

## Creep and Creep Crack Growth Behaviors for Alloy 800H for Use in VHTR System

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### 1. Introduction

A very high temperature reactor (VHTR) is one of the most promising Gen-IV reactors for the economic production of electricity and hydrogen. Its major components are the reactor internals, reactor pressure vessel (RPV), hot gas ducts (HGD), and intermediate heat exchangers (IHX). Alloy 800H is the primary candidate for use a control rod system (CRS), a HGD, a core barrel, core supports, and a shutdown cooling system (SCS) in VHTR system[1]. Alloy 800H, which is a modification of Alloy 800, was developed for applications in which additional creep resistance is required. Alloy 800H is approved for use up to 760°C under ASME Code Section III Subsection NH for nuclear applications [2]. Many studies for Alloy 800H base metal (BM) were done and the data for creep properties are available in several reported documents [3-6]. However, creep data for its weld metal (WM) are rare and not available in the ASME code as well, and especially, creep crack growth (CCG) behavior. Therefore, the creep and CCG behaviors should be investigated for design use in reactor internals of Alloy 800H.

In this study, creep rupture behavior for Alloy 800H WM, which was fabricated by a gas tungsten arc welding (GTAW) procedure, was investigated through a series of creep tests at 800°C. A comparison for creep rupture properties between the BM and WM was done. In addition, CCG behavior for Alloy 800H was investigated in terms of the  $C^*$ -fracture parameter through a series of CCG tests at 800 °C.

### 2. Methods and Results

#### 2.1 Experimental procedures

Commercial grade “Alloy 800H” (Brand name: ATI 800H) stainless steel, which was a hot-rolled plate with a 25 mm thickness made by Allegheny Ludlum Company, was used. In the chemical composition, the amount of each element was identified to be included well within the ASME specifications.

The weld metal for Alloy 800H was fabricated by a GTAW procedure. The shape of the weld joint has a single V-groove with an angle of 80°. A filler metal was used for KW-T82 (brand name), manufactured by KISWEL Co. Alloy 82 (N06082) bare filler metal was prepared according to the American Welding Society (AWS) specifications, AWS SFA 5.14 ERNiCr-3 and

its diameter was 2.4 mm. Creep test specimens were a cylindrical form of 30 mm in gauge length and 6 mm in diameter, and the WM specimens were taken for fully welding region.

In addition, CCG tests were carried out for Alloy 800H BM under a constant load with different applied load levels at 800°C. Compact tension (CT) specimens had a width ( $W$ ) of 25.4mm, a thickness ( $B$ ) of 12.7mm, and side grooves of a 10% depth. The initial crack ratio ( $a/W$ ) was about 0.5, and the pre-cracking size was 2.0mm. The specimens were machined at room temperature by fatigue pre-cracking to introduce a sharp crack tip starter. Load-line displacement was measured using a linear gauge assembly attached to the specimen, and the crack length was determined using a direct current potential drop (DCPD) technique. Crack extension data were continuously collected using a data acquisition system. All of the experimental procedures followed the recommendations of the ASTM standard E1457 [7]. After the CCG testing, the CT specimens were broken open at liquid nitrogen temperature to measure the actual crack length. The actually measured final crack length ( $a_{mf}$ ) was calculated from measurements made on the fracture surface at nine equally spaced points (so-called “nine points method”) using the enlarged photo of the fractured surfaces, because the individual measurements on the fracture surface vary due to crack front irregularities.

#### 2.2 Creep and CCG behaviors

From the creep tests at 800°C of Alloy 800H BM and WM, creep rupture data such as rupture time, creep strain rate, rupture elongation were obtained.

Fig. 1 (a) shows a comparison of log (stress) vs. log (rupture time) obtained for the BM and WM. The WM and BM are almost similar in creep strength or the WM is a little higher than the BM in the rupture time beyond about 3,000h. However, in the creep strain rate and the creep rupture elongation, the WM is lower than the BM, as shown in Fig. 2 and Fig. 3. The reason for the lower creep strain rate in the WM is due to the lower rupture ductility than the BM. Also, as reported in author previous study [8], it is clearly supported that the WM had higher tensile strength and lower tensile elongation than those of the BM.

In addition, to evaluate creep crack growth rate (CCGR) for Alloy 800H BM, a series of the CCG tests was performed at 800°C, and the CCGR behavior was evaluated using a fracture parameter,  $C^*$ . The general

form between the creep crack growth rate ( $da/dt$ ) and the  $C^*$  can be expressed by [9]

$$da/dt = B [C^*]^q \quad (1)$$

where  $n$  is the creep exponent, and  $B$  and  $q$  coefficients are the material constants which are generally obtained from a regression line of the CCGR data. They are related to the intercept and slope, respectively, of the  $da/dt$  vs.  $C^*$  relationship on a log-log plot. To calculate the  $da/dt$  in Eq. (1), the material constants,  $D$ ,  $m$ ,  $A$ , and  $n$  obtained from the tensile and creep tests.

For CT specimen, the  $C^*$  value and load-line displacement rate ( $\dot{V}_c$ ) due to creep strain was calculated by following equations (2) and (3) [7]:

$$C^* = \frac{P\dot{V}_c}{B_N(W-a)} \left( \frac{n}{n+1} \right) \cdot (2.2) \quad (2)$$

$$(0.4 \leq a/W \leq 0.7)$$

$$\dot{V}_c = \dot{V} - \frac{\dot{a}B_N}{P} \left( \frac{2K^2}{E'} + (m+1)J_p \right) \quad (3)$$

where:  $J_p$  = fully-plastic contributions to J-integral,  $P$  = applied load,  $a$  = crack size,  $W$  = width of the specimen,  $\dot{V}$  = total load-line displacement rate,  $B_N$  = net thickness of specimen,  $E'$  = elastic modulus for plane strain,  $K$  = stress intensity factor,  $\dot{a}$  = crack growth rate, and  $m$  = stress exponent in the Ramberg-Osgood stress versus strain relationship. The relationships between  $da/dt$  and  $C^*$  was obtained for all samples.

Fig. 4 shows a plot of  $C^*$  vs.  $da/dt$  obtained for Alloy 800H BM at 800°C. A solid line is to show the regression curve obtained using the least squares fit method for all of the CCG data. A CCGR law was finally determined, as follows:

$$da/dt = 0.05 (C^*)^{0.75} \quad (4)$$

(validity range:  $0.004 < C < 10$  N/mm-h)

Using the Eq. (4), it is suggested that the CCGR of Alloy 800H can be properly evaluated at a specific  $C^*$  value within the validity range of  $0.004 < C < 10$  N/mm-h. Also, the CCGR law obtained for Alloy 800H was compared with that of Alloy 617 at the identical temperature of 800°C. Alloy 800H was identified to be faster in CCGR than Alloy 617. The reason for this was that Alloy 617 had higher creep strength than Alloy 800H.

In addition, it was identified that SEM fracture surface showed minor cracks as ductile fracture. In the OM structure in front of crack tip, as shown in Fig. 5, cracks are developed with a 45° zigzag pattern along the grain boundaries (GBs). Minor voids (or cavities) are formed

at the GBs, and the cracks are propagated by interconnecting of the cavities. It is evident for typical intergranular fracture mode, as shown in Fig. 5.

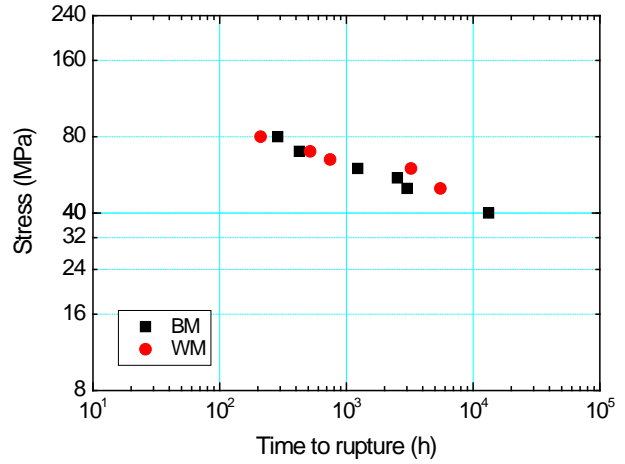


Fig. 1. Comparison of creep strength for the BM and WM of Alloy 800H.

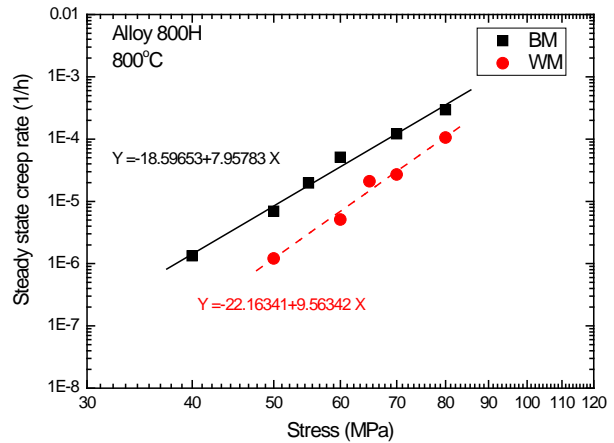


Fig. 2. Comparison of creep strain rates for the BM and WM of Alloy 800H.

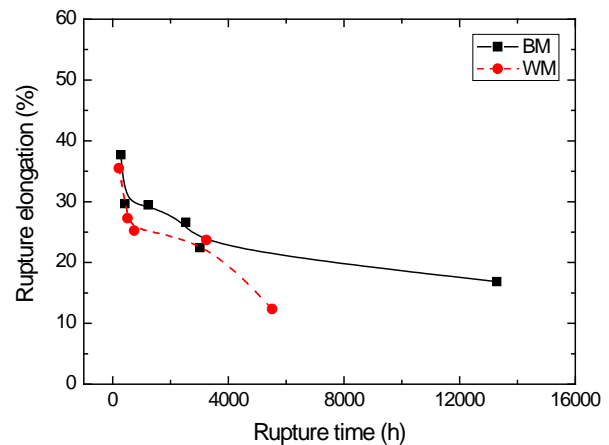


Fig. 3. Comparison of creep rupture elongation for the BM and WM of Alloy 800H.

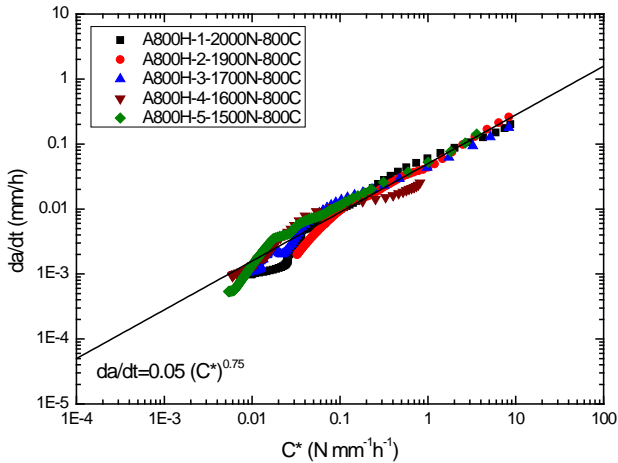


Fig. 4. Plot of  $\log (da/dt)$  vs.  $\log (C^*)$  for evaluating the CCGR for Alloy 800H BM

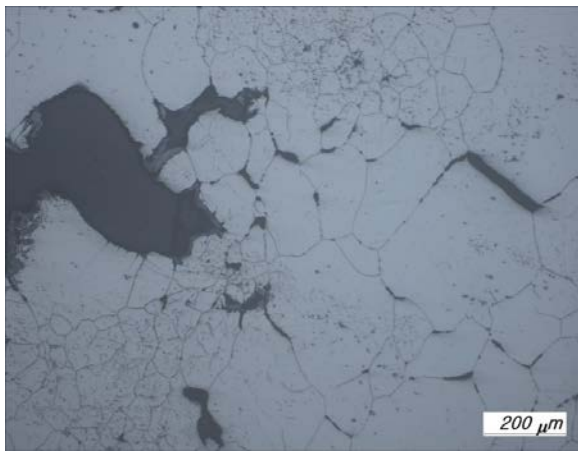


Fig. 5. OM structure showing typical intergranular fracture observed for Alloy 800H BM.

### 3. Conclusions

Alloy 800H WM showed higher creep strength and lower creep rate than Alloy 800H BM, and particularly lower rupture elongation in the WM. The lower creep rate of Alloy 800H WM was due to lower rupture elongation than that of Alloy 800H BM. Through a series of CCG tests at 800°C of Alloy 800H BM, a CCGR law for evaluating CCG rate was developed as  $da/dt = 0.05 (C^*)^{0.75}$ . The CCG fracture mode of Alloy 800H was evident to be typical intergranular fracture along the grain boundaries.

### ACKNOWLEDGEMENTS

This research was supported by Nuclear Research & Development Program of the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (2017M2A8A1014758 and 2016M2A8A1952772).

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