Nitriding & Nitrocarburising

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Bodycote AGI NEE

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Nitriding & Nitrocarburising

- Basic theory, hardening mechanisms, compound layer, diffusion layer etc.
- Steels for nitriding/nitrocarburising
- Wear and Fatigue properties
  *Nitriding vs carburizing*
- Corrosion resistance
  basics, oxidation, CORR-I-DUR
- Dimensions and surface changes
- Case studies
  Some basic examples.
Nitriding gives

- Improved tribological properties
- Improved wear resistance.
- Improved strength
- Improved corrosion resistance
- Improved fatigue strength

The nitriding techniques belongs to a group normally referred to as **thermo chemical diffusion processes**. Nitriding implies that nitrogen is conveyed to a surface of steel at a **raised temperature** usually between 400-600º C and diffused into the matrix.
1. **Solution-hardening**: Solid solution between a alloying element and a base material. ex. Quench (Martensitic) hardening

2. **Precipitation-hardening**: Precipitation of an intermediate phase in a matrix material. ex. Cu in Al, Nitriding

3. **Dispersions-hardening**: Incorporation of hard particles in a matrix material. Metal matrix composites

4. **Grain boundary-hardening**: Smaller grains gives higher strength. ex. Normalising, fine grain treatment

5. **Deformation-hardening**: Deformation forms tensions that increases the hardness. Ex. Cold-rolling of stainless steel
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500°C

20°C
Nitriding & Nitrocarburising

500°C

20°C

Solution hardening
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Djup (mm)

Hårdhet (HV)

0.4\%C steel

Pure iron

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Aluminium + Krom + Vanadin + etc + Nitrogen = Nitrides

Precipitation hardening

[Graph showing hardness (HV) against alloy content (Ni, Al, Ti, Cr, Mo)]
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- 0.4% C steel
- 5% Cr Hot-Work steel
- Nitralloy Cr-Mo-Al
- 1% Cr-Mo Steel
- Pure iron

Hardness (HV) vs. Depth (mm)
Nitriding & Nitrocarburising

> 6% N

Phase transformation

\( \varepsilon \)-nitrid, \( \text{Fe}_{2.3} \text{N} \)

\( \gamma' \)-nitrid, \( \text{Fe}_4 \text{N} \)
Nitriding & Nitrocarburising
Nitriding & Nitrocarburising

-diagram showing the process of nitriding and nitrocarburising with the formation of compound and diffusion zones.

-NH₂/H₂ gas is used in the process.

- αFe + (N) indicates the reaction between iron and nitrogen.
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Nitriding & Nitrocarburising
Steels for nitriding/nitrocarburising

Alloying elements
Al, Cr, V, etc

- Higher hardness
- Thinner Compound layer
- Thinner Diffusion layer

- Lower hardness
- Thicker Compound layer
- Thicker diffusion layer
Steels for nitriding/nitrocarburising
### Steels for nitriding/nitrocarburising

<table>
<thead>
<tr>
<th>Material type</th>
<th>AISI/SAE</th>
<th>DIN</th>
<th>Surface hardness HV 2</th>
<th>Nitride hardness depth, mm</th>
<th>Compound layer Thickness µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural</td>
<td>1020</td>
<td>1.0037</td>
<td>150-350</td>
<td>0,3-0,8</td>
<td>4-10</td>
</tr>
<tr>
<td>Carbon</td>
<td>1045</td>
<td>1.0503</td>
<td>350-500</td>
<td>0,3-0,8</td>
<td>4-15</td>
</tr>
<tr>
<td>Case hardened</td>
<td>5115</td>
<td>1.7131</td>
<td>550-700</td>
<td>0,3-0,7</td>
<td>6-10</td>
</tr>
<tr>
<td>Heat treatable</td>
<td>4140</td>
<td>1.7225</td>
<td>550-650</td>
<td>0,2-0,6</td>
<td>4-8</td>
</tr>
<tr>
<td>Nitriding</td>
<td>A355</td>
<td>1.8550</td>
<td>900-1100</td>
<td>0,2-0,5</td>
<td>2-10</td>
</tr>
<tr>
<td>Hot work</td>
<td>H13</td>
<td>1.2344</td>
<td>900-1200</td>
<td>0,1-0,3</td>
<td>2-10</td>
</tr>
<tr>
<td>Cold work</td>
<td>D2</td>
<td>1.2379</td>
<td>900-1250</td>
<td>0,1-0,2</td>
<td>-</td>
</tr>
<tr>
<td>High speed</td>
<td>M2</td>
<td>1.3343</td>
<td>1000-1250</td>
<td>0,005-0,1</td>
<td>-</td>
</tr>
<tr>
<td>Stainless</td>
<td>316</td>
<td>1.4571</td>
<td>950-1250</td>
<td>0,05-0,1</td>
<td>-</td>
</tr>
</tbody>
</table>
Nitriding & Nitrocarburising

\[ a_n = K \frac{p \text{NH}_3}{p \text{H}_2^{3/2}} \]

- 500-540°C
- Ammonia
- Nitrogen
- 10-100 h

\[ \text{NH}_3 \rightarrow \text{N} + \frac{3}{2} \text{H}_2 \]
Driving Screw for pump

- SS 2142 (OVAKO 2142)
- min 500HV
- 30h / 510°C
Plasmanitriding of forging tools

- SS 2242(Orvar)
- 480°C 30h
- Fz ca 5μm
- γ' nitrid (Fe₄N)
- Ythårdhet >1100 HV
Nitriding & Nitrocarburising

\[
\begin{align*}
NH_3 & \rightarrow N + \frac{3}{2} H_2 & \text{Slow} \\
2 \text{CO} & \rightleftharpoons \text{C} + \text{CO}_2 & \text{Slow} \\
\text{CO} + H_2 & \rightleftharpoons \text{C} + \text{H}_2\text{O} & \text{Fast} \\
\text{HCN} & \rightleftharpoons \frac{1}{2} H_2 + \text{C} + N & \text{Fast} \\
\end{align*}
\]
Nitriding & Nitrocarburising
Hydraulic shafts

- Change to an environmentally friendly process
- Maintained or improved running-in properties
- Improved cleanliness
- Less distortions
- Less variations of surface hardness and thickness of the compound layer
- Lower total cost
Nitriding & Nitrocarburising

Roller bearing cages
- Minimized and reproducible dimension changes
- Controlled porosity in the compound layer
- More accurate values of
  - surface hardness
  - diffusion depth
  - layer thickness
- Increased wear resistance
- Controlled appearance
- Choiceable colours
Wear and Fatigue properties

**Compound layer**
- High hardness
- Small adhesion tendency
- Absorption of lubricant by pores
- Corrosion resistance
- Low ductility
- High strength
- Compressive stresses
- Increased strength at high temperatures

**Diffusion zone**
- Increased resistance to contact fatigue
- Improved fatigue strength
- Improved dimensional stability
- Reduced hot-wear
- Increased resistance to thermal fatigue

**Usage**
- Resistance to wear by abrasion, deformation, shearing and adhesion
Wear and Fatigue properties

Fatigue

MPa

16MnCr5
Sätthärdning 0,7mm

2244, 42Cr4

Nitrering 1.2344

Nitrering 2244, 42Cr4
Wear and Fatigue properties

Blanking tool - ToolSteel

From 1.000 to >50.000 parts
Corrosion resistance

Corrosion

90 miljarder SEK/år
Corrosion resistance
Corrosion protection

Protective layers
• oil, grease
• Paint, polymers, enamel (glass)
• Metallic layers (Ni, Sn, Cr)
• Non metallic layers (nitrides)

Oxides
• metal + oxygen → metal-oxide
• Oxide layers that completely covers the surface gives protection

Cathode protection
• The metal that needs protection is made cathode
Corrosion resistance

Function surface

Wear

Friction

Mechanical properties
(Strength, Hardness, fatigue etc)

Sealing's
Corrosion protection

Protective layers
- oil, grease
- Paint, polymers, enamel (glass)
- Metallic layers (Ni, Sn, Cr)
- Non metallic layers (nitrides)

Oxides
- metal + oxygen → metal-oxide
- Oxide layers that completely covers the surface gives protection

Cathode protection
- The metal that needs protection is made cathode
Corrosion resistance

Cracks in Cr-Layer

Mechanical properties
(Strength, Hardness, fatigue etc)
Corrosion resistance

Mechanical Properties

Case depth
- Strength
- Fatigue
Production cost
Protecting oxide layers

- $\text{Cr}_2\text{O}_3$ on chromium
- $\text{Cr}_2\text{O}_3$ on steel $> 13\%$ chromium
- $\text{Al}_2\text{O}_3$ on Aluminium
- $\text{Fe}_3\text{O}_4$ on nitride layers
Corrosion resistance

Pilling-Bedworth

\[ R = \frac{V_{\text{Metal-oxide}}}{V_{\text{Metal}}} \]

- \( R < 1 \) Tensions, porous/cracks non protecting oxide
- \( R > 1 \) Protective oxide
- \( R > 2 \) Compressive stress
## Corrosion resistance

<table>
<thead>
<tr>
<th>System</th>
<th>R (PB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe$_3$O$_4$ / $\alpha$ - Fe</td>
<td>2.09</td>
</tr>
<tr>
<td>Fe$_3$O$_4$ / $\gamma'$-Fe$_4$N</td>
<td>1.80</td>
</tr>
<tr>
<td>Fe$_3$O$_4$ / $\varepsilon$-Fe$<em>2$N$</em>{1-x}$ (7,3 Gew.-% N)</td>
<td>1.79</td>
</tr>
<tr>
<td>Fe$_3$O$_4$ / $\varepsilon$-Fe$<em>2$N$</em>{1-x}$ (11,0 Gew.-% N)</td>
<td>1.69</td>
</tr>
<tr>
<td>$\gamma$-Al$_2$O$_3$ / Al</td>
<td>1.41</td>
</tr>
</tbody>
</table>
Corrosion resistance

Controlled Nitride layer +
Post oxidation

Mechanical properties
Function surface
Corrosion resistance

CORR-I-DUR®
Corrosion resistance

Ball joint (ZF)

• Description
  – Partname: Ball Pins diameter 27 mm to diameter 30 mm different OEMs
  – Material: 41Cr4 QT, HeatTreatable Steel
  – Treatment: Corr-I-Dur® + Polishing

• Requirements
  – 240 h salt Neutral Spray Test
  – Compound Layer 15-26 µm / 10-20 µm
  – Special Roughness Requirements
Dimensions and surface changes
Dimensions and surface changes

![Graph showing the increase in diameter and compound layer thickness over nitrocarburizing time.](Image)

- Increase in diameter, µm
- Compound layer, µm
- Nitrocarburizing time, min

Data for:
- 16MnCr5+N
- C45+N
Dimensions and surface changes

Untreated Surface

3-D Surface

Indexator

Magnification: 5.18  Pixel size: 1.62 um  Array Size: 736 X 480

Date: 28/10/2003  Time: 09:50:43

Title: Obehandlad kolv  Note: Uppdrag från Mikael Fällström, Bodycote; Normerad
Dimensions and surface changes

Surface after CORR-L-DUR P®

3-D Surface

Magnification: 5.18   Pixel size: 1.62 um   Array Size: 736 X 480

Date: 28/10/2003
Time: 10:35:40

Title: CORR-L-DUR kolv   Note: Uppdrag från Mikael Fällström, Bodycote; Normerad
Dimensions and surface changes

Statistics:
- tp1: 0.0 %
- tp2: 100.0 %
- Htp: 21.96 um
- Mr1: 13.19 %
- Mr2: 91.14 %
- RK: 5359.80 um
- Rpk: 3073.91 nm
- Rvk: 2292.34 nm
- V1: 202.72 nm
- V2: 101.52 nm
- Rz: 1.79 um
- Rq: 2.33 um
- Rz: 21.84 um

Title: Bärighetsjämförelse
Note: Svart: CORR-I-DUR; Röd: obehandlad slipad yta
Dimensions and surface changes

Surface after rubbing up

3-D Surface

Title: CORR-I-DUR A1  Note: Normrad
Dimensions and surface changes

Statistics:

tp1: 0.0 %
tp2: 100.0 %
Htp: 4.39 um
Mr1: 9.92 %
Mr2: 89.47 %
RK: 933.50 nm
Rpl: 434.96 nm
Rvk: 409.92 nm
V1: 21.57 mm
V2: 21.57 mm
Ra: 296.95 mm
Rq: 382.60 mm
Rz: 4.04 um

Title: Bärighetsjämförelse
Note: Röd: Slipad. Polerad CORR-I-DUR Blå: A1; Grön: B2; Svart: B3
The nitriding techniques belong to a group normally referred to as **thermo chemical diffusion processes**. Nitriding implies that **nitrogen** is conveyed to a surface of steel at a **raised temperature** usually between 400-600º C and diffused into the matrix.

### Nitriding gives
- Improved tribological properties
- Improved wear resistance.
- Improved strength
- Improved corrosion resistance
- Improved fatigue strength

\[
2\text{NH}_3 \rightarrow \text{N}_2 + 3\text{H}_2
\]
Thank you!