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Low Cycle Fatigue Behavior of Alloy 617 Base Metal and Welded Joints at Room Temperature and 850℃ for VHTR Applications

Seon Jin Kim [a*], Rando T. Dewa [a], Woo Gon Kim [b], Min Hwan Kim [b]
[a] *Department of Mechanical Design Engineering, Pukyong National Univ., Busan 608-739, Korea*
[b] *Korea Atomic Energy Research Institute (KAERI), Daejeon 305-35,Korea*
[*] *Corresponding author: sjkim@pknu.ac.kr*

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.

Low cycle fatigue (LCF) is an important design consideration for high temperature IHX components. Moreover, some of the components are joined by welding techniques and therefore the welded joints are unavoidable in the construction of mechanical structures.

Since Alloy 617 was introduced in early 1970s, many attempts have been made in the past two decades to evaluate the LCF and creep-fatigue behavior in Alloy 617 base metal at room temperature and high temperature [3-10]. However, little research has focused on the evaluation and characterization of the Alloy 617 welded joints [4]

Current research activities at PKNU and KAERI focus on the study of low cycle fatigue behavior of Alloy 617 base metal and welded joint specimens were machined from GTAW butt-welded plates at room temperature and high temperature, 850℃. To better understand the LCF behavior of Alloy 617/Alloy 617 butt-welded joints, this paper is to investigate systematically the LCF properties and failure behavior of Alloy 617 base metal and Alloy 617/Alloy 617 GTAW butt-welded joints.

2. Experimental

2.1 Materials and Specimens

Low cycle fatigue 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 pad and the microstructures. The dimension of LCF specimens for both base metal (BM) and welded joint (WJ) is 6.0 mm diameter in the reduced section with a gage length of 12.5 mm.

2.2 Low Cycle Fatigue Test Procedures

Low cycle fatigue (LCF) test were performed in air on INSTRON servo hydraulic test machines (INSTRON 8516) at room temperature and 850℃. Fully reversed total strain controlled LCF test were conducted at four different total strain ranges, i.e. 0.6, 0.9, 1.2 and 1.5% for both BM and WJ specimens. In order to compare LCF behavior for the BM and WJ specimens at room temperature, the waveform is chosen in triangular shape with a frequency of 0.25 Hz and strain rate was varied between 3 x 10^{-3}/s to 7.5 x 10^{-3}/s depending on total strain range, whereas in high temperature 850℃ LCF tests, triangular waveform with a constant strain rate of 1 x 10^{-3}/s were applied. The temperature was remained within ± 2°C of the nominal temperature throughout the test. Fatigue life was determined as the number of cycle corresponding to 30% drop in load measured at half-life.

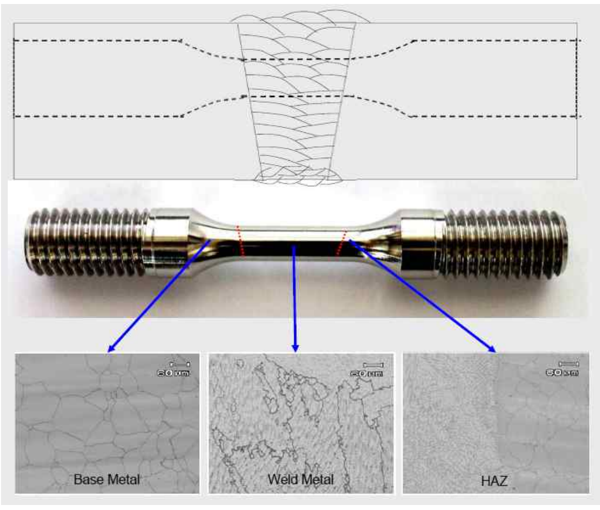

Fig. 1. Schematic diagram showing cutting of specimen with respect to GTAW weld pad and the microstructures.

3. Results and Discussion

Fig. 2 shows the peak tensile and compressive stresses as a function of number of cycle for room temperature (top) and 850℃ (bottom). As shown in Fig. 2, the peak tensile and compressive stresses were observed relatively symmetrical for both BM and WJ at RT, and WJ at 850℃. Fig. 3 shows variation of fatigue life with total strain range for room temperature and 850℃. Both specimens showed a typical Coffin-Manson life dependence on inelastic range. Fatigue lives of GTAW welded joint specimens were lower than those of base metal specimens at room temperature.

Crack initiation and failure mechanism for the BM and WJ specimens was examined as shown in Fig. 4. The crack initiation source of Alloy 617 base metal in all testing conditions is located at one point of specimen surface, whereas that of the welded joint specimens emerged from several points with secondary cracks in weld metal zone. The crack initiation of BM specimen occurred in transgranular mode for all specimens,

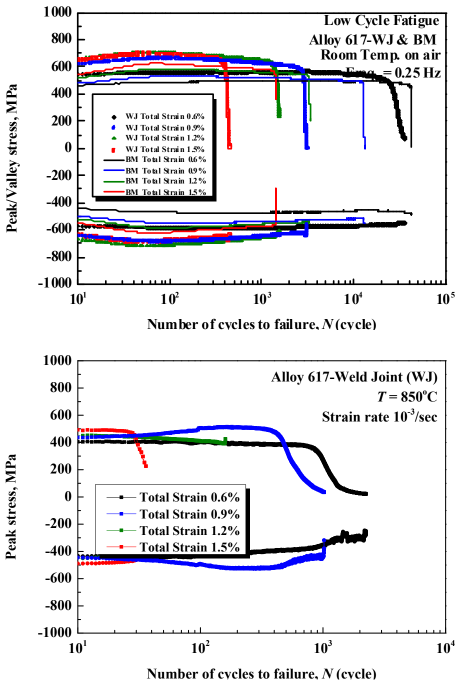

Fig. 2. Cyclic stress response behaviors for RT and 850℃.

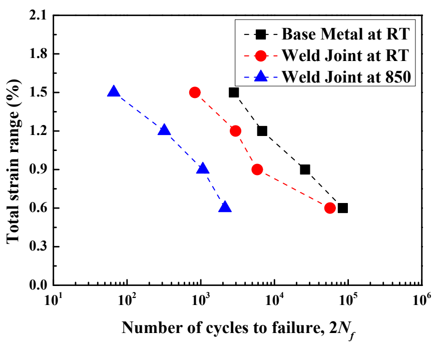

Fig. 3. Variation of LCF fatigue life with total strain range.

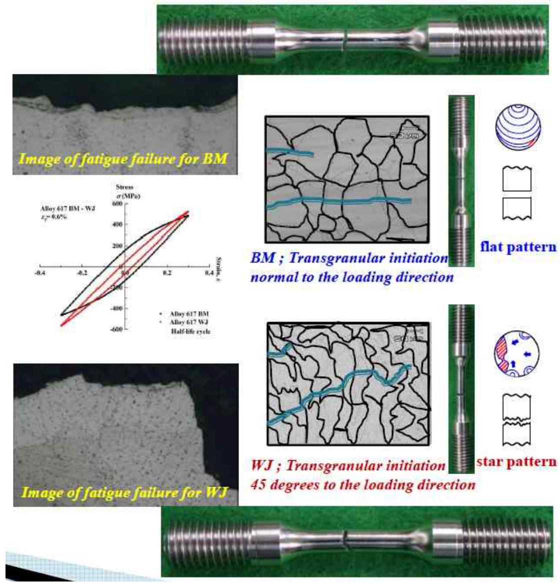

Fig. 4. Comparison of BM and WJ specimens for crack initiation and failure mechanism for LCF test at room temperature, 0.6% total strain range.

whereas WJ specimens showed relatively star (wedge type) mode interdendritic paths, namely 45 degrees normal to the loading axis, as shown in Fig. 4.

4. Conclusions

LCF testing of Alloy 617 base metal and GTAW butt-welded joint specimens was performed at room temperature and 850℃. Fatigue lives of GTAW welded joint specimens were lower than those of base metal specimens. LCF cracking and failure in welded specimens initiated in the weld metal zone and followed transgranluar dendritic paths for both at RT and 850℃.

Acknowledgement

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