

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

G. Gilles, W. Hammami, V. Libertiaux, A.M. Habraken , O. Cazacu,  
L. Duchêne

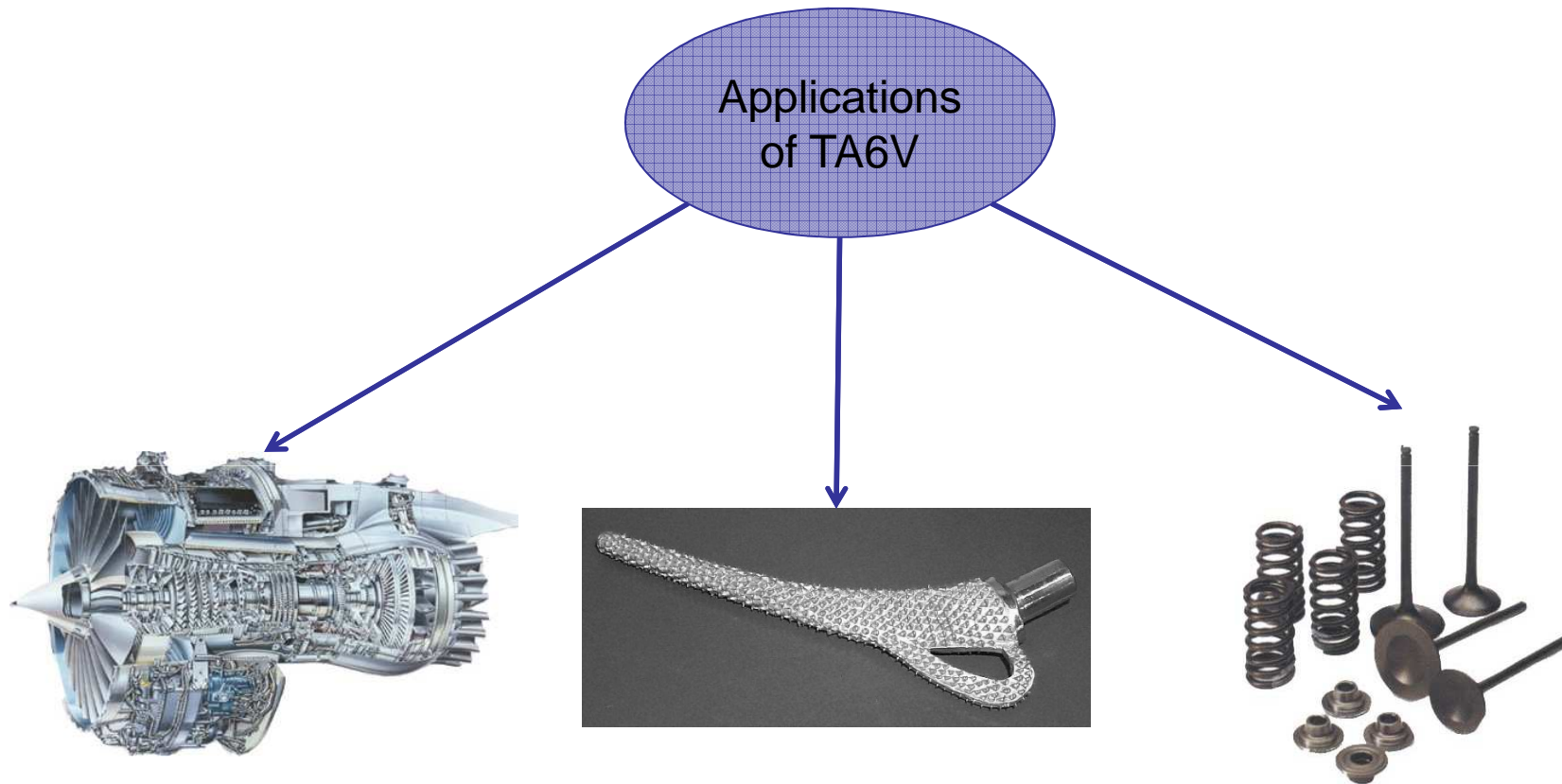
# Outline

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- Introduction
- Experimental characterization
- Modeling
- Results
- Conclusions

# Introduction

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High strength-to-weight ratio, good corrosion resistance, biocompatibility, ...

# Material

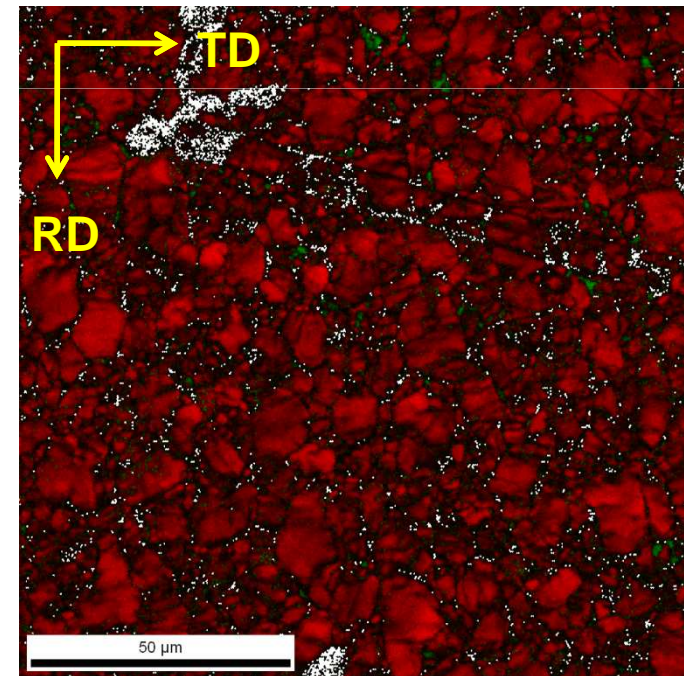
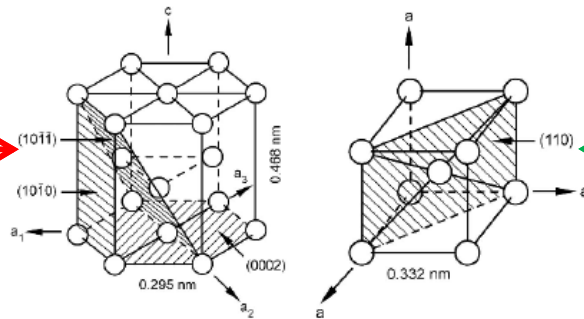
Sheet with 0.6 mm thickness

	Al	V	Fe	C	O	N	Y	Ti
Top	6.22	3.93	0.16	0.008	0.19	0.006	0.0004	Bal.
Bottom	6.27	4.00	0.16	0.009	0.20	0.006	0.0004	Bal.

(in weight %)

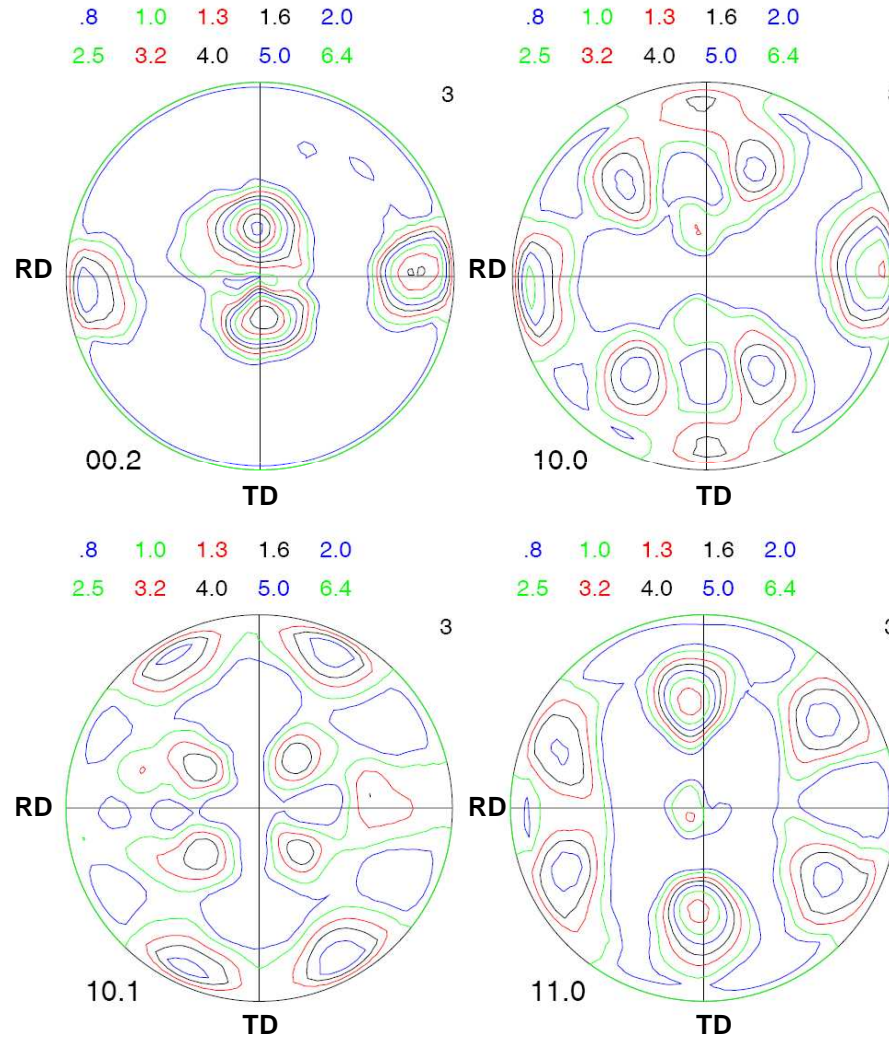
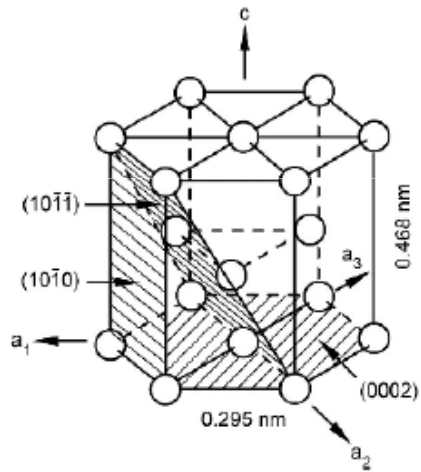
Microstructure:

	Type	Grain size	Fraction
α-phase	Hexagonal closed-packed (hcp)	~11 μm	0.882
β-phase	Body-centered cubic (bcc)	~1 μm	0.093



# Material

Initial texture



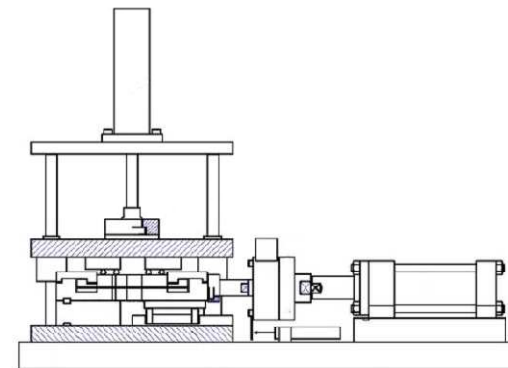
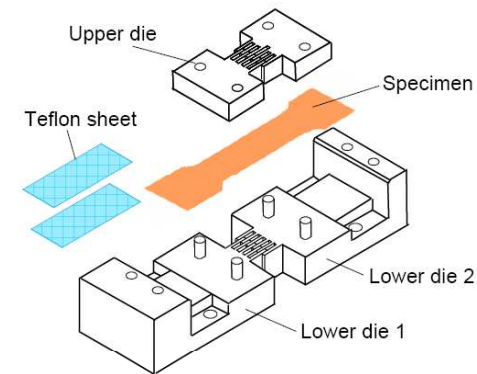
# Experiment

## Tensile tests



Zwick 100 kN

## Compressive tests

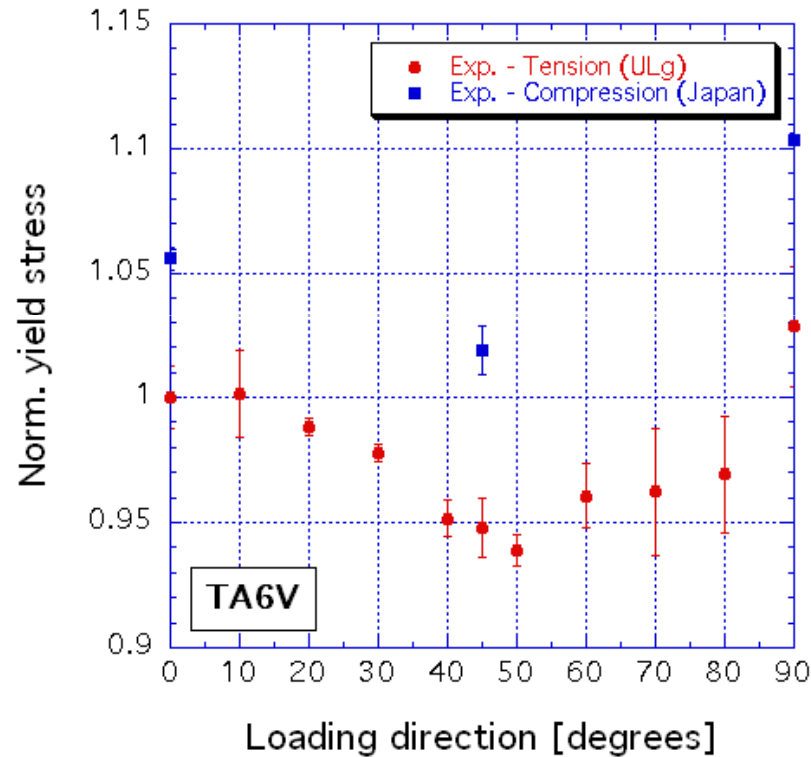


Comb-shaped dies apparatus  
(Kuwabara *et al.*, Int. J. Mater. Form. 2,  
2009)

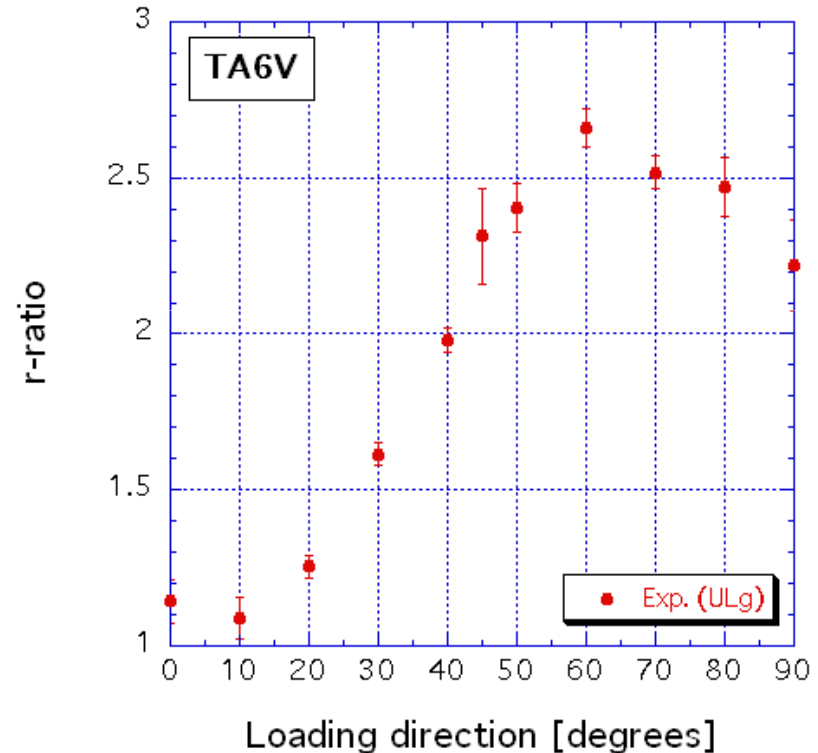
# Experimental results

## Initial yielding

Anisotropy in **tension** and **compression**



r-values (tension)



- High anisotropy
- Tension-compression asymmetry

# CPB06ex3 yield criterion

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

$$\boldsymbol{\Sigma} = \mathbf{C} : \mathbf{s} \quad (\mathbf{C}: \text{4th order orthotropic tensor})$$

$$F(\boldsymbol{\Sigma}) = (|\Sigma_1| - k\Sigma_1)^a + (|\Sigma_2| - k\Sigma_2)^a + (|\Sigma_3| - k\Sigma_3)^a$$

$\mathbf{s}$ : deviator of Cauchy's stress tensor

$a$ : degree of homogeneity

$k$ : strength differential parameter (asymmetry)

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

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)

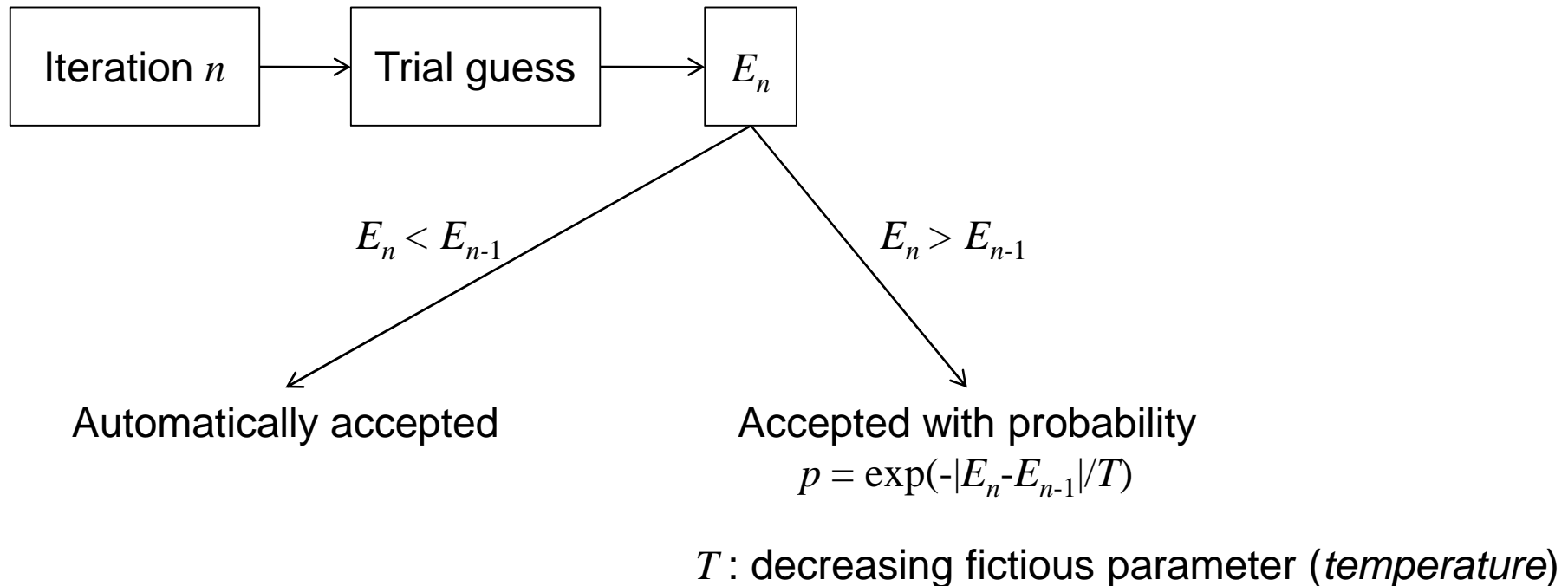
$$\boldsymbol{\Sigma} = \mathbf{C} : \mathbf{s}, \boldsymbol{\Sigma}' = \mathbf{C}' : \mathbf{s}, \boldsymbol{\Sigma}'' = \mathbf{C}'' : \mathbf{s}$$

$$\begin{aligned} F(\boldsymbol{\Sigma}, \boldsymbol{\Sigma}', \boldsymbol{\Sigma}'') &= (|\Sigma_1| - k\Sigma_1)^a + (|\Sigma_2| - k\Sigma_2)^a + (|\Sigma_3| - k\Sigma_3)^a \\ &\quad + (|\Sigma'_1| - k'\Sigma'_1)^a + (|\Sigma'_2| - k'\Sigma'_2)^a + (|\Sigma'_3| - k'\Sigma'_3)^a \\ &\quad + (|\Sigma''_1| - k''\Sigma''_1)^a + (|\Sigma''_2| - k''\Sigma''_2)^a + (|\Sigma''_3| - k''\Sigma''_3)^a \end{aligned}$$

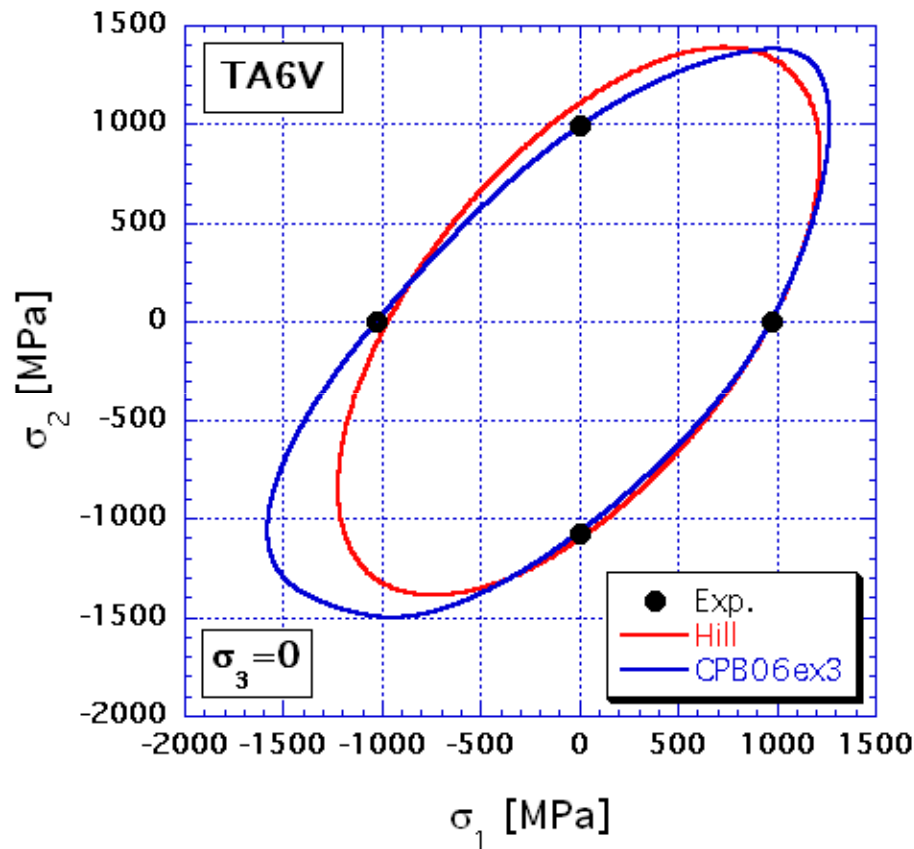
# Parameter identification

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

Optimization using simulated annealing method:



# Yield locus



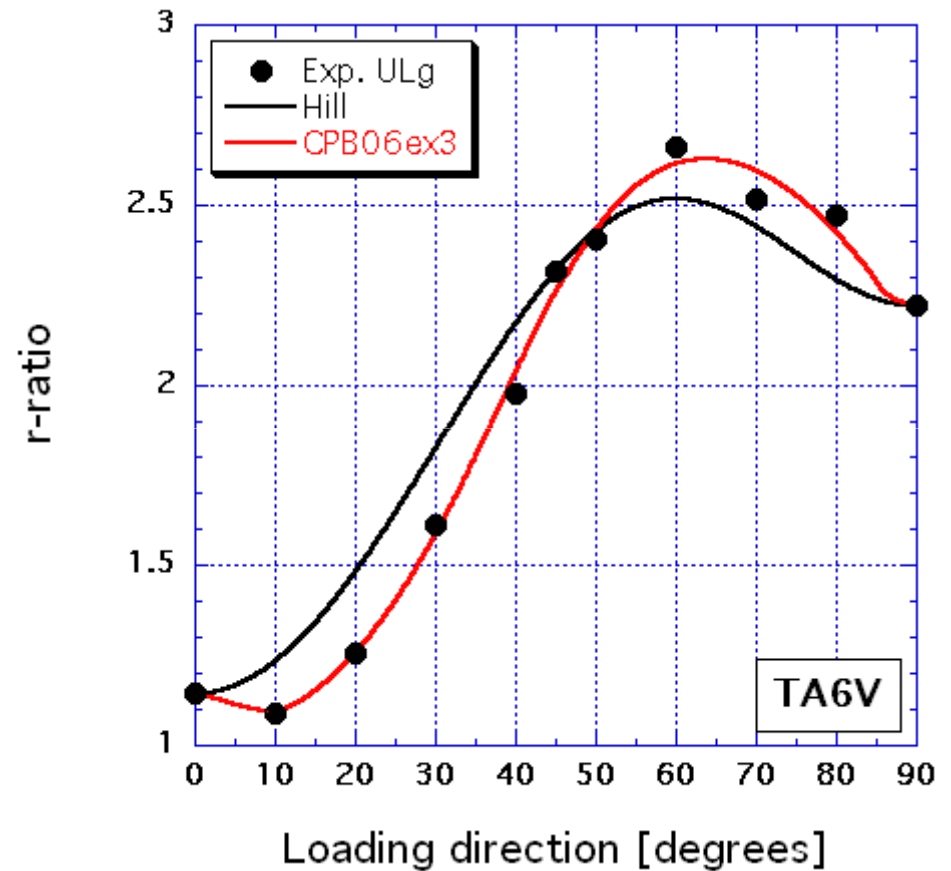
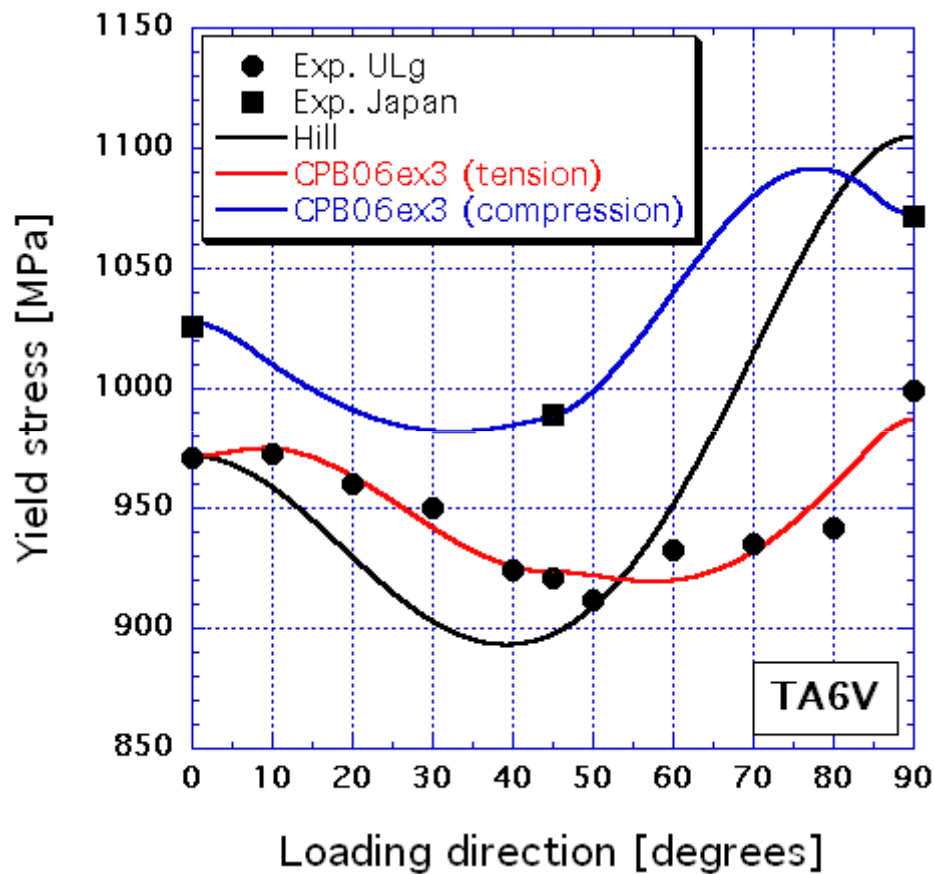
Hill (1948)

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

CPB06ex3

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

# Anisotropy



# Conclusions

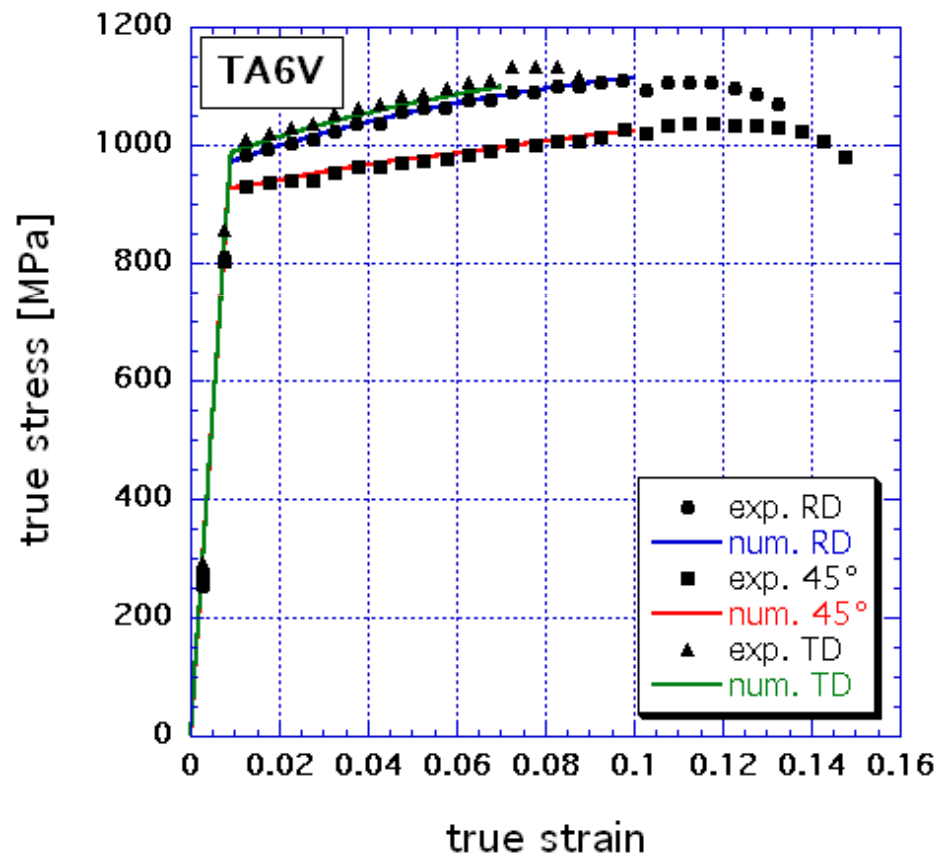
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- Experimental investigation of the anisotropy and the strength differential effects in TA6V (uniaxial tests)
- Parameter identification of CPB06ex3 yield criterion
- Good agreement between experimental data and numerical results

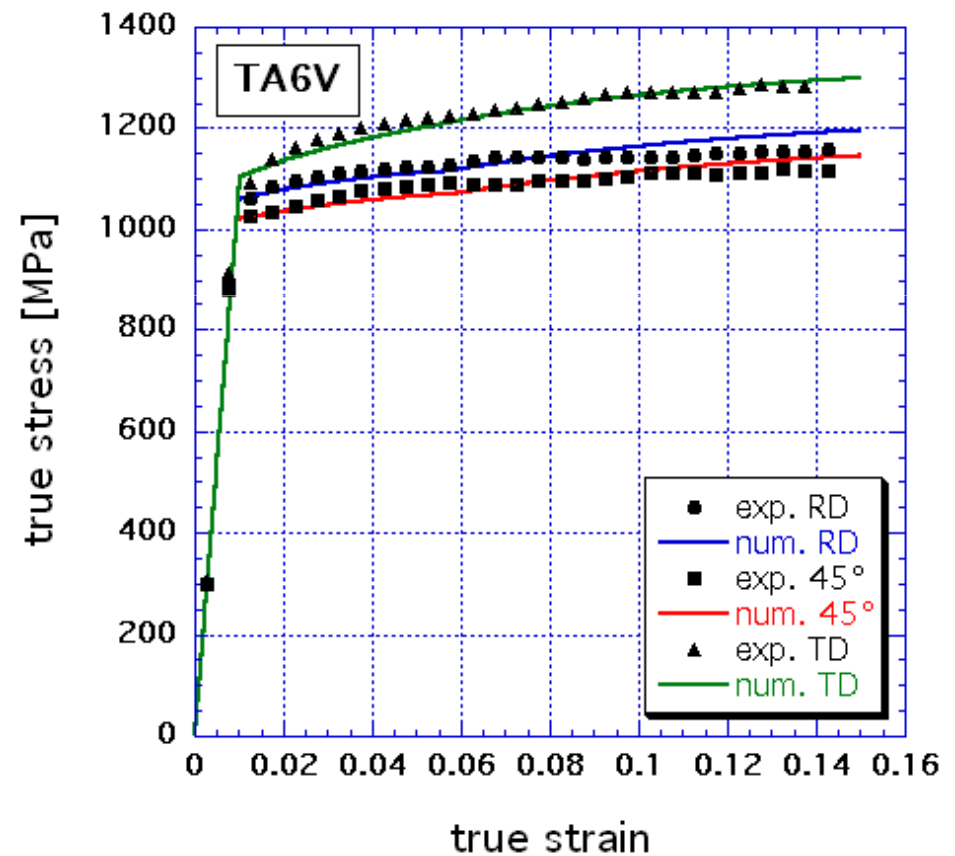
# Future work

## Hardening

### Tension



### Compression



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**Thank you for listening**