High Temperature Low Cycle Fatigue Properties of Cold Worked 316L Stainless Steel

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1. Introduction

The 316L austenitic stainless steel (SS) has excellent strength, ductility, and corrosion resistance[1] in a high temperature environment so it has been widely used as the material for several high temperature components including the reactor vessel and piping.

In this study, low cycle fatigue (LCF) tests on 15% cold worked (CW) 316L SS were carried out in various temperatures from 20°C to 600°C in order to construct the basic data for the decision of the proper material constant of the liquid metal reactor high temperature structure inelastic analysis code NONSTA[2,3] in addition to tensile tests[4]. Also the fatigue strength properties and fatigue life was obtained.

2. Experimental Details

The material used in this study was 15% CW 316L SS. Tensile and LCF test specimens were aligned in the rolling direction and machined into a cylinder with a 7mm diameter and a 15mm gauge length according to ASTM standard E606-92. 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 20°C, 300°C, 500°C and 600°C, respectively. The test temperature was maintained constant within ±2°C during the period of the test. All the specimens were held at the test temperature for 100 minutes before 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 $2\times10^{-3}/s$. An extensometer (gauge length: 12.5mm) was directly attached to the narrow part of the specimen.

In addition, the tensile tests were carried out under different strain rates at 600°C. The effects of the strain rates $\dot{\varepsilon}$ ($2\times10^{-3}/s, 2\times10^{4}/s$) on the tensile behavior was examined.

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 half-life.

3. Results and discussion

The variation of the LCF life with the total strain amplitude is shown in Fig. 1 at each temperature. In the temperature range of 500°C-600°C, the fatigue life decreased drastically with an increase in the strain range. However, in the temperature range of 20°C-300°C there is little difference between the N_f of the strain range (1.5%) and 2.0%.

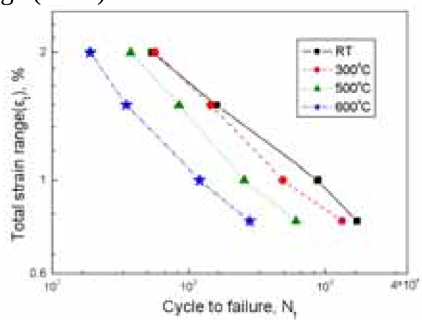

Figure 1. Total strain range-fatigue life curves.

Fig. 2 and Fig. 3 were obtained through the stabilized hysteresis loops with respect to the temperature and the strain range, respectively. As shown in Fig. 2, the plastic strain ranges at 500°C were decreased by as much as 5%-23% the compared with those at other temperatures because of the dynamic strain ageing (DSA) effect.

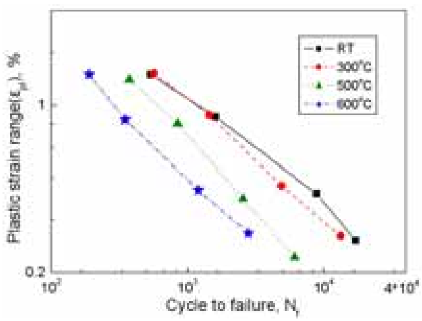

Figure 2. Plastic strain range-fatigue life curves.

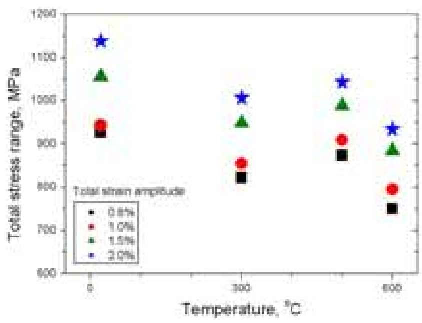

Figure 3. The variation of total stress range with temperature and strain amplitude.

The increase in the stress range was associated with the reduction in the plastic strain range. The variation of the total stress ranges at all the temperatures is depicted in Fig. 3. The stress range generally decreased with an increase of the temperature at all the strain ranges except for 500^{o}C, where it increased due to the DSA effect.

Fig. 4 shows the cyclic stress responses with a cycle count in the strain range 0.8-2.0% at 600^{o}C. Here, the fatigue life N_f decreases with respect to the strain range but the peak tensile stress increases. It is noteworthy that the peak tensile stress of 1.0% is smaller than those of the other strain range values during the initial few cycles in Fig. 4.

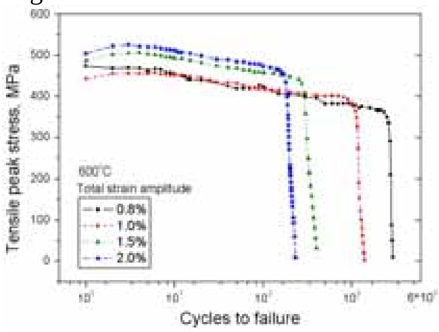

Figure 4. Evolution of peak stresses during LCF deformations.

In each case, the tensile peak stress increased rapidly during the first 3 to 5 cycles. Beyond that, a gradual softening took place before the regime of a nearly stable stress response commenced. The saturation stress state continued until the stress decreased rapidly due to the formation of micro-cracks and their growth. It is considered that the cyclic hardening at an early stage was due to the DSA effect[5].

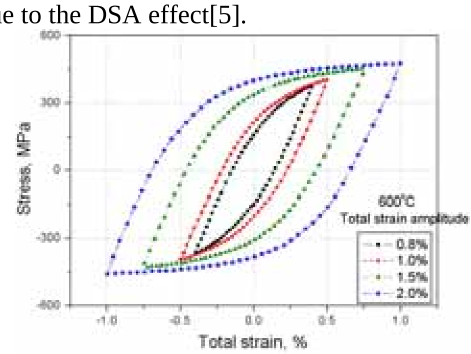

Figure 5. Strain-stress hysteresis loops at steady state (600^{o}C).

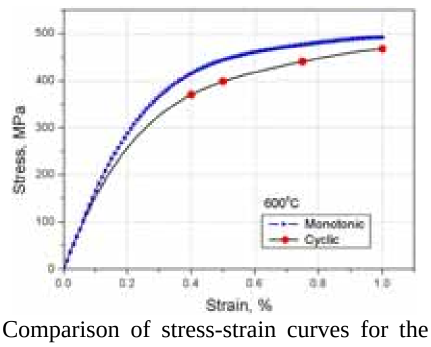

Figure 6. Comparison of stress-strain curves for the tensile test and LCF tests at 600^{o}C.

If the cyclic stress responses are stable through the slow-down of a cyclic softening, the hysteresis loops are almost fixed as in Fig. 5. The monotonic tensile curve and the cyclic curve which was fitted to the vertex of the hysteresis loops (obtained Fig. 5) are shown in Fig. 6. The cyclic softening deformation was observed as expected.

Additionally, the tensile tests by applying different strain rates($2\times10^{-3}/s$, $2\times10^{4}/s$) were performed to examine the time dependent stress-strain responses. As shown in Fig. 7, the tensile stress for $2\times10^{3}/s$ increased approximately by 20MPa beyond the yield point when compared to that for $2\times10^{4}/s$. With this data, the time dependency parameters of the NONSTA code can be determined.

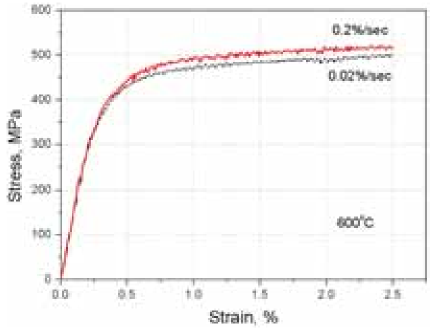

Figure 7. Segments of tensile curves for strain rates: 2×10^{-3}/s, 2×10^{-4}/s at 600^{o}C.

4. Conclusion

To construct the basic material test data of the cold worked 316L SS for the analysis code NONSTA, the tensile test and LCF tests were carried out at various temperatures. The cyclic curve and the tensile curves with different strain rates were obtained. The fatigue life noticeably decreased with respect to the temperature and the strain range. The cyclic softening behaviors were observed throughout a whole life except for the initial few cycles at all the test conditions. In the test results, an increase in the fatigue strength and a decrease in the plastic strain range were induced by DSA at 500^{o}C.

Acknowledgement

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