International standardization of high temperature fracture test method

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In the safety assessment and the remaining life prediction of high temperature structural components, it is important to establish the technology to predict the probability and rate of growth of a detected crack under high temperature creep and creep-fatigue conditions using the fracture mechanics. Regarding the creep crack growth test method, the ASTM E1457 standard and the ISO/TTA 5: 2007(E) were published based on the VAMAS activities (TWA11, TWA19, TWA25, TWA31). Currently, a new standard (ISO 4596) is being proposed and discussed in ISO/TC164/SC1, which adds the handling of welds and strain-controlled creep-fatigue crack growth tests to ISO/TTA 5.

1. Introduction

In high temperature structural components, there is a phenomenon that cracks generated during service grow with time, which is called creep crack growth. For the safety assessment and remaining life prediction of high temperature structural components such as power plants and chemical plants, it is important to establish the technology that predicts the probability and rate of growth of detected cracks under high temperature creep and creep-fatigue conditions using fracture mechanics. Since there was no standard of the test method for creep crack growth, it was taken up as one of the subjects of VAMAS in 1987, and then, its activities have been continued with different subjects such as 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) was issued [2)].

Since coal-fired power plants have a large amount of CO_2 emissions, high efficiency is required. The conditions of use of heat-resistant steels and Ni-based alloys used in ultra-supercritical pressure (USC) power plants and next-generation advanced ultra-supercritical pressure (A-USC) power plants are severe and complex (high temperature and pressure, multi-axial stress, start-up, and shutdown, etc.), and the development and standardization of life prediction techniques are required. TWA31 conducted a round robin test (RRT) of crack initiation and growth under high temperature creep-fatigue conditions for high Cr heat-resistant steels, Ni-based alloys, and their welded joints, with the support of a project commissioned promotion business consignment fee (FY2017-2019) by the Ministry of Economy, Trade and Industry (METI) to promote the acquisition and diffusion of international standards for energy conservation. Based on the results of the RRT, an ISO standard was proposed as an NP and registered, which is currently under discussion at ISO/TC164/SC1. This study will contribute to the improvement of the safety and reliability of high temperature structural components 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 variable load and strain to a test specimen at a high temperature. In the test, 1) the specimen is heated to a specified temperature, 2) the specified load or displacement is applied to the test specimen, and 3) the crack opening displacement and crack length is measured with

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sufficient accuracy. The crack length in a high temperature furnace is measured by the DC potential difference method and converted to the crack length. A constant current is applied to the specimen and the potential difference between two points sandwiched between the cracks is measured. The potential difference increases as the decrease in the cross-sectional area occur with crack growth. In the creep-fatigue crack growth test, it is also necessary to measure the change of load and displacement with cycle with sufficient accuracy.

3. Test results

3.1 Creep crack growth test

In 600°C class USC plants, high Cr heat-resistant 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 has occurred in the heat-affected zone of welds of high Cr heat-resistant steels that have been used for a long time. For this reason, VAMAS TWA31 has conducted international collaborative research on creep crack growth test methods for welds [3), 4)]. The ASTM E1457 standard was revised [1)] based on the research results.

Ni-based alloys are used in the high temperature parts of 700°C class A-USC plants. Therefore, creep crack growth RRT was carried out on Alloy 617, a Ni-based alloy for A-USC. Figure 1 shows the relationship between the obtained creep crack growth rate and the high temperature fracture mechanics parameter (C^*). Creep crack growth rate is higher at 700°C than 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 property of

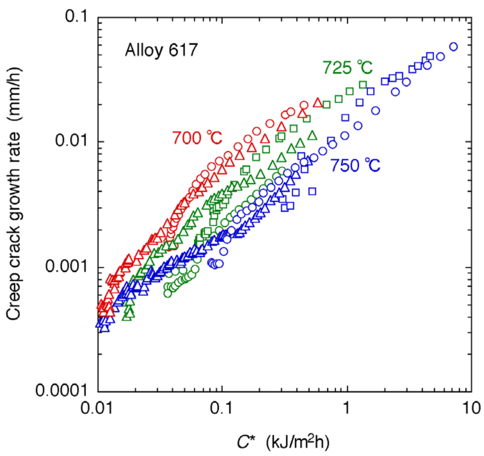

Figure 1. Creep crack growth rate of Alloy 617.

Alloy 617 was not much different from those of high Cr heat-resistant steels.

3.2 Strain-controlled creep-fatigue crack growth test

The high temperature components are often subjected to constrained creep deformation and equipment start-up and shutdown, so crack growth rate data under strain-controlled creep fatigue is necessary. However, this test has scarcely been conducted. TWA31 performed a strain-controlled creep-fatigue crack growth test RRT for high Cr heat-resistant steel, Ni-based alloys, and welded joints. A circular notched specimen was subjected to cyclic strain-controlled fatigue with tension hold, trapezoidal wave, and the change

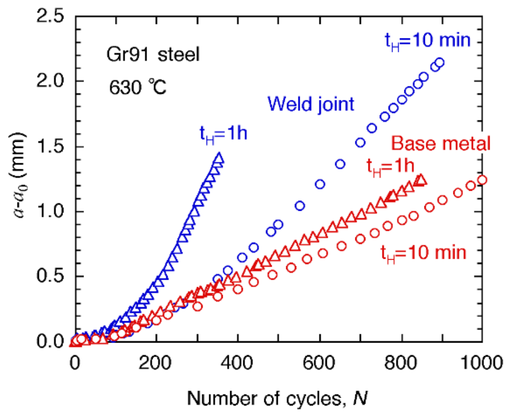

Figure 2. Relationship between creep-fatigue crack length and number of cycles for base metal and welded joints of 9Cr steel (630°C).

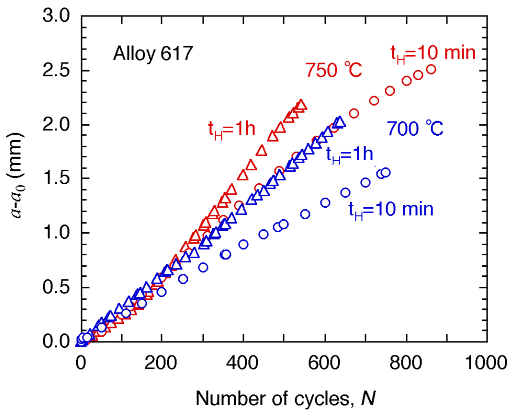

Figure 3. Relationship between creep-fatigue crack length and number of cycles for Alloy 617 at 700°C and 750°C.

in crack length with the number of cycles was measured using the DC potential difference method.

Figure 2 shows the results of strain-controlled creep-fatigue crack growth tests for base metal and welded joints of 9Cr steel (Gr. 91 steel) at 10 min and 1 h tension hold. It can be seen that the crack growth rate of the welded joint is faster than that of the base metal. In the base metal, the effect of hold time (t_H) is small, but in the welded joint, the crack growth rate becomes faster when the hold time is increased. This means that the creep strength of the heat-affected zone of the weld is lower than that of the base metal and is affected by the deformation constraint, and thus is more susceptible to creep damage.

Figure 3 shows the results of the same test for Alloy 617, where the crack growth rate is faster at 750°C than at 700°C. This is because the creep damage is larger at 750°C. It can also be seen that the crack growth rate accelerates as the hold time increases because the creep damage becomes larger.

4. ISO standard proposal

On the results of the above activities of VAMAS TWA31, a presentation was made at the international conference of ISO/TC164 (Mechanical testing of metals) and a draft test standard was proposed. As a result of the NP ballot, the proposed standard was registered as ISO 4596 "Metallic materials - High temperature creep/fatigue crack growth testing method" and is now under discussion in the ISO/TC164/SC1 for standardization.

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.