In situ micro tensile testing of He+ ion irradiated single crystal nickel film

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Introduction

Radiation damage can cause increase in strength and decrease in ductility, thus reducing the service life of structural parts in reactors. Ion beam irradiation has been a method of choice to simulate the effects of neutron irradiation in a reactor for some time now [1], since it enables the attainment of reasonable doses within hours, instead of years inside a reactor. A major problem in this method is that the damaged region is very shallow, and mechanical testing of such thin layers is extremely difficult. In this study, we have used in situ micro-tensile testing in the scanning electron microscope (SEM) to understand the effects of high energy ion beam irradiation on the mechanical properties of a single crystal nickel thin film.

Experiments

Single crystal Nickel foils, ~12.8-13.1 μm thick, were irradiated with 6 MeV He+ ions in the Tandetron "STAR" accelerator at ANSTO. The samples were irradiated to two different fluences – (i) 2 x 10^{17} ions/cm^2 (peak damage of ~ 10 displacements per atom or dpa), and (ii) 3.8 x 10^{17} ions/cm^2 (peak damage of ~19 dpa). Damage profiles calculated using the SRIM software [2], showed that there is a long, low tail of the profile beginning at the entry face and extending to approximately 9-10 μm depth, after which the damage rises sharply (Fig. 1(a)). Micro-tensile samples of approximate dimensions 25-30 μm (l) x 10 μm (w) x 12-13 μm (h) were fabricated using a Zeiss® Auriga 60™ Cross-Beam™ instrument. The free end of the sample was milled to obtain a rectangular hole which was used as a grip. The end of the tensile device, shaped as an L shaped hook, was inserted into the aforementioned rectangular hole. The sample was then subjected to tension by applying a voltage to a piezo-electric device attached to the tensile head, causing it to move at a rate of ~20 nm/sec. SEM images were taken at regular intervals, and the strain measured using two fiducial markers, one on each side of the gauge length.

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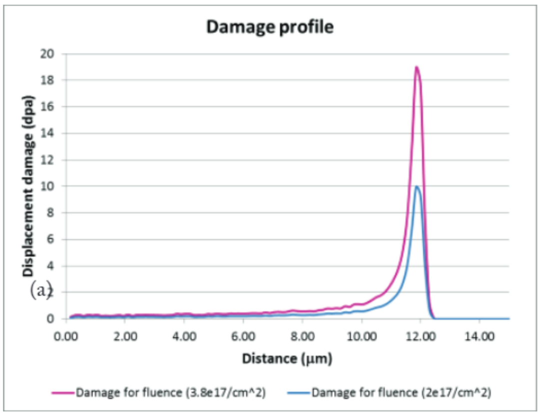
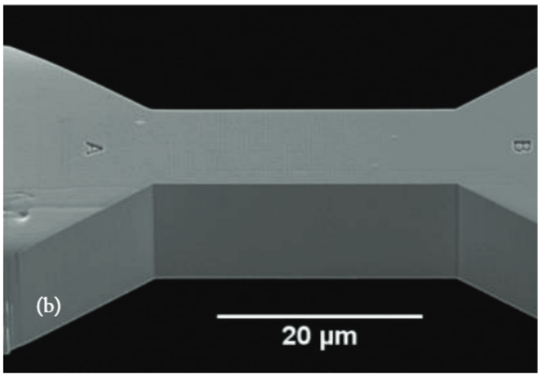
Results

An image of a typical tensile sample used in these tests is shown in Figure 1(b), before the start of the test. The SEM image in Figure 1(c) shows the unirradiated sample after a tensile strain of e ~ 56%. The sample had a Y.S. of ~70-100 MPa, and an U.T.S. of ~240 MPa (see Fig. 2). There was significant strain hardening up to the U.T.S., and subsequently it underwent plastic strain with large slip bands passing on two major sets of planes in an alternate manner. The formation of these slip bands was accompanied by small drops in the stress and increases in strain. A post-test SEM image of a sample irradiated with 6 MeV He+ ions to a fluence of ~2e17 ions/ cm^2 and a peak damage of ~ 10 dpa is presented in Fig. 1(d), showing slip bands passing through the whole thickness of the sample and fracture at the lower surface, which in this case is the "exit surface" of the ions. This sample had a Y.S. of ~ 195-230 MPa, and a peak strength of ~358 MPa before first rupture at the surface near peak damage, at a strain of about 1.9% (Fig. 2). A post-test SEM image of the sample fabricated from the foil irradiated with He+ ions to a total fluence of 3.8e17 ions/ cm2 and a peak damage of ~ 19 dpa is shown in Figure 1(e). This sample showed a Y.S. of ~ 400 MPa and a peak strength of ~ 500 MPa before first rupture at the exit surface of the ions, which is the top surface in this case.

Conclusions

The effect of He+ ion irradiation on the tensile strength of Ni single crystals was measured successfully by in situ micro-tensile testing of FIB-fabricated samples which included the damaged layers. The results showed increase in average strength of up to ~118 MPa for a total fluence of 2e17 ions/ cm^2 and ~260 MPa for a peak damage of ~3.8e17 ions/cm^2. Brittle fracture was observed in the irradiated samples at the surface nearer to the peak damage layer. [3]





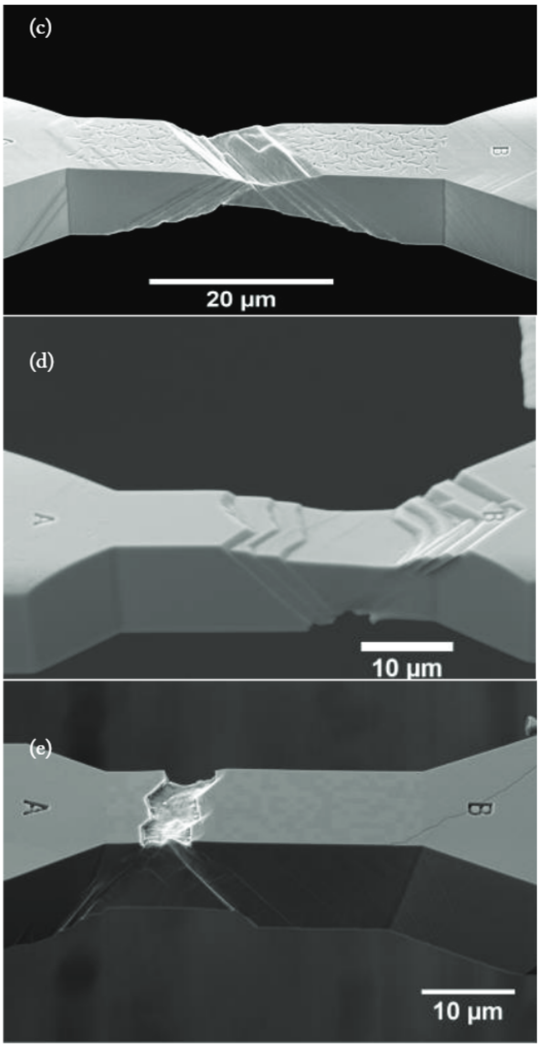


Figure 1. (a) SRIM profile of damage due to 6 MeV He+ ions, (b) Tensile sample before test, (c) Unirradiated sample after plastic strain of ~56%, (d) Irradiated to 2e17 ions/cm^2, plastic strain of 25%, (e) Irradiated to 3.8e17 ions/cm^2, plastic strain of 22%.

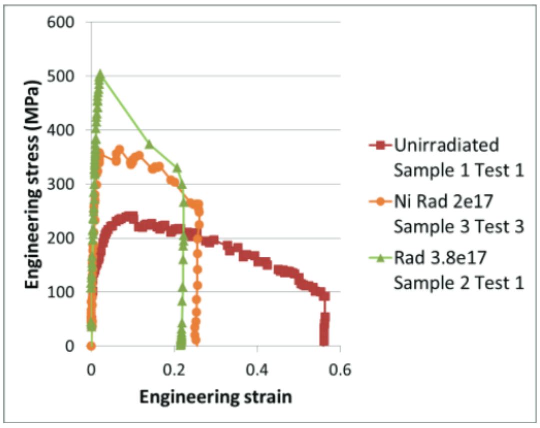


Figure 2. In situ tensile test results of unirradiated and 6 MeV He+ ion irradiated samples showing significant strengthening due to irradiation..

References

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