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Cyclic Deformation and Fatigue Behaviors of Alloy 617 Base Metal and Weldments at 900℃ for VHTR Applications

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1. Introduction

Nowadays, the Korea Atomic Energy Research Institute (KAERI) is developing a nuclear hydrogen development and demonstration project with a capacity of 200 MW_{th} with thermal and core outlet temperature 950℃. The components have a projected plant design service life of 40-60 year operation and 3-8 MPa in He impurities, the most important consideration is the creep-fatigue and fatigue behavior for the materials [1,2].

Alloy 617 is the leading candidate material for the intermediate heat exchangers (IHX) of a very high temperature gas-cooled reactor (VHTR) system. Fatigue behavior is expected to be an important damage mode for the IHX.

An analysis of cyclic deformation can contribute to a deeper understanding of the fatigue fracture mechanisms as well as to improvements in the design and application of VHTR system.

However, the studies associated with cyclic deformation and low cycle fatigue (LCF) properties of Alloy 617 have focused mainly on the base metal, with little attention given to the weldments. Totemeier studied on high-temperature creep-fatigue of Alloy 617 base metal and weldments [3].

Current research activities at PKNU and KAERI focus on the study of cyclic deformation and LCF behaviors of Alloy 617 base metal (BM) and weldments (WM) specimens were machined from GTAW butt-welded plates at very high-temperature of 900℃. In this work, the cyclic deformation characteristics and fatigue behaviors of Alloy 617 BM and WM are studied and discussed with respect to LCF.

2. Experimental Materials and Procedures

2.1 Materials and Specimens

LCF tests were performed on specimens machined from a 25 mm thick plate of Alloy 617. The chemical composition of the Alloy 617 used in this work was well within the ASTM specifications. The shape of GTAW butt-welded joint has a single V-groove with an angle of 80 degree and 10 mm root gap. A filler metal was used for KW-T617 that was prepared according to AWS specifications. Cylindrical LCF specimens were machined from Alloy 617 base metal plate and GTAW butt-welded pad. Fig. 1 shows the schematic diagram showing cutting of specimen with respect to welded plate and the microstructures. The dimension of LCF specimens for both BM and WM is 6.0 mm diameter in the reduced section with a gage length of 12.0 mm.

2.2 Low Cycle Fatigue Test Procedures

LCF test were performed in air on MTS servo hydraulic test machines (MTS 370) at 900℃. Fully reversed total strain controlled LCF tests were conducted at 0.6% total strain range for both BM and WM specimens. In order to evaluate cyclic deformation and LCF behaviors for the BM and WM specimens at 900℃, the waveform is chosen in triangular shape. Namely, one cycle was defined as the combination of both a tension and compression load reversal using a symmetric waveform. And a constant strain rate of 1 x 10^{-3}/s was applied. The temperature was remained within ± 2°C of the nominal temperature throughout the test. The number of cycles to failure was evaluated as N_f, the point at which the ratio of the peak stresses was 80% of its constant or steadily decreasing value [4]. Fig. 2 illustrates this failure criterion and the number of cycles to macrocrack initiation, N_i.

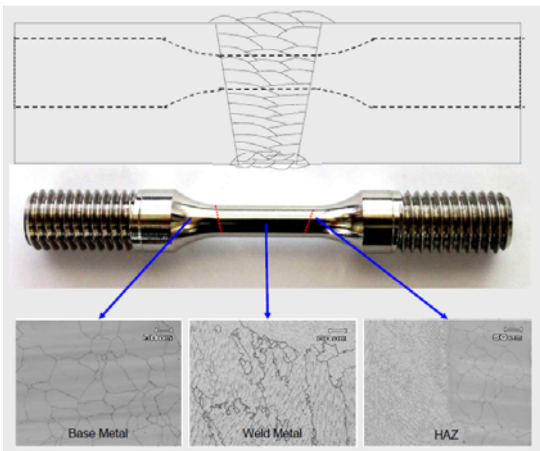

Fig. 1. Schematic diagram showing cutting of specimen with respect to GTAW welded plate, and the microstructures.

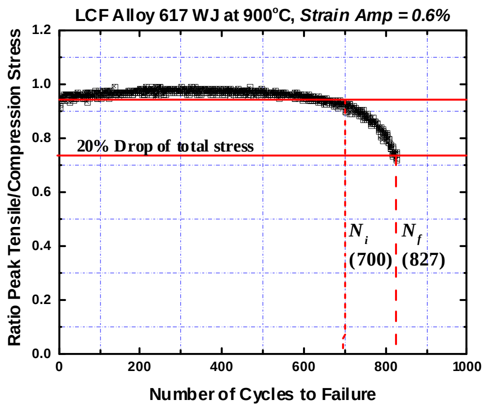

Fig. 2. Illustration of LCF failure criterion for BM specimen.

3. Results and Discussion

Fig. 3 presents the cyclic stress response curves for BM and WM specimens at 0.6% total strain range for 900℃. At the same total strain range of 0.6%, the sample for both BM and WM specimens exhibited cyclic hardening for a short period. The initial tensile and compression stresses for WM specimen showed more a higher value than those of BM specimen. The degree of initial cyclic hardening in early stage for BM specimen indicated more a higher value than that of WM specimen, because of influence of the material ductility for high-temperature. Generally, a material's initial cyclic hardening phenomenon during LCF is known to be work hardening contribution due to dislocation slip band interactions.

The shapes of hysteresis loops for BM and WM specimens are shown in Fig. 4. In this work, the hysteresis loop at half-life was taken as the stable loop. As shown in this figure, the WM specimen had exhibited larger a plastic strain amplitude than BM specimen.

At the testing condition, WM specimen showed lower fatigue life compared with BM specimen. This can be considered to the microstructural influence on the fatigue crack initiation and propagation.

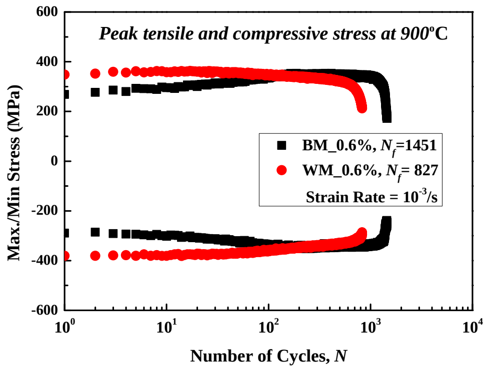

Fig. 3. Cyclic stress response curves.

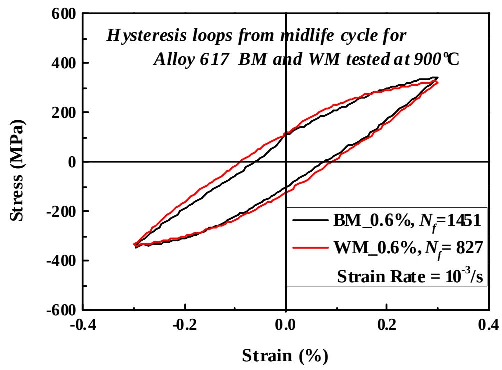

Fig. 4. Hystresis loops for BM and WM specimens.

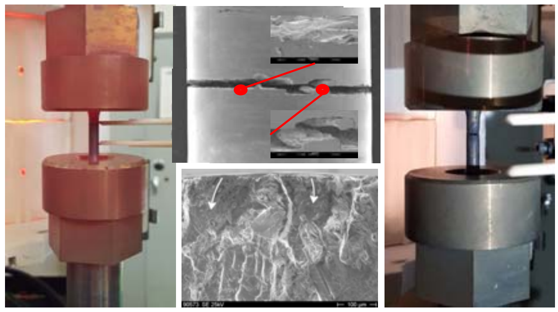

Fig. 5. Failure photographs and SEM after LCF testing.

Fig. 5 shows failed samples and SEM fractograph for BM and WM specimens after LCF testing. It is found that the crack initiation and propagation are dominated by the crack that traveled cut along the grain boundary.

3. Conclusions

In this paper, cyclic deformation and low cycle fatigue behaviors of Alloy 617 base metal and weldments was evaluated using strain-controlled LCF tests at 900℃for 0.6% total strain range. Results of the current experiments can be concluded; The WM specimen has shown a higher cyclic stress response than the BM specimen. The fatigue life of WM specimen was reduced relative to that of BM specimen.

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