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About dislocation density distribution in titanium alloys after hot-deformation in the $\alpha+\beta$ domain

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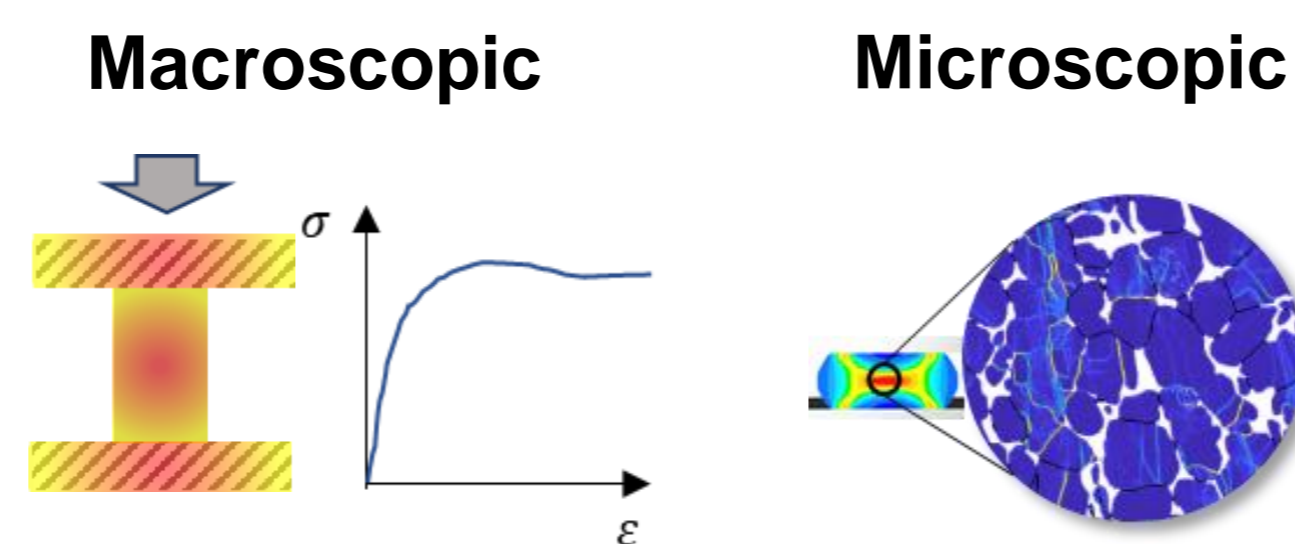
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Introduction

- The initial microstructure to be deformed has great influence on plastic deformation and on the storage of dislocations. In turn, microstructure evolution is tightly correlated to the organization and distribution of dislocations.
- The assessment of dislocation density is quite a laborious task, where all possible different approaches only allow for getting more or less accurate estimates, and the task is even harder when dealing with dual phase materials.

Aim of this work : Estimate and compare the dislocation density in the Ti-6Al-4V alloy, with equiaxed and lamellar morphology, after hot-deformation in the two-phase domain, by two different approaches :



Materials and Methods

2 different industrial billets of Ti-6Al-4V

Equiaxed: $f_\alpha = 92 \pm 1\%$, Grain Size = 13 μm

Lamellar: $f_\alpha = 93 \pm 1\%$, Lath width = 11 μm

2 different sample geometries appropriate for each approach

Macroscopic (bulk analysis): $\varnothing : 8 \text{ mm}$, 12 mm

Microscopic (local analysis): $\varnothing : 11 \text{ mm}$, 12.6 mm, $\varnothing : 17.6 \text{ mm}$ [1]

Sampling direction : along billet radius to mimic conversion process

Macroscopic approach

2 min, 10 min

Equiaxed: $f_\alpha = 53 \pm 1\%$, $f_\alpha = 37 \pm 1\%$

Lamellar: $f_\alpha = 46 \pm 1\%$, $f_\alpha = 37 \pm 1\%$

σ vs ϵ curves

Quenching ($\sim 75^\circ\text{C/s}$)

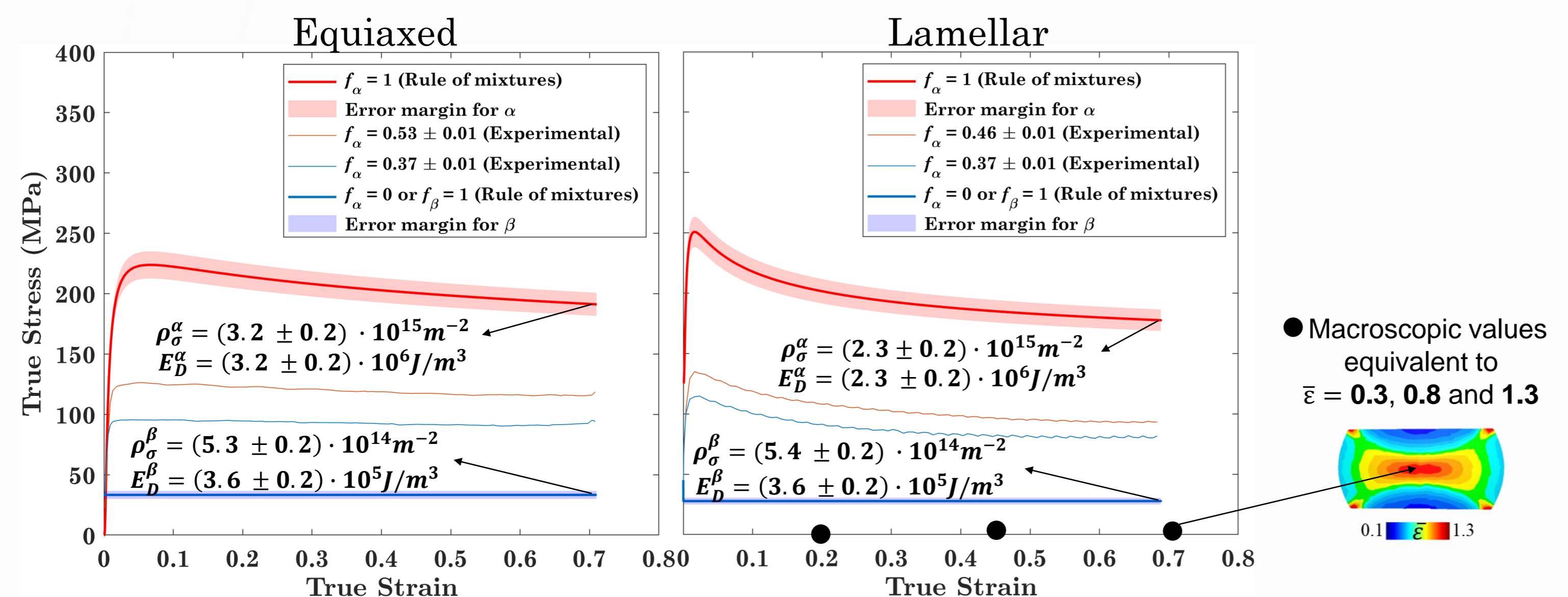
Estimation of the total dislocation density (ρ_σ)

$\rho_\sigma = a M_\varphi G_\varphi b_\varphi \rho_\sigma^{0.5}$

$\sigma = \sigma_\alpha f_\alpha + \sigma_\beta (1 - f_\alpha)$

Estimation of the Stored Energy (E_D)

$E_{D\alpha,\beta} = C \cdot \rho_{\alpha,\beta} \cdot G_{\alpha,\beta} \cdot b_{\alpha,\beta}^2$



- By the analysis of the curves of each phase separately, the presence of the peak on the experimental curves above (orange and light blue) can be attributed to the behavior of the α phase (red curves), as shown in [2] for an equiaxed morphology.
- The dislocation density of the β seems to be independent of the morphology of the α phase.

Microscopic approach

Equiaxed: $f_\alpha = 36 \pm 2\%$

Lamellar: $f_\alpha = 36 \pm 2\%$

Quenching ($\sim 75^\circ\text{C/s}$)

Estimation of the GND density ($\rho_{GND} \approx \rho_{EBSD}$)

EBSD analysis: Fixed step sizes between different levels of deformation

Denosing: Half-Quadratic Filter (MTEX) \rightarrow Preserves substructures

Method based on the GND tensor: Misorientation axis and angle

Energy minimization approach (ρ_{EBSD}): $(\rho_{EBSDm})_{m=1..M}$ which minimizes $\sum_{m=1}^M |\rho_{EBSDm}| e_{Lm}$

Only for the α phase because the β phase transforms into $\alpha+\beta$ during cooling and is thus very poorly measured by EBSD.

Formation of substructures

Comparison between approaches for the α phase

ρ_σ^α vs ρ_{EBSD}^α

Considering the hypothesis that $\rho_\sigma^\alpha = \rho_{EBSD}^\alpha + \rho_{SSD}^\alpha$ [11]

ρ_{SSD}^α seems $\gg \rho_{EBSD}^\alpha \rightarrow$ more remarkable for the lamellar morphology at a low level of deformation.

The formation of substructures is restrained, and the overall rate of hardening at low strains tends to be higher for lamellar microstructures [10]. However, this large ratio (22) might be also due to additional phenomena increasing the flow stress (e.g. orientation/kinking of laths).

GNDs contribution becomes further important at higher levels of plasticity, possibly due to the substructure formation.

Conclusions

- The peak on the stress-strain curves of Ti-6Al-4V seems to be due to the behavior of the α phase, for both equiaxed and lamellar morphologies.
- The dislocation densities obtained from the macroscopic flow stress are higher on the analyzed cases, which is consistent, as they take into account both GND and SSD, contrary to the dislocation densities estimated from EBSD data which concern only the GNDs.
- The evolution of the ρ^α seems to be dependent on the morphology, where, for the lamellar microstructure at high deformation levels (1.3), the ρ^α might have decreased due to the lath rotation to a softer configuration.
- ρ_{SSD}^α seems $\gg \rho_{EBSD}^\alpha$ in all analyzed hot-deformed samples, especially in the case of lamellar morphology at a low level of deformation, may be due to the restrained formation of substructures, but also to additional phenomena.
- GNDs contribution becomes further important at higher levels of plasticity, possibly due to the substructure formation, with higher local disorientation (thus better detected).

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