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Elevated Temperature Low Cycle Fatigue Damage Mechanism for Alloy 800H Base Metal and its Weldments

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1. Introduction

Alloy 800H is currently being considered as one of the near-term candidate materials for design and construction of some major high temperature components of a very high temperature reactor (VHTR) [1]. The main component structure in which will be utilized for Alloy 800H is the intermediate heat exchanger (IHX) system. This system has extreme design temperature up to 950°C. System start-ups and shut-downs as well as power transients will induce low cycle fatigue (LCF) loadings and creep-fatigue (CF) of the components. Therefore, it is important to understand the LCF and CF behaviors for this alloy at high temperature. The current criteria for design of elevated temperature components, bearing on the American Society of Mechanical Engineer Boiler and Pressure Vessel Code (ASME B&PV code) Section 3 Subsection NH of Alloy 800H for nuclear service, is up to 760°C. However, the near-term purpose is to extend the utilization until 850°C of high temperature environment.

Most of the investigations indicate the LCF testing and behaviors for parent materials[2-4]. However, the data of LCF behaviors for the weldments are still not available in ASME code or elsewhere, although the data for base metal are available in some reported documents. In today assumption for operation of nuclear power plants, complex interaction of combined loading involving creep and fatigue loads also needs to be investigated due to the more flexible service application. Consequently, reliable data on the LCF and CF behaviors are required for current investigated materials.

In this study, four different total strain ranges (TSR) for Alloy 800H were tested in low cycle fatigue with no hold time and hold time at 750°C. Especially, this paper focuses on the experimental study of the low cycle fatigue and creep-fatigue behaviors of Alloy 800H base metal and its weldments, which were fabricated by the gas tungsten arc welding (GTAW) process. The addition of holding time at the maximum tensile strain is further examined to understand the effect on both materials' low cycle fatigue life and their complex interactions with environment.

2. Experimental

The material investigated in this study is Alloy 800H with a chemical composition (wt %) of 0.07C, 30.18Ni, Bal. Fe, 20.43Cr, 0.54Ti, 0.49Al, 0.45Cu, 0.42Si and 0.98Mn. Alloy 800H is an austenitic iron–nickel base superalloy with arranged contents of carbon (0.05–0.10 wt.%), aluminum and titanium (Al + Ti (0.85–1.20 wt.%)), silicon, and manganese. The weldments were fabricated through the GTAW technique with a filler metal of KW-T82 (A800H filler wire). During the welding, steel plates were placed between the material to avoid the distortion and the residual stress was released during the machining of the specimens.

Cylindrical LCF button head specimens were extracted from the plate (also weldments plate) with a gauge length of 12 mm and diameter of 6 mm in the reduced section. The extensometer was attached axially to the gauge section for collecting real-time strain data during the test. The LCF specimens for weldments were extracted horizontally from the welding direction of the weldments plate. The width of the weld includes the heat-affected zone (HAZ) was varied from 12 to 13 mm, but does not exceed the limited range of the extensometer. Thus, the gauge section for weldments consist of weld and HAZ materials only. All specimens were prepared in accordance with Section IX of the ASME B&PV code.

LCF tests was performed under fully reversed strain control ($R = -1$) in the air with servo-hydraulic fatigue testing equipment (MTS 370 Landmark, 100kN). Total strain amplitude is fixed with different total strain ranges of 0.6%, 0.9%, 1.2%, and 1.5% at 750°C during all low cycle fatigue test, whereas the strain rate is constant of 10-3s-1. The target temperature was only allowed to vary about ±2 °C. Before the commencement of the test, the target temperature was held at zero stress level for 30 min to allow the temperature to stabilize. For the CF tests, holding time was applied at the maximum tensile strain of 0.6% total strain range for 60 seconds. Finally, the fatigue life criterion was selected in order to reach a 20% drop in the stress ratio (peak tensile over compressive stress) for all tests.

3. Results and discussion

As one of examples, Fig. 1 shows the peak tension and compression stresses during LCF test and the number of cycles has been given in a logarithmic scale to better display the initial material behaviour. Base metal shows a small hardening phase the first 100 cycles. The saturation regime is then noticed with a plateau in the peak stress. This result indicates that the cyclic stress response established a stable cycle after 100 cycles. Finally, a cyclic softening can be seen until a rapid drop of about 95% of total life. The degree of initial hardening is related to the increase of strain amplitude or plasticity of the testing condition. The result shows that lower plasticity also stands with small initial hardening phase, indicating small number of dislocation density. The weldments manifest the behaviour of cyclic softening under the loading of cyclic strain for the entire life. This softening behavior could be characterized into two phases, which are the slow softening phase and following the rapid softening just prior to failure.

To further understand the LCF behaviour between base metal and weldments, Fig. 2 shows the relationship between plasticity and stress amplitude of the tested materials. From the results, it is noted that the weldments exhibit higher stress response compared with the base metal, however, base metal has higher plasticity than the weldments for all tests.

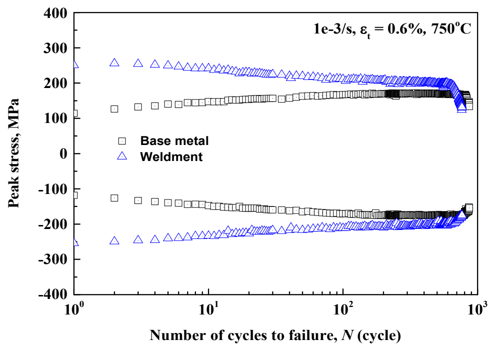

Fig.1 Peak tension and compression stresses for LCF test (TSR=0.6% at 750°C)

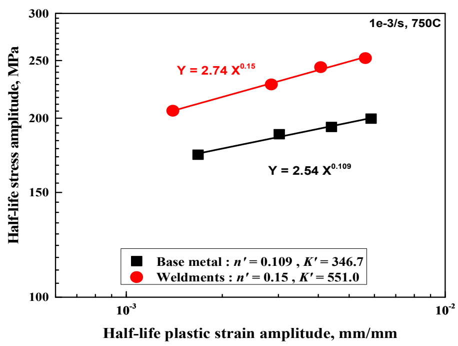

Fig. 2 Relationship between stress and plastic strain amplitude for LCF test

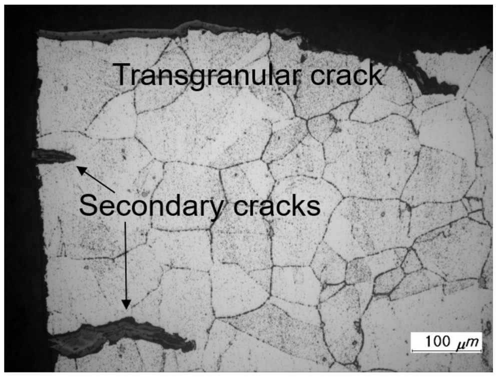

Fig. 3 OM image for fractured specimen (TSR=1.5%)

As one of examples, Fig. 3 shows OM images for fractured specimen of base metal at 1.5% total strain range condition. It is also observed that the higher stress is able to generate more secondary cracks at the specimens. The fracture behavior reveals that there is no significant differentiation in terms of fractography between base metal and weldments under LCF loadings. The results will be presented in this conference.

4. Conclusions

The LCF and CF tests of Alloy 800H base metal and its weldments have been performed to fulfil the baseline understanding and knowledge for application in the extreme environment of the VHTR nuclear system. Cyclic tests were conducted with total strain ranges of 0.6%, 0.9%, 1.2%, and 1.5% at 750 °C. The cyclic behavior of the steel was strongly related to the material property and total strain range. During pure LCF test, the fracture mechanism were controlled entirely by the plasticity of materials. Meanwhile for CF test, somehow, temperature and monotonous load were affecting the fatigue life.

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