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EXPERIMENTAL ASSESSMENT OF NANOVOIDS GROWTH

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Summary The growth of nanovoids in crystalline metallic material is assessed experimentally as a function of the applied macroscopic plastic strain, stress triaxiality and crystal orientation. Nanovoids - of diameter ranging from 20 to 80nm - are generated by performing heavy-ion irradiation on austenitic steel, leading to a model material constituted of a well-defined nanovoids distribution. Pre- and post-straining Transmission Electron Microscope (TEM) observations allow to quantify the growth and the evolution of aspect ratio as a function of plastic strain. Size and crystal orientation effects are evaluated. Experiments are compared to the results of crystal plasticity finite element simulations.

BACKGROUND

Numerous theoretical and numerical studies have been conducted to assess the growth of nanovoids under mechanical loading [1], showing size effects (the lower the size of the void, the lower the growth rate), crystal orientation effects (growth rate depending on the crystallographic orientation) and describing dislocation mechanisms involved as a function of the applied macroscopic stress. However, very limited experimental data are available in literature, and only for high strain rates / high applied stress. Thus the aim of this study is to assess experimentally nanovoid growth in the low stress regime, as a function of applied strain, stress triaxiality and crystal orientation.

EXPERIMENTAL INVESTIGATIONS

Nanovoids are usually observed in metallic materials under irradiation in nuclear power plant. These voids come from interactions between high energy particles and atoms of the material, that generate point defects ultimately leading to nanosized defects [2]. Irradiation is therefore used here to generate well-defined distributions of nanovoids, creating a model nanoporous material. Ion-irradiation was performed at the JANNUS facility [3] on austenitic steel (316L), leading to spherical nanovoids - of diameter ranging from 20 to 80nm - in high density (Fig. 1), observed with Transmission Electron Microscope (TEM). As void growth under mechanical loading is very sensitive to stress triaxiality [4], tensile and biaxial tensile samples were used in this study. Post irradiation, specimens were strained up to different levels of macroscopic plastic strain. Quantification of the evolutions of void size and aspect ratio as a function of plastic strain and crystal orientation, for different stress triaxiality, was done using TEM observations (Fig. 2).

RESULTS AND DISCUSSION

Nanovoid deformation under mechanical loading is shown to be sensitive to crystal orientation, as predicted by numerical and theoretical predictions: for some orientations, the void aspect ratio stays close to unity, while very elongated voids have been observed for other orientations (Fig. 2). The evolution of void size and aspect ratio as a function of plastic strain is studied as a function of applied strain, for some crystal orientations. Results are finally compared to predictions of finite elements simulations using crystal plasticity constitutive equations.

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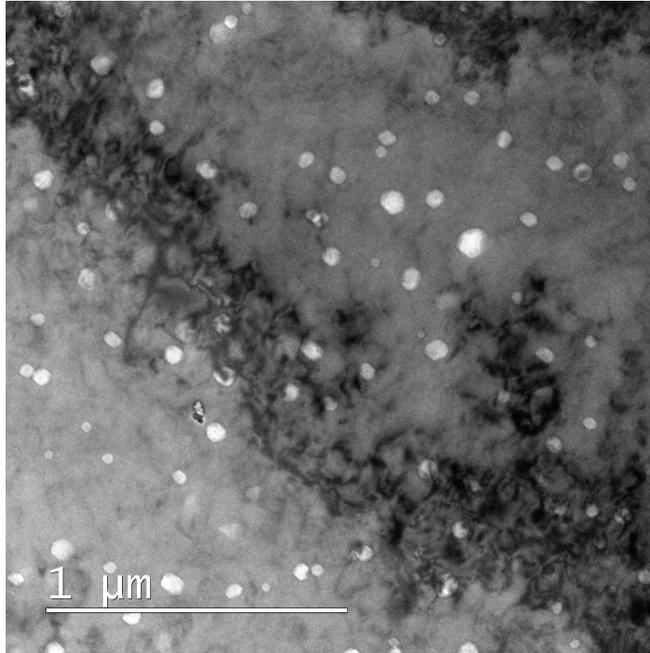


Figure 1: Spherical nanovoids observed by Transmission Electron Microscope (TEM) after ion-irradiation in austenitic steel

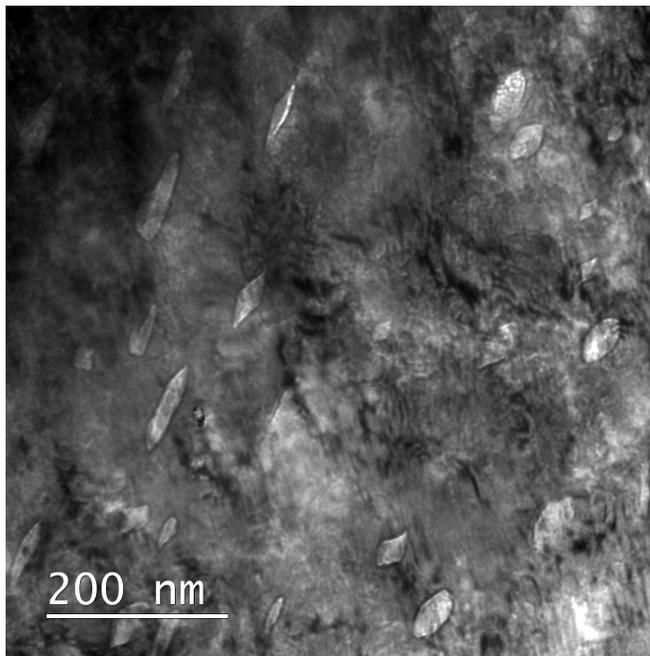


Figure 2: Nanovoids observed by Transmission Electron Microscope (TEM) in ion-irradiated austenitic steel after straining to 30%