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Creep Rupture Properties for Base and Weld Metals of Alloy 617

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1. Introduction

A very high temperature reactor (VHTR) is one of the most promising Generation-IV reactor types for the economic production of electricity and hydrogen. Its major components are the reactor internals, reactor pressure vessel (RPV), piping, hot gas ducts (HGD), and intermediate heat exchangers (IHX). The IHX is a key component, and Alloy 617 is a prime candidate material owing to its superior creep resistance above 800°C compared with other potential superalloys [1-6].

Since weld metals may originally have some defects, creep strength can be worse than those of the base metals. Thus, in the design rules of the high-temperature components, the allowable stresses in the welds are restricted to the lower value of the following: (i) the allowable stress in the base metal is based on 67 % of the stress to rupture, 80 % of the stress to cause the onset of a tertiary strain, and 100 % of the stress to cause a 1 % total strain, and (ii) the product of 0.8 $\sigma_{min} \times R$, where σ_{min} is the expected minimum stress for the base metal and R is the appropriate ratio of the creep rupture strength of the weld metal compared to that of the base metal [7]. The allowable deformation in the welds is also restricted to half the deformation permitted for the base metal, since the ductility of the welds at elevated temperatures is generally low. For a design use, the data of the tensile and creep properties for Alloy 617 WM should be sufficiently provided, and in particular, to develop a design code of Alloy 617 WM. However, the data for the WM are very rare and limited until now, although the data for the BM are available in the ASME draft code case, which was suspended at the end of the 1980s owing to a lack of support and interest [8].

In this report, the creep data for Alloy 617 WM, which was fabricated by a gas tungsten arc welding (GTAW) procedure, were obtained by a series of creep tests at 800°C, and the creep properties of the WM were compared with those of the BM.

2. Methods and Results

2.1 Weld method

Commercial grade nickel-based superalloy, Alloy 617 (Haynes 617), was used for this work, which was a hot-rolled plate with a 25 mm thickness. The shape of the weld joint has a single V-groove with an angle of 80°. A filler metal was used for KW-T617 (brand name), manufactured by KISWEL Co. It was prepared according to the American Welding Society (AWS) specifications, AWS A 5.14-05 ERNiCrCoMo-1 (UNS N06617), and its diameter was 2.4 mm. Two types of root gaps were fabricated at 10 mm and 50 mm. The specimens of the 10 mm root gap were prepared to evaluate the weld joint (WJ) and the specimens with a 50 mm root gap were prepared to evaluate a weld metal (WM), Herein, it is written as 10A and 10B for a 10 mm root gap and 50A and 50B for a 50 mm root gap. To shield a welding pool from the atmosphere during welding, a pure argon gas of 99.99 % was supplied at 10-15 liter/min. The GTAW conditions are given as follows:

- Polarity: DC straight polarity
- Current range: 180-200 A
- Voltage range: 14-16 V
- Welding speed: 18-22 cm/min
- Pre-heating temperature: min. 18 °C
- Temperature between passes: under 177 °C

2.2 Creep test method

Total welding layers and pass number were applied with 14 layers and 41 passes for 10 A and 10B specimens, and 15 layers and 133 passes for 50 A and 50B specimens. In addition, to prevent a bending deformation of the weldments, some passes to the back side were added for each specimen. A post heat-treatment was not conducted because a Ni-based superalloy is not normally applied. After welding, the soundness of the weldments was identified through an ultrasonic test (UT), a tensile test, and a bending test.

Creep specimens of the WM were taken from fully weld metal for a 50 mm root gap. The specimens were machined into the longitudinal direction (LD) against the welding direction. Creep test specimens were machined with a cylindrical form of 30 mm in gauge length and 6 mm in diameter. A series of creep tests was performed under different stress levels of 120 MPa, 100 MPa, 90 MPa, 80 MPa, 70 MPa, 60MPa, and 50 MPa for both the base metal (BM) and weld metal (WM) at an identical temperature of 800°C. In the present creep tests, four specimens for the BM and WM specimens are running under long-term tests at 50 and 60 MPa. The pull rod and jig used for the creep tests were manufactured with Ni-based superalloy materials to endure oxidation and thermal degradation sufficiently during creep. Creep strain data with elapsed times were taken automatically by a PC through a high precision LVDT. The creep strain rate was measured as the minimum creep rate in the experimental creep curves.

2.3 Comparison of creep properties for BM and WM

Fig. 1 shows a comparison of the plot of log stress vs. log rupture time obtained for the BM and WM at 800^{o}C. The WM was a little higher in the creep strength (or creep rupture life) than the BM. In the present creep tests, four specimens for the BM and WM are running with long-term period. A better comparison for the creep properties between the WM and BM will be investigated after the long-term creep rupture of four running specimens.

Fig. 2 shows a comparative plot of creep strain rate as a function of applied stress for the BM and WM tested at 800^{o}C. The minimum creep rate, $\dot{\varepsilon}_{ss}$ is usually described by Norton's power-law function of applied stress, $\dot{\varepsilon}_{ss} = A\sigma^n$. The minimum creep rate of the WM is lower by one order than the BM, but this indicates that the stress exponent for the WM and BM is almost the same. Thus, it is regarded that the same creep mechanism is operative in both the BM and WM tested at 800^{o}C. It is considered that a little longer rupture life of the WM is due to a lower creep rate in the WM. The WM had a significant reduction in the rupture elongation than the BM. This result is similar to the results in the heat resistance steels in which the ductility of welds at elevated temperatures was reduced.

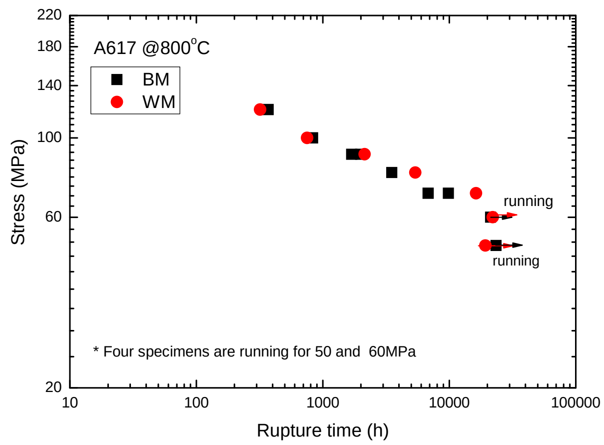

Fig. 1. Comparison of creep strength for the BM and WM.

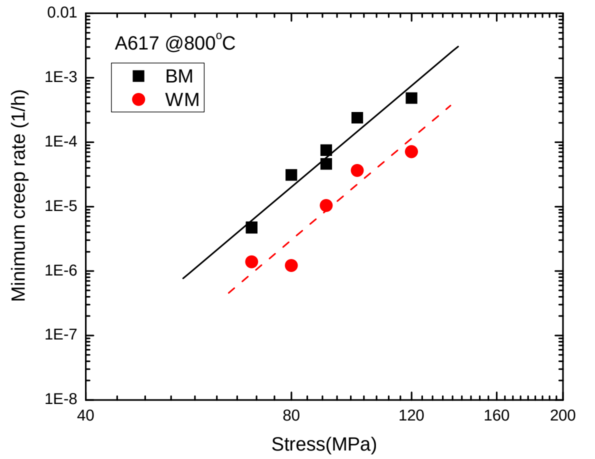

Fig. 2. Comparison of the creep rate for the BM and WM.

Accordingly, during the current test period at the present test conditions, the WM of Alloy 617 revealed a little higher creep life (or strength) owing to the lower creep strain rate. The lower creep rate in the WM is because the BM was lower in rupture elongation than the BM. In addition, Alloy 617 revealed creep deformation of the cavity formation and growth during creep, it is regarded to be fairly adapted to the BM and WM of Alloy 617. A linear line of the WM is shifted to the left side with one order in the creep strain rate. Thus, if the creep rupture time is the same, the creep rate is lower in the WM than the BM. The reason for this is the lower rupture elongation in the WM,

3. Conclusions

The high-temperature creep properties for Alloy 617 WM, fabricated by a gas tungsten arc welding (GTAW) procedure, were investigated by a series of creep tests with different stress levels at 800^{o}C, and the creep test data for the WM were compared with those of the BM. From the results, it was found that the WM had a slightly longer creep rupture life and lower creep rate than the BM, and a particularly lower rupture elongation. The lower creep rate in the WM was due to the lower rupture elongation than the BM.

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