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Low Cycle Fatigue Behavior of Alloy 617 at 950℃ 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].

The components for high temperature systems are often subjected to repeated thermal stresses due to the temperature gradients arising from heating and cooling during start-ups and shut-downs. One of the major damage mechanisms for the nuclear reactors that operate at high temperature is fatigue by thermal gradients and by cyclic mechanical loading [3,4]. Hence, it is essential to evaluate the low cycle fatigue properties of Alloy 617 at service high temperature.

In this work, the low cycle fatigue properties of Alloy 617 have been investigated using a constant strain rate at 950℃ over the total strain ranges varying between 0.9% and 1.5%.

2. Specimens and Experimental Procedures

2.1 Specimens Preparation

A commercial grade Alloy 617 is approved for non-nuclear construction in the ASME Code. Thus the composition (wt %) of the Alloy 617 used for material chosen in this study is 53.11Ni, 22.2Cr, 12.3Co, 9.5Mo, 1.06Al, 0.08C, 0.949Fe, 0.4Ti, 0.084Si, 0.029Mn, 0.027Cu, 0.003P, <0.002S, and <0.002B. Alloy 617 used in this study was solution treated hot rolled plate with thickness of 25 mm were machined into cylindrical LCF test specimens were machined with shape and dimensions with 6.0 mm diameter in the reduced section with a gage length of 12mm.

The initial microstructure analysis of Alloy 617 is a fully austenitic face centred cubic (fcc) structure. The fcc matrix, known as, γ, mainly consists of nickel, cobalt, iron, chromium and molybdenum. Fig. 1 shows the microstructure of the base metal with a well-uniformed equiaxed grains are approximately 10-30 μm and 40-100 μm for a larger grain.

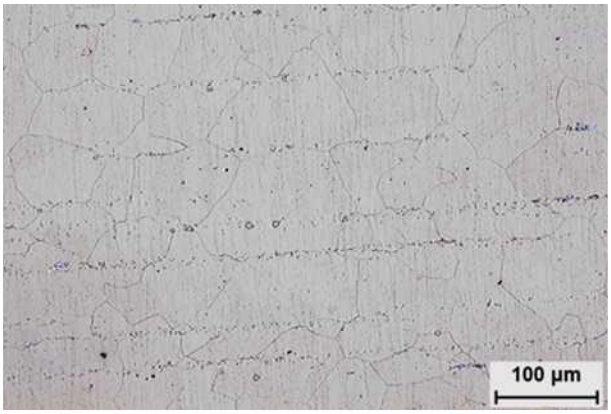

Fig. 1. Microstructure of the as-received Alloy 617.

2.2 Experimental Procedures

The Fully reversed (R = -1) total axial strain-controlled LCF tests have been conducted on MTS servo hydraulic test machines (MTS 370) regarding to the three different total strain ranges of 1.5, 1.2, and 0.9% at 950°C on Alloy 617 in air environment with a constant strain rate of 10^{-3}/s. The temperature was remained within ± 2°C of the nominal temperature throughout the test. The failure criteria was defined as the number of cycles which means a 20% reduction in the stress ratio (peak tensile over compressive stress ratio).

3. Results and Discussions

LCF testing of Alloy 617 was completed by carrying out a series of fully reversed strain-controlled to provide a baseline data of the fatigue behavior. Fig. 2 shows the LCF resistance on Alloy 617 at 950°C as a function of total strain range. The results of fatigue tests consistently show that an appropriate decrease of fatigue life as a number of cycles to failure according to increase in total strain range.

The peak tensile and compressive stress response under different total strain ranges were of the same magnitude, as shown in Fig. 4. Almost all of the stress amplitude paths of Alloy 617 at 950°C show a cyclic softening region for the major portion of the life. At the end of the test, the stress amplitude decreased rapidly as a formation of macro-crack initiation or just prior to failure.

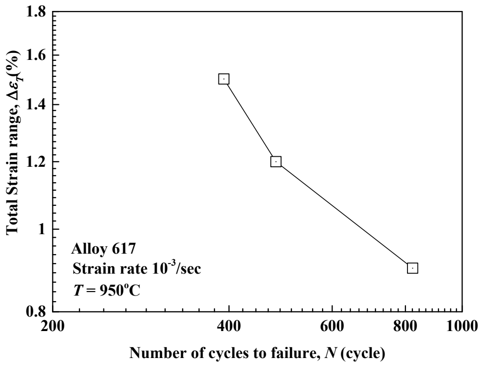

Fig. 2. Comparison of low cycle fatigue life on Alloy 617 at 950°C as a function of total strain range.

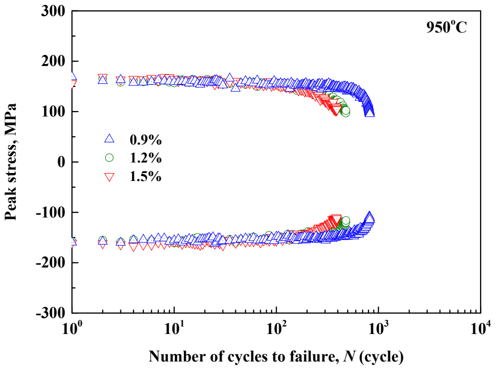

Fig. 3. Comparison of cyclic stress response on Alloy 617 tested at 950°C as a function of total strain range.

Fig. 4 shows the stress-strain hysteresis loops plotted at half-life cycle and monotonic properties of Alloy 617 at 950°C condition. The hysteresis loops show more clearly a decrease in the stress response with increasing in the total strain range, although, the plastic strain also becomes wider significantly as a function of total strain range. Similar as literature review [3], they confirmed that a peak flow stress followed by an exponential decrease with increasing strain is characteristic of a solute drag creep mechanism.

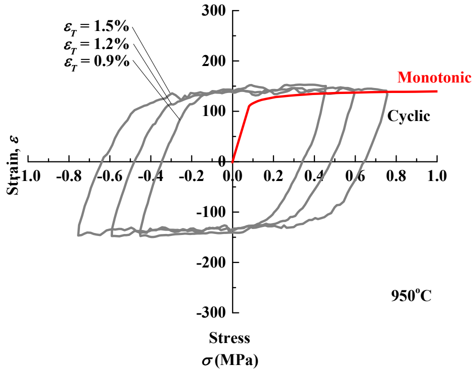

Fig. 4. Monotonic and cyclic properties of Alloy 617 at 950°C as a function of total strain range.

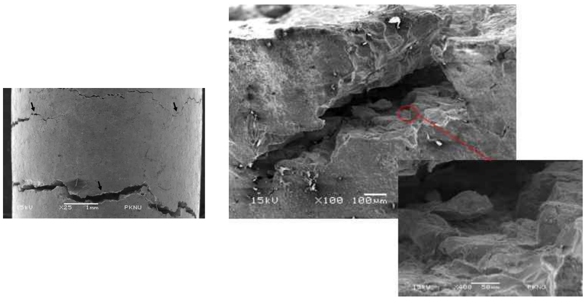

Fig. 5. Typical SEM micrographs of the failed samples of Alloy 617 at 950°C at 1.5% total strain range.

Fig. 5 shows the typical scanning electron micrograph (SEM) micrographs of the cracking and failure location of the Alloy 617 are within the gauge section. Also, the LCF cracks of Alloy 617 illustrate a flat-type with a necking phase due to high temperature process. The crack initiation site was found at the free surface with intergranular crack initiation resulting from oxidation of surface connected grain boundaries. However, we believe that the LCF primary cracks mechanism propagated in transgranular mode due to strengthening phase of grain boundary carbides.

4. Conclusions

In this work, a fully reversed total strain-controlled LCF tests of the Alloy 617 were conducted at 950°C in the air. The results of fatigue tests consistently showed that an appropriate decrease of fatigue life according to increase in total strain range. We can find the reduction in fatigue life as a more superior of plastic strain magnitude results in large plastic deformation. The cyclic stress response behavior showed the cyclic softening mechanism as a function of strain range. We also found phenomena of solute drag creep mechanism, which was observed by a peak flow stress followed by an exponential decrease with increasing strain.

Acknowledgment

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