**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 (Rc) of Steel see fig. (15).
  - Improve Toughness.

- Certain alloys exhibit a phenomenon known as (Temper Britteness) which is a loss of notched – bar toughness when tempered in the range of (1000 - 1250 °F) 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.

![Diagram](image-url)
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 °f) followed by cooling rapidly in a salt – bath (400 – 800 °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.

![Image of Austempering process](image-url)
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_0) just above (M_s) with cooling rate faster than (CCR).
3) Held at (T_0) sufficiently long for the entire piece of Steel to become the same (T_0) without transformation to Bainite.
4) Cooled in Air to change (γ) to (M).
5) The Steel is tempered.

**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 (N₂)).
  - Cyaniding or Carbonitriding (adding C + N₂).
  - 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°) → 1700°f.
- The following reaction occurs:
  \[ \text{Fe} + 2\text{CO} \rightarrow \text{FeC} + \text{CO₂} \]  
  (C is dissolved in (γ).
- The part is furnace cooled & examined microscopically (fig. (19)).

Fig. (19): Microscopical schematic of Case hardening.
\[ X = \sqrt{2D \cdot t} \]

**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).

**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:

![Diagram showing heat treatment after carburizing](image-url)

**Fig. (21):** Heat treatment after Carburizing.
### Various Heat Treatment for Carburized Steel

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