Steels for Cold Formed Parts without Heat Treatment
Conventional Process

- Hot Rolling
- Spheroidizing
- Annealing
- Cold Heading
- Quenching & Tempering
- Straightening
- Fastener

Sidenor | Cold Forging Pre-Treated Steels
Technical Challenge: Slender Bolts

- Quenching and tempering of slender long bolts is particularly challenging, due to distortions. A subsequent straightening is compulsory, what extends the leadtime, increases the number of rejected parts and the scattering of properties between bolts with different straightening deformation.

- Fortunately, there are technological solutions that skip quench and tempering, but achieve the mechanical properties of grade 8.8.
Alternative Processes

- **Deformation hardening** (equivalent reduction 30-60%) of a **microalloyed** steel thermomechanically hot rolled

- **Cold forming of a quench and tempered wire rod** of a low carbon steel *(DUCTIL)* with high ductility
MICROALLOYED Steels
Ferrite-Pearlite Steel with High Ductility
Microalloyed Steels are...

- Low-medium carbon steels that, by microalloying and thermomechanical hot rolling, can be cold forged to achieve the properties required for grade 8.8 fasteners.

![Diagram showing the process of microalloyed steels through Hot Rolling, Annealing, Cold Forging, Quenching, and Tempering.](image-url)
Hardening Mechanisms in Steels

• The tensile strength of an alloyed steel of a certain carbon content can be increased by...
  - Grain size refinement
  - Precipitation of carbonitrides of microalloying elements (B, Ti, V, Nb)
  - Plastic deformation

• A **high deformation** during **cold forging** allows rising noticeably the yield and tensile strength looking out:
  - As much homogeneous deformation as possible between extruded and stamped zones
  - A narrow scatter of metallurgical and mechanical properties in the as-rolled wire rod
Effect on the Mechanical Properties

- Deformation Hardening leads to:
  - An equivalent ductility loss
  - Heterogeneity of mechanical properties between areas with very different deformation ratios

![Graph showing mechanical properties vs deformation ratio]
Adjustment of Forging Process

- The current forging process generates great hardness divergences in areas with dissimilar deformation ratios.
- An adequate balance of deformation, wire rod diameter and equilibrated mechanical features of the raw material allow minimizing the scattering of bolt properties.
Direct-Use 20MnB5 for Grade 8.8

- Microalloyed steel with high ductility ferrite-pearlite suitable for grade 8.8 after a 30-60% plastic deformation

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Al</th>
<th>B</th>
</tr>
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<tbody>
<tr>
<td>0.15</td>
<td>0.8</td>
<td>0.15</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.0010</td>
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<tr>
<td>0.25</td>
<td>1.5</td>
<td>0.5</td>
<td>0.03</td>
<td>0.03</td>
<td>0.05</td>
<td>0.0060</td>
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</table>

<table>
<thead>
<tr>
<th>Rm (MPa)</th>
<th>Z (%)</th>
<th>A (%)</th>
<th>Hardness (HB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 700</td>
<td>≥ 65</td>
<td>≥ 25</td>
<td>≤ 180</td>
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</table>
24MnV6 for Grade 10.9

- Microalloyed steel with high ductility ferrite-pearlite suitable for grade 10.9 when $\varepsilon > 30\%$

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Al</th>
<th>V</th>
<th>Ti</th>
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<tr>
<td>0,2</td>
<td>1</td>
<td>0,25</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0,08</td>
<td>-</td>
</tr>
<tr>
<td>0,28</td>
<td>1,6</td>
<td>0,75</td>
<td>0,03</td>
<td>0,03</td>
<td>0,05</td>
<td>0,15</td>
<td>0,005</td>
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- Nevertheless, fastening standard introduces some restrictions at the grades 10.9 and upper that limit the use of deformation-hardened steels to special applications (under particular agreements between supplier and end user)
DUCTIL Steels
Cold Formable Quenched & Tempered Low Carbon Steels
Pre-treated Steels

- Low carbon cold formable tempered-martensitic steels
- Quench and tempering are carried out on the wire rod, therefore final mechanical properties are achieved at the raw material
- Final microstructure is tempered martensite
Ductile Low Carbon Martensite

- Lowering carbon content, the tetragonal lattice of martensite distorts less, leading to a microstructure of a **ductile, deformable cubic martensite**
**Chemical Composition**

- A balanced alloying makes DUCTIL steels able to be direct quenched and ductile enough for cold forging, achieving grades 8.8 and 10.9 without subsequent heat treatment.

### DUCTIL80 (grade 8.8)

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Mo</th>
<th>Ti</th>
<th>Nb</th>
<th>B</th>
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<tbody>
<tr>
<td></td>
<td>0.04</td>
<td>1.3</td>
<td>0.2</td>
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<tr>
<td></td>
<td>0.12</td>
<td>1.8</td>
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### DUCTIL100 (grade 10.9)

<table>
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<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Mo</th>
<th>Ti</th>
<th>Nb</th>
<th>B</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0.05</td>
<td>1</td>
<td>0.1</td>
<td>-</td>
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<td>-</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>2</td>
<td>1</td>
<td>0.8</td>
<td>0.2</td>
<td>0.05</td>
<td>0.08</td>
<td>0.004</td>
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Adjustment of Properties by Wire Rod Tempering

- Depending on the reduction ratio applied during cold forging, it is possible to tune the wire rod strength to attain the required properties for grade 8.8 fasteners.

![Graph showing the relationship between tensile strength and deformation ratio for low and high temperature tempering.](image)
Wire Rod Online Quenching

• Low carbon steel can be quenched directly after hot rolling in a water cooling bed, obtaining a microstructure of cubic martensite, ductile and cold formable
• Subsequent tempering allows to obtain the desired strength and ductility levels
• Pretreated wire rod shows a microstructure of tempered martensite and about 800MPa of UTS
DUCTIL80 – Wire Rod Features

- Microstructure: Tempered Martensite
- Mechanical Properties:

<table>
<thead>
<tr>
<th>UTS (MPa)</th>
<th>RofA (%)</th>
<th>Upsetting</th>
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</thead>
<tbody>
<tr>
<td>&gt;800</td>
<td>&gt;65</td>
<td>&gt;1/4</td>
</tr>
</tbody>
</table>

- Tolerances: Ø 5,5-15 (±0,2)
- Surface Quality: Defects below 0,03mm (Ø<10)/0,04mm (Ø>10)
- Descarburizing:
  - Total: nil
  - Partial: 0,06mm (Ø<10) and 0,08mm (Ø>10)

- Cleanliness:

<table>
<thead>
<tr>
<th>Jerkontoret</th>
<th>Fine</th>
<th>Coarse</th>
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<tbody>
<tr>
<td>A</td>
<td>1,5</td>
<td>1,5</td>
</tr>
<tr>
<td>B</td>
<td>1,5</td>
<td>1,5</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>1,5</td>
</tr>
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</table>
Fastener Forging

- Skin-pass, extrusion and cold heading increase fastener hardness and strength, but fit requirements of standard EN20898

![Graph showing Vickers Hardness over samples 1 to 10]

<table>
<thead>
<tr>
<th>Property</th>
<th>Range</th>
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<tbody>
<tr>
<td>Head hardness (HB)</td>
<td>280-310</td>
</tr>
<tr>
<td>Shank hardness (HB)</td>
<td>235-280</td>
</tr>
<tr>
<td>Axial Strength (MPa)</td>
<td>800-910</td>
</tr>
<tr>
<td>Wedge Strength (MPa)</td>
<td>800-890</td>
</tr>
<tr>
<td>Toughness Shank/Head</td>
<td>No cracks</td>
</tr>
</tbody>
</table>
Cost Savings

- Final heat treatment is avoided when DUCTIL steels are used, keeping a microstructure of tempered martensite.
- As forged parts are not quenched, distortions are also avoided, particularly in slender bolts.
- A total saving of 15% is estimated.
**DUCTIL 100 – Q&T Wire Rod Features**

- A higher carbon and alloy content allows DUCTIL100 achieving properties required by grade 10.9 fasteners
### Pros and Cons of Direct Use steels

#### PROS
- Ability to manufacture **long slender parts** with final straightening
- **Cost savings**
- **Reduction of operations** and simplification of the manufacturing chain
- **Lower process time**

#### CONS
- **Higher heterogeneity** of properties
- **Higher tool wear**
- **Higher forging stresses**
- Lower residual ductility
- Higher susceptibility to hydrogen embrittlement