Tensile deformation and tensile test - I

- Tensile test
- Tensile loading of monocrystal
- Plastic deformation
- True stress – true strain curve
Tensile loading

- Leonardo da Vinci tensile test of wires
- 15th century!
Tensile test
Metallic materials – tensile test at room temperature

Europe: (ČSN) EN 10 002 – 1 /2002

USA: ASTM E 8 – 01 (ASTM E8 M)
EN 10002 consists of 5 parts

**part 1:** Test method at room temperature
(ČSN EN 10 002-1)

**part 2:** Verification of force measuring system for tensile test machines (ČSN EN 10 002-2)

**part 3:** Calibration of load cells used for verification of test machines for tensile tests (ČSN EN 10 002-3)

**part 4:** Verification of extensometers used for ensile test (ČSN EN 10 002-4)

**part 5:** Test method at increased temperature (ČSN EN 10 002-5)
## General guidelines for the test samples

<table>
<thead>
<tr>
<th>Sheet Metal</th>
<th>Profiles, Rods, Wires</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thickness</strong></td>
<td><strong>Typical Dimension</strong></td>
</tr>
<tr>
<td>0.1 to 3 mm</td>
<td>&lt; 4 mm</td>
</tr>
<tr>
<td>3 mm and more</td>
<td>&gt; 4 mm</td>
</tr>
</tbody>
</table>

**Tensile Test**
General guidelines for the test samples

- Proportional test specimens ($L_0 = kS_0^{1/2}$), where $k = 11.3$ or $5.65$ initially ($L_0 = 5d_0$ or $10d_0$)
- Unproportional–nonstandard must be allowed by special product standard
- Original–unmachined surface must be prescribed by special product standard
- Fabrication and machining turning–grinding may have effect on plastic deformation beginning and yield stress

Tensile test

A 1.6 ČSN 014915 (2x)

© 0.02 A

© 0.02

0.4

R6

0.4

ϕ6±0.01

M11x1

1x45°

35

70±0.02
General guidelines for the test procedure

- **Loading axis of the machine**: The loading axis must keep one axis (assured by cardan shaft, alignment fixture, grips/fixture with spherical contact surface).

- **Loading rate**: (according to characteristics we need to measure)

- **Visual inspection and measurement**: Specimen preloading gripped state before the test, measurement of gauge length before the test.
Tensile test

Engineering stress-strain curve

- Ultimate tensile strength
- Fracture strength
- Yield strength
- Necking

- Young’s modulus = slope = stress/strain
- Elastic deformation
- Uniform plastic deformation
- Non-uniform plastic deformation

- Elastic strain
- Plastic strain
- Total strain

- Stress vs. Strain graph with labeled regions.
Engineering tensile curve
load vs elongation trace

- stress characteristics $R_e, R_m$
- strain characteristics $A, Z$
**Engineering tensile curve**

Measuring the force (load) $F$

Calculation of engineering stress

Measuring the relative elongation $\Delta L$

Calculation of relative elongation

$$R = \frac{F}{S_0}$$

$$\varepsilon = \frac{\Delta L}{L_0}$$
Tensile test

\[ R = \frac{F}{S_0} \]

\[ R_e, R_m, A = \frac{\Delta L}{L_0} \times 100 \]

\[ \varepsilon = \frac{\Delta L}{L_0} \]
<table>
<thead>
<tr>
<th>sp. nr.</th>
<th>$S_0$ [mm$^2$]</th>
<th>$R_e$ [MPa]</th>
<th>$R_m$ [MPa]</th>
<th>$A_g$ [%]</th>
<th>$A$ [%]</th>
<th>$E$ (t) [GPa]</th>
<th>$E$ (s) [GPa]</th>
<th>$\mu$ [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28,29</td>
<td>695,5</td>
<td>806,9</td>
<td>7,49</td>
<td>16,40</td>
<td>206,0</td>
<td>196,0</td>
<td>0,287</td>
</tr>
<tr>
<td>2</td>
<td>28,30</td>
<td>722,6</td>
<td>812,8</td>
<td>6,64</td>
<td>14,53</td>
<td>210,3</td>
<td>196,0</td>
<td>0,296</td>
</tr>
<tr>
<td>3</td>
<td>28,28</td>
<td>730,0</td>
<td>820,0</td>
<td>7,67</td>
<td>18,46</td>
<td>222,4</td>
<td>196,0</td>
<td>0,295</td>
</tr>
<tr>
<td>4</td>
<td>28,29</td>
<td>733,0</td>
<td>820,5</td>
<td>7,37</td>
<td>15,70</td>
<td>204,0</td>
<td>195,7</td>
<td>0,299</td>
</tr>
<tr>
<td>5</td>
<td>28,29</td>
<td>711,9</td>
<td>812,5</td>
<td>7,64</td>
<td>16,94</td>
<td>188,6</td>
<td>196,0</td>
<td>0,304</td>
</tr>
</tbody>
</table>
Tensile test
determining the yield strength or proof stress

\[ R_{eH} \]

\[ R_{eL} \]

\[ \Delta \varepsilon_L \]

\[ R_e \]

\[ R_{p0,2} \]

\[ 0,002 \]

\[ \varepsilon \]
Proof stress

- $p = \text{plastic deformation}$
- $t = \text{total deformation}$
- $r = \text{remanent deformation}$
Tensile test

\[ R_{eH} \quad R_{eL} \]

\[ R_pX \]

\[ 0 \quad X \]
Tensile diagram of polycrystal

\[ R_{eL} = \sigma_i + k \cdot d^{-1/2} \]

Hall - Petch relation
<table>
<thead>
<tr>
<th>Weldable steels</th>
<th>Machinable steels</th>
</tr>
</thead>
<tbody>
<tr>
<td>S185</td>
<td>E295</td>
</tr>
<tr>
<td>S235</td>
<td>E335</td>
</tr>
<tr>
<td>S275</td>
<td>E360</td>
</tr>
<tr>
<td>S355</td>
<td></td>
</tr>
</tbody>
</table>
Deformation characteristics

- contraction

\[ Z = \frac{S_0 - S_u}{S_0} \times 100[\%] \]
**EN ISO 2566 (420308)**

- Transferability for ductility for carbon and low carbon steels

\[
k^I = \frac{L^I}{\sqrt{S^I_0}}, k^{II} = \frac{L^{II}}{\sqrt{S^{II}_0}}
\]

\[
\frac{A^{II}}{A^I} = \left(\frac{k^I}{k^{II}}\right)^{0.4}
\]

Nechť \( k^I = 5.65, k^{II} = 11.3 \) pak platí \( A_{II,3} = A_{5.65 \cdot 0.759} \)
Energetic characteristics

• Metals / standard tensile diagram

Resilience (resilience modulus): material characteristics quantifying energy unit in volume unit loaded under stress of $R_e$. Deformation energy which can be accumulated

$$w_{el} = \frac{R_e^2}{2E} \left[ MPa = \frac{MN.m}{m^2.m} = \frac{MJ}{m^3} \right]$$

$$w_f = \frac{R_m + R_e}{2} \cdot \frac{A}{100} \left[ \frac{MJ}{m^3} \right]$$

$$w_f = \frac{2}{3} R_m \cdot \frac{A}{100} \left[ \frac{MJ}{m^3} \right]$$

Brittle materials

Tensile toughness (toughness modulus) energy needed for materials fracture
Energetic characteristics

Tensile test

\[ W_{pl} \]

\[ W_{el} \]

\[ F \]

\[ \Delta L_{pl} \]

\[ \Delta L_{el} \]

\[ \Delta L \]
Metallic materials – strain hardening

- Metal – engineering diagram diagram
- Proportional to Rm to Re ratio

\[
\frac{R_m}{R_e} \geq 1,4 \quad \text{high hardening}
\]

\[
\frac{R_m}{R_e} \leq 1,2 \quad \text{small hardening}
\]
Tensile test

engineering stress – engineering strain
Plastics – EN ISO 527

Tensile test / plastics

\( \sigma_M \) - tensile strength
\( \sigma_y \) – yield stress
\( \sigma_B \) – yield stress
a - brittle
b – ductile with \( \sigma_y \)
C – ductile with \( \sigma_y \)
D – ductile without \( \sigma_y \)
Tensile test - ceramics

- limited machinability - simple geometry
- high brittleness – premature fracture
- susceptibility to loading axis alignment
- preference to flexural test
Energetic characteristics

- energy accumulated during damage

EN 658-1 (Cumulative damage energy)

Mechanical properties of ceramic composites at room temperature – based on tensile test data

\[
\Phi = \frac{1}{S_0L_0} \int_0^{\Delta L_f} Fd(\Delta L) \left[ \frac{kJ}{m^3} \right]
\]
- Evaluation of the materials quality
- Purchase and sale (technical delivery conditions)
- Accidents analysis
- Strength calculations (fatigue)
- Basic materials properties – material databases

\[ F - \Delta L \]
\[ R - \varepsilon \]