MODE I AND MIXED MODE I/III CRACK INITIATION AND PROPAGATION BEHAVIOR OF V-4Cr-4Ti ALLOY AT 25°C

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OBJECTIVE

To investigate mode I and mixed-mode I/III crack initiation and propagation behavior of the production-scale heat (#832665) of V-4Cr-4Ti using compact tension specimens and modified compact tension specimens.

SUMMARY

The mode I and mixed-mode I/III fracture behavior of the production-scale heat (#832665) of V-4Cr-4Ti has been investigated at 25°C using compact tension (CT) specimens for a mode I crack and modified CT specimens for a mixed-mode I/III crack. The mode III to mode I load ratio was 0.47. Test specimens were vacuum annealed at 1000°C for 1 h after final machining. Both mode I and mixed-mode I/III specimens were fatigue cracked prior to J-integral testing. It was noticed that the mixed-mode I/III crack angle decreased from an initial 25 degrees to approximately 23 degrees due to crack plane rotation during fatigue cracking. No crack plane rotation occurred in the mode I specimen. The crack initiation and propagation behavior was evaluated by generating J-R curves. Due to the high ductility of this alloy and the limited specimen thickness (6.35 mm), plane strain requirements were not be met so valid critical J-integral values were not obtained. However, it was found that the crack initiation and propagation behavior was significantly different between the mode I and the mixed-mode I/III specimens. In the mode I specimen crack initiation did not occur, only extensive crack tip blunting due to plastic deformation. During J-integral testing the mixed-mode crack rotated to an increased crack angle (in contrast to fatigue precracking) by crack blunting. When the crack initiated, the crack angle was about 30 degrees. After crack initiation the crack plane remained at 30 degrees until the test was completed. Mixed-mode crack initiation was difficult, but propagation was easy. The fracture surface of the mixed-mode specimen was characterized by microvoid coalescence.

PROGRESS AND STATUS

1. Material and Experimental Method

The production-scale heat (#832665) of V-4Cr-4Ti was used for this study. CT specimens were machined from 6.35 mm thick plates. The plate was received in the warm-rolled condition and was heat treated at 1000°C for 1 hour in a vacuum of 10^{-7} torr (HT1) at PNNL following machining of specimens. CT specimens were used to evaluate mode I fracture and modified CT specimens were used for mixed-mode I/III fracture. The modified CT specimen geometry has been reported previously [1]. The crack angle used in this work was 25 degrees. With 25 degree crack angle the ratio of resolved mode III to mode I load component is 0.47. All specimens had the T-L orientation and all testing was performed at room temperature. J-integral tests were performed according to the J-integral test procedure given in ASTM E 813. Fracture surfaces were examined in a scanning electron microscope (SEM) to determine the failure mode.

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2. Results And Discussion

J-integral values versus crack growth increments (Δa) for both mode I and mixed-mode I/III specimens are plotted in Figure 1. From Figure 1, it can be seen that V-4Cr-4Ti is very tough in the unirradiated condition at room temperature. No crack initiation took place in the mode I specimen. The crack extension resulted from severe crack tip blunting and necking. Most of the J-Δa data fall outside the lower exclusion line (see Figure 1) because of the severe crack blunting. The exclusion line is defined by Eq. 1

$$J = \frac{(\sigma_y + \sigma_u)}{2}(\Delta a - 0.0015) \qquad (1)$$

Where σ_y is the yield strength (387 MPa) and σ_u is the ultimate tensile strength (454 MPa). Δa is the crack growth increment (m).

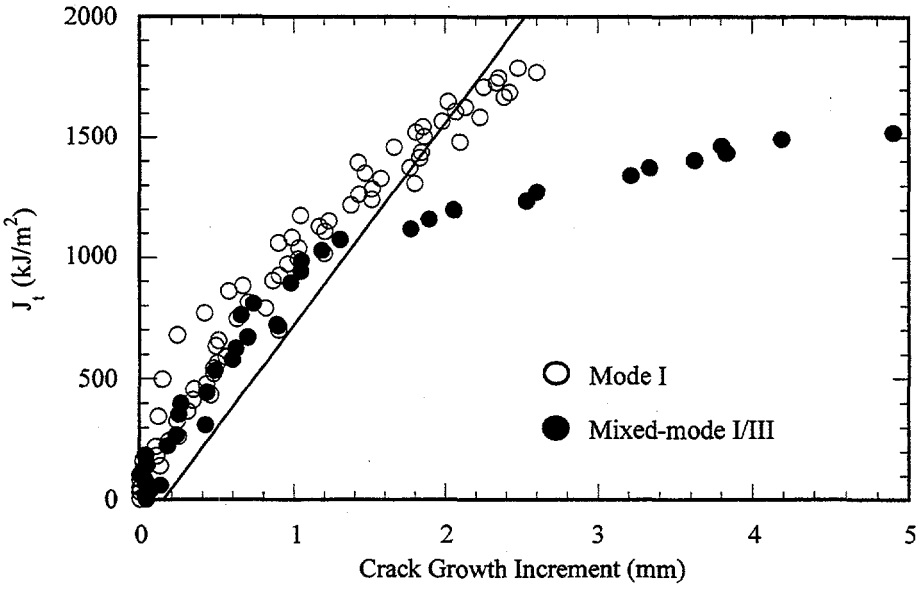


Figure 1. Effect of loading mode on J-R curves of a production scale heat of V-4Cr-4Ti.

A valid fracture toughness for the mode I specimen could not be determined because the alloy was extremely ductile and no crack initiation occurred, as shown in Figure 1. All of the crack "growth" indicated in Figure 1 for the mode I specimen was due to plastic deformation at the crack tip.

The mixed-mode specimen behaved differently from the mode I specimen. During fatigue precracking the crack plane rotated from 25 degrees to 23 degrees. However, during J testing, the crack plane angle increased from 23 degrees to about 30 degrees when the crack started to grow. After crack initiation, the crack plane angle remained at 30 degrees until the end of the test. Total crack growth was up to 5.2 mm. The mixed-mode specimen also experienced extensive plastic deformation similar to the mode I specimen. The estimated J_{Mq} value for crack initiation (not valid per ASTM criteria) was 1100 kJ/m2, indicating that crack initiation was difficult. The reasons for the high J_{Mq} have not been determined. Crack plane rotation before crack initiation was one of the factors which contributed

to the high J_{Mq} value. While the mixed-mode crack was difficult to initiate, it propagated easily. The slope of the mixed-mode I/III J-R curve beyond the exclusion line was only 140 kJ/m^2/mm.

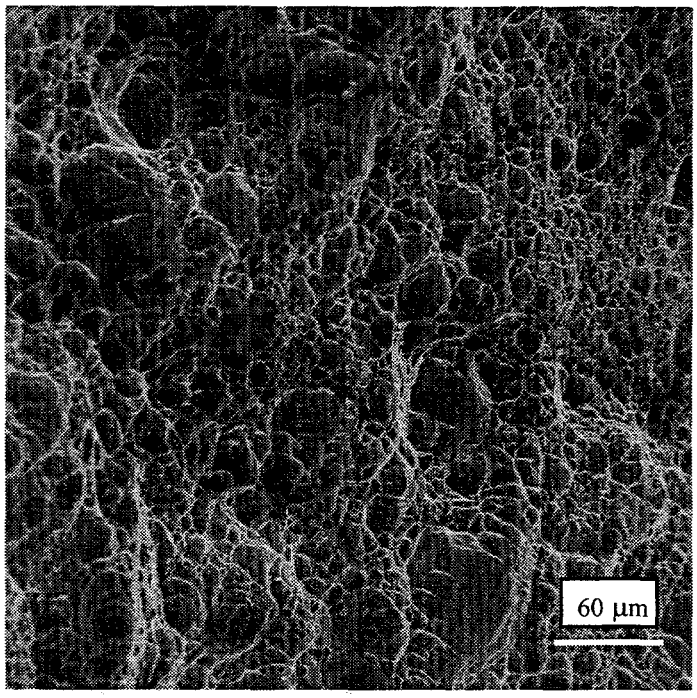
Because no crack initiation occurred in the mode I specimen, SEM examination was only done on the mixed-mode I/III specimen. The mixed-mode specimen failed by microvoid coalescence, as depicted in Figure 2a and 2b. Microvoids were distorted along the shear loading component (see Figure 2).

FUTURE WORK

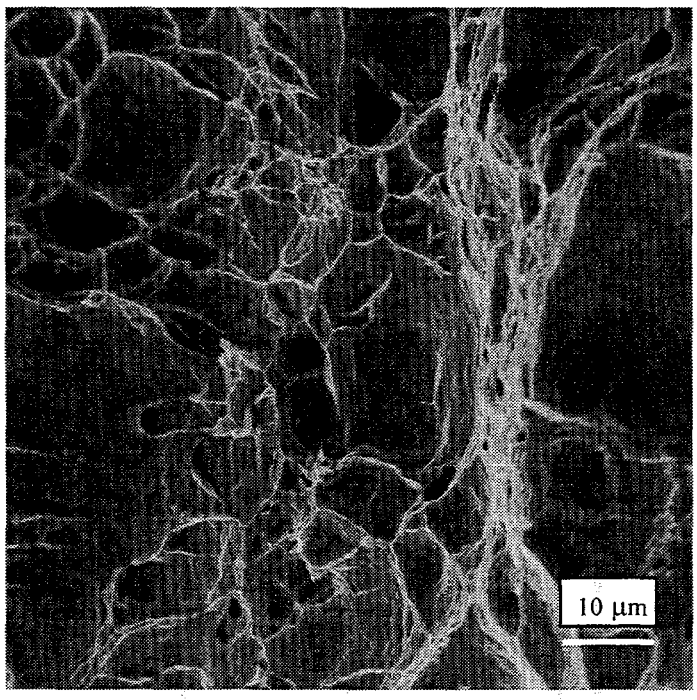
Mixed-mode I/III fracture toughness under a higher mode III component (45 degree crack angle specimens) will be tested for the V-4Cr-4Ti alloy and mode I fracture toughness will be measured using 1 in. thick plate (GA Heat #832864).

REFERENCE

1. H. Li, R. H. Jones, and J. P. Hirth, Fusion Materials Semiannual Progress Report, DOE/ER-0313/16, Oak Ridge National Laboratory , Oak Ridge, TN, March 1994.



(a)



(b)

Figure 2. SEM photograph of mixed-mode fracture surface in V-4Cr-4Ti specimen tested at 25°C.