Variant selection in red gold alloys during Phase transformation under 4 point bending

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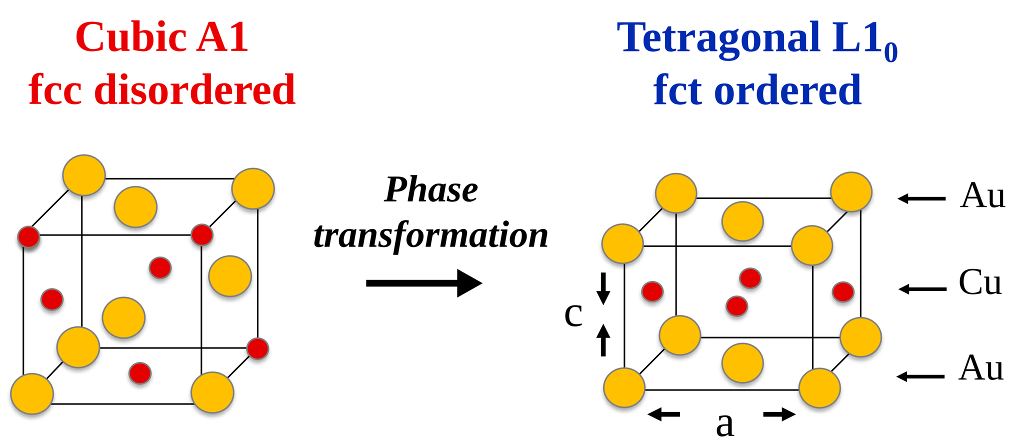
Introduction

For compositions close to equiatomic, red gold alloys undergo a phase transformation of type A1→ $L1_0$. This phase transformation has been widely studied by TEM since the beginning of the 20th century. The transformation results in a complex microstructure formed by the arrangement of nano-scale ordered tetragonal domains. In 1998, an interesting shape memory effect has been reported and barely studied since then. The shape memory effect must involve variant selection during displacive transformation occurring under stress. In this work, the transformation is studied for the first time by EBSD and analyzed as a displacive transformation.

1/ Phase transformation

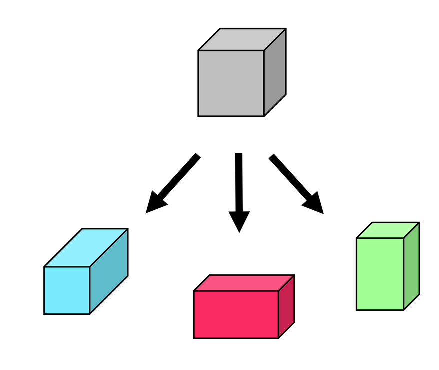
- **Ordering** of the atoms
- **Tetragonal distortion** of the FCC lattice
- **Diffusive** because of the kinetics and local diffusion of the atoms
- **Displacive** because of the shape memory effect
- Transformation during heat treatment **at 300°C**

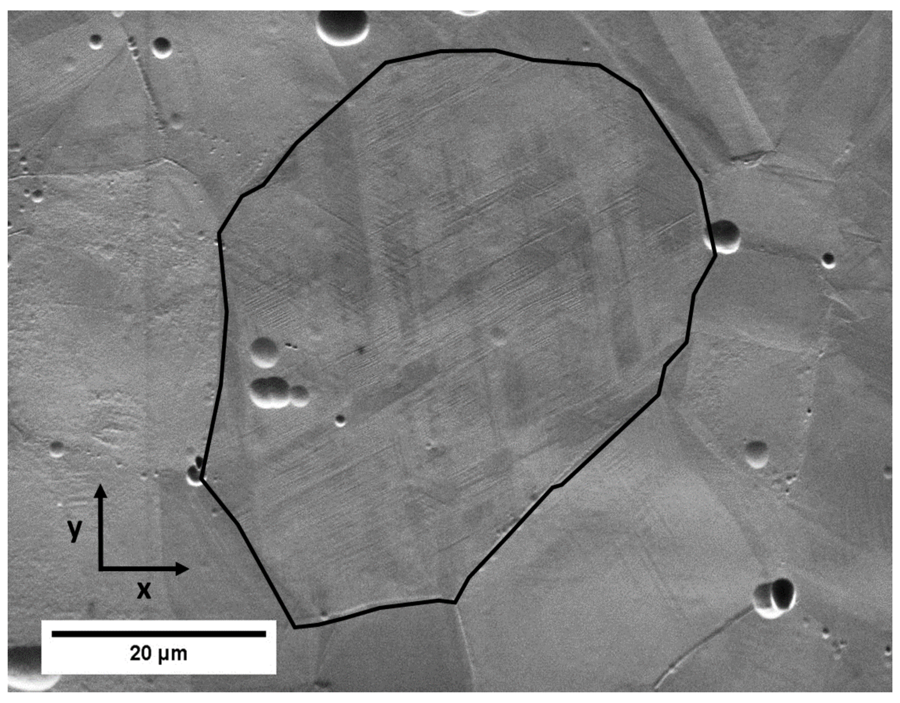


Which crystallographic orientation is favored when stress is applied during the transformation?

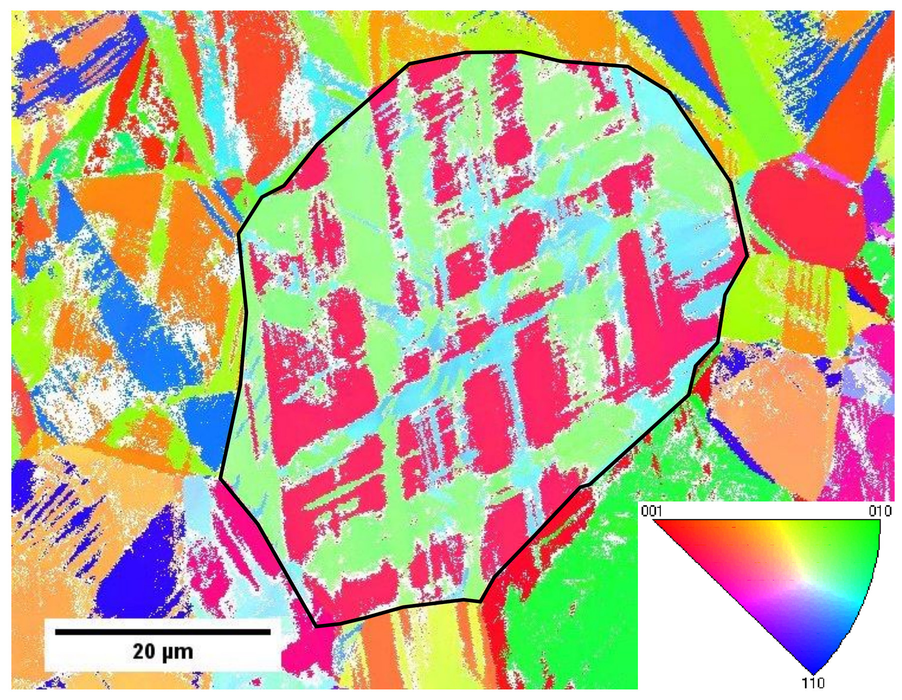
2/ EBSD

- Reference stress-free sample
- Study of the **orientation relationship**
- 12 variants approximated in **3 groups** with close orientations
- EBSD gives information on the **orientation** of the crystal





SE image of one grain highlighted in black



EBSD map of the tetragonal domains

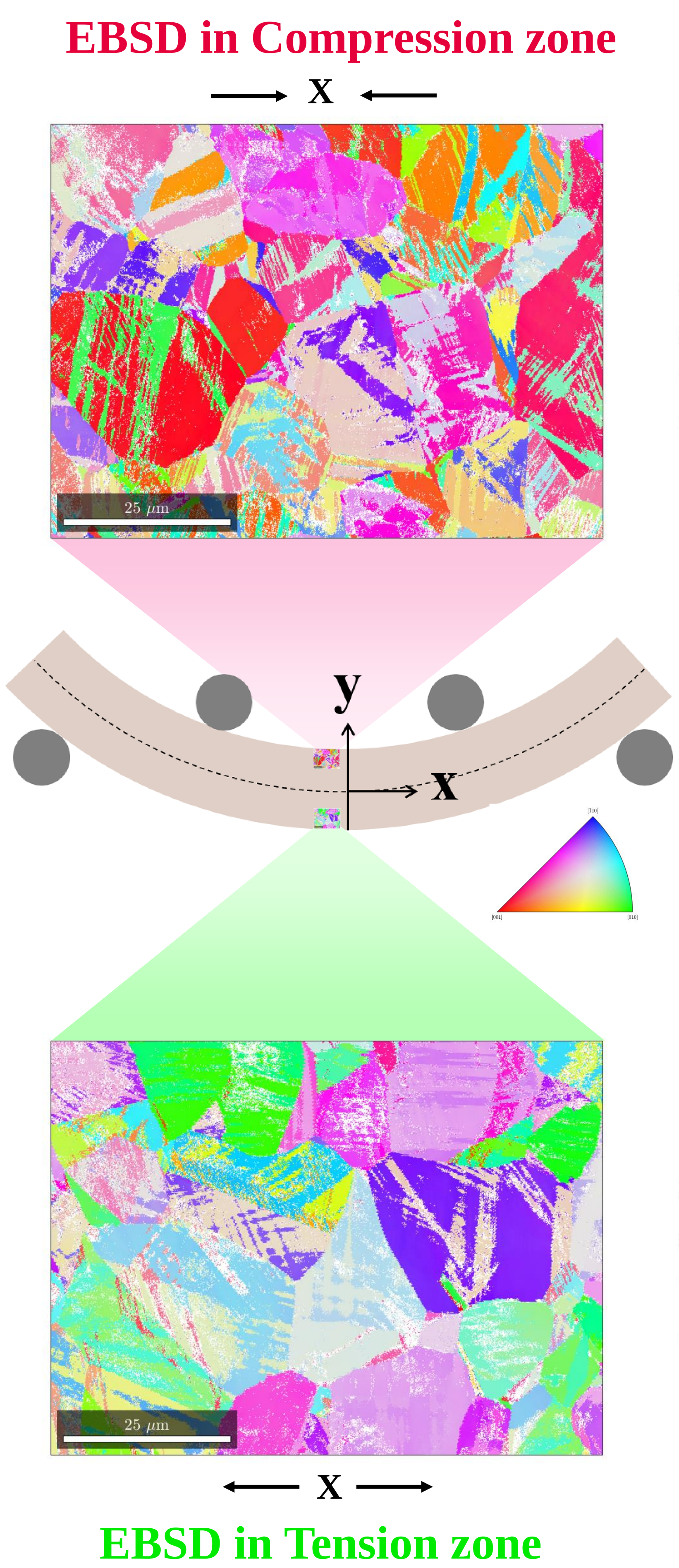
3/ Process

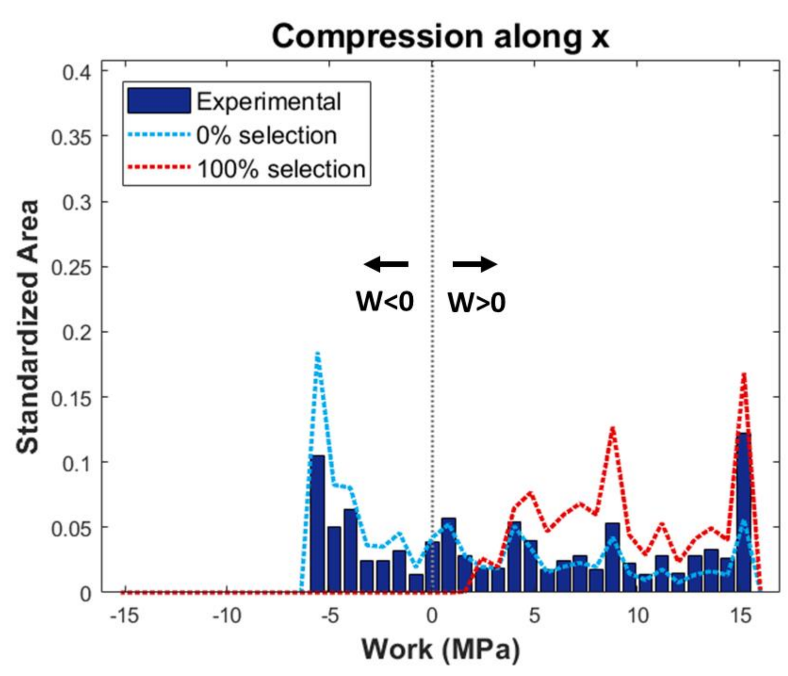
→ 4 **point bending** on polycrystalline cubic samples
→ Phase transformation by **heat treatment**
→ **EBSD maps** on traction and compression sides
→ From EBSD data, **calculation of work** and area of each variant
→ Plotting the histograms **area as a function of work**
→ Comparing with calculated 0% and 100% selection

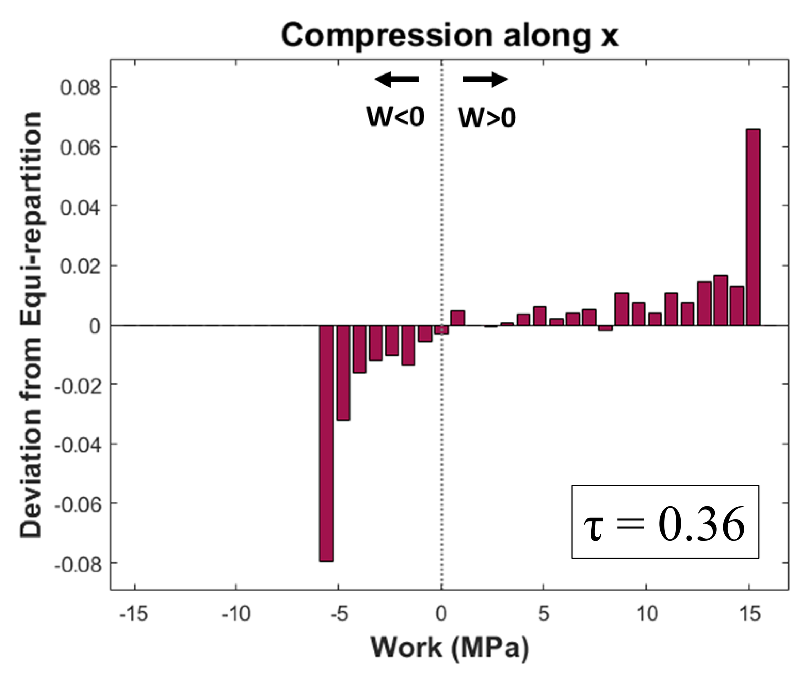
Maximal work criterion:

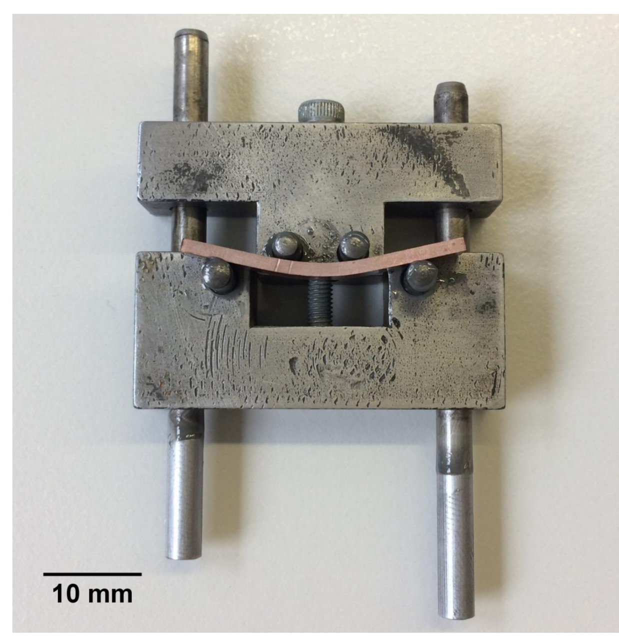
- The higher the work the easier the variant is formed
- The higher the work the more likely is the variant
- Calculation of the work in 3d: $W = \boldsymbol{\sigma}_{/s} : \boldsymbol{\varepsilon}_{/s} = \sigma_{ij}\,\varepsilon_{ij}$

σ: the stress state
ε: the deformation of the variant calculated from EBSD orientation





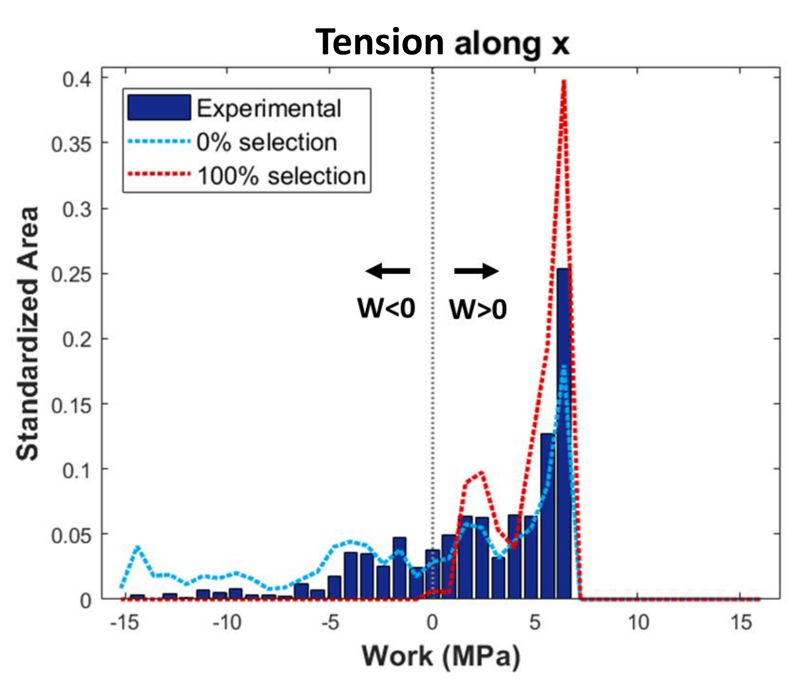


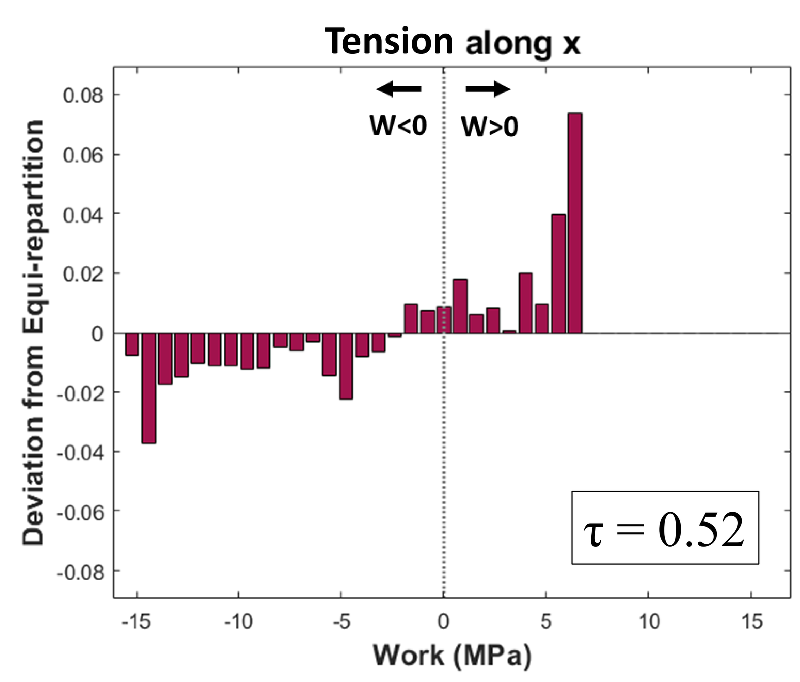


The four point bending device

Hypothetical situations:
0% selection: the 3 variants with equal proportions in all grains
100% selection: only the maximal work variant in each grain

Difference between **Experimental** and **0% selection**





4/ Results

- **Variants of higher work are more present** than expected in the case of no-variant selection
- The maximal work criterion works well, both **in tension and in compression**

5/ Quantification

- The degree of selection is calculated in both zones with the formula:

$$\tau = \frac{\overline{W} - \overline{W}_{equi}}{\overline{W}_{max} - \overline{W}_{equi}}$$

- τ is 0 if no variant selection
- τ is 1 if maximal variant selection

Reference
Larcher, M. N. D., Cayron, C., Blatter, A., Soulignac, R. & Loge, R. E. (2019). J. Appl. Cryst. 52, 1202-1213.

Conclusion

For the first time, in this work the tetragonal domains could be detected by the EBSD technique despite the close c/a ratio. The orientation relationship was successfully determined and the maximal work criterion could be applied. Thanks to the large scale analysis, variant selection in polycrystalline $L1_0$ type alloy could be studied with statistical relevance and successfully quantified both in tension and compression loading.