Irradiation induced creep in Al-Sc alloys using *in-situ* TEM

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1. Introduction

A newer trend in irradiation damage research is to employ ion irradiations in combination with newly developed micromechanical testing on miniaturized specimens [1-3]. To have a better knowledge on irradiation damage in nanocrystalline materials, irradiation induced creep measurements on nanocrystalline metals were performed. The simpler damage structure in Al greatly facilitates comparison with theoretical models, hence Al alloy system is selected in this study. This results shows that in-situ micro beam bending IIC test on nanocrystalline Al–Sc works reliably and this is a promising method for other nanocrystalline Al alloy systems.

2. Methods and Results

2.1 Experimental

The irradiation creep tests using a cantilever beam geometry were performed inside of TEM. For the irradiation induced creep measurement using the beam bending apparatus, a 6 MeV tandem accelerator, connected to a customized JEOL 2100 LaB6 TEM, was used for in-situ ion irradiation. Details of the instrument/experiments on ion irradiation have already been described [4].

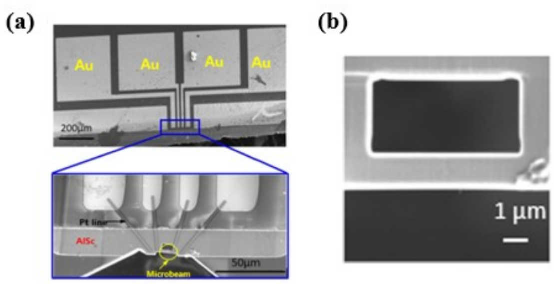

Fig. 1(a) Fabricated 4 Au pads (lines) and the Pt lines connect Au pads and a creep sample. E-beam assisted deposition was performed to deposit Pt wire; (b) a SEM image of a microbeam for in-situ TEM irradiation test.

2.2 Irradiation creep tests

Irradiations were performed using a 1 MeV and 5.5 nA Al ion beam. P means the total power of the laser out of fiber optics and P0 refers the power of laser before it enters the alignment optics, respectively. As laser power increases, the innermost ring diameter increases and at P/P0 = 120% the diameter of innermost ring is the largest, i.e., smallest lattice spacing. Since P/P0 = 120% represents the highest temperature, this presumably is due to Sc coming out of solution, indicating the specimen temperature is greater than ~ 350 °C.

The results for IIC are shown in Fig. 2(a–c). TEM images in Fig. 2(a) provide a typical example showing how the microbeam indentation creep tests are performed. The image #4 was obtained after the test and the plastic deformation (beam bending) is clearly seen. Although, there was no rupture during the measurement, as seen in Fig. 2(b), a crack was observed at the center of the beam. Figure 2(c) shows the corresponding strain behaviors as a function of time for samples tested at different stresses and laser power (temperatures) between 0 and P/P0 = 120%. Higher laser power (temperature) results in higher strain rates as expected. To see the mechanical behavior according to the stress, stress was increased several times during the measurement, and corresponding points can be found as sudden 'strain rate jumps' in Fig. 2(c) Not that each given stress was held ~ 300 s. At P/P0 = 120%, a dramatic increase in the strain is observed at ~ 400 s. Based on this observation, the steep strain may be associated with the crack and the combination of temperature and stress results in rapid deformation. A plot of strain rate versus stress is shown in Fig. 2(d). The beam tested at room temperature shows very low strain rates. Again, high laser power results in a high strain rate. The temperature can be predicted based on previous studies [3, 5] and temperature range of 300 – 400 °C for the Al alloys.

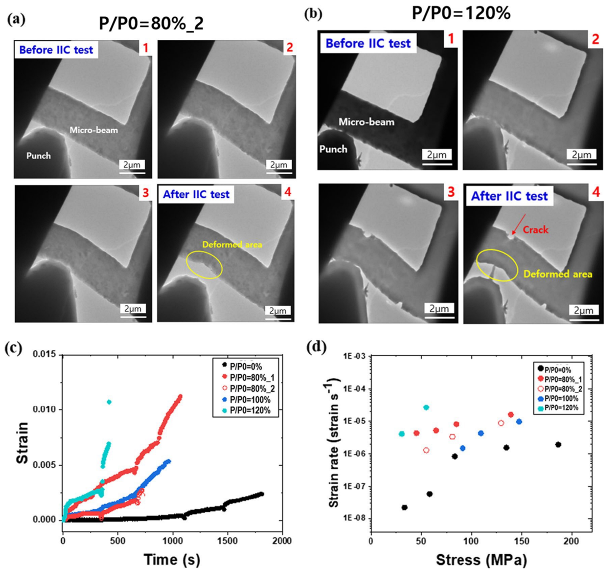

Fig. 2(a) Time-lapse bright field images sequence of SI 80_2, (b) bright filed TEM images sequence of in-situ microbeam creep test beam with power level P/P0 = 120%, (c) Variation of IIC strain with time for microbeams tested at different laser power (temperature), (d) shows the linear dependence of IIC strain rate with stress.

Calculated creep compliances (B_0) using $\dot{\varepsilon} = B_0 \bar{\sigma} \phi$ are provided in Table 1. where $\dot{\varepsilon}$ is the strain rate, $\bar{\sigma}$ is the effective stress and $\dot{\phi}$ is the displacement rate per seconds. This equation is applicable if swelling is negligible.

Table 1 Creep compliance

Power intensity (%)	**Bo (DPA^{-1} MPa^{-1})**
0	~ 7.3×10^{-5}
80	~ 2.5×10^{-4}
80	~ 3.5×10^{-4}
100	~ 5.5×10^{-4}
120	~ 1.8×10^{-3}

*Power intensity refers P/P_0

3. Conclusions

In summary, in-situ irradiation induced creep (IIC) behavior of a dilute Al–Sc binary alloy was measured using a cantilever beam method. We confirmed that this cantilever beam-bending method is a more general method to measure irradiation-induced creep under high stress and high temperature compared to thin film bulge testing. This study is reasonably agreement with previous predictions of IIC [6], and thus, it is useful for future work and some technical problems have been highlighted.

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