The Low Cycle Fatigue Characteristics of Solution Annealed 316L Stainless Steel in High Temperature Conditions

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1. Introduction

316L austenitic stainless steel (SS) is the currently favored structural material for several high temperature components in the primary side of a liquid metal reactor [1]. The components are subjected to a temperature gradient induced cyclic thermal stresses as a result of a plant heat-up and shut-down. Hence, a low cycle fatigue (LCF) represents one of the typical failure modes, necessitating a significant consideration in the design and life assessment of such components.

In this study, LCF tests on solution annealed (SA) 316L SS were carried out in various temperatures from 20℃ to 600℃ in order to construct the basic data for a decision of the proper material constants of an inelastic structure analysis code NONSTA[2,3]. Also the fatigue strength properties and fatigue life were obtained.

2. Experiments and Results

2.1 Material and Testing Methods

The material used in this study was SA (Solution Annealed) 316L stainless steel and its chemical compositions are shown in Table 1. LCF test specimens were aligned in the rolling direction and machined into a cylinder with a 7mm diameter and a 12.5mm gauge length according to ASTM standard E606-92[4].

Table 1 Chemical composition of specimen (wt%)

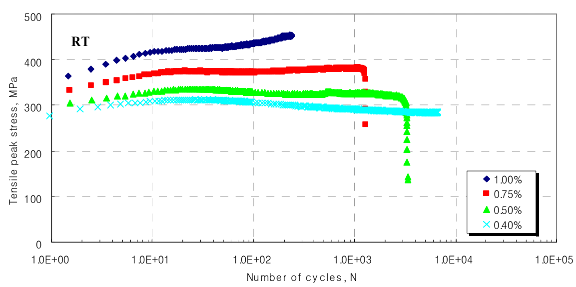
C	Si	Mn	P	S	Cr	Ni	Mo	N
0.02	0.58	1.26	0.032	0.001	16.77	10.75	2.06	0.026

LCF tests were conducted in air under a fully reversed, total axial strain control mode by employing a symmetrical, triangular strain-time wave-form at room temperature(20℃), 300℃, 500℃ and 600℃, respectively. The test temperature was maintained constant to within ±2℃ during the whole period of the test. All the specimens were held at the test temperature for 100 minutes before a testing. LCF tests were performed at strain amplitude ranges of ±0.4%, ±0.5%, ±0.75% and ±1.0%, respectively. The strain rate was fixed at 2×10^{-3} /s. An extensometer (gauge length: 12.5mm) was directly attached to the narrow part of the specimen to measure a uni-directional elongation which can be converted directly to a strain.

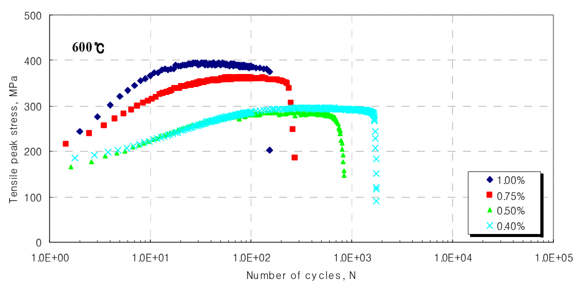
An INSTRON 8516 closed loop, servo hydraulic testing system equipped with a 3-zone resistance type furnace was used. The fatigue life (N_f) was defined to be the number of cycles corresponding to a 25% reduction in the peak tensile stress from the stabilized cycle at a half-life.

2.2 Cyclic Stress Response

The cyclic stress response (CSR) here was defined as a variation of the cyclic tensile peak stress with the number of cycles. Fig. 1 (a),(b) shows the tensile peak stresses under the four total strain amplitude ranges (±0.4%, ±0.5%, ±0.75% and ±1.0%) at room temperature and 600℃, respectively. At all the testing conditions, the material exhibits an initial hardening followed by a saturated stress response just before the final load drop and fracture. A rapid hardening regime can be seen at a relatively high temperature condition. The rapid drop of a load for each CSR curve was believed to be caused by a formation of micro-cracks and a sub-sequent growth. Here, the fatigue life N_f decreases with respect to the strain range but the peak tensile stress increases [5, 6].



(a)



(b)

Figure 1. Tensile peak stress during the test at room temperature and 600℃.

The variation of the total stress ranges at all the temperatures is depicted in Fig. 2. In general, the stress range of the steels decreased with an increase of the temperature. In this test of SA 316L, the stress range slightly increases at all the strain ranges for the 500°C and 600°C temperature conditions. This behavior is caused by the dynamic strain aging (DSA) effect and bothers a simple monotonic prediction along the temperature values.

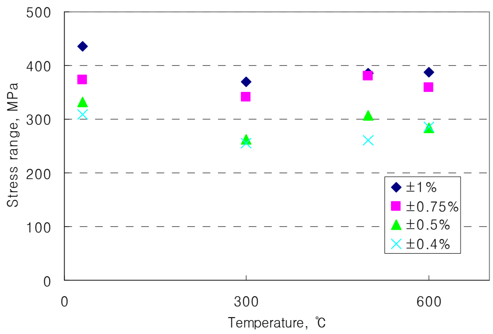


Figure 2. The variation of delta stress range with temperature and strain amplitude.

2.3 Fatigue Life Curves

The variation of the LCF life with the total strain amplitude at each temperature condition is shown in Fig. 3. The fatigue life decreased drastically with an increase in the strain range for the temperature range of 500°C-600°C. However, in the temperature range of room temperature (20°C) and 300°C there is little difference between the N_f of the strain range 0.75% and 1.0% [7].

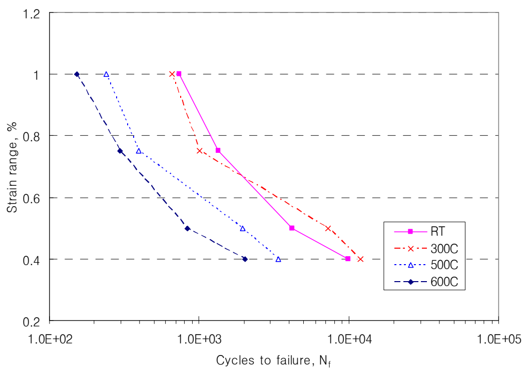


Figure 3. Fatigue life curves for various strain ranges.

3. Conclusion

To construct the basic material test data of the solution annealed 316L SS for the analysis code NONSTA, the LCF tests were carried out at various temperatures. The cyclic stress response curves with different strain amplitude ranges were obtained. The marked cyclic hardening behaviors exhibited in the early stages of a cycle life were followed by a saturated stress response before a load drop associated with the initiation and propagation of fatigue cracks. The fatigue life noticeably decreased with respect to the temperature and the strain range. From the test results, a significant reduction in the fatigue life is noticed when the testing temperature is increased over 500°C with increased strain amplitude ranges. The peak dynamic strain aging effect can be seen at 500°C.

Acknowledgement

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