International standardization of high temperature fracture test method

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In the safety assessment and residual life prediction of high temperature structural component, it is important to establish the technologies to predict growth probability and rate of a detected crack under high temperature creep and creep-fatigue conditions using the fracture mechanics. Regarding the creep crack growth test method, ASTM E1457 standard and ISO/TTA 5:2007 (E) were published based on the VAMAS activities (TWA11, TWA19, TWA25, TWA31). We are active aiming to propose a new standard adding the crack growth testing in weldment and the strain-controlled creep-fatigue crack growth testing to the ISO/TC164. The round robin tests (RRT) for this is underway.

1. Introduction

In the high-temperature structural components such as power plants and chemical plants, cracks, which initiate during operation, grow with elapse of time. This phenomenon is called creep crack growth. For the safety assessment and residual life prediction of high temperature structural component, it is important to establish the technologies that predicts growth probability and rate of cracks detected under high temperature creep using fracture mechanics. Since there was no standard of the test method for creep crack growth, it was taken up as one of the subject of VAMAS in 1987, and then, the activities relating to this problem have been conducted as follows; TWA11; Creep Crack Growth (Low alloy steels), TWA19; High Temperature Fracture of Brittle Materials (Low ductility alloys), TWA25; Creep/Fatigue Crack Growth in Component (Components), TWA31; Creep/Fatigue Crack Growth in Weldments (High Cr steels and welded joints). In the meantime, the ASTM E1457 standard was issued and revised [1)] and ISO/TTA 5: 2007 (E) [2)] was also issued.

Since a coal-fired power plant has a large amount of CO_2 emission, high efficiency operation is required. The heat-resistant steels and Ni-based alloys used in the ultra-supercritical (USC) power plants and the next-generation advanced ultra-supercritical (A-USC) power plants are subjected to severe operating conditions (high temperature, high pressure, start-stop and multiaxial stress etc.), the development and standardization of life prediction technologies are required. Currently, TWA31 has acquired the international standard acquisition and diffusion promotion business consignment fee (FY2017-2019) from the Ministry of Economy, Trade and Industry (METI). With this support, a test evaluation method to predict crack initiation and growth under high temperature creep-fatigue conditions for high Cr heat resistant steels, Ni-based alloys, and their welded joints used in USC, A-USC plants, etc. is under development. With this, we are aiming for this international standardization. This research will contribute to the improvement of safety and reliability of high temperature structural materials for USC and A-USC plants.

2. Test method

Creep and creep-fatigue crack growth tests aim to observe the behavior of crack initiation and growth by applying a constant load or cyclic loading or cyclic straining to a test piece at high temperature. In this test, 1) a test piece is heated to the specified temperature, 2) a specified load or displacement is applied to the test piece, and 3) crack opening displacement (or load line displacement) and crack length is measured with sufficient accuracy. The crack length in a high temperature furnace is measured by the direct current (D.C.) potential difference method and converted to the crack length. A constant current is applied to the test piece and the potential difference between the two points sandwiching the crack is measured. The potential difference increases as the decrease of cross-sectional area

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with crack growth. In the creep-fatigue crack growth test, it is also necessary to measure the change of load and displacement with cycles with sufficient accuracy.

3. Test results

3.1 Creep crack growth test

In a 600°C-class USC plant, high Cr ferritic steels containing 9-12% Cr (Gr.91 steel, Gr.92 steel, Gr.122 steel, etc.) are used. It has been reported that creep damage called Type IV occurred in the heat affected zone of high Cr steel weldment used for a long time. For this reason, VAMAS TWA31 has conducted international joint research on creep crack growth test methods for welds [3), 4)]. The ASTM E1457 standard was revised based on the research results [1)].

Ni-base alloys are used in the high temperature parts of the 700℃ class A-USC plant. Therefore, creep crack growth RRT was carried out on Alloy 617, a Ni-base alloy for A-USC. Figure 1 shows the relationship between the obtained creep crack growth rate and the high temperature fracture mechanics parameter (C^*). At 700°C, the crack growth rate is faster than that at 750°C because the creep ductility of the material differs depending on the temperature. As a result of RRT, it became clear that the creep crack growth characteristics of Alloy 617 are not so different from those of high Cr ferritic steels.

3.2 Strain-controlled creep-fatigue crack growth test

The high temperature structural components are operated under start and stop conditions, and the creep deformation of components are constrained. Therefore, the data of crack growth rate under strain-controlled creep-fatigue are necessary. However, this test is scarcely conducted. TWA31 performs the strain-controlled creep-fatigue crack growth test RRTs on high Cr ferritic steels, Ni-based alloys, and welded joints for USC and A-USC plants. The cyclic strain of a trapezoidal strain-hold wave was applied to circumferentially notched bar specimens, and the change in the crack length with the number of cycles was measured using the D.C. potential difference method. Figure 2 shows the results of RRT (strain range: ±0.2%, tensile strain hold time: 10 min, test temperature: 700°C) for Alloy 617. The relationship between the peak stress on the tension side and that on the compression side and the number of cycles is shown. Obtained data in NIMS and Imperial College London coincide well. Since the Ni-base alloy is cyclic hardening material, the peak stress on the tensile side increases at the beginning of the test, but it gradually decreases as a crack propagates and the number of cycles increases.

Figure 3 shows the results of a strain-controlled creep-fatigue crack growth test of 9Cr steel (Gr.91 steel) base metal and welded joints with the hold time for 10 min and 1 h. It is clear that the welded joint has a higher crack growth rate than the base metal. In addition, although the effect of hold time (t_H) is small for the base metal, it can be seen that in the welded joint, the crack growth rate increases as the hold time increases. This means that the creep strength of the heat-affected zone of welding is lower than that of the base metal and is affected by deformation constraint, so it is more susceptible to creep damage.

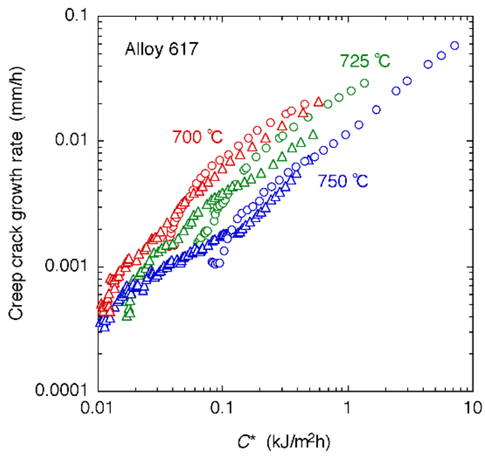

Figure 1. Creep crack growth rate of Alloy 617.

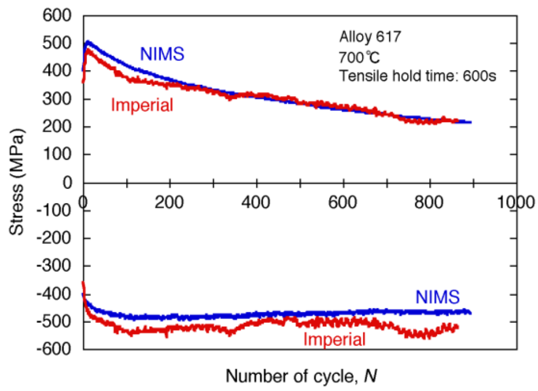

Figure 2. RRT of strain-controlled creep-fatigue crack growth test of Alloy 617.

4. ISO standard proposal

Regarding the above VAMAS TWA31 activity results, we had a presentation at the ISO/TC164/SC1 international conference (September 2019, Ulm, Germany) and made an NP proposal for the test method. An ISO standard draft; "Metallic materials - High temperature creep/fatigue crack growth testing method" was created based on the results of RRT and submitted to ISO/TC164/SC1. NP voting was conducted from December 2019 to February 2020, and it was agreed and registered.

References

1) ASTM E1457-15: Standard Test Method for Measurement of Creep Crack Growth Times in Metals.
2) ISO/TTA 5: 2007(E): Code of Practice for Creep/ Fatigue Testing of Cracked Component.
3) M. Tabuchi et al: Engineering Fracture Mechanics, 77 (2010) pp.3066-3076.
4) M. Tabuchi et al.: Strength, Fracture and Complexity, 9 (2015) pp.31–41.

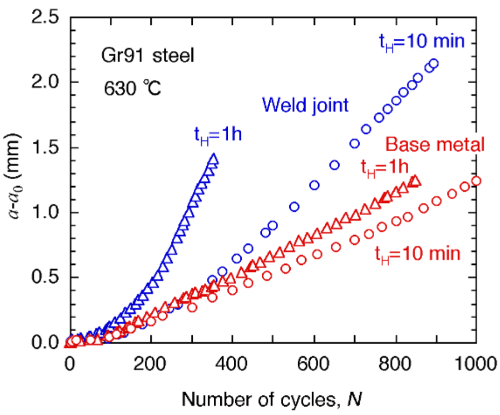

Fig. 3. Relationship between creep-fatigue crack length and number of cycles for the base metal and welded joint of 9Cr steel (Gr.91 steel) at 630℃.