Heat Treatment

Tempering:

❖ Reheating a quenched – hardened or a normalized Ferrous alloys to a Temp. below the transformation range & then cooling at any rate desired.

❖ The purpose of Tempering is to:
- → Relief residual stress.
- → Improve ductility attained at the sacrifice of (R_c) of Steel see fig. (15).
- → Improve Toughness.

❖ Certain alloys exhibit a phenomenon Known as (Temper Brittleness) which is a loss of a notched – bar toughness when tempered in the range of (1000 - 1250 ºf) followed by relating slow cooling.

(Mn, P, Cr) are promote susceptibility Temper Brittleness. ↑

(Mo) have a retarding effect of Temper Brittleness. ↓

❖ Transformation product of (γ) & (M) for (0.8% C) steel is shown in fig. (16) below.

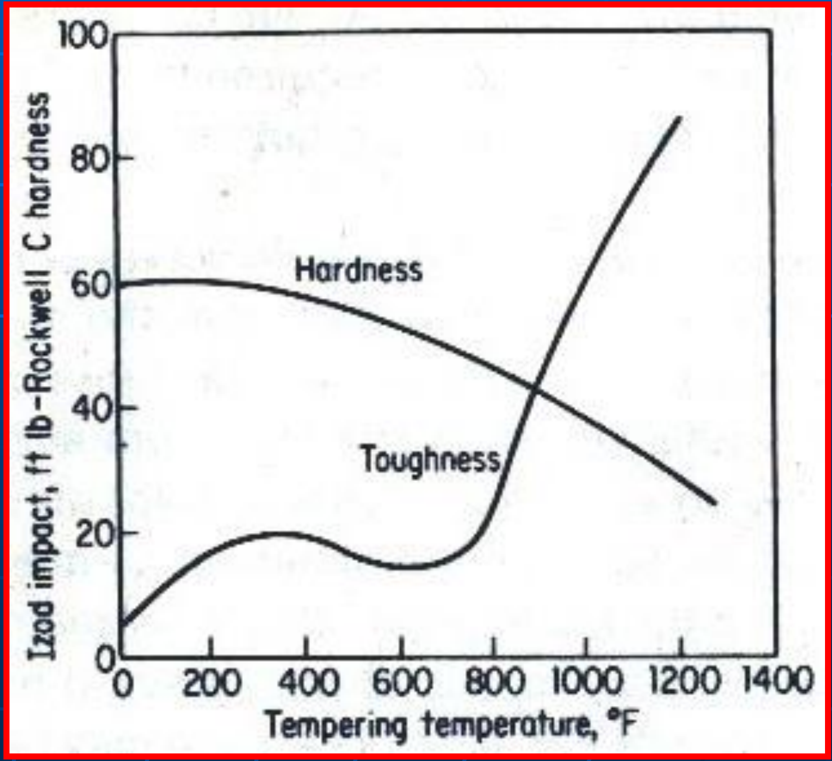
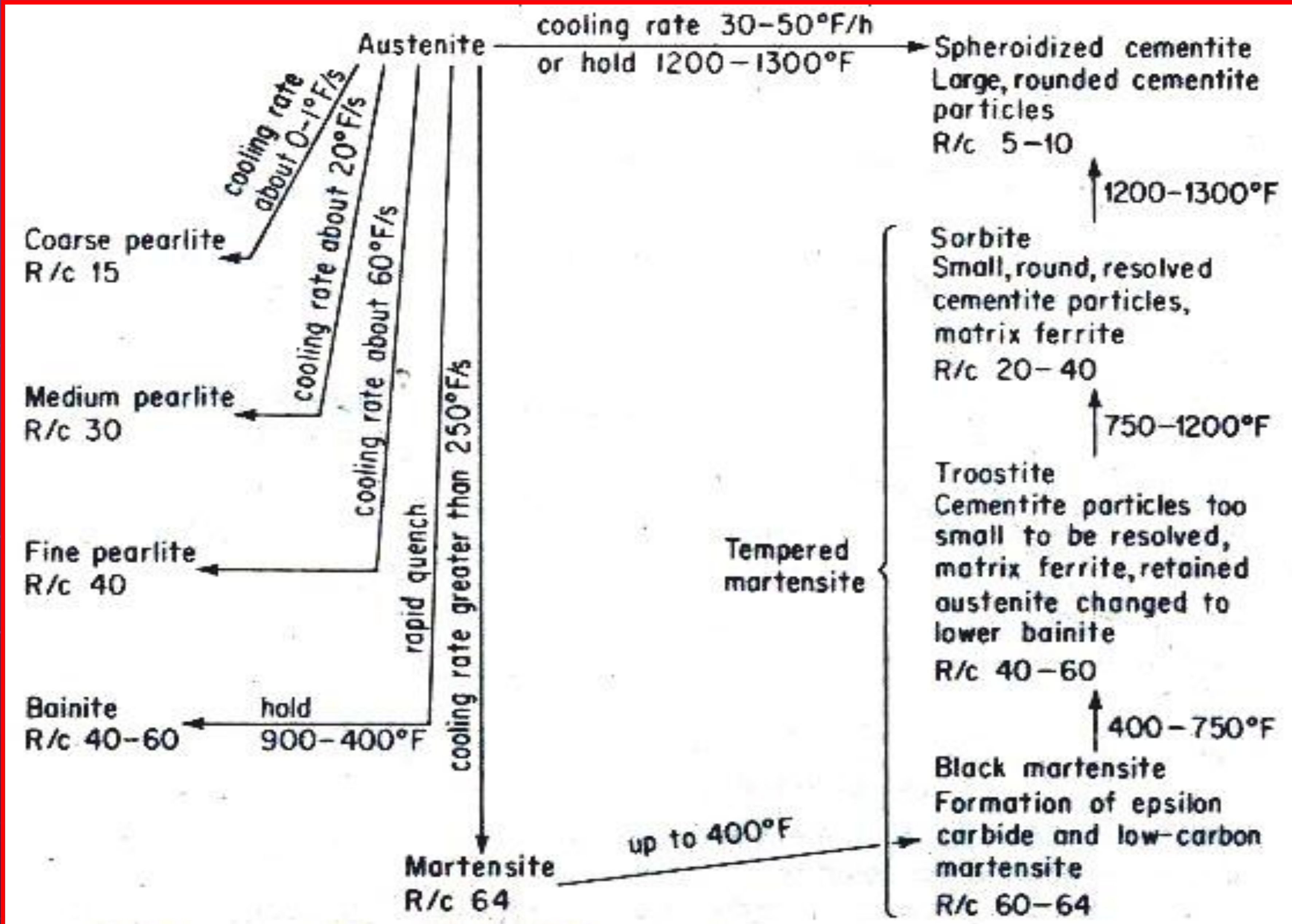


Fig. (15)



Austenite
cooling rate 30-50°F/h
or hold 1200-1300°F
Spheroidized cementite
Large, rounded cementite particles
R/c 5-10
1200-1300°F
cooling rate about 0-1°F/s
cooling rate about 20°F/s
cooling rate about 60°F/s
rapid quench
cooling rate greater than 250°F/s
Coarse pearlite
R/c 15
Medium pearlite
R/c 30
Fine pearlite
R/c 40
Bainite
R/c 40-60
hold
900-400°F
Sorbite
Small, round, resolved cementite particles, matrix ferrite
R/c 20-40
750-1200°F
Troostite
Cementite particles too small to be resolved, matrix ferrite, retained austenite changed to lower bainite
R/c 40-60
400-750°F
Tempered martensite
Black martensite
Formation of epsilon carbide and low-carbon martensite
R/c 60-64
up to 400°F
Martensite
R/c 64

Fig. (16)

Austempering:

❖ This is a heat – treating process developed from the I. T. diagram to obtain structure which is 100% Bainite (B).

❖ It is accomplished by:

1 – heating the part to (γ) Temp. > (1400 ^{o}f) followed by cooling rapidly in a salt – bath (400 – 800 ^{o}f).

2 – The piece is left for a long time until transformation to Bainite is completed.

3 – No reheating is involved as in Tempering.

❖ Fig. (17) shows Austempering.

❖ The advantages of Austempering are:

1 – High reduction of area.

2 – High resistance to impact (as compared with (Quench + Temper).

3 – Greater ductility & toughness along with high hardness.

4 – Less distortion & less danger of Quench Crack.

❖ Limitation of Austempering is section of < ½ in. thick is used.

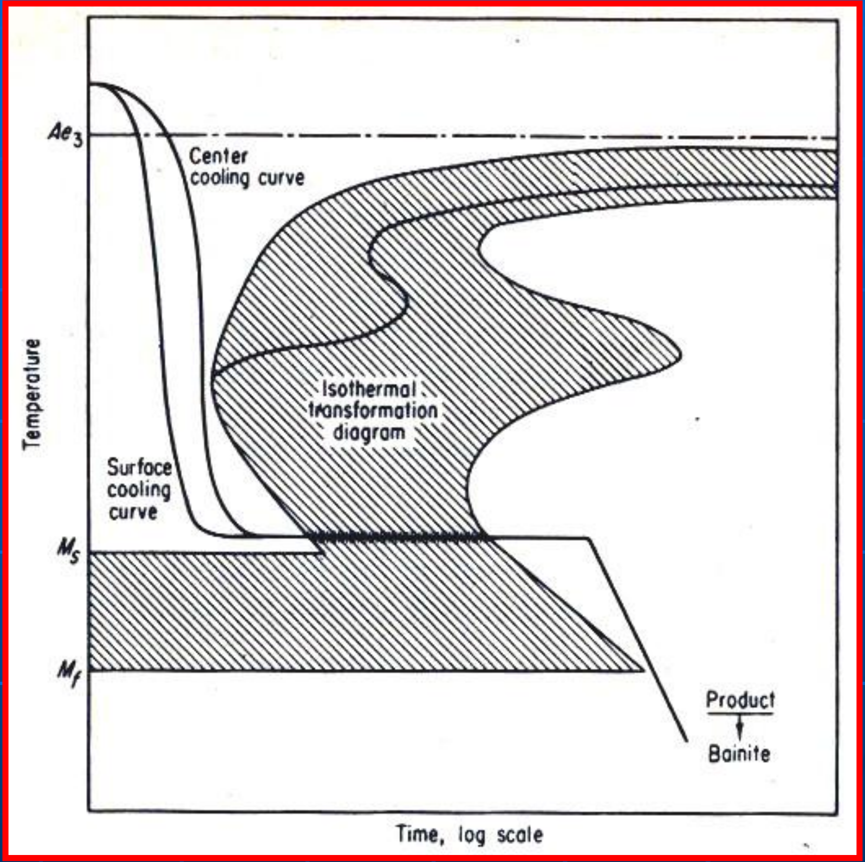


Fig. (17): Austempering.

Martempering:

❖ *Quenching an (γ) alloy in a medium at a Temp. at the upper part of (M) range & holding it in the medium until the Temp. throughout the alloy is substantially uniform, the alloy is then allowed to cool in Air through the (M) range see fig. (18).*

Martempering: is Martensite tempered to a temp. of about (M_s). It is produced by following steps shown in fig. (18):

1) *Heating a Steel to (γ) range above (A_3).*
2) *Quenching to a Temp. (T^o) just above (M_s) with cooling rate faster than (CCR).*
3) *Held at (T^o) sufficiently long for the entire piece of Steel to become the same (T^o) without transformation to Bainite.*
4) *Cooled in Air to change (γ) to (M).*
5) *The Steel is tempered.*

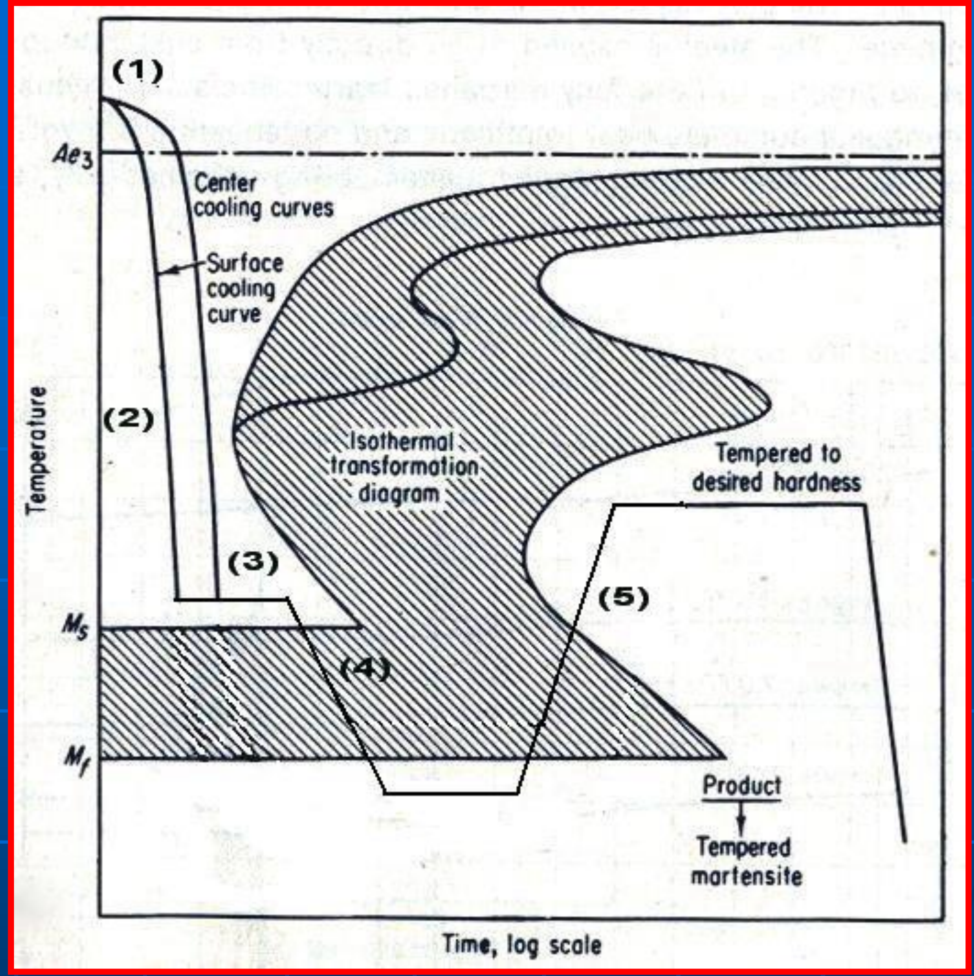


Fig. (18): Martempering.

Advantages of Martempering:

→ minimize cracking.

→ minimize distortion.

→ reduce thermal shock.

Case Hardening (Surface heat treatment):

- *Hardening a Ferrous alloy so that the outer portion or Case is made substantially harder than the inner portion or Case.*
- *Method of Case Hardening are:*
  - *Carburizing (adding Carbon (C)).*
  - *Nitriding (adding Nitrogen (N_2)).*
  - *Cyaniding or Carbonitriding (adding C + N_2).*
  - *Flame Hardening.*
  - *Induction Hardening.*
- *The first three methods change the chemical composition and the last two methods don't change the chemical composition.*

Carburizing:

- *Oldest + Cheapest method.*
- *Low (C) Steel (< 0.2% C) placed in atmosphere contain (CO).*
- *The usual carburizing Temp. (T° $\longrightarrow$ 1700 °f).*
- *The following reaction occurs:*

  $Fe + 2CO \longrightarrow Fe\,C + CO_2$ (C is dissolved in (γ).
- *The part is furnace cooled & examined microscopically (fig. (19)*

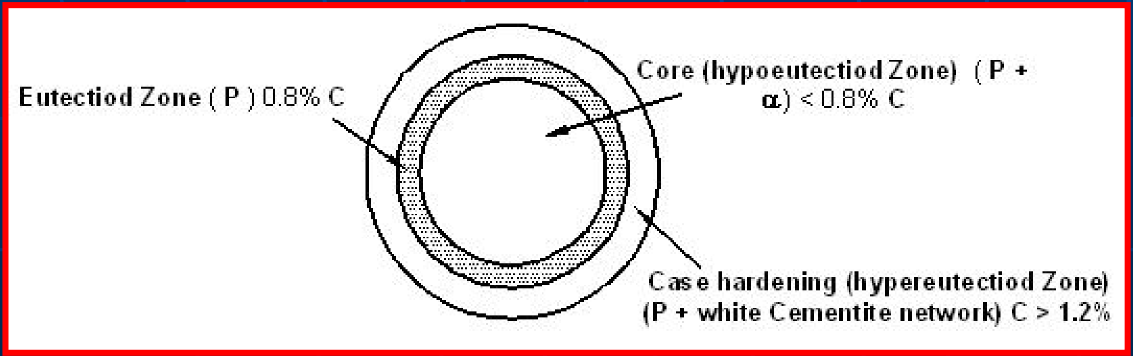


Fig. (19): Microscopical schematic of Case hardening.

$$X = \sqrt{2D * t}$$

Where: X = thickness in (cm).

D = Diffusion coefficient (cm^2 / sec).

t = Time in (sec).

- *Relation between time & Temp. for Case depth is shown in fig. (20).*

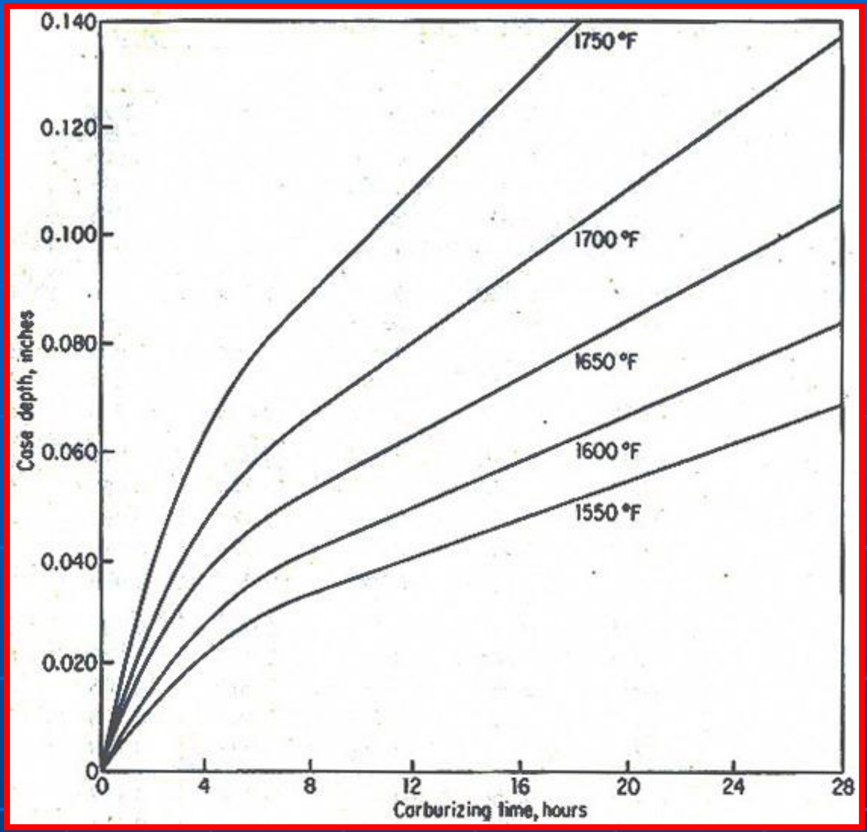


Fig. (20): Relation of Time & Temp. for Case hardening.

Decarburizing (opposite of Carburizing):

- *Removing (C) from the surface layer if the Steel is heated in atmosphere containing (CO_2) [the carburizing equation is reversible and may proceed to the left].*

- **Types of Carburizing**
  - *Pack Carburizing (hardwood charcoal, Cook + 20% $BaCO_3$).*
  - *Gas Carburizing (CH_4, C_2H_6, C_3H_8) [3 – 4 hour].*
  - *Liquid Carburizing (40% $NaCO_3$ + 20% NaCN) [Bath of molten] (max. 1 hour) [0.5 mm depth].*

Heat Treatment after Carburizing:

❖ *It is illustrated as shown in fig. (21) below:*

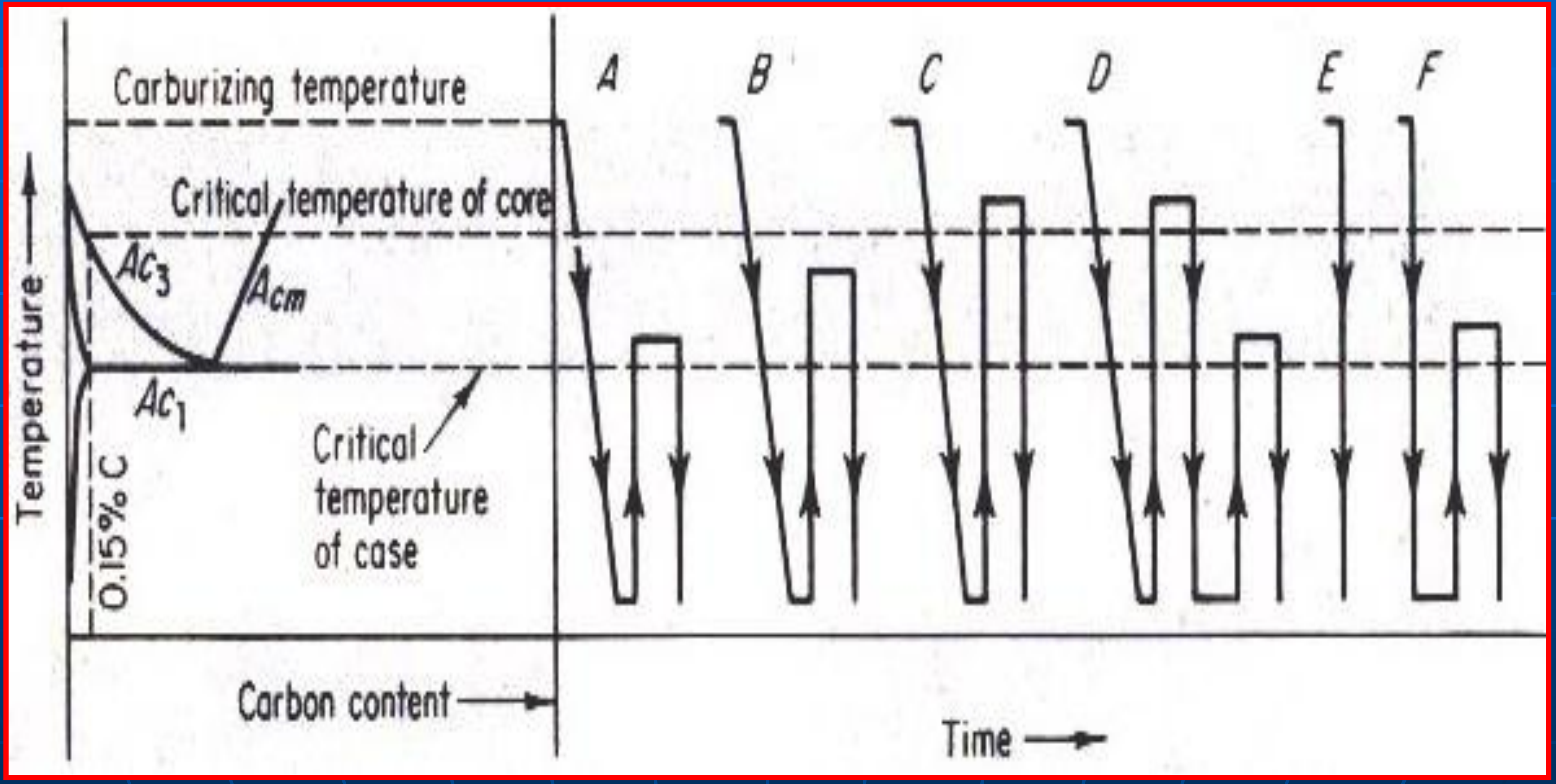


Fig. (21): Heat treatment after Carburizing.

Various Heat Treatment for Carburized Steel

TREATMENT	CASE	CORE
A—best adapted to fine-grained steels	Refined; excess carbide not dissolved	Unrefined; soft and machinable
B—best adapted to fine-grained steels	Slightly coarsened; some solution of excess carbide	Partially refined; stronger and tougher than *A*
C—best adapted to fine-grained steels	Somewhat coarsened; solution of excess carbide favored; austenite retention promoted in highly alloyed steels	Refined; maximum core strength and hardness; better combination of strength and ductility than *B*
D—best treatment for coarse-grained steels	Refined; solution of excess carbide favored; austenite retention minimized	Refined; soft and machinable; maximum toughness and resistance to impact
E—adapted to fine-grained steels only	Unrefined with excess carbide dissolved; austenite retained; distortion minimized	Unrefined but hardened
F—adapted to fine-grained steels only	Refined; solution of excess carbide favored; austenite retention minimized	Unrefined; fair toughness