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## Plastic flow and damage of $\alpha$ -zirconium polycrystals

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### ABSTRACT

In order to analyse the influence of texture and grain size on the damage mechanisms of  $\alpha$ -zirconium polycrystals, tensile tests on a instron machine and in situ tensile tests in a scanning electron microscope (SEM) were performed. We have observed that grain boundary triple points or boundary irregularities induce cavity formation.

### INTRODUCTION

In the nuclear industry, the reprocessing of fuel elements involves zirconium tanks because of its resistance to nitric acid from 300 to 500K. Although zirconium presents good mechanical properties, problems arise due to the forming process. In addition, the prediction of the tanks lifetime appears to be difficult.

Despite considerable scientific activity in the investigation of the mechanical properties of zirconium (influence of texture, interstitial elements, temperature), very little work has been done concerning the damage mechanisms of zirconium. The present experimental work intends to investigate the influence of texture and grain size on the damage mechanisms of  $\alpha$ -zirconium polycrystals.

### EXPERIMENTAL PROCEDURE

The experiments were carried out at room temperature on cold-rolled zirconium sheets in recrystallized state. Two recrystallized states are considered, each state being characterized by an average grain size (15  $\mu\text{m}$  and 100  $\mu\text{m}$ ), the texture and precipitation remaining unchanged. Composition and mechanical properties are given in table 1.

At room temperature, zirconium exhibits a hexagonal close-packed crystal structure. The basal poles are preferentially parallel to the normal direction with a tendency to spread by  $37^\circ$  toward the transverse direction (figure 1). The precipitates were observed to be distributed randomly not only at the grain boundary but also within the grain. Furthermore they are aligned along the rolling direction.

*In situ* tensile tests in a scanning electron microscope (SEM) were performed along two directions (rolling direction -RD- and transverse direction -TD-) in the sheet plane. Square microgrids with a 5  $\mu\text{m}$  pitch have been deposited on the sample surface. The *in situ* tensile tests show, in real time, the evolution of strain inhomogeneities and the inception and evolution of damage.

Furthermore tensile tests on a instron machine were performed until fracture at a tensile test rate of 2.8 s<sup>-1</sup>. After tensile tests, samples were sectionned into the thick part and were examined using metallography procedure for SEM observations.

### RESULTS AND DISCUSSION

Most of the observations come from the in situ tensile tests performed in the SEM.

The observations in the SEM are in concordance with previous works showing that the activated deformation systems depend on the tensile axis orientation (rolling or transverse direction) (1) and on the grain size (2). The twin growth is easier when the tensile axis is parallel to the transverse direction. In small grain material, twins of the type  $\{10\bar{1}2\}$  appear, whereas in coarse grain material both  $\{10\bar{1}2\}$  and  $\{11\bar{2}1\}$  twins are active.

As for the slip bands, in all the cases more than two kinds of them are seldom observed in the grain. It must be prismatic slip (1).

Furthermore deformation becomes located near the grain boundaries for both the small and coarse grain material: twinning, slip and deformation bands can be seen. But the bigger the grains, the more clearly visible deformation bands appear near the grain boundaries. It is still unknown whether these deformation bands are shear bands or intense slip bands.

As for the damage mechanisms, most of the observations come from small grain material: the voids nucleate at grain boundaries. Coarse grain material is used to get a better understanding, although damage mechanisms are slightly different: voids can also be seen inside the grain.

In small grain material, the first damaging events coincide with the appearance of necking. When tensile tests are performed along the rolling direction or the transverse direction, grain boundary triple points or boundary irregularities induce cavity formation. Twinning activated near grain boundary can also induce cavities because of the stress concentration at its tips (figure 2). The observations on surface of samples sectionned in the volume confirm that the voids nucleate at grains boundaries in the whole volume of the samples.

In the coarse grain material, voids can also nucleate at grain boundary triple points and the figure 3 shows that the continuity of the displacement field in the surrounding of the cavity is checked (thanks to the microgrids). We think that there is no free boundary plane influence because of presence of in plane shear. The interior of each grain deforms predominantly by single slip, and in a region on either side of the grain boundary the lattice of microgrids is rotated (indicating gradients of simple shear) and secondary slip or twinning occurs.

If we assume here that only the most favorably orienting prismatic slip systems operated in the plastic deformation (with  $\langle 10\bar{1}2 \rangle$  parallel to the rolling direction), and that only the external force was exerted on the slip systems of individual grains, we can calculate the schmid factors of individual grains. When tensile tests are performed along the rolling direction or the transverse direction, only two out of three prismatic slip systems can operate, so that compatibility at the interface between adjacent grains may not be maintained and intergranular cracks develop. Furthermore the deformation becomes located near the grain boundaries, so that the appearance of cavities can be delayed. The figure 2 shows that twinning is induced in the accommodation process, when the tensile test is performed along the transverse direction. The interactions between grains to make up for the lack of deformation modes is complex.

The lack of slip systems can explain why twinning can activate when the material is performed along the transverse direction. But the magnitude of deformation due to twinning is small (compared with that of slip), so cavities can develop. It can explain why the cavities appear after 7% deformation (when the necking appears) when the material is performed along the transverse direction, compared to 12% when the material is performed along the rolling direction.

### CONCLUSION

Our observations show that the activated deformation systems depend on the tensile orientation and the grain size.

As for the damage mechanisms, the cavities appear at grain boundary. We expect to achieve a complete understanding of the damage mechanisms by taking the texture into account.

We didn't determine whether the voids are nucleated by precipitates along the grain boundaries.

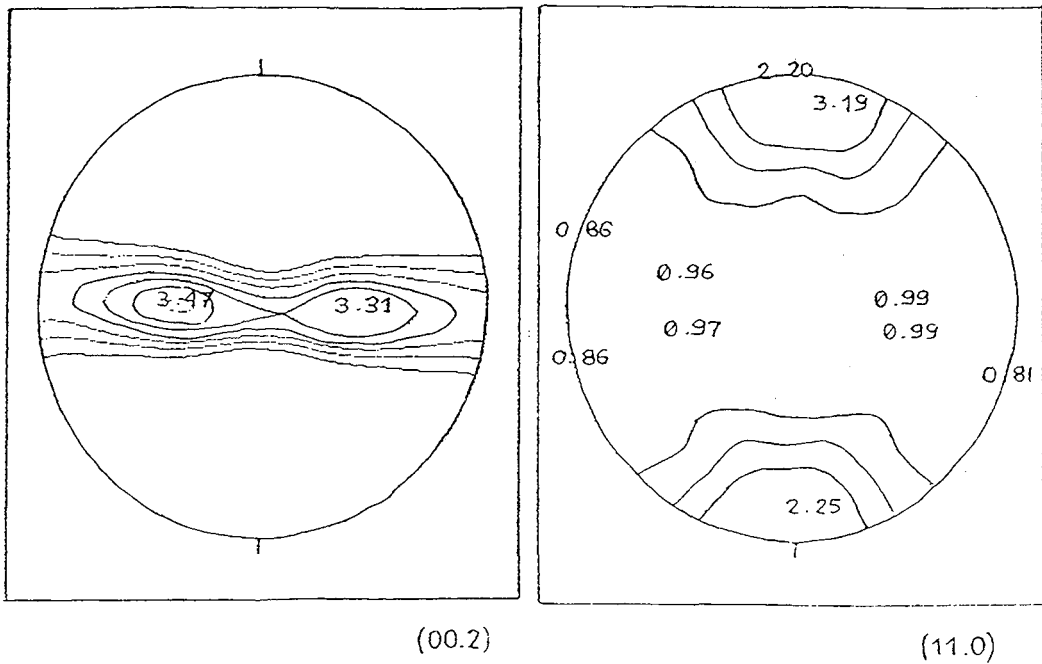
### ACKNOWLEDGMENTS

The financial support of Commissariat à l'Energie Atomique (Saclay, CEREM/ DTM/ SRMA, France) is greatly acknowledged.

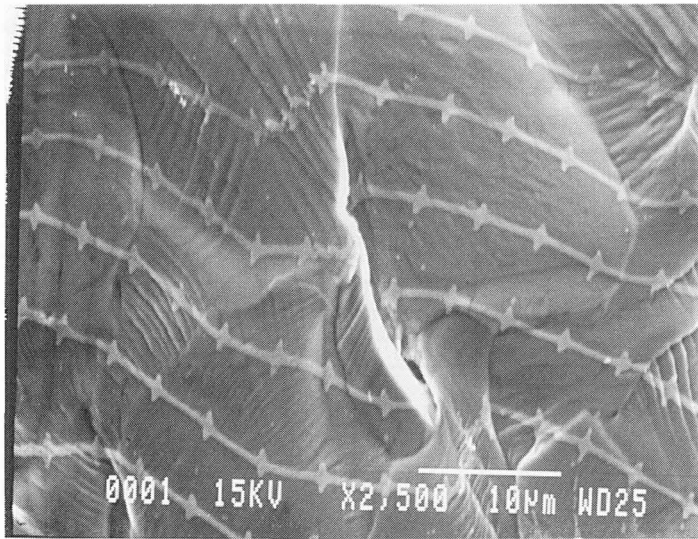
**Table 1:** Chemical analyse and tensile properties of the zirconium used in this work.

FE + CR	NI	CU	C	H	N	O
≈840	≈60 ppm	≈10 ppm	≈56 ppm	5 ppm	24 ppm	1230ppm

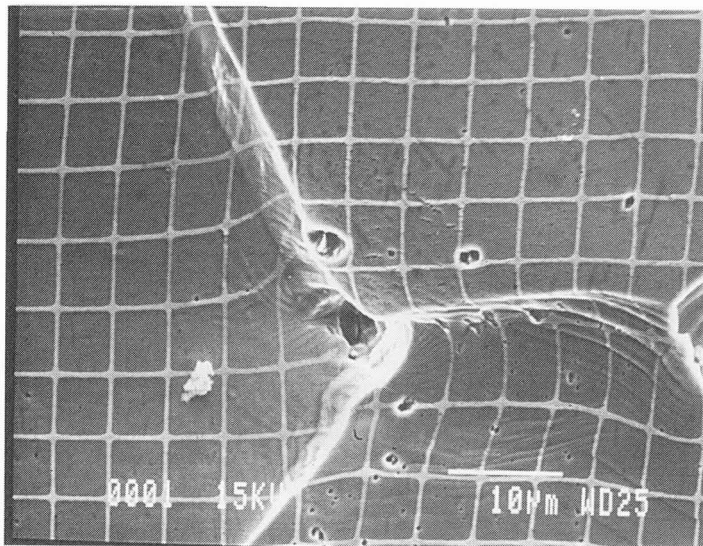
	Rolling direction	Transverse direction
Yield stress	150 MPa	200 MPa
Ultimate tensile stress	430 MPa	430 MPa
Strain to necking	12%	7%
Fracture strain	28%	23%



**Figure 1:** Texture of the zirconium used in this work.  
(Document CEREM/DTM/SRMA)



**Figure 2:** Small grain material deformed along the transverse direction.



**Figure 3:** Coarse grain material deformed along the rolling direction.

#### REFERENCES

- (1) TENCKHOFF E., ASTM STP 966 (1988).
- (2) VÖHRINGER O., Z. Metallkde. 67 (1976) 518.