below critical temperature and is held for a period of time, and then slowly cooled in air to room temperature



STEEL HEAT TREATMENT PROCESS

- Heating to Hardening Temperature
  - In every heat treatment, the heating process is named ramping
- Holding Time at Hardening Temperature
  - The temperature is maintained constant for a certain amount of time
  - The holding time can be calculated as $t=\alpha \cdot K \cdot H$ usually with $\alpha=2min/mm$ for GB #45 steel
- Quenching
  - Maximum cooling rate: heat conductivity of the material, the cooling capacity of the quenching media and the cross-section of the material
- Tempering
  - The temperatures are related to the function of the parts
  - Cutting tool: 230 – 300 ℃




AKO

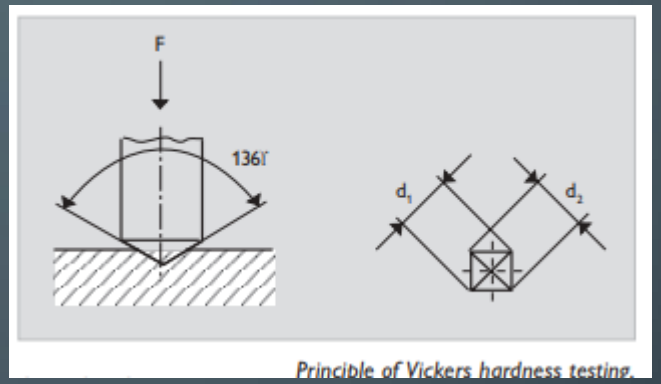

MERRY

HARDNESS TESTING

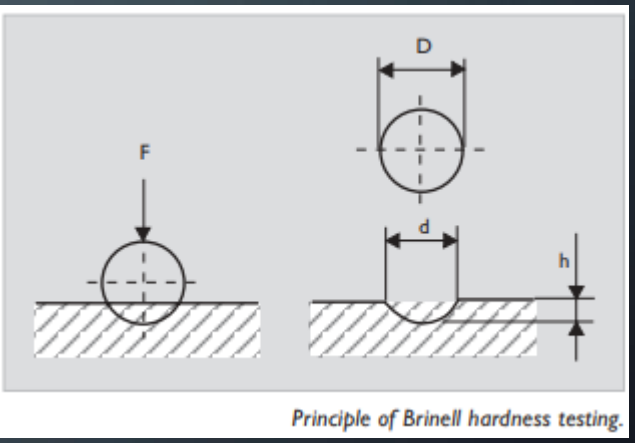
- Hardness is the resistance of metal to plastic deformation, usually by indentation.
- The term may also refer to stiffness or temper, or to resistance to scratching, abrasion, or cutting.
- It is the property of a metal, which gives it the ability to resist being permanently, deformed (bent, broken, or have its shape changed), when a load is applied.
- The greater the hardness of the metal, the greater resistance it has to deformation.

HARDNESS TESTING

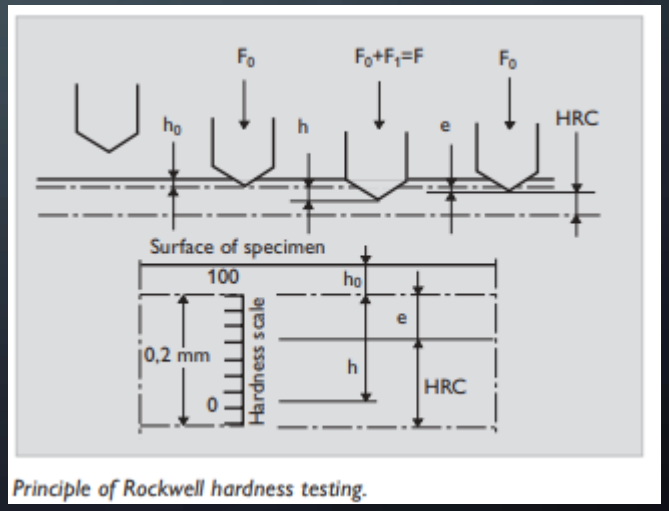
- When the steel is hardened and tempered, its strength is affected and in turn its tensile/compression properties.
- Hardness testing is the most popular way to check the results of hardening.
- The most common methods are:
  - Brinell (HBW).
  - Vickers (HV)
  - Rockwell (HRF)



Principle of Vickers hardness testing.

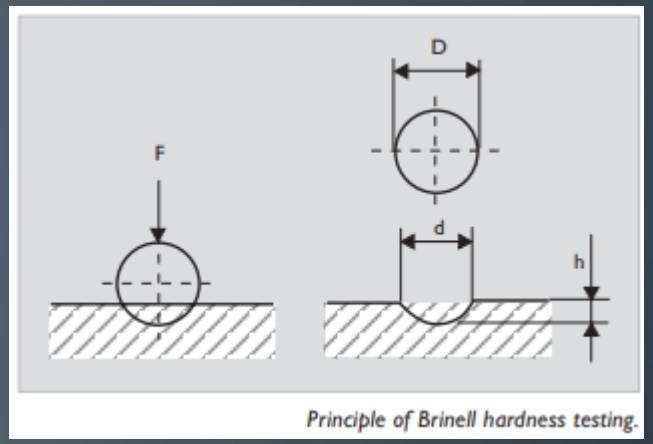


Principle of Brinell hardness testing.



Principle of Rockwell hardness testing.

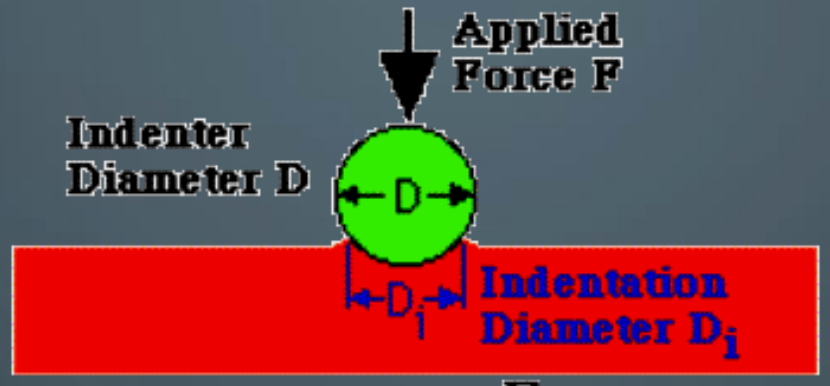
BRINELL HARDNESS TEST



Principle of Brinell hardness testing.

- Brinell hardness is determined by forcing a hard steel or carbide sphere of a specified diameter (2.5mm) under a specified load into the surface of a material and measuring the diameter of the indentation left after the test.
- The Brinell number, is obtained by dividing the load used, in kilograms, by the actual surface area of the indentation, in square millimeters.
- After the impression is made, a measurement of the diameter of the resulting round impression is taken.
- The hardness is calculated by dividing the load by the area of the curved surface of the indention, (the area of a hemispherical surface is arrived at by multiplying the square of the diameter by 3.14159 and then dividing by 2).

BRINELL HARDNESS TEST CONT.



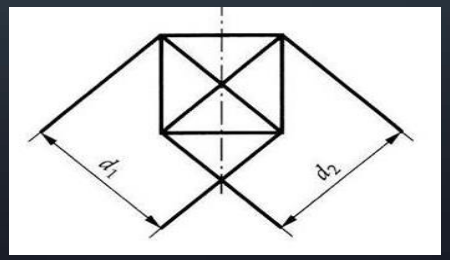
$$BHN = \frac{F}{\frac{\pi}{2} D \cdot \left(D - \sqrt{D^2 - D_i^2}\right)}$$

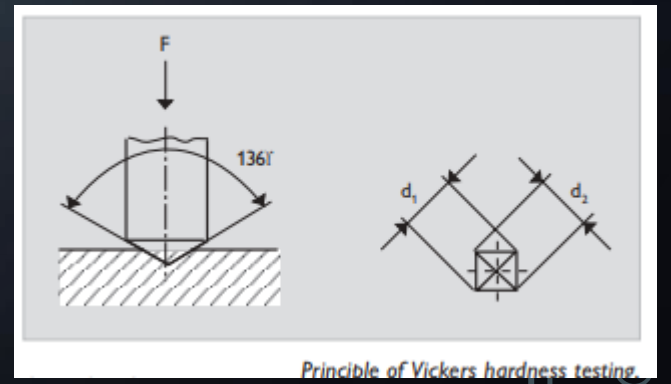
- BHN = Brinell Hardness Number
- F = the imposed load in kg
- D = the diameter of the spherical indenter in mm
- Di = diameter of the resulting indenter impression in mm

Brinell Hardness Test

VICKERS HARDNESS TEST

- It is the standard method for measuring the hardness of metals, particularly those with extremely hard surfaces: the surface is subjected to a standard pressure for a standard length of time by means of a pyramid-shaped diamond.
- Vickers hardness is a measure of the hardness of a material, calculated from the size of an impression produced under load by a pyramid-shaped diamond indenter.
- The indenter employed in the Vickers test is a square-based pyramid whose opposite sides meet at the apex at an angle of 136°.
- The Vickers number (HV) is calculated using the following formula:
  - HV = 1.854(F/D^2)
  - F : the applied load (measured in kilograms-force)
  - D : arithmetic mean of the length of the two diagonals of the indentation, in mm





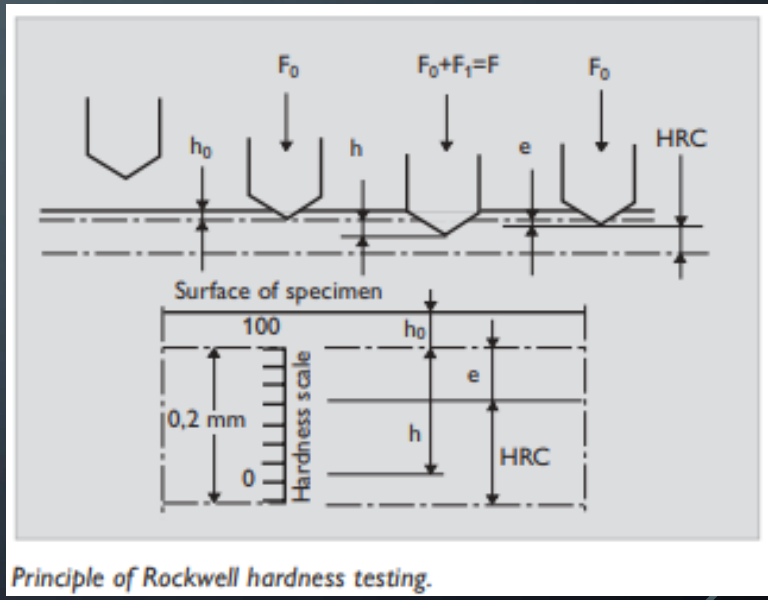
Principle of Vickers hardness testing

Vickers

Hardness Test

ROCKWELL HARDNESS TEST

- The indenter may either be a steel ball of some specified diameter or a spherical diamond-tipped cone of 120° angle.
- A minor load of 10 kg is first applied, which causes an initial penetration and holds the indenter in place.
- Then, the major load is applied (60,100,150) for HRA, HRB and HRC respectively .
- Upon removal of the major load, the depth reading is taken while the minor load is still on. The minor load of 10 kg is NOT taken into account in the computation.
- Then, the hardness number can be read directly from the scale.



Principle of Rockwell hardness testing.

ROCKWELL STANDARDS TESTS

Hardness Scale	Rockwell A	Rockwell B	Rockwell C	Rockwell F
Load applied	60kg	100 kg	150 kg	60kg
Indenter	Diamond cone 120 ^{0}	Steel Ball 1/16 inch dia	Diamond cone 120 ^{0}	Steel Ball 1/16 inch dia

Rockwell Hardness Test

Scale C

HARDNESS TESTING METHOD COMPARISON

Method	Time	Accuracy	Cost
Brinell	※※※	※※※	※※※
Vickers	※※※※	※※※※	※※※※
Rockwell	※※	※※※※	※※※