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Surface Hardening
Surface Hardening

- Many engineering must be very hard to resist surface indentation or wear and yet possess adequate toughness to resist impact damage.

- Surface Hardening is a process by which a steel is given a hard, wear resistant surface, while retaining a ductile but tougher interior.

- Surface hardening is usually done for the following reasons:
  - To improve wear resistance
  - To improve resistance to high contact stresses
  - To improve fracture toughness
  - To improve fatigue resistance, and, sometimes,
  - To improve corrosion resistance
Components that usually require surface hardening include:

- gears  - bearings  - valves
- cams  - hand tools  - rolls
- shafts  - machine tools  - bearing races

Surface hardening techniques can be classified into two major categories:

1. Processes that change the surface chemical composition (case hardening or thermochemical processes)
2. Processes that do not change the surface chemical composition (selective surface hardening or local thermal surface hardening)
1. Case Hardening

- Case hardening methods include:
  1. Carburising
  2. Nitriding
  3. Carbo-nitriding
  4. Cyaniding
Carburising

Carburising is a hardening process in which carbon is introduced into the surface layer of the steel.

1. The steel is heated in contact with a substance that has a high carbon content.
2. The steel is held at a temperature above the UCT (850 – 950 °C) for a suitable period of time.
3. Then quenched rapidly to produce a hardened surface layer or “case” over a softer and tougher core.
4. The steel is then tempered to the desired hardness.
Carburising is done on low C steel (< 0.25 %)

The carburising time varies between 4 – 70 hours

The length to time the steel is left in the furnace determines the depth of carburising

Case depths ranging from 0.08 mm - 6.4 mm may be specified, depending on the service requirements of the product

The carburising process does not harden the steel, it only increases the carbon content to a desired depth below the surface
1. **Pack Carburising**

- In pack carburising, the steel piece is packed in a steel container and completely surrounded with charcoal.
- The charcoal is treated with $\text{BaCO}_3$, which promotes the formation of $\text{CO}_2$.
- $\text{CO}$ reacts with the low carbon steel surface to form atomic $\text{C}$, which diffuses into the steel.
- Quenching is difficult in pack carburising. Usually the part is allowed to cool slowly and then hardened and tempered.

- **Carburising time**: 4 – 10 hours
- **Carburising depth**: no limit (< 1.3 mm)
2. **Gas Carburising**

- Carburising is done with carbonaceous gases, such as: methane, ethane, natural gas or propane at around 930 °C.
- The advantage of gas carburising is that the steel can be quenched directly from the carburising temperature.

3. **Liquid Carburising**

- Carburising is done in liquid salts, which contain cyanide compounds such as NaCN.
- Shorter carburising time compared to pack and gas carburising.
- Environmental hazards of the salts used.
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
- Since nitriding does not involve austenitizing the steel and subsequent quenching to form martensite, it can be carried out at comparatively low temperatures and thus produce less distortion and deformation
Nitriding

\[ 2NH_3 \rightarrow 2N + 3H_2 \]
This process involves both the diffusion of C and N into the steel surface.

Nitriding is performed in a gas atmosphere furnace using a carburising gas such as propane or methane (source of C) mixed with several vol% of ammonia (NH$_3$) (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
Carbonitriding
Cyaniding

- This process also involves both the diffusion of C and N into the surface layers of the steel.
- In cyaniding, the steel is heated in a liquid bath of cyanide – carbonate – chloride salts and then quenched in brine, water or oil.
Selective Surface Hardening

- These processes are also called localised heat treatment because only the surface is austenitised and quenched to produce martensite.

- The basic requirement for these processes is that the steel must have sufficient carbon and hardenability to achieve the required hardness at the surface (medium carbon steels are usually suited for these processes).

- Selective surface hardening are classified according to the heating source into:
  1. Flame hardening
  2. Induction hardening
  3. Laser hardening
  4. Electron-beam heat-treating
Selective Surface Hardening

Selective hardening is applied because of one or more of the following reasons:

1. Parts to be heat-treated are so large as to make conventional furnace heating and quenching impractical and uneconomical - examples are large gears, large rolls, and dies

2. 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

3. Better dimensional accuracy of a heat-treated part

4. Overall cost savings by using inexpensive steels to have the wear properties of alloyed steels.
Flame Hardening

Induction Hardening
<table>
<thead>
<tr>
<th></th>
<th>Heat treatment</th>
<th>Case hardening</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>%C Austenized</strong></td>
<td>0.4-0.6 surface</td>
<td>0.2 all</td>
</tr>
<tr>
<td><strong>Speed of procedure</strong></td>
<td>Fast (secs)</td>
<td>Slow (~10hrs)</td>
</tr>
<tr>
<td><strong>Surface chemistry</strong></td>
<td>No change</td>
<td>0.8-1.0% C (or N)</td>
</tr>
<tr>
<td><strong>Depth</strong></td>
<td>1-10mm</td>
<td>0.5-2mm</td>
</tr>
<tr>
<td><strong>Surface hardness</strong></td>
<td>R₃ 57-60 martensite</td>
<td>R₃ 65 surface martensite;</td>
</tr>
<tr>
<td></td>
<td>(may be through part)</td>
<td>centre pearlite</td>
</tr>
<tr>
<td><strong>Microstructure</strong></td>
<td>difficult</td>
<td>easy</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>Surface compressive</td>
<td></td>
</tr>
<tr>
<td><strong>Residual stress</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Core toughness</strong></td>
<td>Medium (high C)</td>
<td>Good (low C)</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Cheap $/part</td>
<td></td>
</tr>
</tbody>
</table>
INDUCTION HARDENING

Process:
• Induced current.
• Metal will be surrounded in a quickly changing magnetic field.
• Heating temperature: 750°C – 850°C
• Quench in water.

Advantages:
No scaling effect.
Reduce distortion.
Consistent surface texture.

Disadvantages:
High cost

Applications:
Crankshafts.
Gears.
Automotive components which require high core strength.
**Process:**
Heated to $\gamma$ region with ‘oxyacetylene’ flame.  
Quenching.  
Thin surface hardening.  
Thickness control by temp. and time.

**Advantages:**
- No scaling effect.  
- Cheap and portable.

**Disadvantages:**
- ‘Overheating’ can damage components.

**Applications:**
- Crankshafts.  
- Gears.  
- Automotive components which require high core strength.
<table>
<thead>
<tr>
<th>PROCESS</th>
<th>TEMP. °C</th>
<th>DIFFUSING ELEMENTS</th>
<th>PROCESS MEDIA</th>
<th>STEELS</th>
<th>CASE CHARACTERISTICS</th>
<th>PROCESS CHARACTERISTICS</th>
<th>APPLICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARBURISING</td>
<td>900-1000</td>
<td>Carbon</td>
<td>Pack</td>
<td>Low-carbon steels, mild and low-alloy</td>
<td>• Medium to deep cases</td>
<td>• Care required to minimise distortion</td>
<td>• High surface stress conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Salt</td>
<td></td>
<td>• Oil quenched</td>
<td></td>
<td>• Alloy steels – large sections</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gas</td>
<td></td>
<td>• Typical surface hardness 57-62 HRC (650-800 HV) after low-temperature tempering.</td>
<td></td>
<td>• Mild steels – small sections (&lt;12.5mm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fluidised bed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CARBONITRIDING</td>
<td>800-880</td>
<td>Carbon + Nitrogen</td>
<td>Salt</td>
<td>Low-carbon steels, mainly mild steels</td>
<td>• Shallow to medium cases</td>
<td>• Less distortion than carburising</td>
<td>• High surface stress conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Carbon) predominates</td>
<td>Gas</td>
<td></td>
<td>• Oil quenched</td>
<td></td>
<td>• Mild steels – to section sizes above 12.5mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fluidised bed</td>
<td></td>
<td>• Typical surface hardness 57-62 HRC (650-800 HV) after low-temperature tempering.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NITRIDING</td>
<td>500-550</td>
<td>Nitrogen</td>
<td>Gas</td>
<td>Alloy steels, and some tool steels, with appropriate levels of nitride-forming elements</td>
<td>• Shallow to medium cases</td>
<td>• Very low distortion</td>
<td>• Severe surface stress conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Plasma</td>
<td></td>
<td>• No quenching required</td>
<td></td>
<td>• Gives highest hardness and temperature resistance (up to 200-300°C)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fluidised bed</td>
<td></td>
<td>• Surface hardness in range 650-1100 HV depending on steel.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NITROCARBURISING* (“Ferritic”)</td>
<td>560-570</td>
<td>Nitrogen + Carbon</td>
<td>Salt</td>
<td>Wide range of steels, from low-carbon/non-alloy to tool steels</td>
<td>• Thin (10-20μm) hard surface compound layer</td>
<td>• Very low distortion</td>
<td>• Low to medium surface stress conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Nitrogen predominates)</td>
<td>Gas</td>
<td></td>
<td>• Underlying nitrogen diffusion zone</td>
<td></td>
<td>• Good wear resistance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fluidised bed</td>
<td></td>
<td>• Surface hardness depends on steel type and process route. Can range from 350-550HV1 on low-carbon/non-alloy steels to 1000 + HV1 on some tool steels</td>
<td>• No post-heat treatment machining possible</td>
<td>• Post oxidation/impregnation gives salt corrosion resistance</td>
</tr>
</tbody>
</table>

*Nitrocarburising treatments above 590°C ("Austenitic") can produce a variety of deeper underlying hardened cases.
<table>
<thead>
<tr>
<th>Surface Hardening Method</th>
<th>Does/Does Not Change Chemical Composition</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induction Hardening</td>
<td>Does not change chem. comp.</td>
<td>For medium carbon steel &amp; alloy steel.</td>
</tr>
<tr>
<td>Flame Hardening</td>
<td>Does not change chem. comp.</td>
<td>For carbon steel (0.3-0.6% C).</td>
</tr>
<tr>
<td>Carburising</td>
<td>Changed chem. comp.</td>
<td>Additions of C on the surface. Oldest, cheapest technique. For low carbon steel</td>
</tr>
<tr>
<td>Nitriding</td>
<td>Changed chem. comp.</td>
<td>Additions of N through NH$_3$ gas.</td>
</tr>
</tbody>
</table>
How to select the right surface hardening method

- Carburizing is the best method for low carbon steel

- Nitriding is a lower distortion process than carburizing but it can be used for certain type of steel such as chromium-molybdenum alloy steel

- Flame hardening is preferred for heavy cases or selective hardening of large machine components.

- Induction hardening works best on parts small enough and suitable in shape to be compatible with the induction coil

- Electron beam and laser hardening are limited to the low alloy steels and plain carbon steels