ADI JS/800-10 in substitution of Nitrided EN-GJS 700-2 for precision Planetary Gearbox

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<table>
<thead>
<tr>
<th>EN 1563:2011</th>
<th>$R_M$ [MPa]</th>
<th>$R_S$ [MPa]</th>
<th>A% [-]</th>
<th>HV</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN-GJS-700-2</td>
<td>700</td>
<td>420</td>
<td>2</td>
<td>284-237</td>
</tr>
<tr>
<td>EN-GJS-700-2 Nit-Ox</td>
<td>700*</td>
<td>420*</td>
<td>2</td>
<td>450-520</td>
</tr>
</tbody>
</table>

Casting → Rough machining → Broaching → Heat treatment → Finishing

HV>450

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<table>
<thead>
<tr>
<th></th>
<th></th>
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<tbody>
<tr>
<td>EN-GJS-800-8</td>
<td>800</td>
<td>500</td>
<td>8</td>
<td>260-320</td>
</tr>
<tr>
<td>EN-GJS-1000-5</td>
<td>1000</td>
<td>700</td>
<td>5</td>
<td>300-380</td>
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<tr>
<td>EN-GJS-1200-2</td>
<td>1200</td>
<td>850</td>
<td>2</td>
<td>340-440</td>
</tr>
<tr>
<td>EN-GJS-1400-1</td>
<td>1400</td>
<td>1100</td>
<td>1</td>
<td>380-480</td>
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</tbody>
</table>

Casting → Rough machining → Broaching → Finishing

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ADI JS/800-10 in substitution of Nitrided EN-GJS 700-2 for precision Planetary Gearbox

<table>
<thead>
<tr>
<th>Failure</th>
<th>Type</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending</td>
<td>Fatigue</td>
<td>Catastrophic</td>
</tr>
<tr>
<td>Pitting</td>
<td>Chafing fatigue</td>
<td>Acceptable ?</td>
</tr>
<tr>
<td>Micropitting</td>
<td>Chafing fatigue</td>
<td>Acceptable ?</td>
</tr>
<tr>
<td>Scuffing</td>
<td>Local welding (failure of the lubricant)</td>
<td>Progressive damaging</td>
</tr>
</tbody>
</table>
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**Failure**
- Bending
- Pitting
- Micropitting
- Scuffing
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**Failure**

- Bending
- Pitting
- Micropitting
- Scuffing
**ADI JS/800-10 in substitution of Nitrided EN-GJS 700-2 for precision Planetary Gearbox**

### Failure
- Bending
- Pitting
- Micropitting
- Scuffing

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**Failure**

- Bending
- Pitting
- Micropitting
- Scuffing

[Image of gear failure modes: Bending, Pitting, Micropitting, Scuffing]

SEM photo

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Calculation of tooth bending strength

\[ \sigma_{MAX} = \frac{M_f}{W} = \frac{F_{bn} \cdot h_{Fa} \cdot \cos \alpha_{an}}{1 \cdot b \cdot \frac{2}{6} \cdot S_{Fn}^2} \]

Austempering, A Technology for Substitution
Calculation of tooth bending strength

Tooth root stress \( \sigma_F \leq \sigma_{FP} \) Permissibile bending stress

\[
\sigma_F = Y_{Fa} \cdot Y_{Sa} \cdot Y_\beta \cdot \frac{F_t}{b \cdot m_n} \cdot \left( K_A \cdot K_V \cdot K_{Fa} \cdot K_{F\beta} \right)
\]

\[
\sigma_{FP} = \frac{\sigma_{F\text{lim}} \cdot Y_{ST} \cdot Y_{NT} \cdot Y_{\delta T} \cdot Y_{R\text{RelT}} \cdot Y_{X}}{S_{F\text{min}}}
\]
Calculation of tooth bending strength

Tooth root stress  \[ \sigma_F \leq \sigma_{FP} \]  Permissibile bending stress

\[ \sigma_F = Y_{Fa} \cdot Y_{Sa} \cdot Y_\beta \cdot \frac{F_t}{b \cdot m_n} \cdot \left( K_A \cdot K_V \cdot K_{F\alpha} \cdot K_{F\beta} \right) \]

Stress correction factor (notches)
Helix angle factor
Application factor
Load factors (uneven load distribution)

\[ \sigma_{FP} = \frac{\sigma_{F\text{lim}} \cdot Y_{ST} \cdot Y_{NT}}{S_F \text{min}} \cdot Y_{R\text{relT}} \cdot Y_{R\text{relT}} \cdot Y_X \]

Tooth form factor (outer point of single contact)
Dynamic factor (tollerances)

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Calculation of tooth bending strength

Tooth root stress

\[ \sigma_F \leq \sigma_{FP} \quad \text{Permissibile bending stress} \]

\[
\sigma_F = Y_{Fa} \cdot Y_{Sa} \cdot Y_{\beta} \cdot \frac{F_l}{b \cdot m_n} \cdot \left( K_A \cdot K_Y \cdot K_{Fa} \cdot K_{F\beta} \right)
\]

Stress correction factor = 2

Life factor

Size factor

Sensitivity factors

\[
\sigma_{FP} = \frac{\sigma_{F\text{lim}} \cdot Y_{ST} \cdot Y_{NT}}{S_{F\text{min}}} \cdot Y_{\Delta R\text{elT}} \cdot Y_{R\text{elT}} \cdot Y_X
\]
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Calculation of tooth bending strength

Tooth root stress \( \sigma_F \leq \sigma_{FP} \) Permissibile bending stress

\[
\sigma_F = Y_{Fa} \cdot Y_{Sa} \cdot Y_{\beta} \cdot \frac{F_t}{b \cdot m_n} \cdot \left( K_A \cdot K_V \cdot K_{Fa} \cdot K_{F\beta} \right)
\]

Nominal stress \( \rightarrow \) EXPERIMENTAL

\[
\sigma_{FP} = \frac{\sigma_{F\text{lim}} \cdot Y_{ST} \cdot Y_{NT} \cdot Y_{\delta_{\text{RelT}}} \cdot Y_{R_{\text{relT}}} \cdot Y_X}{S_{F \text{min}}}
\]

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Calculation of surface durability

\[ P_H = \sqrt{\frac{1}{\pi \left( \frac{1-v_1^2}{E_1} + \frac{1-v_2^2}{E_2} \right)}} \cdot \sqrt[\text{u+1}]{\frac{2}{b \cdot d_1}} \cdot \frac{F_t}{u} \]
Calculation of surface durability

Contact stress \( \sigma_H \leq \sigma_{HP} \) Permissibile contact stress

\[
\sigma_H = Z_H \cdot Z_E \cdot Z_\varepsilon \cdot Z_\beta \cdot \sqrt{\frac{F_t}{b \cdot d_1 \frac{u \pm 1}{u}}} \cdot \sqrt{K_A \cdot K_V \cdot K_{H\alpha} \cdot K_{H\beta}}
\]

\[
\sigma_{HP} = \frac{\sigma_{H\lim}}{S_{H_{min}}} \cdot Z_N \cdot Z_L \cdot Z_R \cdot Z_V \cdot Z_W \cdot Z_X
\]
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**Calculation of surface durability**

**Contact stress**

\[ \sigma_H = Z_H \cdot Z_E \cdot Z_\varepsilon \cdot Z_\beta \cdot \sqrt{\frac{F_t \cdot u \pm 1}{b \cdot d_1 / u}} \sqrt{K_A \cdot K_V \cdot K_{H\alpha} \cdot K_{H\beta}} \]

**Permissibile contact stress**

\[ \sigma_{HP} = \frac{\sigma_{H\text{lim}}}{S_{H\text{min}}} \cdot Z_N \cdot Z_L \cdot Z_R \cdot Z_V \cdot Z_W \cdot Z_X \]

**Factors**

- Elasticity factor
- Helix angle factor
- Application factor
- Contact ratio factor
- Dynamic factor (tollerances)
- Load factors (uneven load distribution)
- Zona factor (Herzian pressure)

Austempering, A Technology for Substitution
Calculation of surface durability

Contact stress \[ \sigma_H \leq \sigma_{HP} \] Permissibile contact stress

\[ \sigma_H = Z_H \cdot Z_E \cdot Z_\varepsilon \cdot Z_\beta \sqrt{\frac{F_t}{b \cdot d_1}} \cdot \frac{u \pm 1}{u} \cdot \sqrt{K_A \cdot K_V \cdot K_{H\alpha} \cdot K_{H\beta}} \]

- Life factor
- Roughness factor
- Size factor
- Lubricant factor
- Velocity factor
- Work hardening factor

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ADI JS/800-10 in substitution of Nitrided EN-GJS 700-2 for precision Planetary Gearbox

Calculation of surface durability

Contact stress

\[ \sigma_H \leq \sigma_{HP} \]

Permissible contact stress

\[ \sigma_H = Z_H \cdot Z_E \cdot Z_\varepsilon \cdot Z_\beta \cdot \sqrt{\frac{F_t}{b \cdot d_1}} \cdot \frac{u \pm 1}{u} \cdot \sqrt{K_A \cdot K_v \cdot K_{H_\alpha} \cdot K_{H_\beta}} \]

\[ \sigma_{HP} = \frac{\sigma_{H \text{lim}}}{S_{H \text{min}}} \cdot Z_N \cdot Z_L \cdot Z_R \cdot Z_v \cdot Z_w \cdot Z_x \]

Allowable stress number \( \rightarrow \) EXPERIMENTAL

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Tooth bending strength characterization

$F \perp$ flank: property of the circle evolvent

$W_3$
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Tooth bending strength characterization

Moving part

Fixed part

Moving punch

Fixed punch

Pin: centering

W3
ADI JS/800-10 in substitution of Nitrided EN-GJS 700-2 for precision Planetary Gearbox

Tensile bending strength characterization

Results of the Bending Test - ADI grade JS 800-10

<table>
<thead>
<tr>
<th>Test No</th>
<th>F [kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>42.8</td>
</tr>
<tr>
<td>2</td>
<td>44.3</td>
</tr>
<tr>
<td>3</td>
<td>46.5</td>
</tr>
<tr>
<td>4</td>
<td>48.2</td>
</tr>
<tr>
<td>5</td>
<td>50.8</td>
</tr>
</tbody>
</table>

X Failure  ○ RunOut

Dixxon

Table: Results of the Bending Test - ADI grade JS 800-10

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Surface durability characterization

Motor
Actuator
Slave gearbox
Gears on test

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Surface durability characterization

Results of Pitting Test - ADI grade JS 800-10

<table>
<thead>
<tr>
<th></th>
<th>Running in</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_1$ (Nm)</td>
<td>100</td>
<td>200-280</td>
</tr>
<tr>
<td>$\omega$ (rpm)</td>
<td>1500</td>
<td>3000</td>
</tr>
<tr>
<td>$\theta$ (°C)</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

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Conclusions

Experimental test were preformed on ADI JS/800-10 gear samples.

ADI JS/800-10 results comparable in terms of tooth root bending strength as well as surface durability with the EN-GJS 700-2 nitrided cast iron and suitable for gear applications.

The low distortion induced by the austempering treatment, allows to reduce or avoid a further machining.

Eventual finishing operations are made on a low-hardness material: this implys faster and cheaper operations.