Degradation Mechanism of Grain Boundaries in Nickel-Based Alloy 625 Under Creep-Fatigue Loadings at Elevated Temperatures

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Introduction

In order to reduce CO₂ emission and improve the efficiency of power generation, the steam temperature in A-USC (Advanced-Ultra Super Critical) is going to be elevated higher than 700°C[1]. Therefore, the heat-resistant materials used in A-USC should be replaced from conventional ferritic steels to new materials such as nickel-base super-alloys. Alloy 625 is an outstanding candidate alloy[1] for boiler tube and pipes of A-USC power plants due to its superior mechanical properties at elevated temperatures. However, it has been reported that the effective lifetime of Ni-base alloy decreased drastically under the random change of output of power plants in order to assure the stable power supply with various renewable energies. Therefore, it is very indispensable for developing a quantitative method for evaluating the total damage of heat-resistant materials under complicated creep-fatigue loading conditions for assuring the safe and reliable operation and its long-term reliability.

Materials and methods

The material used in this study was commercial Alloy 625 supplied by Allegheny Ludlum Corp. The mechanical properties of the alloy were measured by Kobe Material Testing Laboratory, and the result is summarized in Table 1. The geometry of the specimens used for creep-fatigue tests is shown in Fig. 1. The creep-fatigue tests were performed at 750°C(1023K) in a high temperature testing machine with tensile-tensile uniaxial cyclic loading in Ar gas. The holding time at peak stress (130 MPa) was 10 minutes, and then, the stress went down to 40MPa. The stress change rates were 9 MPa/s and -9 MPa/s, respectively.

After the creep-fatigue test, the surface of each specimen was slightly polished for removing the surface oxide layer. The surface of each broken specimen was observed by using FE-SEM (SU70). The EBSD analysis was performed by using an OIM (Orientation Imaging Microscopy) system commercialized by TSL.

Results and Discussion

All the specimens showed clear plastic deformation before the final fracture. The fracture occurred around the center with clear necking deformation. Even though the magnitude of the applied stress was lower than the yielding stress of the alloy at 750°C, the fracture lifetime, however, greatly varied with each other. It took about 45 hours (262 cycles) to break for the first sample. The fracture lifetime of the second sample was about 1.4 hours (9 cycles). And, it was unbelievable that the final one did not survive one cycle. It only took 350 seconds.

The surface of the broken specimens were observed by using FE-SEM and EBSD analysis and compared with as-received specimens as shown in Fig. 2. It was found that all initial cracks appeared at grain boundaries and they monotonically grew and made large jointed cracks. Crack propagation path was almost along grain boundaries. In addition, many randomly distributed carbides and fine voids were found on the sample surface. Since both the size and distribution of carbides varied sample by sample, the fracture of the samples was dominated by the local stress concentration of the carbides with surrounded fine voids.

Conclusions

Grain boundary cracking was found to be the dominant factor of the decrease in the lifetime of Alloy 625 under creep-fatigue loading at elevated temperature. Distribution of carbides is another important structural factor of the lifetime.

Reference

[1] M. Fukuda, Proc. of the 7th Int. Conf. on Advances in Materials Technology for Fossil Power Plants (2013) pp.24-40.

Table 1. Mechanical properties of Alloy 625 in RD

| Temperature | YS (MPa) | UTS (MPa) | EL (%) |
|-------------|----------|-----------|--------|
| R.T (23°C)  | 586      | 960       | 40.0   |
| 750°C       | 377      | 487       | 60.7   |

Fig. 1 Geometry of the Inconel 625 alloy specimen

Fig. 2 Example progress of grain boundary cracking