Deformation Mechanisms in Zircaloy-4

O. Zanellato, M.E. Fitzpatrick and L. Edwards
Dept. of Materials Engineering, The Open University, Walton Hall, Milton Keynes, UK, MK7 6AA

Background Zirconium alloys combine a low neutron cross section with good mechanical and corrosion properties. The nuclear industry uses them for structural applications in the reactor (fuel claddings, reflector vessels…). However the hexagonal crystal arrangement of the atomic structure is very anisotropic both thermally and mechanically. In a polycrystal this can give rise to high intergranular stresses which can lead to premature failure. It is critical to assess the microscopic behaviour for better understanding of the material properties. In the present work the behaviour of Zircaloy 4 was studied. A compression test was carried out in-situ in the neutron beam at the ENGIN-X diffractometer of the ISIS pulsed neutron source, UK. The diffraction technique was used to follow the evolution of the elastic strain for various grain orientations (reflections).

Material

The material was hot rolled and highly textured (figure 1). Coupons were cut out for compression along each processing direction.

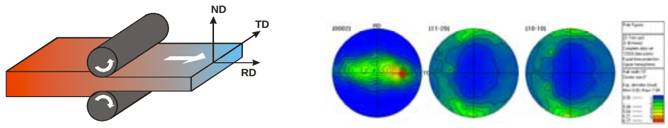

Figure 1 – Rolling process and texture obtained by Electron Backscatter Diffraction

Experiment

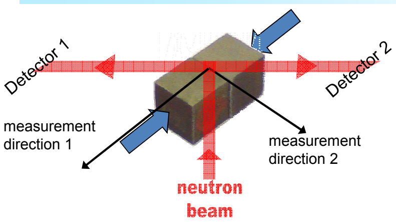

Figure 2 – Schematic view of the set-up

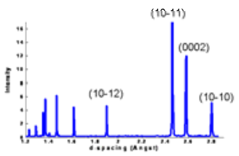

Figure 3 – Typical diffraction peak for Zry-4 at ENGIN-X

Figure 2 shows how the coupons were compressed and orientated relative to the neutron beam

• The compression tests were performed in load control at up to 10% total deformation.

• At several stages of the compression test, neutron diffraction measurements were taken (time of flight measurement):

-11 reflections in the diffraction spectrum (figure 3)

-two detectors→ elastic strains in 2 directions

Results

• The macroscopic stress-strain curves evidence a mechanical anisotropy: there is more hardening during compression along the normal direction ND than along TD and RD (figure 4).

• Figure 5 shows the behaviour of three reflections during compression along the transverse direction (TD). The elastic strain in TD reaches –8000 microstrain for the (0002) reflection, which bear more load than (10-10) and (10-11).

• After unloading the elastic strain in the grains did not disappear: there are high inter-granular strains after compression (see figure 6).

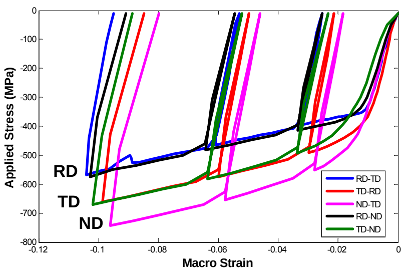

Figure 4 – Macroscopic behaviours of the different processing directions

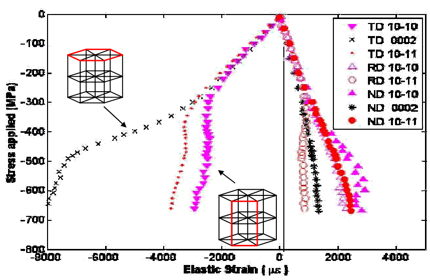

Figure 5 – Elastic strain evolution in 3 reflections for compression along the transverse direction

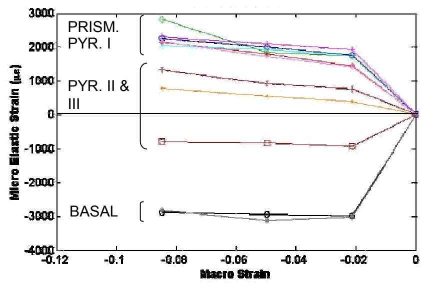

Figure 6 – Residual strains in the reflections after unloadings (compression along the transverse direction)

Conclusion

• The crystal anisotropy has been successfully measured in Zircaloy 4 during real-time deformation.

• After the unloading, high intergranular residual strains were measured.

• The macroscopic anisotropy can be explained by the combination of strong texture and crystal anisotropy.

• Understanding the behaviour of the polycrystal in this way is important when determining the stress state and the stress response in welds, for example. These data are being used to develop 'self-consistent' elasto-plastic models of the materials behaviour.