A SEARCH FOR CHANNEL DEFORMATION IN IRRADIATED VANADIUM TENSILE SPECIMENS—

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OBJECTIVE

The objective of this effort is to investigate channel deformation in deformed irradiated vanadium alloys in order to better understand deformation behavior in this class of materials.

SUMMARY

A miniature tensile specimen of V-4Cr-4Ti which had be irradiated in the 17J test at 425°C to 3.7 dpa was mechanically polished, deformed to 3.9% strain at room temperature, and examined by scanning and transmission electron microscopy in order to look for evidence of channel deformation. It was found that uniform deformation can occur without channel deformation, but evidence for channeling was found with channels appearing most prominently after the onset of necking. The channeling occurs on wavy planes with large variations in localized deformation from channel to channel.

PROGRESS AND STATUS

Introduction

Recent tensile tests on selected irradiated V-4Cr-4Ti specimens showed unstable response, possibly due to channel deformation [1-3]. Channel deformation is often found in irradiated materials and is characterized by extensive shear on specific planes such that localized deformation can be very high. An excellent example is in the recent work of Fukumoto and coworkers on V-(3-5%)Cr-(3-5%)Ti deformed after irradiation at 300ºC [4-6]. In that work, confocal microscopy was used to examine the specimen surface during tensile testing, and it was possible to stop testing at the ultimate tensile stress. Surfaces in the necked region showed surface steps and TEM revealed that deformation bands were present in the microstructure that were free of irradiation induced defects and dislocations. The deformation bands showed up to a 10º rotation with respect to adjacent undeformed regions. More recent work showed examples where these channels could not penetrate grain boundaries, with tangles of dislocations in the vicinity of the boundary. Our recent examinations of compression test specimens irradiated in the RB-17J test at 425ºC did not provide definite evidence of channel deformation [7,8]. To determine if the propensity for channel deformation is influenced by stress-state, a tensile specimen of the same composition as the compression specimens was examined.

Experimental Procedure

Miniature tensile specimens UN01 and UB36 were obtained from Oak Ridge National Laboratory for testing and examination. UN01 was an SS-J2 geometry of the Japanese NIFS-2 heat and UB36 was an SS-J1 geometry of the US heat 832665, so that UN01 was approximately twice as thick as UB36 but otherwise was very similar. Both had been irradiated in the RB-17J experiment at 425ºC to 3.7 dpa [9,10]. Both specimens were surface ground to a 0.3 µm diamond polish finish, so that UN01 was reduced to about the thickness of UB36 and then both were tested in a miniature test frame at room temperature and a low strain rate of ~0.051 mm/min. Following testing, the samples were examined by SEM in a JEOL 840 to identify surface features and failure modes, where relevant, and then the UB36 sample was prepared for transmission electron microscopy using standard ion milling procedures. This involved gluing gauge sections to 3 mm molybdenum washers, dimple grinding and polishing, and then ion milling in a Gatan PIMS using argon ions at 5 KeV. Following thinning, the edge of the gauge section was visible, so it was possible to identify the tensile axis in micrographs. Transmission microscopy was performed on a JEOL 2010F and images were recorded digitally.

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Results

Specimen UN01 broke at a very low applied stress, with a brittle cleavage fracture surface at approximately right angle to the tensile axis. It was presumed that extensive surface grinding might have caused embrittlement. UB36 was deformed to ~4% strain, with a yield stress of 525 MPa, fairly typical for these irradiation conditions. The tensile trace is shown in Figure 1.

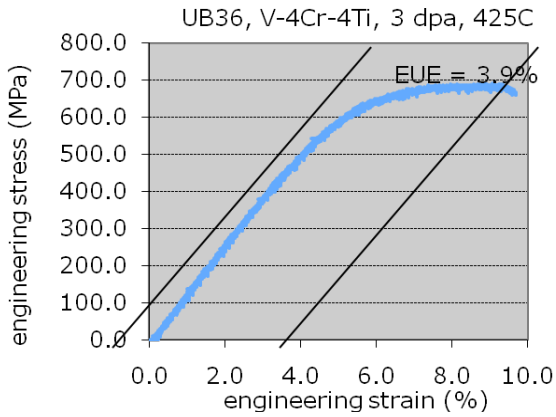

Figure 1. Tensile trace for specimen UB36 tested at room temperature following irradiation at 425ºC to 3.7 dpa.

SEM revealed that the sample was necking at one end of the gauge section, but otherwise showed no apparent effects of deformation. However, the two sides did show significant differences. Images of the more interesting side are provided in Figures 2 through 5 at increasing magnifications. Figure 2 shows the complete gauge section at low magnification with the necked region near the end on the right. Figure 3 shows the necked area at higher magnification revealing some regions with surface steps, but with adjacent regions showing no steps. Figures 4 and 5 provide examples at higher magnifications of a region containing steps; the steps are non-uniformly spaced, wavy in nature and with large variations in apparent height.

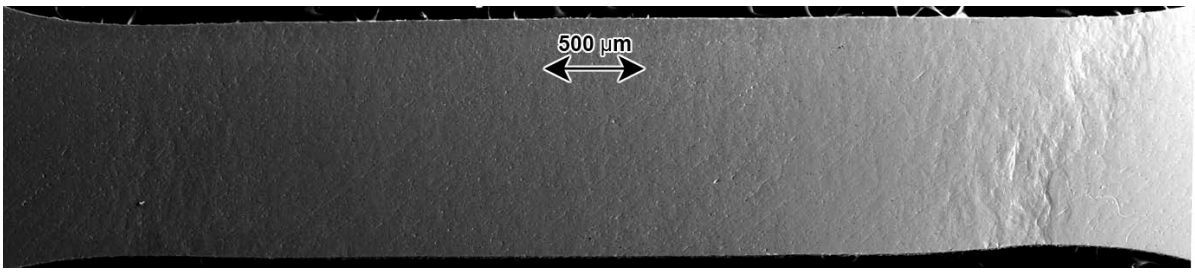

Figure 2. Surface damage at low magnification on UB36 following deformation.

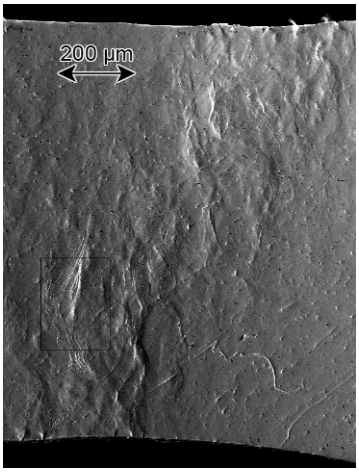

Figure 3. Necked region on UB36 following deformation.

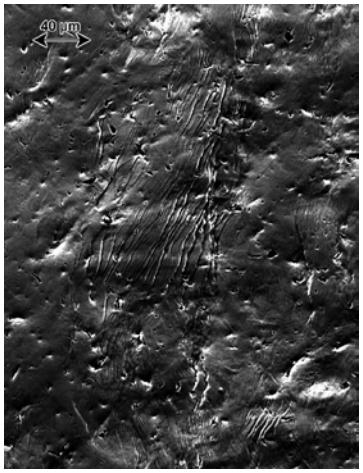

Figure 4. Surface steps in the necked region of UB36.

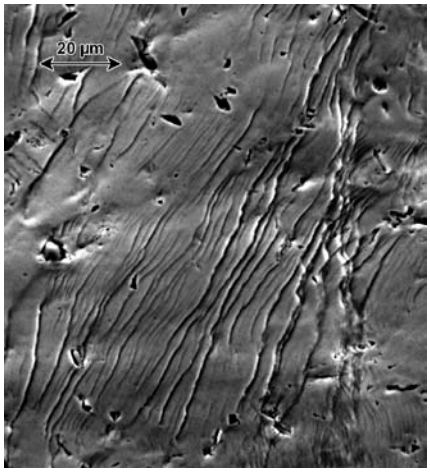

Figure 5. Surface steps at higher magnification on UB36.

The other side of specimen UB36 showed less structure resulting from deformation. Surface steps were not found; instead cavities appeared. An example is shown in Figure 6. The behavior is understood to be a result of a poor surface polish which left an oxide coating on the specimen. Deformation resulted in fractures in the oxide coating with resultant deformation restricted to regions below these fractures. Therefore, deformation induced surface steps are only created on clean surfaces.

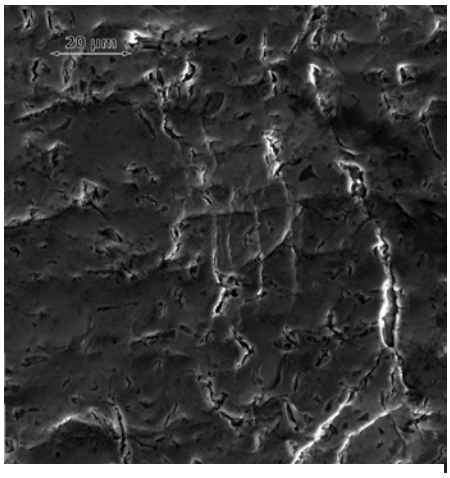

Figure 6. Surface features in the necked region on the other side of UB36.

Two samples were prepared from specimen UB36 for TEM, one centered in the necked region and a second in a region that had undergone uniform deformation. Each had been dimpled from the oxide-coated side so that thin area was closer to the well polished surface. Both had developed many perforations that had merged, giving a good deal of thin material covering an area on the order of 200 µm by 300 µm. Both samples revealed microstructures that appeared deformed, with complex bend contours throughout. However, imaging of dislocations was difficult due to the high density of precipitate particles present following irradiation. Similar precipitation response had been previously observed [11,12]. Both samples were examined during tilting experiments so that the movement of bend contours could be followed as the sample was tilted, in order to identify areas where discontinuous bend contour motion occurred, in order to reveal evidence of high local deformation. The two samples differed in that the one with uniform deformation showed no evidence of local high deformation areas whereas the necked sample contained several "steps." An example of a step is provided in Figure 7. The sample has been tilted so that one side is in strong g=110 contrast, whereas the other side is in weak contrast because the orientation is different. Corresponding convergent beam diffraction patterns are superimposed to show the tilt between these regions.

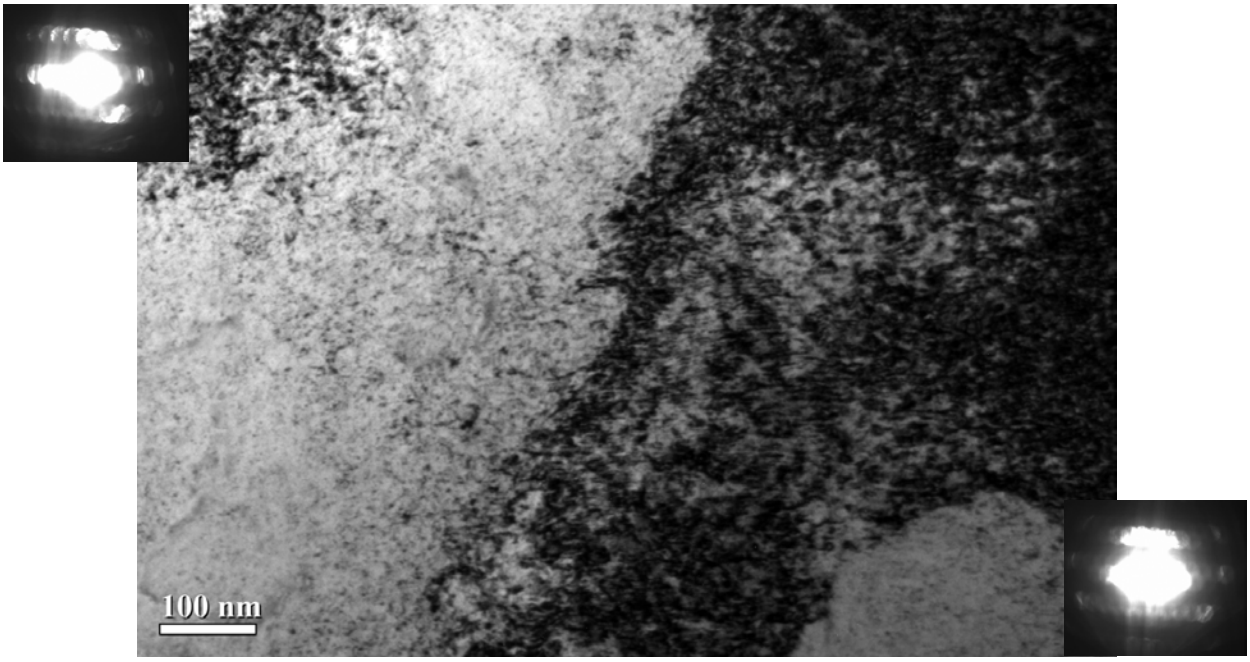

Figure 7. An area in the necked region of UB36 showing a shift in contrast between adjacent regions.

Figure 7 provides a typical example of the deformed microstructure in UB36. Dislocation images are difficult to identify. Under strong imaging conditions, they can be seen, but under weaker imaging conditions, they are hard to resolve because of the high density of precipitate strain fields. A step in contrast extends from upper right to lower left and approximately parallel to the applied stress direction. The nature of the step interface can be seen to be non-planar and complex. The closely spaced horizontal fringes in the strongly contrasted region possibly designate an inclined plane that separates the two regions.

Discussion

The phenomenology of channel deformation, if it exists in V-4Cr-4Ti following irradiation at 425ºC to 3.7 dpa in HFIR, appears to be as follows. Uniform deformation can occur without channel deformation, and channels appear most prominently after the onset of necking. Channeling occurs on wavy planes with large variations in localized deformation from channel to channel.

This is very different from that observed by Fukumoto and co-workers for V-(3-5%)Cr-(3-5%)Ti following irradiation at 300ºC and also by Garza and co-workers for V-4Cr-4Ti following ion irradiation and neutron irradiation in EBR-II to 4 dpa at 390ºC [13]. Following irradiation at the lower temperatures, the behavior follows classical response whereby dislocations are able to remove irradiation induced defects in their path and thereby reduce drag stresses. Following irradiation in our experiment at the higher temperature, the irradiation-induced obstacles are in the form of oxy-carbo-nitride precipitates [11,12] that are not easily destroyed by passing dislocations. Therefore, it appears that a different mechanism is required to create deformation channels where dislocation drag is more complex.

The nature of the mechanism required to overcome oxy-carbo-nitride precipitates at moderate strains is not yet understood. It appears to require significant cross slip as would be available in the complex stress state developed during necking. It can be argued that similar behavior was found in Fe-9Cr following irradiation and tensile deformation, where surface steps were found but dislocation free channels could not be identified [14]. Instead, evidence for channel deformation in the microstructure was limited to the observation of bands of distorted voids with adjacent regions containing undistorted voids.

CONCLUSIONS

Evidence for channel deformation is found as surface steps in a specimen of V-4Cr-4Ti irradiated at 425ºC to 3.7 dpa in the RB-17J that had been deformed at room temperature. Steps were only prominent in the necked region of the specimen after uniform strains on the order of 3.9% had been achieved. Microscopy indicated that the surface steps could be correlated with rough transgranular planes that represented complex tilt boundaries. This behavior was different from the more classical behavior found in V-(3-5%)Cr-(3-5%)Ti following irradiation at the lower temperature of 300ºC and is ascribed to the presence of oxy-carbo-nitride precipitate particles with greater obstacle strength.

References

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