§15. Development of High Temperature Fatigue Test Technology using Small Specimen

Nogami, S., Guan, W.H., Hasegawa, A. (Tohoku Univ.),
Nagasaka, T., Muroga, T.,
Hisaka, C., Kim, T., Fujiwara, M., Minamiyama, F. (Kobe Material Testing Laroratory)

1. Introduction

It is important to improve life assessment methods in order to meet demands of structural reliability and economy of fusion reactors. Because the fatigue is one of the most important material issues related to the life, improvement of the test technology is expected.

Degradation of the fatigue life due to neutron irradiation cannot be negligible for fusion reactors design and operation. Therefore, the fatigue life database of the unirradiated and irradiated materials under various test conditions is expected. The standard tests can show reliable and robust mechanical properties data in general. However, the utilizing a small specimen is not avoidable because limited volume is allowed for the neutron irradiation experiment of materials. Thus, the development of the reliable fatigue test technology using a small specimen is important.

The objective of this study is development of fatigue test technology for fusion reactor materials, especially focusing on the testing using a small specimen.

2. Test technology

2.1 Specimen

The rules of the ASTM standard were adopted as much as possible in the specimen design of this study. A round-bar (RB) and an hourglass (HG) shaped specimens with a diameter of test section below 2 mm were considered.

It was clearly observed in reduced activation ferritic/martensitic (RAFM) steels (F82H and JLF-1) that the fatigue life of small specimens was the same as that of the standard-size specimen under room temperature tests. On the basis of these evaluations, the effect of specimen size on the fatigue life could be negligible for both round-bar and hourglass shaped specimens.

In general, the round-bar specimen with test section diameter of 5~10 mm is defined as the standard specimen. Thus, potentially, there are no effects of specimen shape in the round-bar specimen. On the other hand, in case of the hourglass specimen, the fatigue life of the small hourglass specimen was slightly longer than that of the standard specimen under the higher strain conditions, where the plastic strain was dominant. Under the lower strain conditions, where the elastic strain was dominant, the fatigue life of the small hourglass specimen was significantly shorter than that of the standard specimen. The micro-crack growth behavior until the fatigue life was investigated by replica method to clarify the reason of the difference of the fatigue life under the low strain conditions. The micro-crack initiation life of the round-bar specimen was longer than that of the hourglass specimen, and this difference lengthened with decreasing the plastic strain range. There was no significant difference in the crack growth rate. On the basis of these evaluations, the shorter fatigue life of the small hourglass specimen under low strain conditions could be attributed to the shorter micro-crack initiation life.

To summarize this evaluations, the round-bar specimen was thought to be a primary candidate. However, in the high plastic strain conditions, buckling should be considered and the hourglass specimen is partially effective.

2.2 Testing machine

To perform high temperature fatigue tests using round-bar specimen with a diameter of test section below 2 mm, a new testing machine was developed in this study. This testing machine mainly consists of a piezo-driven actuator, a load cell, a molybdenum heater, a vacuum chamber, an extensometer for the displacement measurement of the test section of specimen, and a stroke sensor. Maximum load, maximum test speed, maximum temperature, and vacuum degree were +/– 1 kN, 0.2 mm/s, 1073 K, and 10^{-4} Pa, respectively. By introducing a new test jig system for avoiding bending and torsion of the specimen, stable fatigue tests with suppression of unexpected failure of the test such as buckling of specimens was realized under the push-pull fatigue test condition.

3. Validation of the test technology

Fig. 1 shows the fatigue life of the standard and small specimens fabricated by F82H steel tested at room temperature and 823 K in air and in vacuum. The small specimen data was obtained by the test technology developed in this study. The fatigue life at 823 K by standard specimen was 20~30% of that at room temperature. The effect of environment (in air vs. in vac.) was negligible at 823 K. No specimen size effect on the fatigue life was observed regardless of the test temperature and environment. Based on this study, the high temperature fatigue life could be evaluated with acceptable accuracy using a new small specimen fatigue test technology.

Further development is planned as future work for clarifying the applicability of the test technology for the typical fusion reactor materials (RAFM steels, tungsten, and SiC/SiC composites).

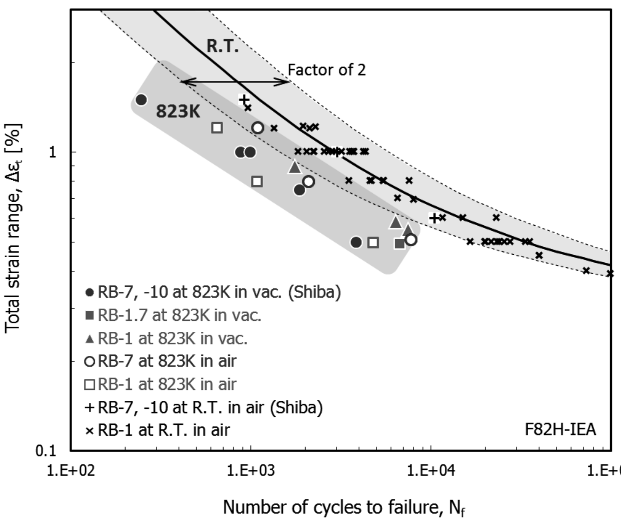

Fig. 1 Fatigue life of standard specimens (RB-7 and -10) and small specimen (RB-1) fabricated by F82H steel tested at room temperature and 823 K in air and in vacuum.