# Unit-III
# Heat Treatment

# Introduction

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- The properties of metals and alloys can be changed as desired by the heat treatment process
- Heat treatment is the controlled heating and cooling of metals for the purpose of altering their properties

# Heat Treatment - Definition

- It is an operation (or) combination of operations involving heating and cooling of metal/alloy in solid state to obtain desirable properties

# Brain Teaser

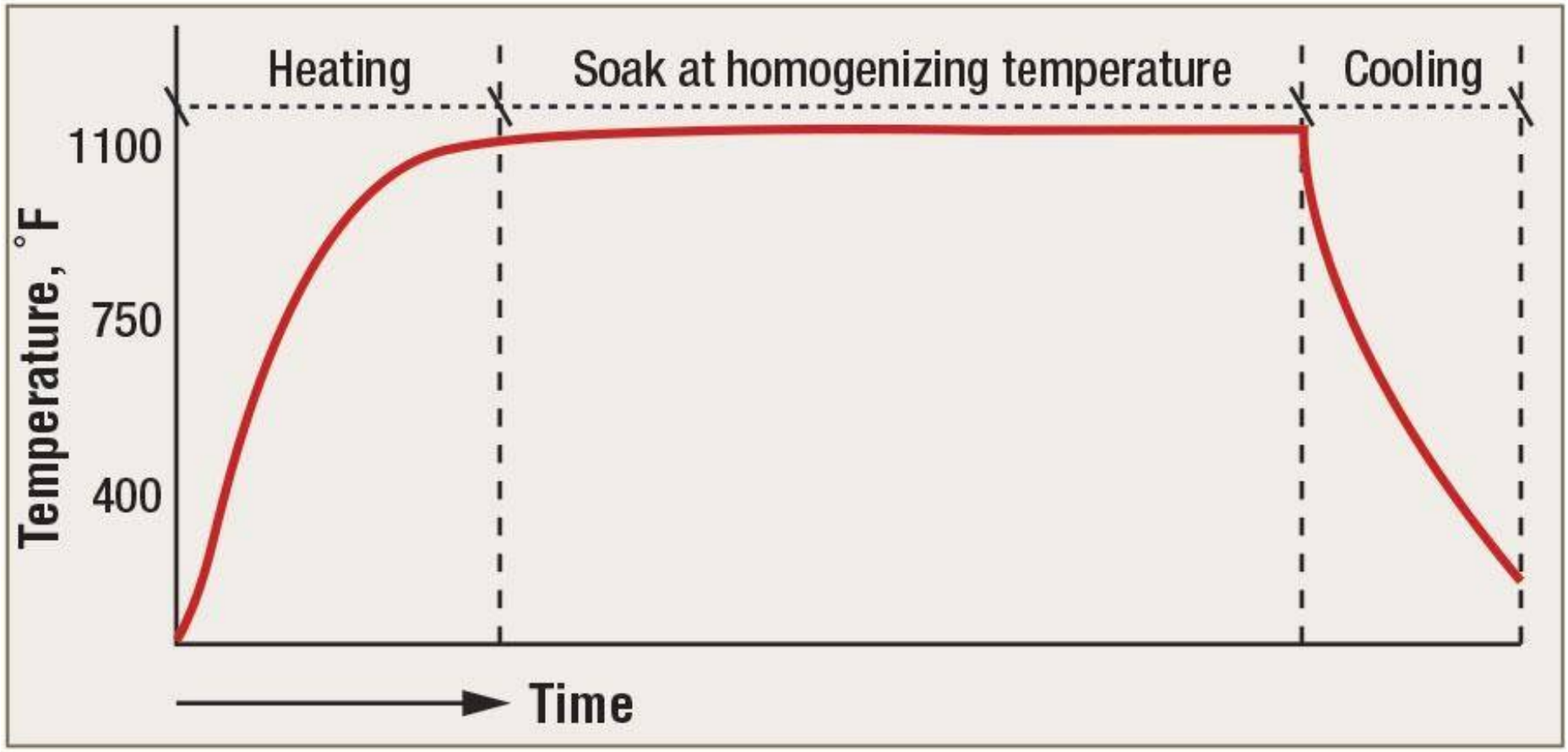
Look at the chart and say the COLOR not the word

YELLOW BLUE ORANGE
BLACK RED GREEN
PURPLE YELLOW RED
ORANGE GREEN BLACK
BLUE RED PURPLE
GREEN BLUE ORANGE

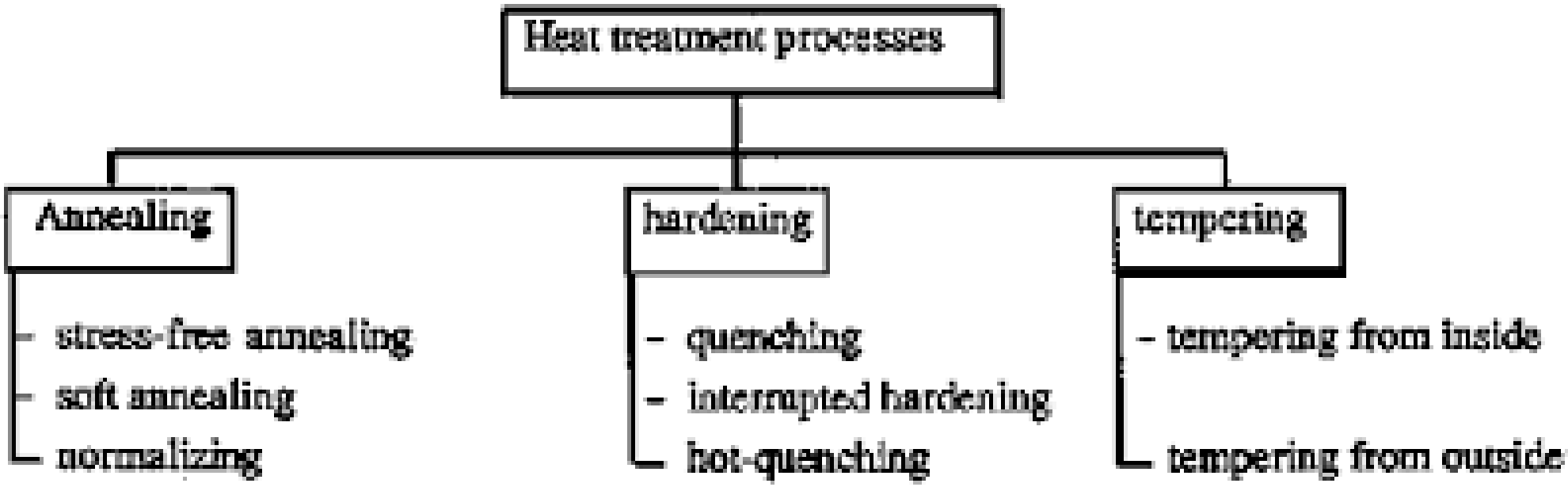
**Left - Right Conflict**

Your right brain tries to say the color but your left brain insists on reading the word

# Stages of Heat Treatment



# Types of Heat Treatment processes



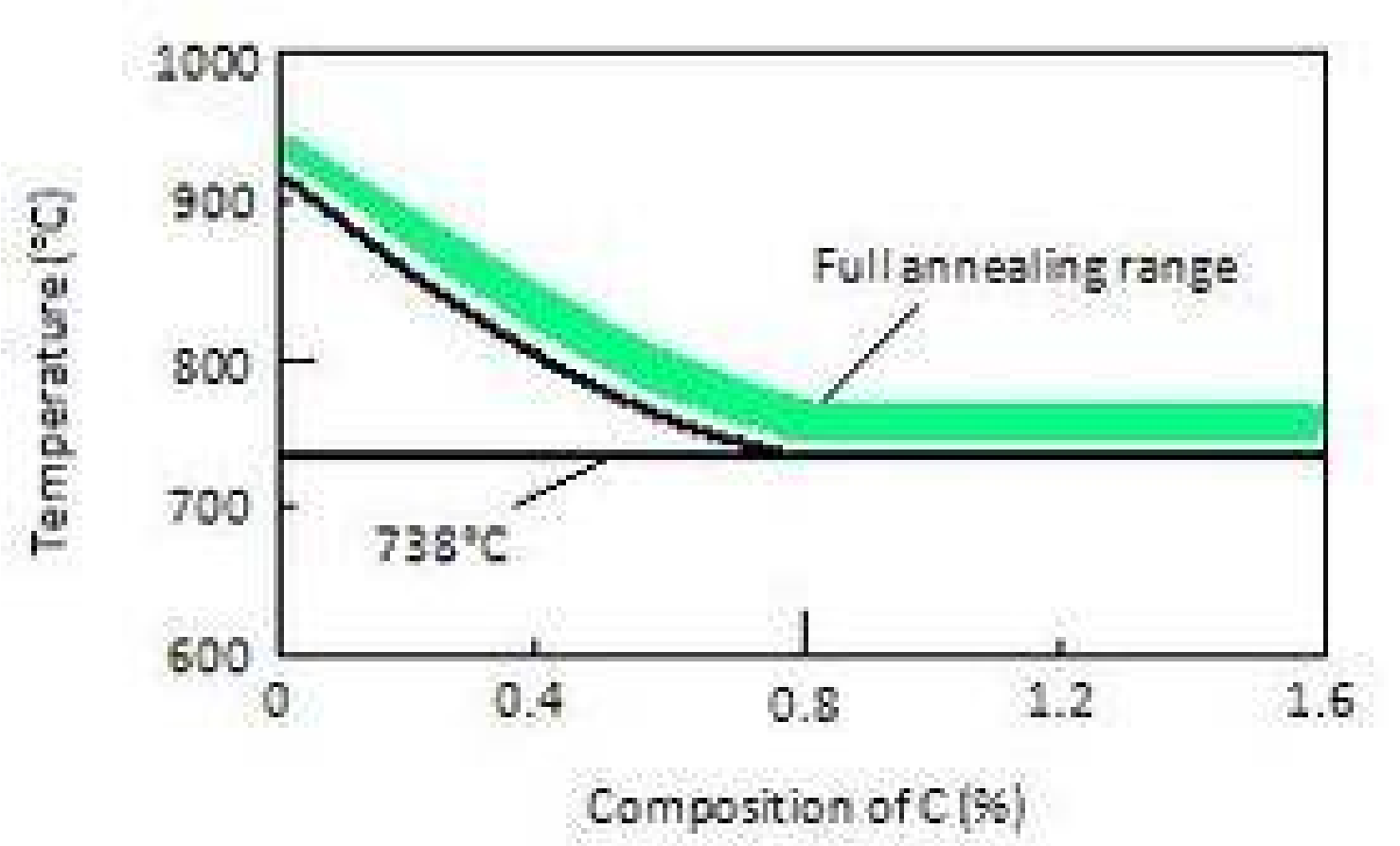
# Annealing

- It is a heat treatment process in which a material is exposed to an elevated temperature for an extended time period and then slowly cooled
- It is one of the most widely used processes in the heat treatment of iron and steel

# Types of Annealing

1) Full Annealing
2) Process Annealing
3) Stress relief Annealing
4) Recrystallization Annealing
5) Spheroidise Annealing

# Full Annealing



# Full Annealing

- Actual definition of annealing describes only the full annealing

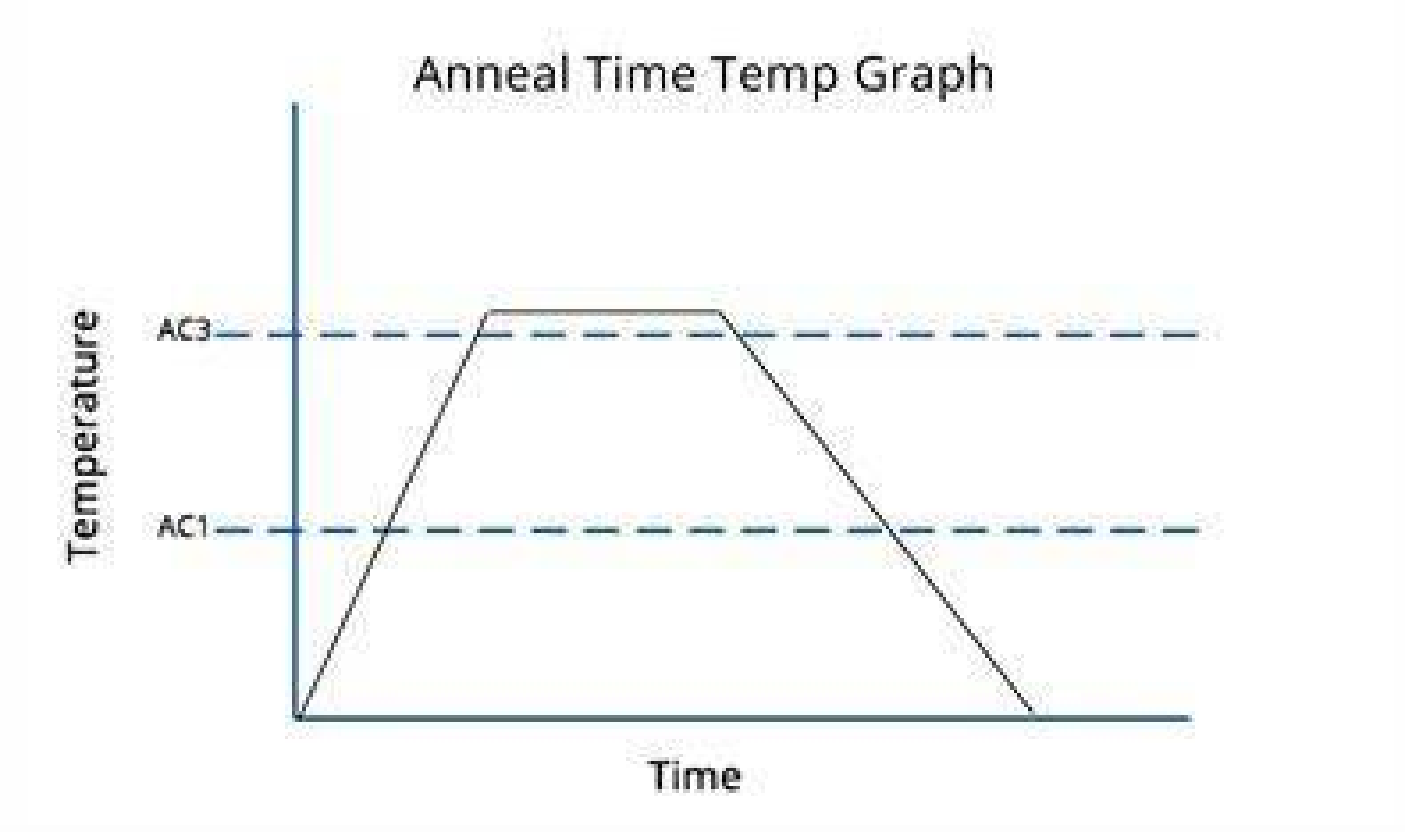
- Full annealing consists of heating the steel to a temperature at or near the critical point, holding there for a time period and then allowing it to cool slowly in the furnace itself
- Temp: 723°C to 910°C

**Objectives :**

- To soften the metal
- To refine its crystalline structure
- To relieve the stress

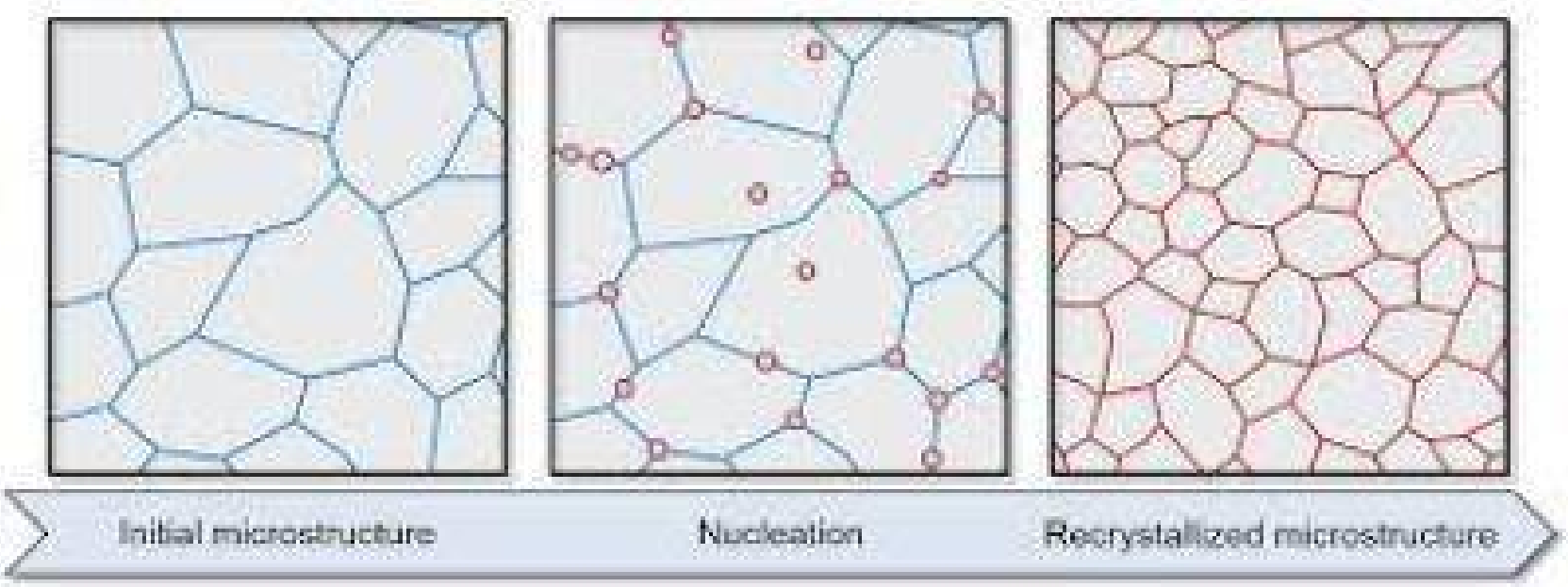
# Stress relief Annealing

- It’s a heat treatment process that is employed to eliminate internal residual stresses induced by casting, quenching, machining, cold working , welding etc.



# Recrystallization Annealing

- **Recrystallization:** It is a process by which distorted grains of cold worked metal are replaced by new, strain free grains during heating above a specific minimum temperature.
- **Recrystallization temperature:** the temperature at which crystallization takes place



# Spheroidizing Annealing

- Medium and high carbon steels having a microstructure containing even coarse pearlite is too hard to conveniently machine or plastically deform.

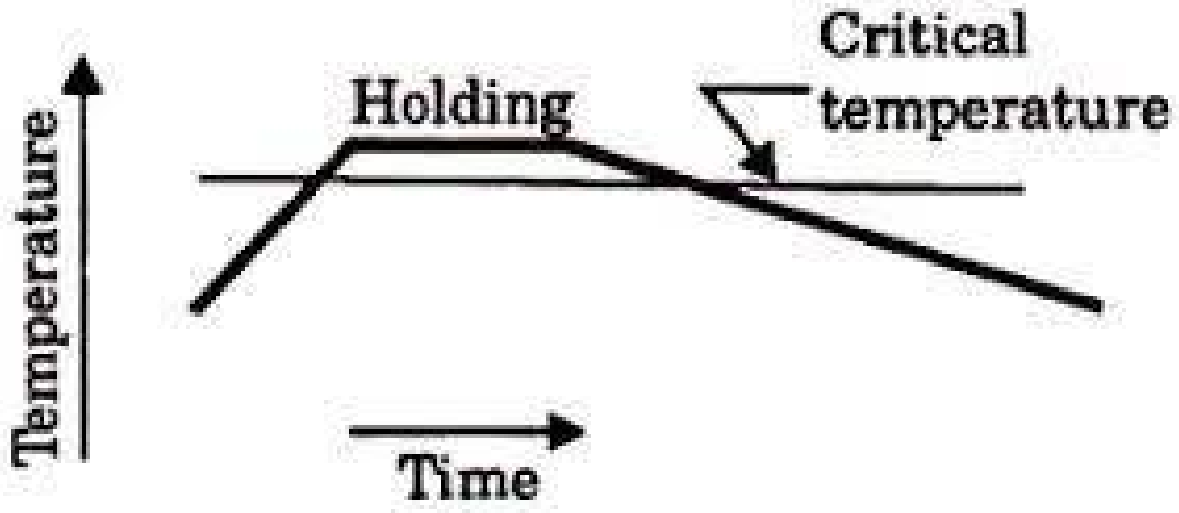
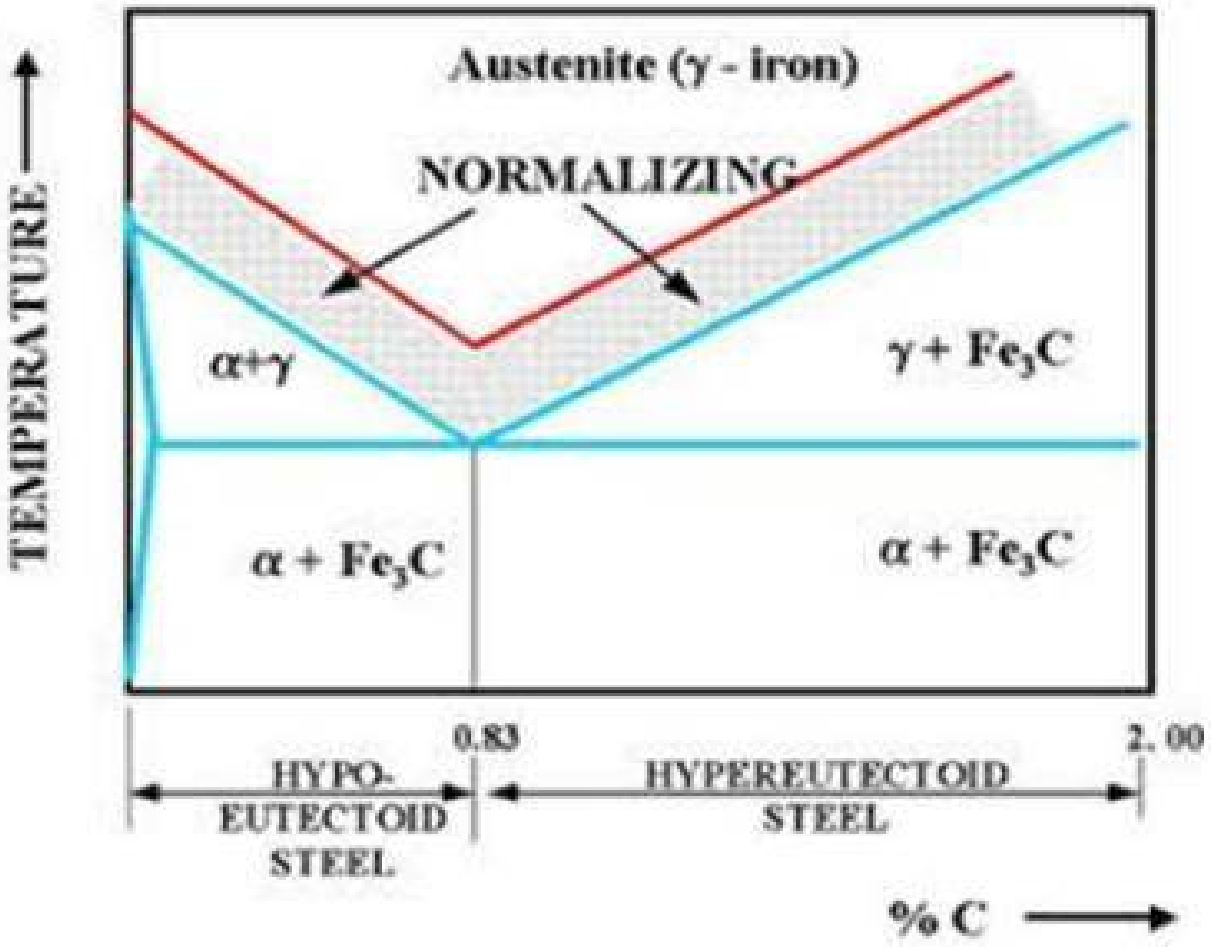



*Fig. 5.20. Spheroidise annealing.*

# Normalising

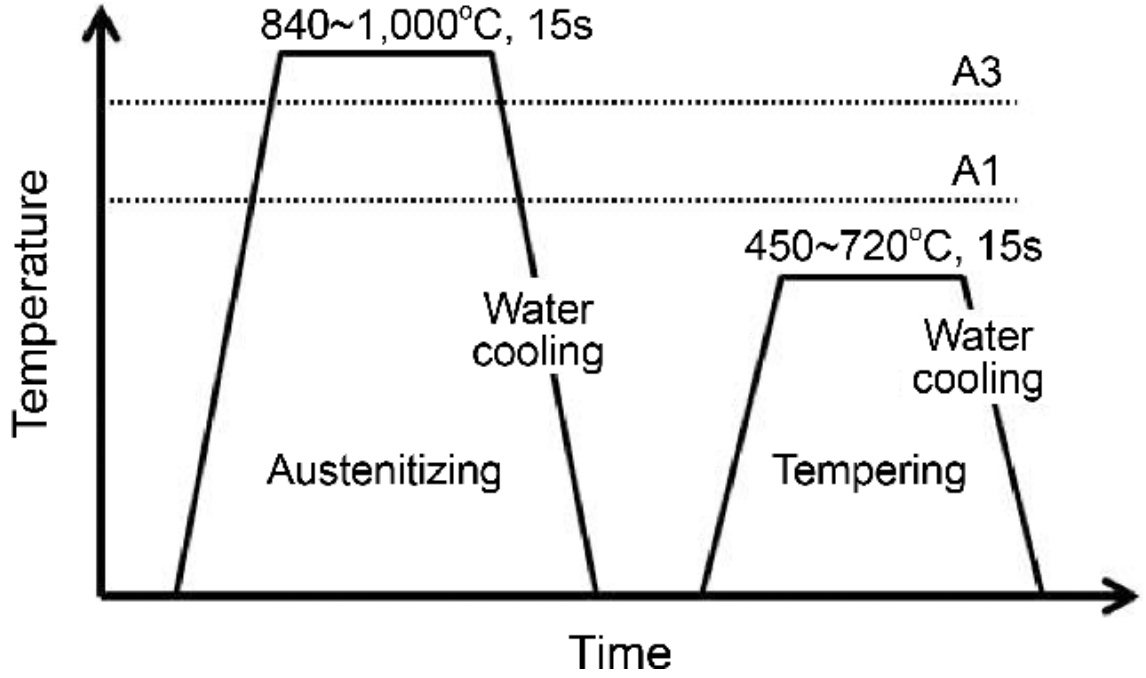
- Normalising is similar to full annealing, but cooling is established in air rather than in the furnace
- Full annealing is an expensive and time consuming process. when a reasonably soft and ductile material is required and cost savings are desired, then the normalizing process is used instead of full annealing
- Steel is heated to 50°C to 60°C above its upper critical temperature

# Normalising



# Quenching

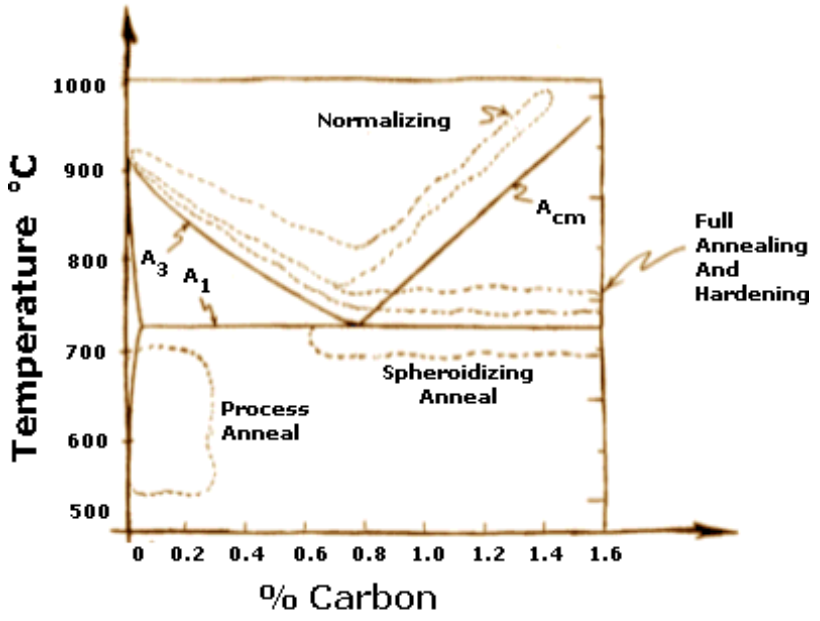
- Its an accelerated cooling
- The cooling can be accomplished by contact with the a quenching medium which may be a gas , liquid or solid
- Most of the times liquid quenching media is widely used to achieve rapid cooling



# Hardening (By Quenching)

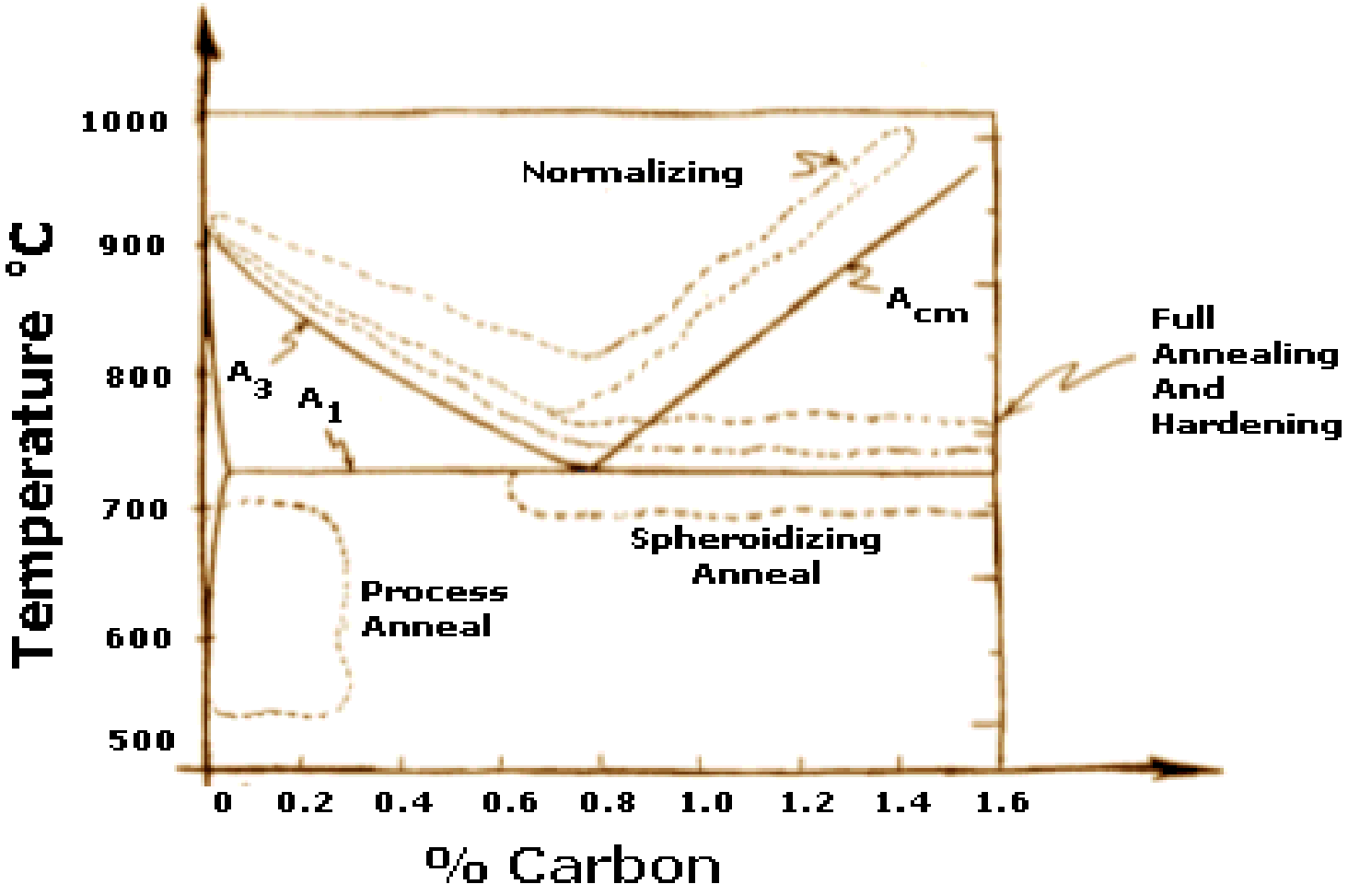
## Operation:

- **Heating**: the steel to be heat treated is heated slowly in a furnace to 30°C to 50°C above the upper critical temperature
- **Soaking**: The heated steel is held at this temperature for considerable length of time



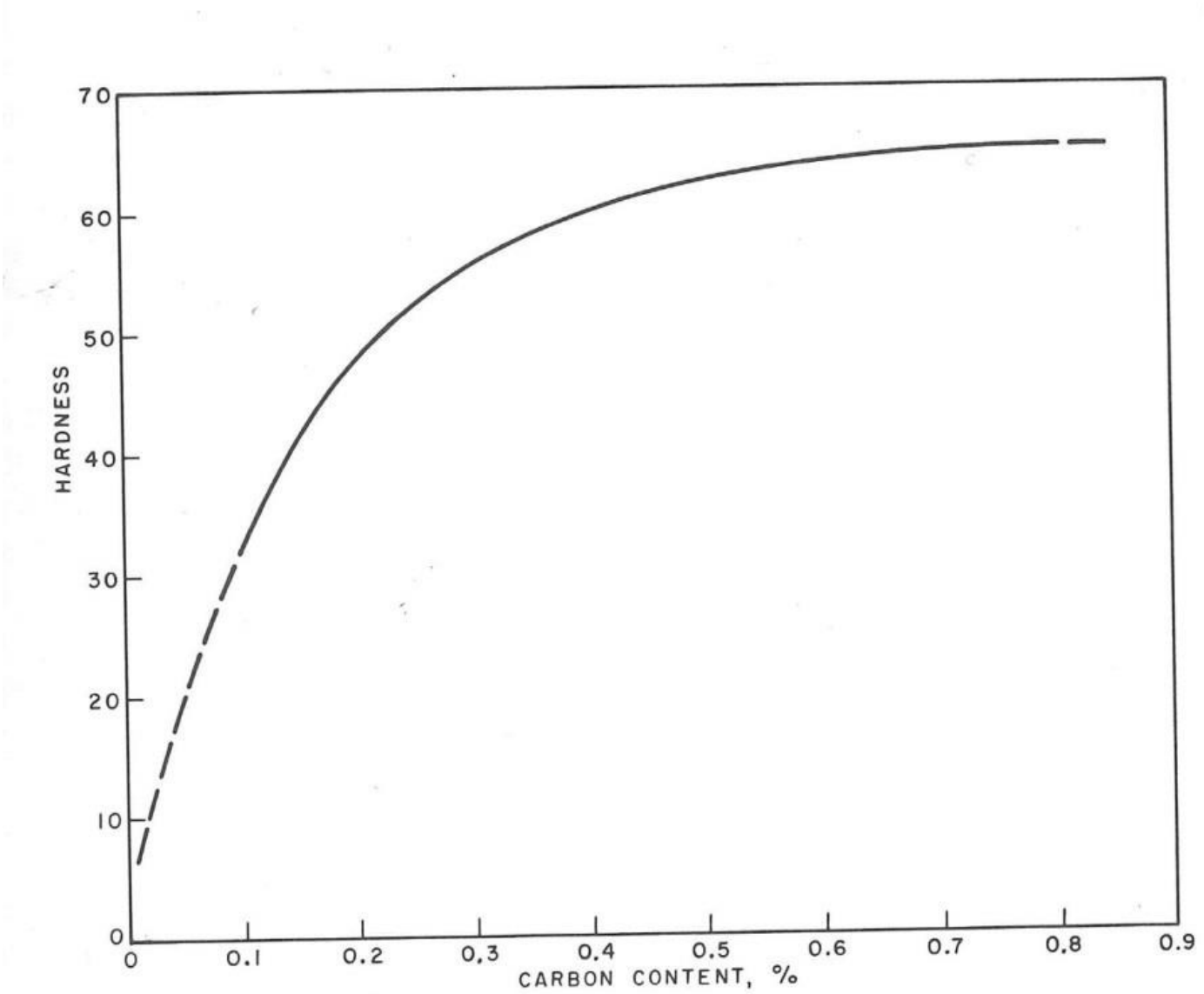

HEAT TREATMENT PROCESS

# Hardening (By Quenching)

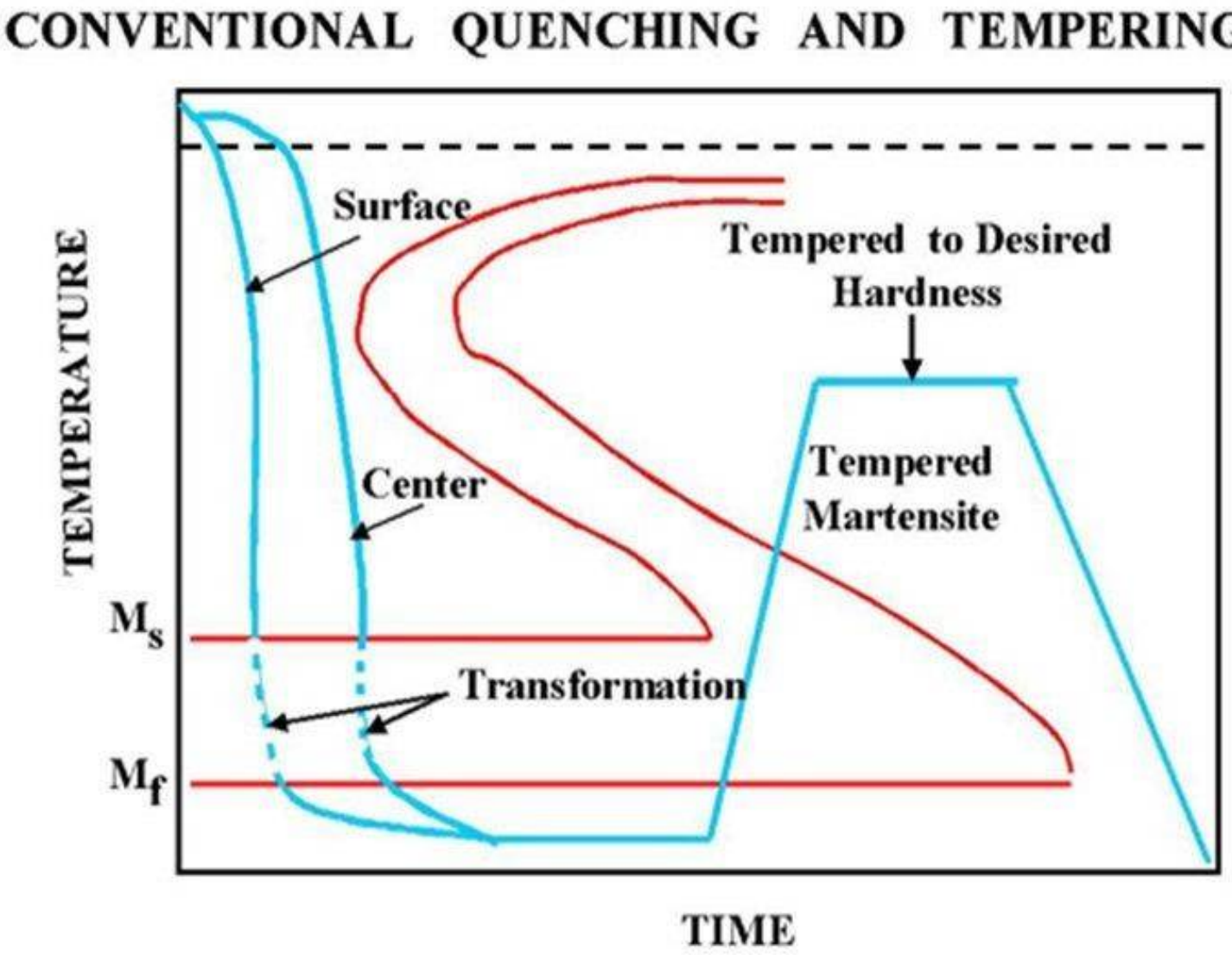


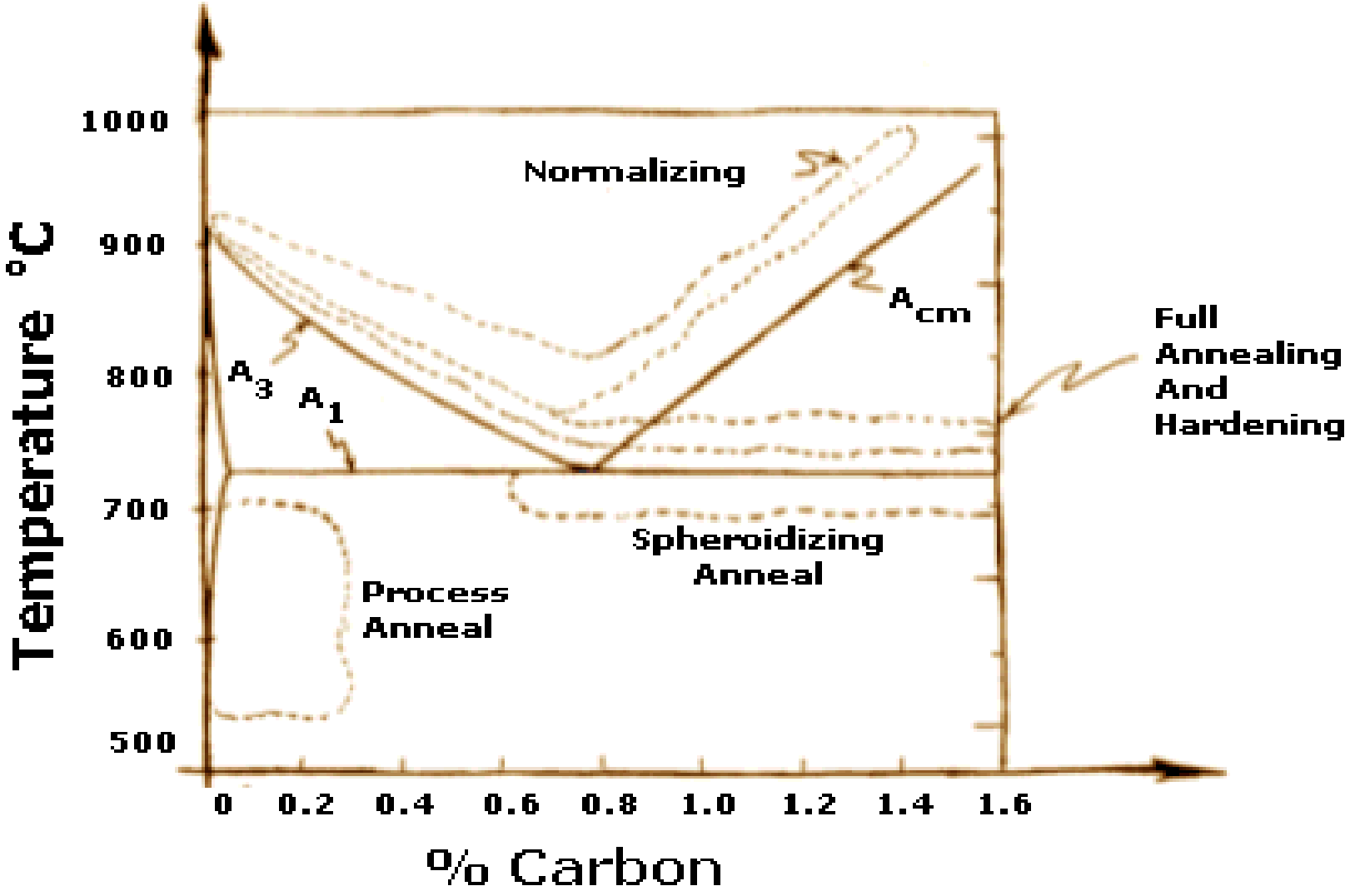

HEAT TREATMENT PROCESS

# Factors affecting the Hardness



# Tempering


CONVENTIONAL QUENCHING AND TEMPERING
TEMPERATURE
Surface
Center
Tempered to Desired Hardness
Tempered Martensite
$M_s$
Transformation
$M_f$
TIME



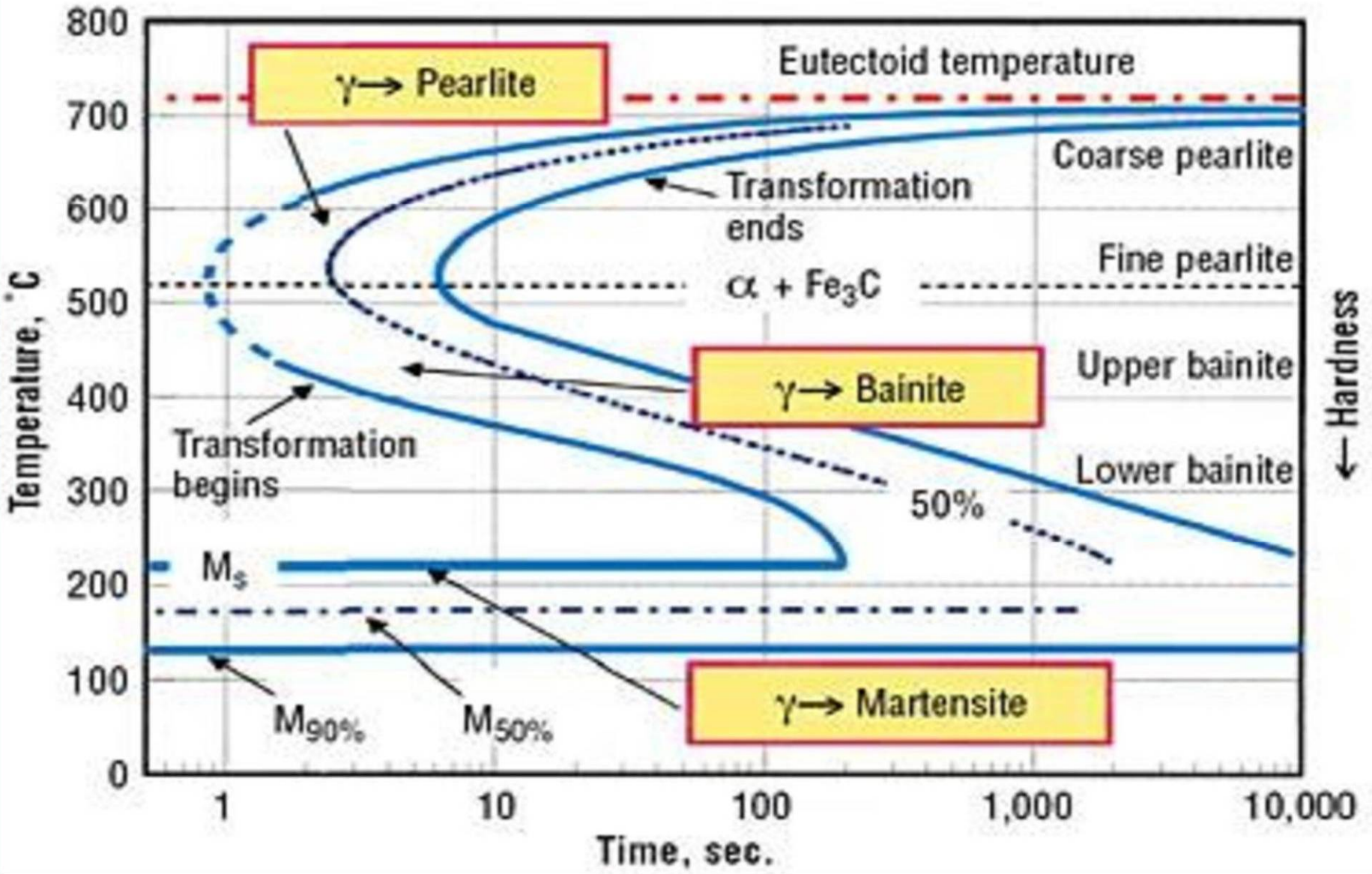

HEAT TREATMENT PROCESS

# TTT Diagram

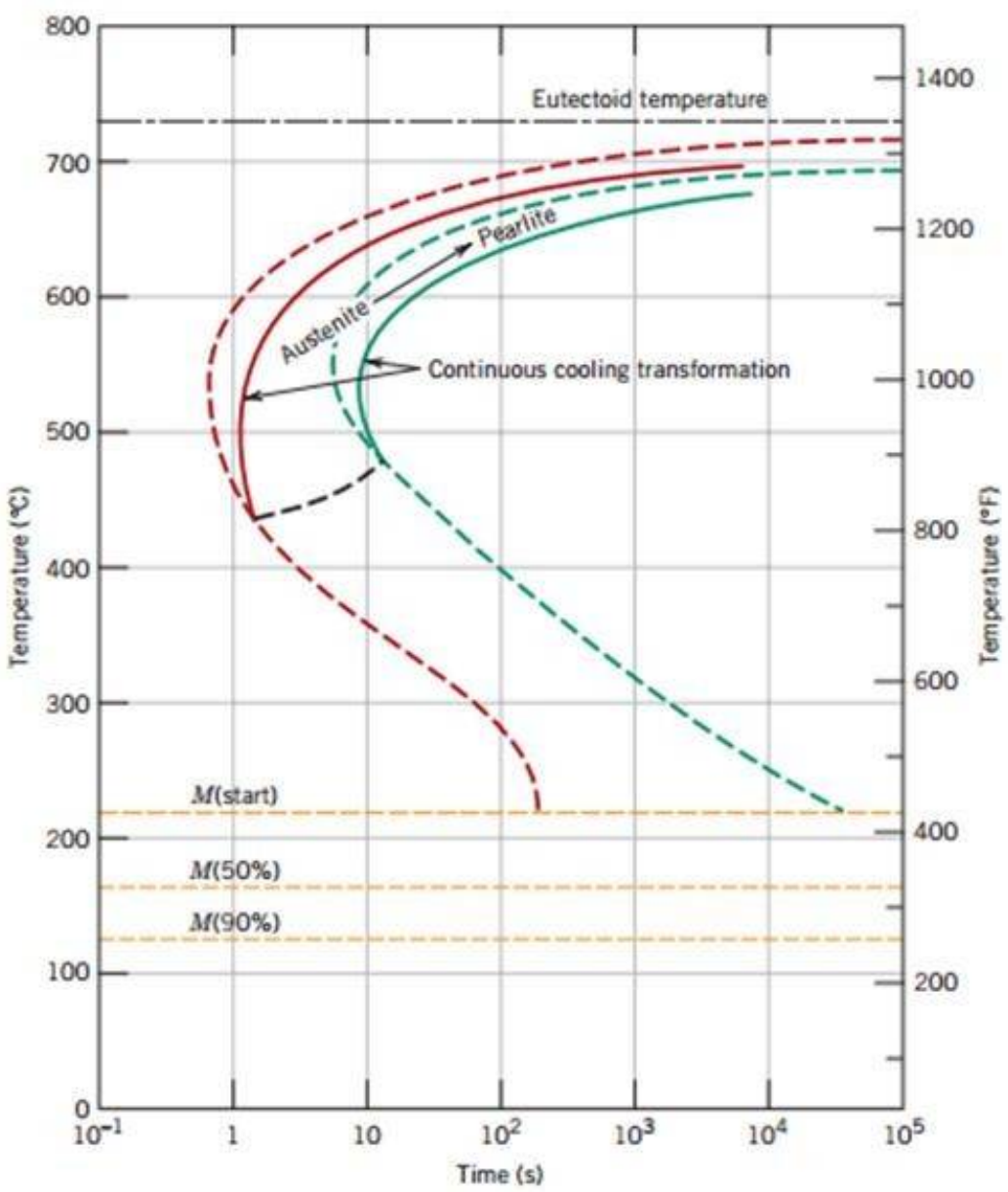
- Its also called as ***Isothermal Transformation (IT) diagram***
- It's a tool used by heat treaters to predict quenching reactions in steels.
- Because of the shape, it is also called ***S Curves*** or ***C Curves.***
- Sometimes TTT diagram is also known as ***Bain's Curve.***
- Temperature Vs Time diagram
- Temperature is constant during transformation
- Its is used to determine when transformations begin and end for an isothermal heat treatment of a previously austenitized alloy

- **Austenitizing heat treatment is heating a steel above the critical temperature, holding for a period of time long enough for transformation to occur.**

# TTT DIAGRAM


800
700
600
500
400
300
200
100
0
Temperature, °C
γ→ Pearlite
Eutectoid temperature
Coarse pearlite
Transformation ends
Fine pearlite
α + Fe3C
γ→ Bainite
Upper bainite
Transformation begins
Lower bainite
50%
Ms
M90%
M50%
γ→ Martensite
Hardness
1
10
100
1,000
10,000
Time, sec.

# CCT Diagram


Eutectoid temperature
Austenite
Pearlite
Continuous cooling transformation
M(start)
M(50%)
M(90%)
Temperature (°C)
Temperature (°F)
Time (s)
800
700
600
500
400
300
200
100
0
1400
1200
1000
800
600
400
200
10⁻¹
1
10
10²
10³
10⁴
10⁵

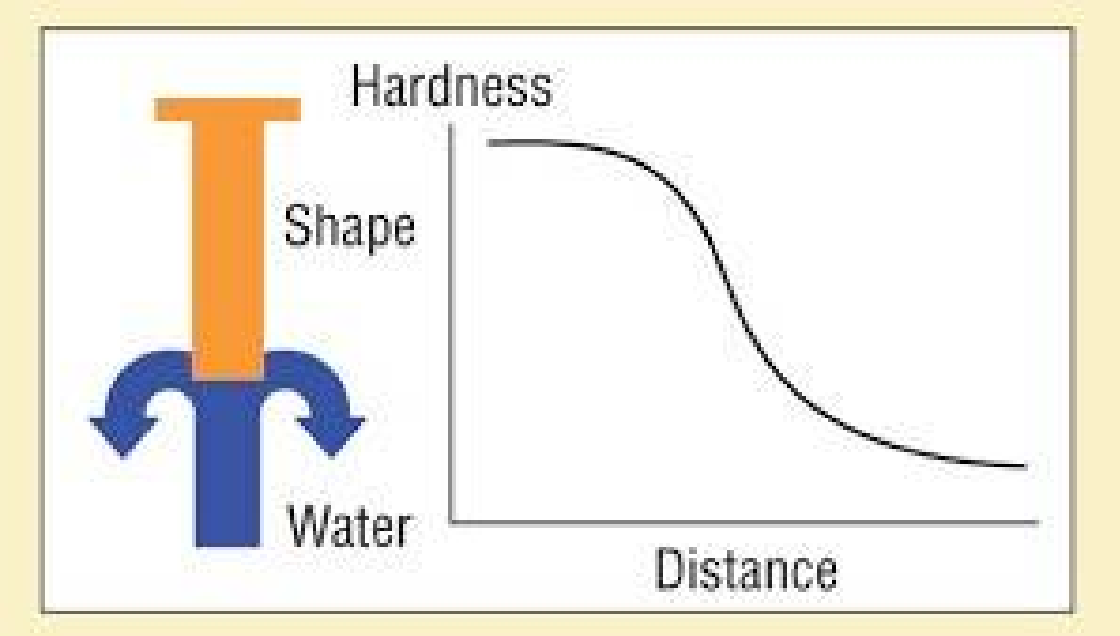
# Critical cooling rate

- The slowest rate of cooling of austenite that will result in 100% martensite transformation is known as critical cooling rate
- Critical rate is most important in hardening. In order to obtain 100% martensitic structure on hardening, the cooling must be much higher than the critical cooling rate

# Hardenability

- The property which determines the depth and distribution of hardness induced by quenching from the austenitic condition

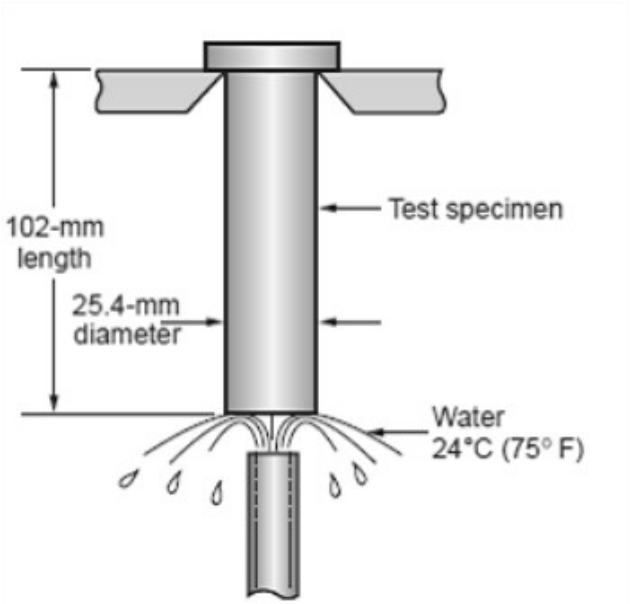
- Hardenability is a measure of ease of forming martensite



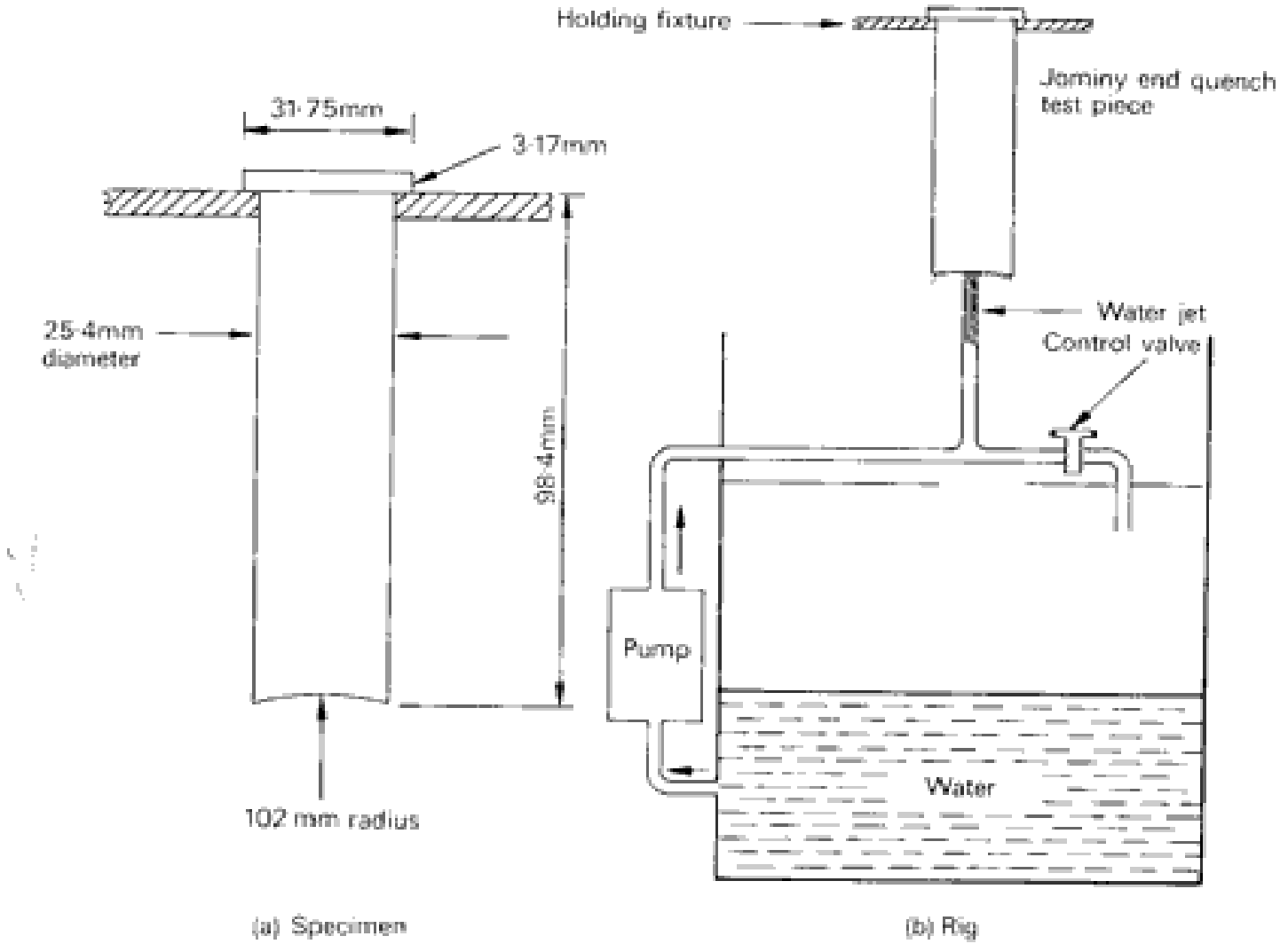
# Specimen

- A bar of steel to be tested is machines to give a cylinder shape

- ✓ Long – 102 mm (4 inch)
- ✓ Diameter with an upper lip – 25.4 mm (1 inch)




# Jominy End Quench test



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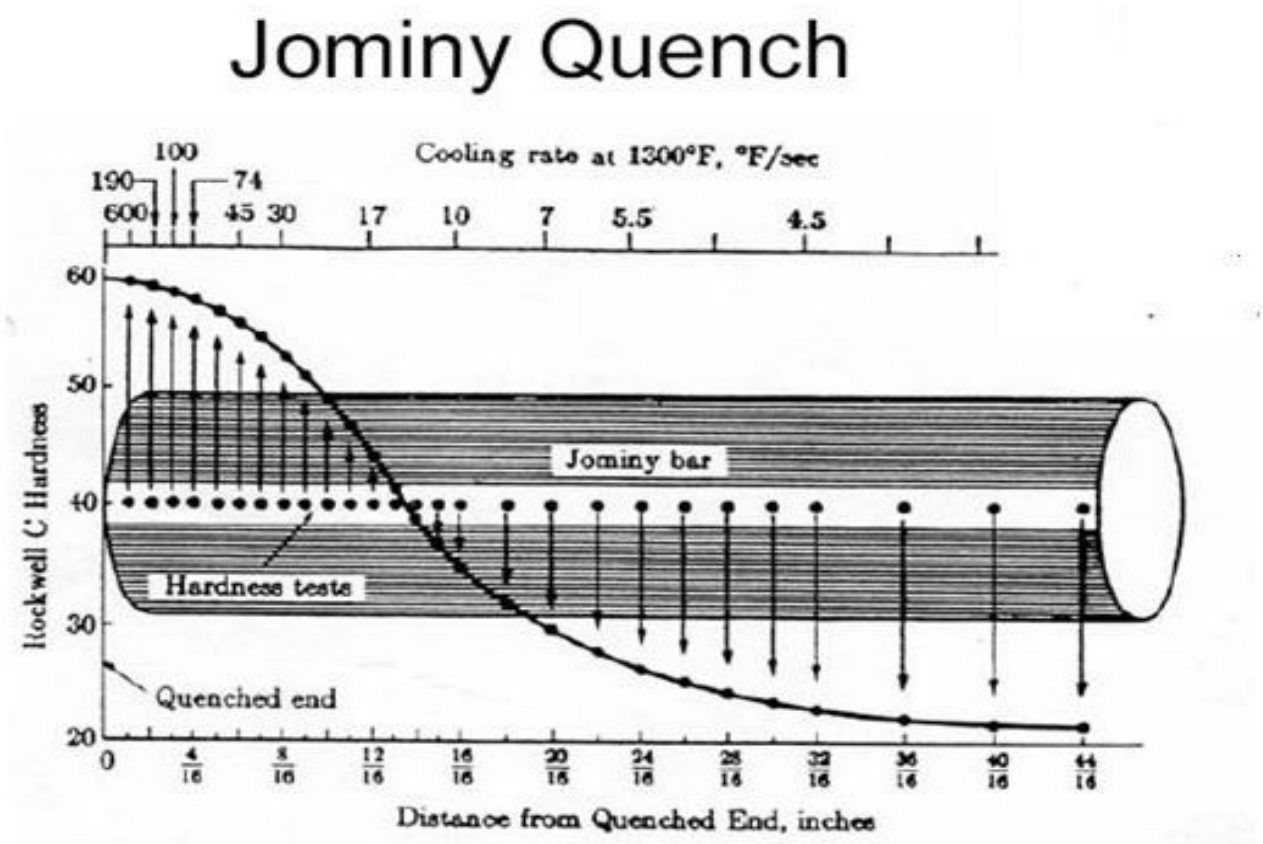



**Greatest hardness at the quenched end**

# Case Hardening (surface Hardening)

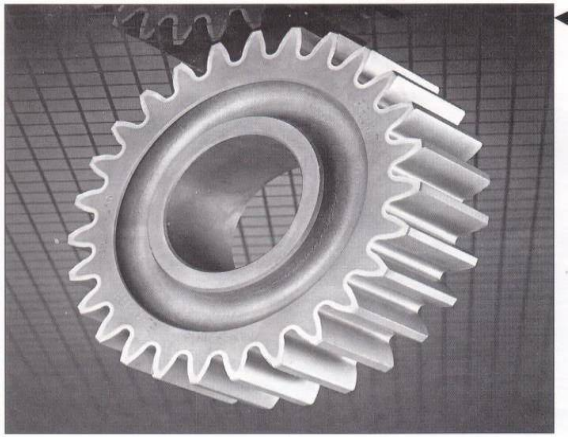
- It is desirable to that the surface of the components should have high hardness, while the inside (or) core should be soft. The treatment given to steels to achieve this are called surface heat treatments (or) Surface hardening

- Required soft and ductile for shock resistance
- Surface hardens – for resisting wear and tear

# Case Hardening (surface Hardening)

Parts that are case hardened are

- Gears
- Cams
- Bearing balls
- Universal joints





# Types of Surface heat treatments

- Diffusion methods
  - ✓ Carburizing
  - ✓ Nitriding
  - ✓ Cyaniding
  - ✓ Carbonitriding
- Thermal Methods
  - ✓ Flame hardening
  - ✓ Induction Hardening

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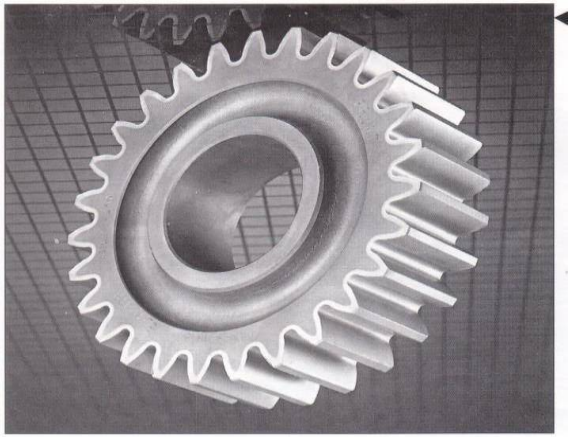



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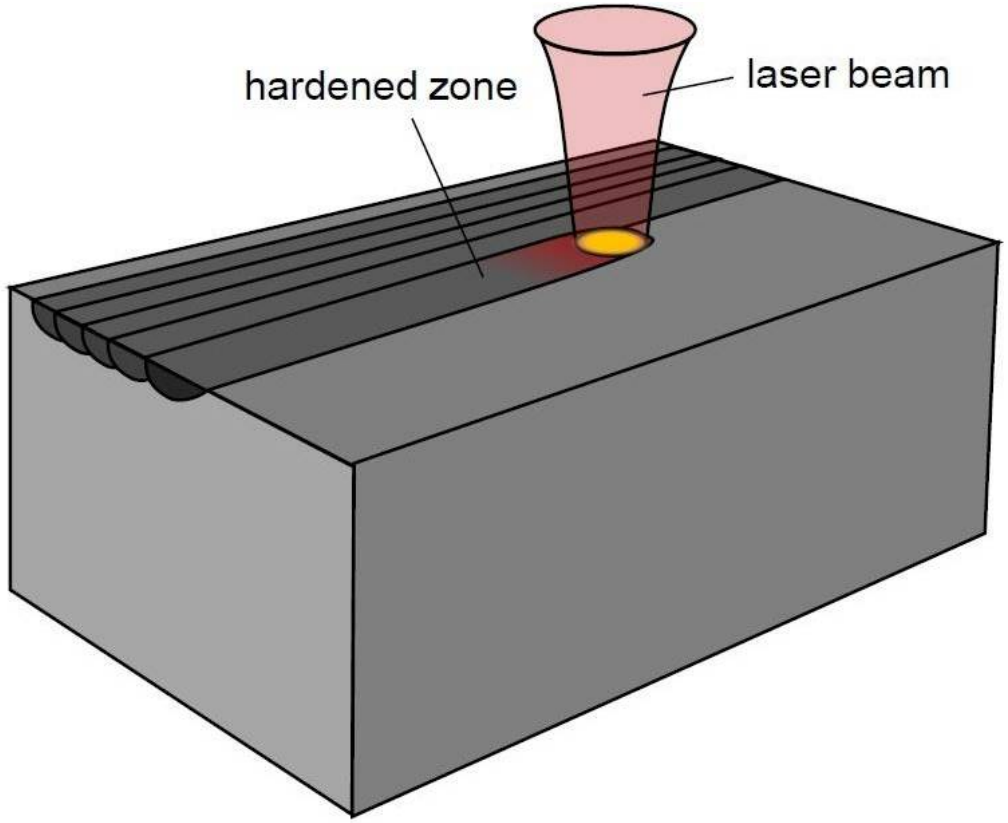
# Diffusion Surface Hardening Treatments

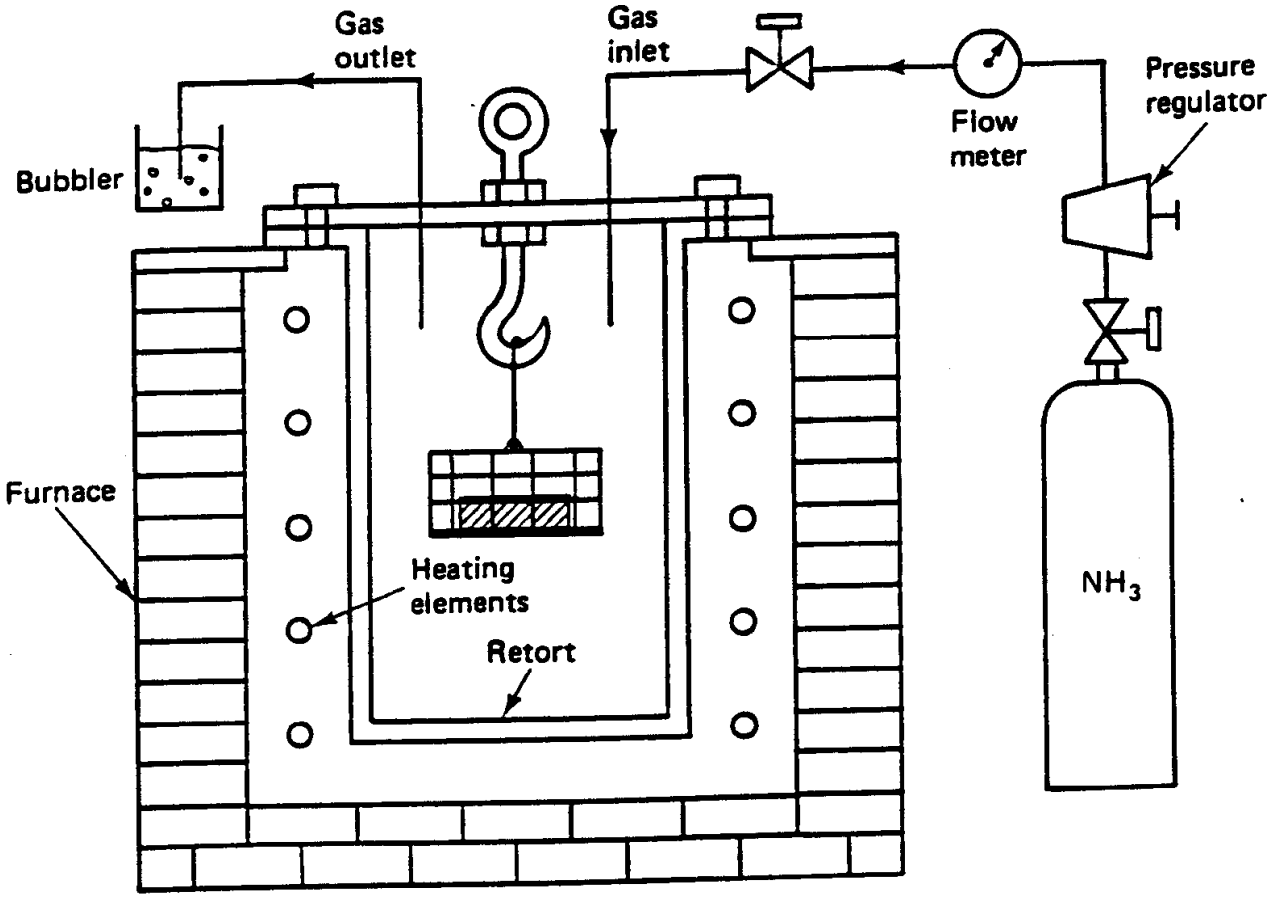
- Hardness of the surface is improved by diffusion interstitial elements like carbon, nitrogen or both into surface of steel components



# Nitriding

- Another process by which a case of hardened steel can be achieved
- In Nitriding, the steel piece is heated in a furnace between 500 – 600°C and at the same time is exposed to ammonia gas (NH3)
- The heat from the furnace causes the ammonia to decompose into hydrogen (H2) and nitrogen (N2)
- Nitrogen reacts with elements in the steel to form nitrides in the outer layer of the steel providing high hardness and wear resistance
- Nitriding times range between 1–100 hours depending on steel composition and depth of hardening desired

# Nitriding

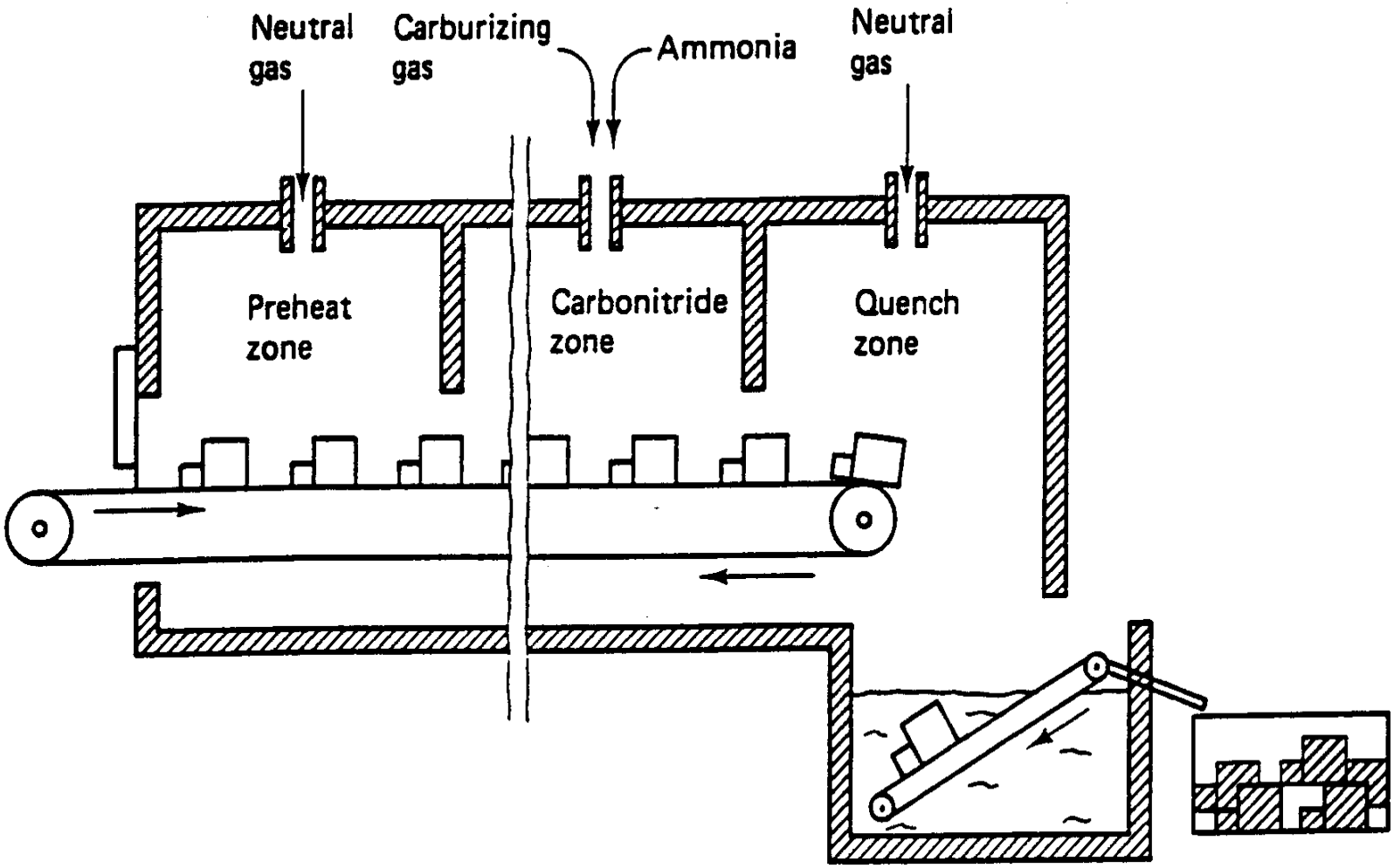



$$2NH_3 \rightarrow 2N + 3H_2$$

# Carbonitriding

- This process involves both the diffusion of C and N into the steel surface
- Nitriding is performed in a gas atmosphere furnace using a carburizing gas such as propane or methane (source of C) mixed with several vol % of ammonia (NH3) (source of N)
- Carbonitriding is performed at temperatures above the UCT (700 – 800°C)
- Quenching is done in a gas which is not as severe as water quench (the result is less distortion on the material to be treated).

# Carbonitriding



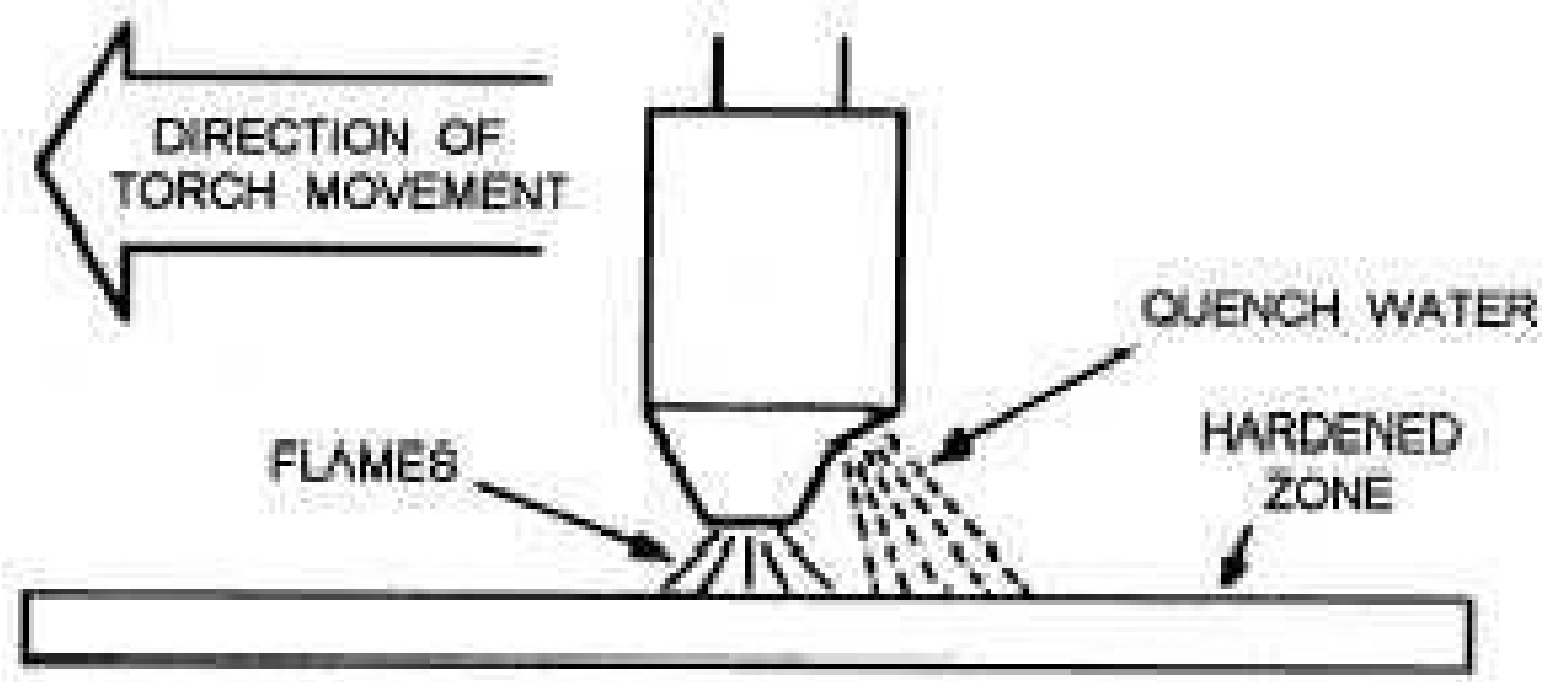
# Thermal Methods – Surface Hardening

- Flame Hardening
- Induction hardening

Thermal Methods is applied because of one following reasons:

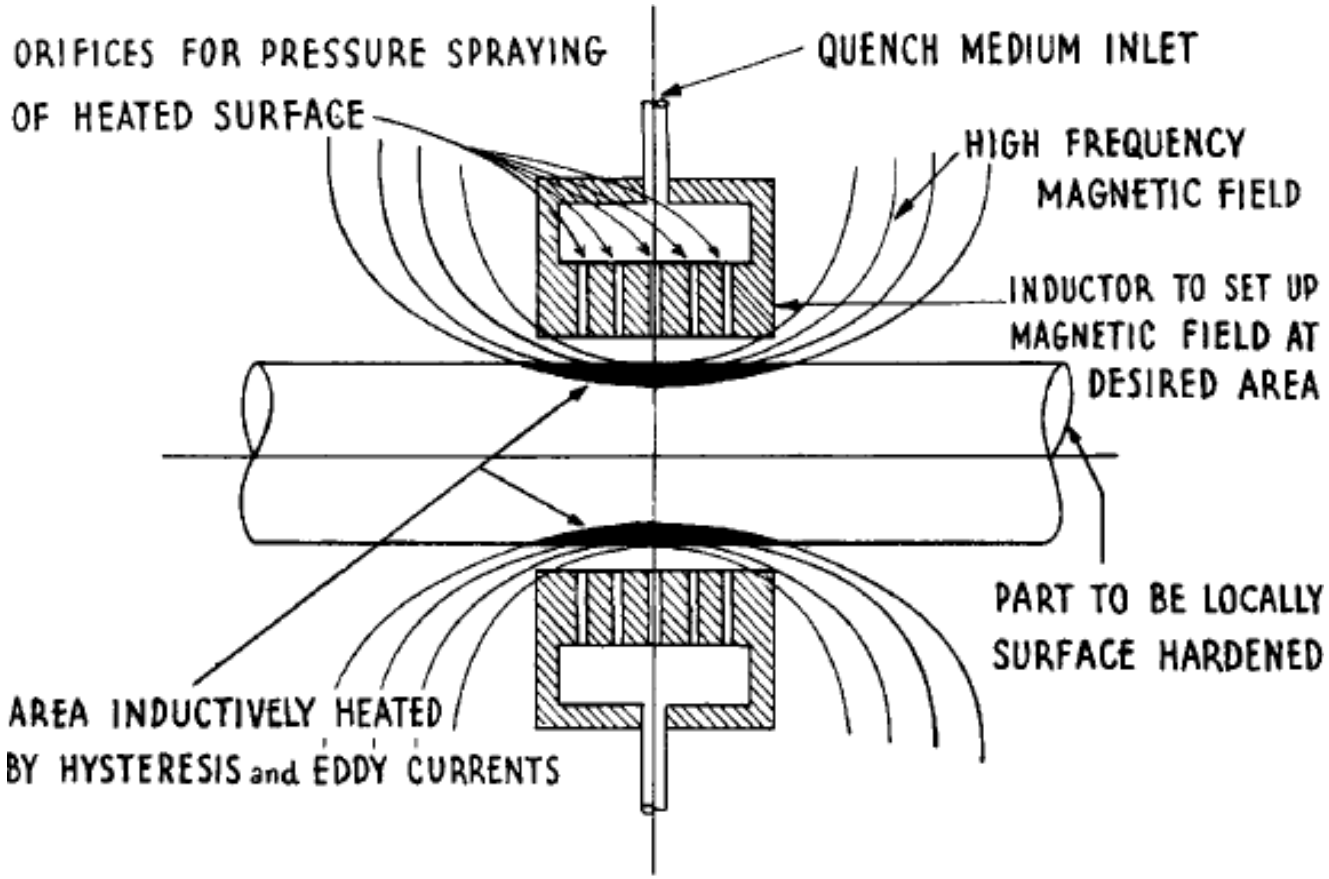
1. Only a small segment, section, or area of the part needs to be heat-treated. Typical examples are ends of valve stems and push rods, and the wearing surfaces of cams and levers
2. Better dimensional accuracy of a heat-treated part
3. Overall cost savings by using inexpensive steels to have the wear properties of alloyed steels.

# Flame Hardening




Flame Hardening

# Induction Hardening




● Schematic diagram of piece being inductively heated. Note limited effective magnetic field.

**Induction Hardening**