Comparison of Mechanical Properties for Alloy 800H Base and Weld Metals

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1. Introduction

A very high temperature reactor (VHTR) is one of the most promising Generation-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-a modification of Alloy 800, which was developed for applications requiring additional creep resistance – is the primary candidate for use as the reactor internals: a control rod system (CRS), a core barrel, core supports, and a shutdown cooling system (SCS) in the VHTR system [1]. Alloy 800H is approved for use up to 760ºC under ASME Code Section III Subsection NH for nuclear applications [2]. Many studies were done for Alloy 800H base metal (BM) and its mechanical data are available in several reported documents [3-6], whereas the mechanical data for the weld metal (WM) of Alloy 800H are not available under the ASME code or elsewhere. Therefore, the hot mechanical properties such as the tension, creep, and creep crack growth (CCG) for the WM should be investigated for design use in reactor internals of Alloy 800H.

In this study, the tension and creep behaviors for the Alloy 800H WM which was fabricated by a gas tungsten arc welding (GTAW) procedure were assessed in comparison with those of Alloy 800H BM. In addition, the CCG behavior for Alloy 800H BM was investigated in terms of the C^*-fracture parameter through a series of CCG tests at 800ºC.

2. Experimental Method

"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. Chemical composition was given, as follows; C=0.07, Ni=30.18, Fe=Bal. Si=0.42, Mn=0.98, Cr=20.43, Ti=0.54, P=0.022, Al=0.49, Cu=0.45. The amount of each element was identified to be included well within the ASME specifications. Alloy 800H WM was fabricated by GTAW method. The shape of the weld joint has a single V-groove with an angle of 80º. 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.

The tension and creep test specimens of Alloy 800H were a cylindrical form of 30 mm in gauge length and 6 mm in diameter. The tensile tests were conducted under a slow strain rate of 5.55E-4 (1/s) at R.T to 850ºC. The creep tests were performed under different stress levels at the identical temperature of 800ºC. Creep strain data with elapsed times were taken automatically by a PC through a high precision extensometer. In addition, the CCG tests of Alloy 800H BM were carried out at a constant load with different applied load levels at 800ºC. 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].

3. Results

3.1 Tensile properties for the BM and WM

Fig. 1 shows a comparison of ultimate tensile strength (UTS) for the BM and WM of Alloy 800H. The WM presents higher tensile strength than the BM. However, in the tensile elongation, the WM was identified to be lower than the BM. It means that the WM was reversely reduced in ductility due to higher strength than the BM.

In addition, to describe well the hot tensile curves of Alloy 800H, the GA model developed by Smith in General Atomic Company is used herein. The GA model can be given as follows [8]:

$$\ln S = B_1 + B_2 (\ln e) + B_3 (\ln e)^2 + B_4 (\ln e)^3 \quad (1)$$

where, B_1, B_2, B_3, and B_4 are the coefficients determined for each temperature. The hot tensile curves are fitted to the third order polynomials in natural log stress (S) and natural log strain (e) for a series of strain up to UTS at each temperature curve. The GA model uses only an equation to model the full tensile curves from elastic stress to ultimate tensile strength (UTS), as given in Eq. (1). Generally, the Ramberg-Osgood (R-O) model well known as a typically strong tensile model has been used to model the tensile curves of various materials. The R-O model is given as $S = Se + D (e_p)^m$, where S_e is the proportional limit stress as an elastic component, and e_p is the plastic strain. The D and m are the coefficients which are determined for each temperature. As defined in the R-O equation, to model the full tensile curves from elastic stress to UTS, the values of elastic and plastic stress should be separately obtained. Contrarily to R-O model, the GA model can describe the tensile curves up to UTS using the only one equation. Thus, the GA model is convenient compared with the R-O model. Fig. 2 shows the fitted results obtained using the GA model. The GA model reveals a good match with the experimental data for the both of BM and WM of Alloy 800H. It is thus verified that the GA model can be utilized as a useful model to describe the hot tensile curves of Alloy 800H.

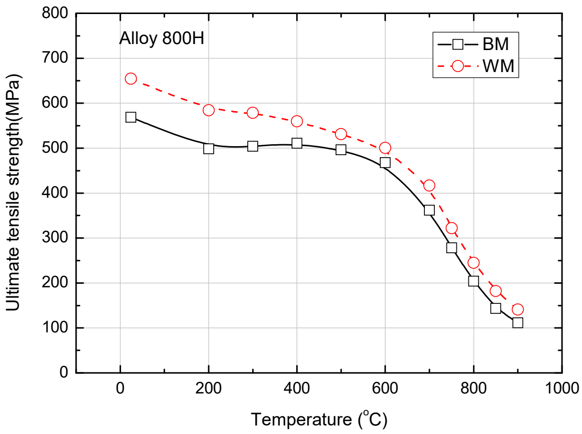

Fig. 1. Comparison of the tensile strengths for Alloy 800H BM and WM

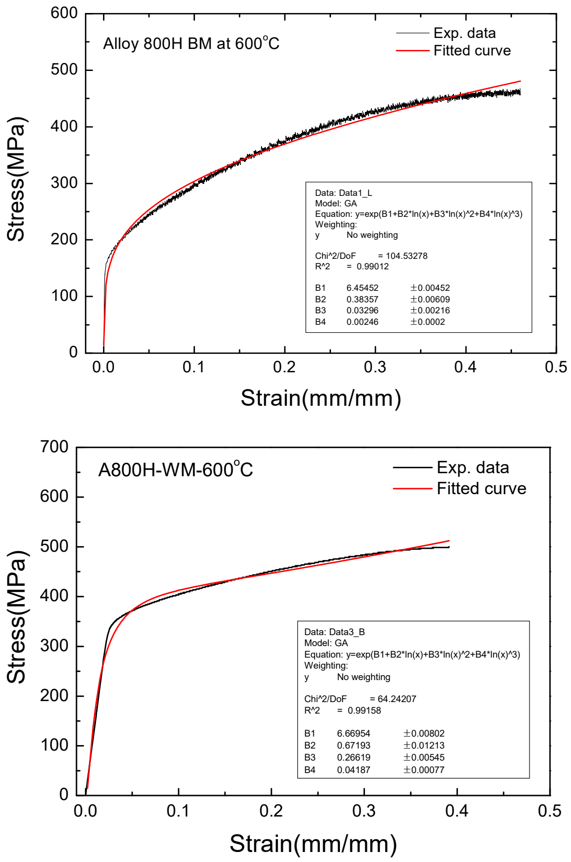

Fig. 2. Tensile curve modelling by GA model at 600°C of Alloy 800H BM and WM

3.2 Creep and CCG behaviors

From the creep tests at 800°C of Alloy 800H BM and WM, the creep rupture data such as rupture time, creep strain rate, and rupture elongation were obtained, respectively. Fig. 3 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, the WM is significantly lower than the BM, as shown in Fig. 4. The WM were investigated to be lower in the creep rupture ductility than the BM. Therefore, the reason for this is due to the lower rupture ductility in WM. Also, as described in the tensile test results above, it can be described from that the WM had higher in tensile strength and lower in tensile elongation than the BM.

In addition, to evaluate the creep crack growth rate (CCGR) for Alloy 800H BM, a series of the CCG tests was performed under various applied loads at 800°C, and the CCGR behavior was evaluated using typical facture parameter, C^*. The general form between the creep crack growth rate (*da*/*dt*) and the C^* can be expressed by [9]

$$da/dt = B\,[C^*]^{\,q} \qquad (2)$$

where *n* is the creep exponent, and the *B* and *q* coefficients are material constants, which are generally obtained from a regression line of the CCGR data. The coefficients 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. (2), the material constants, *D*, *m*, *A*, and *n* were experimentally obtained from the tensile and creep tests for Alloy 800H BM and WM, respectively. All procedures for calculating the C^* values referred to the the recommendations of the ASTM standard E1457.

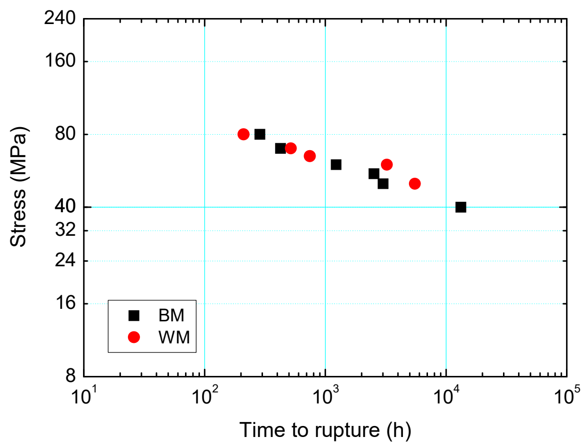

Fig. 3. Comparison of the creep stress at 800°C of Alloy 800H BM and WM

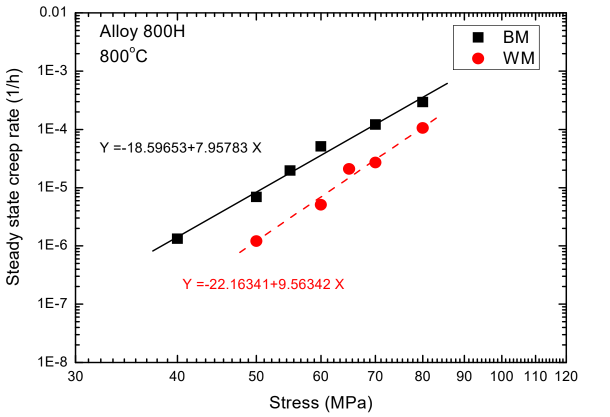

Fig. 4. Comparison of the creep rate at 800°C of Alloy 800H BM and WM

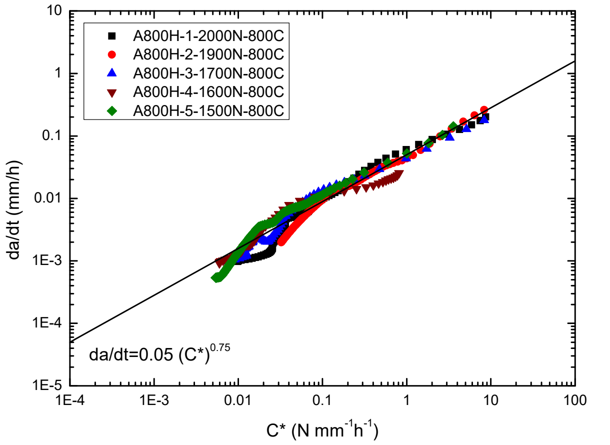

Fig. 5. Plot of *da*/*dt* vs. C^* for evaluating the CCGR of Alloy 800H BM

Fig. 5 presents a log-log plot of the 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 CCG data. A CCGR law can be finally determined, as follows:

$$da/dt = 0.05\,(C^*)^{0.75} \quad (3)$$

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

Using the Eq. (3), a CCGR for Alloy 800H BM can be properly evaluated at any given C^* value in the validity range of $0.004 < C^* < 10$ N/mm h.

4. Conclusions

The Alloy 800H WM was significantly higher in the tensile strength than the Alloy 800H BM in the all temperature ranges, but it was reversely lower in tensile elongation. In the modelling of the tensile curves, the GA model revealed a good match with the experimental data. The GA model can be utilized as a useful model to describe the hot tensile curves regardless of the BM and WM. The Alloy 800H WM showed higher creep strength 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. In addition, through a series of the CCG tests of Alloy 800H BM, a CCGR law for evaluating the creep crack growth rate was developed as *da*/*dt* $=0.05\,(C^*)^{0.75}$.

Acknowledgements

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