Collaboration with Miskolc University

Mechanical behavior of niobium submitted to cold working and heat treatment

Adrià Gallifa - EN/MME/MM (CERN)

CERN – 11/02/2019
EDMS XXXXXX
Agenda

1. Choice of thickness reductions (based on data from simulations)

2. Sample geometry for tensile tests (at RT and 4K)

3. Cutting of the samples

4. Addendum document → repartition of tasks between CERN and Miskolc Uni
### Initial test matrix

<table>
<thead>
<tr>
<th>Thickness reduction</th>
<th>before HT</th>
<th>after HT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
<td>4 K</td>
</tr>
<tr>
<td>0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Specimens:
- 3x tensile test at RT
- 3x tensile test at 4 K (1 backup)
- 2x metallography + hardness + texture + EBSD

#### Data obtained:
- Yield Strength
- Ultimate strength
- Elongation at rupture
- Hardness
  - Other data: microstructure, texture, residual stresses...

Representative of the final properties of the cavity!
Benchmark with real Crab Cavity

- Same heat treatment seen by Crab Cavities (650°C x 24h x 5x10^-6 to 10^-7 mbar)

- % thickness reductions of cold rolling chosen according to the effective plastic strain seen by the cavity during deep drawing.
Benchmark with real Crab Cavity

- Same heat treatment seen by Crab Cavities (650°C x 24h x 5x10^-6 to 10^-7 mbar)

- % thickness reductions of cold rolling chosen according to the effective plastic strain seen by the cavity during deep drawing.

Example of data from 3 elements issued from the FEA:

<table>
<thead>
<tr>
<th>Data from simulations</th>
<th>e33</th>
<th>e11</th>
<th>e22</th>
<th>Eff. Plastic strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>element 3562</td>
<td>-0.43</td>
<td>0.32</td>
<td>0.1</td>
<td>0.45</td>
</tr>
<tr>
<td>element 3755</td>
<td>-0.27</td>
<td>0.2</td>
<td>0.06</td>
<td>0.28</td>
</tr>
<tr>
<td>element 4006</td>
<td>-0.2</td>
<td>0.209</td>
<td>-0.005</td>
<td>0.24</td>
</tr>
</tbody>
</table>
Benchmark with real Crab Cavity

- % thickness reductions of cold rolling chosen according to the effective plastic strain seen by the cavity during deep drawing.

Histogram representing the effective plastic strain level present in
Benchmark with real Crab Cavity

The von Mises or equivalent strain $\varepsilon_e$ is computed as:

$$\varepsilon_e = \frac{1}{2\sqrt{3}} \left( \frac{1}{2} (\varepsilon_1^2 + \varepsilon_2^2 + \varepsilon_3^2) \right)^{\frac{1}{2}}$$
Benchmark with real Crab Cavity

Data from analytical calculation

Targeted values

Adrià Gallifa – EN/MME (CERN) on behalf of Materials & Metrology team
# Test matrix – proposed thickness reductions

<table>
<thead>
<tr>
<th>Thickness reduction</th>
<th>before HT</th>
<th>after HT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
<td>4 K</td>
</tr>
<tr>
<td>0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Specimens:
- 3x tensile test at RT
- 3x tensile test at 4 K (1 backup)
- 2x metallography + hardness + texture + EBSD

### Data obtained:
- Yield Strength
- Ultimate strength
- Elongation at rupture
- Hardness
- Other data: microstructure, texture, residual stresses..
Effective plastic strain (eq. Von Mises strain) in cold rolling

Assumptions:
- the cold rolling is performed in two perpendicular directions (cross-rolling) in steps of 5% thickness reduction.
- V=constant.
- Dimension in the perpendicular direction to rolling remains constant.

Dimensions in mm
<table>
<thead>
<tr>
<th>initial sample</th>
<th>h0</th>
<th>l0</th>
<th>w0</th>
<th>volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>120</td>
<td>120</td>
<td>57600</td>
</tr>
</tbody>
</table>

Data from analytical calculation

<table>
<thead>
<tr>
<th>thickness reduction %</th>
<th>hf</th>
<th>lf</th>
<th>wf</th>
<th>e33</th>
<th>e11</th>
<th>e22</th>
<th>eq. VM strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3.8</td>
<td>126.3158</td>
<td>120</td>
<td>-0.05</td>
<td>0.052632</td>
<td>0</td>
<td>0.0593</td>
</tr>
<tr>
<td>10</td>
<td>3.6</td>
<td>126.3158</td>
<td>126.6667</td>
<td>-0.1</td>
<td>0.052632</td>
<td>0.055556</td>
<td>0.1027</td>
</tr>
<tr>
<td>15</td>
<td>3.4</td>
<td>133.7461</td>
<td>126.6667</td>
<td>-0.15</td>
<td>0.114551</td>
<td>0.055556</td>
<td>0.1604</td>
</tr>
<tr>
<td>20</td>
<td>3.2</td>
<td>133.7461</td>
<td>134.5833</td>
<td>-0.2</td>
<td>0.114551</td>
<td>0.121528</td>
<td>0.2121</td>
</tr>
<tr>
<td>25</td>
<td>3</td>
<td>142.6625</td>
<td>134.5833</td>
<td>-0.25</td>
<td>0.188854</td>
<td>0.121528</td>
<td>0.2729</td>
</tr>
<tr>
<td>30</td>
<td>2.8</td>
<td>142.6625</td>
<td>144.1964</td>
<td>-0.3</td>
<td>0.188854</td>
<td>0.201637</td>
<td>0.3302</td>
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<tr>
<td>35</td>
<td>2.6</td>
<td>153.6366</td>
<td>144.1964</td>
<td>-0.35</td>
<td>0.280305</td>
<td>0.201637</td>
<td>0.3966</td>
</tr>
<tr>
<td>40</td>
<td>2.4</td>
<td>153.6366</td>
<td>156.2128</td>
<td>-0.4</td>
<td>0.280305</td>
<td>0.301773</td>
<td>0.4609</td>
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<tr>
<td>45</td>
<td>2.2</td>
<td>167.6035</td>
<td>156.2128</td>
<td>-0.45</td>
<td>0.396696</td>
<td>0.301773</td>
<td>0.5356</td>
</tr>
<tr>
<td>50</td>
<td>2</td>
<td>167.6035</td>
<td>171.8341</td>
<td>-0.5</td>
<td>0.396696</td>
<td>0.431951</td>
<td>0.6099</td>
</tr>
<tr>
<td>55</td>
<td>1.8</td>
<td>186.2262</td>
<td>171.8341</td>
<td>-0.55</td>
<td>0.551885</td>
<td>0.431951</td>
<td>0.6981</td>
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<tr>
<td>60</td>
<td>1.6</td>
<td>186.2262</td>
<td>193.3133</td>
<td>-0.6</td>
<td>0.551885</td>
<td>0.610944</td>
<td>0.7883</td>
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<tr>
<td>65</td>
<td>1.4</td>
<td>212.8299</td>
<td>193.3133</td>
<td>-0.65</td>
<td>0.773582</td>
<td>0.610944</td>
<td>0.8998</td>
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<tr>
<td>70</td>
<td>1.2</td>
<td>212.8299</td>
<td>225.5322</td>
<td>-0.7</td>
<td>0.773582</td>
<td>0.879435</td>
<td>1.0195</td>
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<tr>
<td>75</td>
<td>1</td>
<td>255.3959</td>
<td>225.5322</td>
<td>-0.75</td>
<td>1.128299</td>
<td>0.879435</td>
<td>1.1780</td>
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<tr>
<td>80</td>
<td>0.8</td>
<td>255.3959</td>
<td>281.9153</td>
<td>-0.8</td>
<td>1.128299</td>
<td>1.349294</td>
<td>1.3652</td>
</tr>
<tr>
<td>85</td>
<td>0.6</td>
<td>340.5278</td>
<td>281.9153</td>
<td>-0.85</td>
<td>1.837732</td>
<td>1.349294</td>
<td>1.6532</td>
</tr>
<tr>
<td>90</td>
<td>0.4</td>
<td>340.5278</td>
<td>422.8729</td>
<td>-0.9</td>
<td>1.837732</td>
<td>2.523941</td>
<td>2.0918</td>
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<tr>
<td>95</td>
<td>0.2</td>
<td>681.0557</td>
<td>422.8729</td>
<td>-0.95</td>
<td>4.675464</td>
<td>2.523941</td>
<td>3.2776</td>
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<tr>
<td>99</td>
<td>0.04</td>
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<td>2114.365</td>
<td>-0.99</td>
<td>4.675464</td>
<td>16.61971</td>
<td>10.3802</td>
</tr>
</tbody>
</table>

The von Mises or equivalent strain \( \varepsilon_e \) is computed as:

\[
\varepsilon_e = \frac{1}{\sqrt{2}} \left( \left( \varepsilon_1 - \varepsilon_2 \right)^2 + \left( \varepsilon_2 - \varepsilon_3 \right)^2 + \left( \varepsilon_3 - \varepsilon_1 \right)^2 \right)^{\frac{1}{2}}
\]

Source: Ansys 17.0 code: https://www.sharcnet.ca/Software/Ansys/17.0/en-us/help/wb_sim/ds_Equiv_Stress.html
Material

Initial sheet = sheet 800x500x4mm ID:1872102
CA
Rp0.2 = 56.1 MPa (parallel) / 60.4 MPa (transverse)

Sub-sheets to be rolled (minimum 8 needed for the whole campaign)

Tensile specimens will be cut in the rolling direction
Material need and samples

8 sub-sheets of 120x120 mm needed
(The 8 samples distributed randomly to avoid the effect of any gradient of properties along the base material)

Please, track the location and orientation of the samples after cutting and after rolling operations!

CERN will start cutting and testing the base material

Adrià Gallifa– EN/MME (CERN) on behalf of Materials & Metrology team
Tensile specimens

- We don’t have gripping wedges for testing at 4 K… (only until 15 KN!)

From ASTM E8

Mix ASTM E8 + ISO 6892-4

- The reduced specimens with pin whole are non-standard and small cryostat is not available
Tensile specimens

Figure A.2 — Plate test piece with shoulders

Adapted from ISO 6892-4

Original from ISO 6892-4 (tensile test of metallic materials at cryogenic temperatures)
Tensile specimens
Cut 8 sub-sheets by water jet cut

Rolling to different desired thickness

Cut* of specimens by Water jet + EDM

Final BCP 50 to 100 µm (to get rid of incrusted particles during rolling)

Miskolc Uni to cut preforms by water jet
CERN to perform finishing EDM

* Proposed cutting strategy for tensile specimens
Benchmark with real Crab Cavity – study of leftover from RFD pole deep drawing

- Microstructure
- Hardness
- EBSD → dislocation density (trial)
- Texture analysis
Thanks!
Tasks flowchart

Legend

What: 
How: 
Who:

Ship Nb sheet to Misk.
CERN transport
CERN

Cut in smaller sheets
water jet cut / EDM cut
CERN or Misk.

Cold rolling samples x 6 sheets
Rolling machine VON ROLL
University of Miskolc

(Heat treatment) x 4 sheets
Crab Cavity furnace
CERN

Cut + ship
To be def.
To be def.

Cut leftover forming pole
EDM
CERN

(NO Heat treatment) x 2

Microstructure x 4
To be defined
To be defined

Hardness x 4
To be defined
To be defined

Texture / dislocation analysis x 4
To be defined
To be defined

Tensile tests at RT x 12
To be defined
To be defined

Tensile tests at 4K x 8
CERN UTS machine
CERN

Microstructure x 4
To be defined
To be defined

Hardness x 4
To be defined
To be defined

Texture / dislocation analysis x 4
To be defined
To be defined

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