EXPERIMENTAL CHARACTERIZATION AND CONSTITUTIVE MODELING OF TA6V TITANIUM MECHANICAL BEHAVIOR IN TENSION AND COMPRESSION

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Outline

- Introduction
- Experimental characterization
- Modeling
- Results
- Conclusions
Introduction

Applications of TA6V

High strength-to-weight ratio, good corrosion resistance, biocompatibility, …
Material

Sheet with 0.6 mm thickness

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>V</th>
<th>Fe</th>
<th>C</th>
<th>O</th>
<th>N</th>
<th>Y</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>6.22</td>
<td>3.93</td>
<td>0.16</td>
<td>0.008</td>
<td>0.19</td>
<td>0.006</td>
<td>0.0004</td>
<td>Bal.</td>
</tr>
<tr>
<td>Bottom</td>
<td>6.27</td>
<td>4.00</td>
<td>0.16</td>
<td>0.009</td>
<td>0.20</td>
<td>0.006</td>
<td>0.0004</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

(in weight %)

Microstructure:

<table>
<thead>
<tr>
<th>Type</th>
<th>Grain size</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>α-phase</td>
<td>Hexagonal closed-packed (hcp)</td>
<td>~11 µm</td>
</tr>
<tr>
<td>β-phase</td>
<td>Body-centered cubic (bcc)</td>
<td>~1 µm</td>
</tr>
</tbody>
</table>

Introduction – Experimental characterization – Modeling – Results - Conclusions
Material

Initial texture

Introduction – Experimental characterization – Modeling – Results - Conclusions
Experiment

Tensile tests

Zwick 100 kN

Compressive tests

Comb-shaped dies apparatus (Kuwabara et al., Int. J. Mater. Form. 2, 2009)

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 Experimental results

Initial yielding

Anisotropy in tension and compression

r-values (tension)

- High anisotropy
- Tension-compression asymmetry

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CPB06ex3 yield criterion

CPB06 anisotropic yield criterion
(Cazacu, Plunkett, Barlat, Int. J. Plasticity 22, 2006)

\[ \Sigma = C : s \quad (C: \text{4th order orthotropic tensor}) \]

\[ F(\Sigma) = \left( |\Sigma_1| - k\Sigma_1 \right)^a + \left( |\Sigma_2| - k\Sigma_2 \right)^a + \left( |\Sigma_3| - k\Sigma_3 \right)^a \]

\( s \): deviator of Cauchy’s stress tensor
\( a \): degree of homogeneity
\( k \): strength differential parameter (asymmetry)

\[ C = \begin{pmatrix}
C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\
C_{12} & C_{22} & C_{23} & 0 & 0 & 0 \\
C_{13} & C_{23} & C_{33} & 0 & 0 & 0 \\
0 & 0 & 0 & C_{44} & 0 & 0 \\
0 & 0 & 0 & 0 & C_{55} & 0 \\
0 & 0 & 0 & 0 & 0 & C_{66}
\end{pmatrix} \]

9 anisotropy coefficients for 3-D stresses
(due to homogeneity: \( C_{11} = 1 \))

Extension with 3 transformations (CPB06ex3)
(Plunkett, Cazacu, Barlat, Int. J. Plasticity 24, 2008)

\[ \Sigma = C : s, \Sigma' = C' : s, \Sigma'' = C'' : s \]

\[ F(\Sigma, \Sigma', \Sigma'') = \left( |\Sigma_1| - k\Sigma_1 \right)^a + \left( |\Sigma_2| - k\Sigma_2 \right)^a + \left( |\Sigma_3| - k\Sigma_3 \right)^a \]

\[ + \left( |\Sigma'_1| - k'\Sigma'_1 \right)^a + \left( |\Sigma'_2| - k'\Sigma'_2 \right)^a + \left( |\Sigma'_3| - k'\Sigma'_3 \right)^a \]

\[ + \left( |\Sigma''_1| - k''\Sigma''_1 \right)^a + \left( |\Sigma''_2| - k''\Sigma''_2 \right)^a + \left( |\Sigma''_3| - k''\Sigma''_3 \right)^a \]

Introduction – Experimental characterization – Modeling – Results - Conclusions
Parameter identification

Error function: \[ E = \sum_i \eta_i \left( \frac{\sigma_0^T}{\sigma_0^T} - 1 \right)^2 + \sum_j \eta_j \left( \frac{\sigma_0^C}{\sigma_0^C} - 1 \right)^2 + \sum_k \eta_k \left( \frac{r_k}{r_k^\text{exp}} - 1 \right)^2 \]

Optimization using simulated annealing method:

- **Iteration** \( n \)
- **Trial guess**
- **\( E_n \)**

\( E_n \leq E_{n-1} \):
- Automatically accepted

\( E_n > E_{n-1} \):
- Accepted with probability \( p = \exp(-|E_n - E_{n-1}|/T) \)

\( T \): decreasing fictitious parameter (temperature)

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Introduction – Experimental characterization – **Modeling** – Results - Conclusions
Hill (1948)

\[ F(\mathbf{\sigma}) = \frac{1}{2} \left[ F(\sigma_{22} - \sigma_{33})^2 + G(\sigma_{33} - \sigma_{11})^2 + H(\sigma_{11} - \sigma_{22})^2 ight. \\
\left. + 2L\sigma_{23}^2 + 2M\sigma_{13}^2 + 2N\sigma_{12}^2 \right] \]

CPB06ex3

\[ F(\mathbf{\Sigma}, \mathbf{\Sigma}', \mathbf{\Sigma}'') = (|\Sigma_1| - k\Sigma_1)^a + (|\Sigma_2| - k\Sigma_2)^a + (|\Sigma_3| - k\Sigma_3)^a \\
+ (|\Sigma'_1| - k'\Sigma'_1)^a + (|\Sigma'_2| - k'\Sigma'_2)^a + (|\Sigma'_3| - k'\Sigma'_3)^a \\
+ (|\Sigma''_1| - k''\Sigma''_1)^a + (|\Sigma''_2| - k''\Sigma''_2)^a + (|\Sigma''_3| - k''\Sigma''_3)^a \]

Introduction – Experimental characterization – Modeling – Results - Conclusions
Anisotropy

Introduction – Experimental characterization – Modeling – Results – Conclusions
Conclusions

- Experimental investigation of the anisotropy and the strength differential effects in TA6V (uniaxial tests)
- Parameter identification of CPB06ex3 yield criterion
- Good agreement between experimental data and numerical results
Future work

Hardening

Introduction – Experimental characterization – Modeling – Results - Conclusions
Thank you for listening