§12. Effects of Cold Working on Microstructural Development during Irradiation

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1. Introduction

Vanadium alloys are promising candidate for fusion blanket structural materials, because of their low activation characteristics, high temperature performance and neutron irradiation resistance.

From the practical view point, it is important to reveal the effects of cold working on irradiation properties of vanadium alloys. It has been reported that void swelling of 316 type stainless steels is suppressed by cold working. Such cold working effect is expected also for vanadium alloys. In the present study, vanadium alloys with 90 % cold working and the ones annealed at 1273 K were neutron irradiated. The cold working effect on microstructural development during the neutron irradiation was investigated.

2. Experimental procedure

Pure V and 3 alloys, such as V-5 wt% Cr, V-5 wt% Nb, V-4 wt% Cr-4 wt% Ti were prepared for the present study. Final treatment for these alloys are annealed or 90 %-cold-worked. Disks with the size of ϕ 3 mm x 0.2 mm were punched out and neutron irradiated by Japan Materials Testing Reactor (JMTR) at 350 ^{o}C. Neutron fluence was equivalent to 0.02 dpa (displacement per atom). Microstructural observation with trans mission electron microscopy (TEM) and Vickers hardness tests were performed as post irradiation experiments.

3. Results and discussion

Figure 1 shows microstructures of V-4Cr-4Ti alloy after the neutron irradiation. Dislocation loops and high number density of defect clusters with fine dotted contrasts were observed. Present authors has been irradiated V-4Cr-4Ti alloy to 0.01 dpa, and analyzed very similar clusters with 3 dimensional atom probe measurement. According to the measurements, the clusters were identified as Ti-containing precipitates. The clusters in the present study are also considered as Ti precipitates. On the other hand, the dotted defect clusters were not observed in the 90 % cold-worked specimens.

Irradiation hardening for the annealed V-4Cr-4Ti alloy was larger than the 90 %-cold-worked one. The fine defect clusters with high number density can be obstacles for mobile dislocations, thus the large irradiation hardening in annealed alloys is attributed to the formation of the fine and high number density defect clusters.

The size of voids induced by neutron irradiation in pure V with 90 % cold working was larger than the one in annealed specimen. This is understood as dislocation bias effects, where dislocations introduced before neutron irradiation act as sink for interstitial atoms formed by displacement damage, and excess vacancy enhance the growth of the voids. However, no void structure was observed in the alloys other than pure V. Only development of dislocation structure was observed in these alloys. Irradiation hardening for V-Cr and V-Nb alloys was similar for the both final treatment as annealed and 90 % cold worked state.

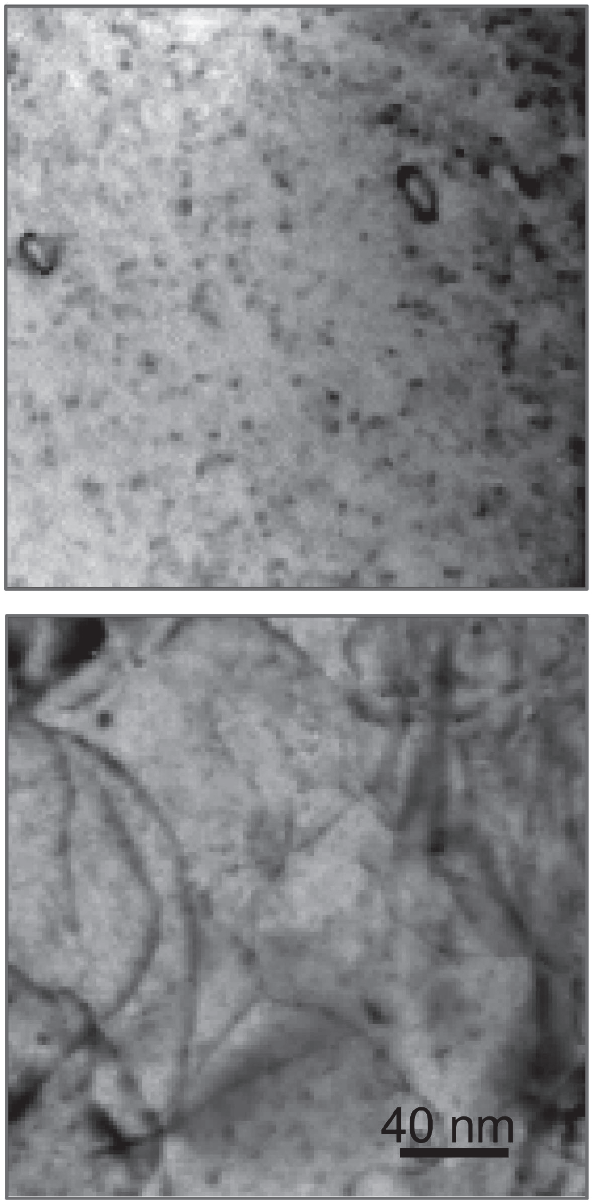

Fig. 1 TEM microstructure of V-4Cr-4Ti alloy after neutron irradiation by JMTR up to 0.02 dpa. (Top: annealed, Bottom: 90 % cold-worked before irradiation)

4. Conclusion

In the present study, enhancement of void growth was clarified in pure V by 90 % cold working. For V-4Cr-4Ti alloys, suppression of Ti precipitation was observed at the working condition. However, void formation was not avoided by cold working, as reported for 316 stainless steels.

Further systematic study on neutron fluence and the initial dislocation densities is necessary for understanding the interaction between irradiation defect clusters and dislocations introduced by cold working.