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# Creep and Creep Crack Growth Behaviors for SMAW Weldments of Gr. 91 Steel

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## 1. Introduction

High Cr ferritic resistance steels with tempered martensite microstructures posses enhanced creep strength at the elevated temperatures [1, 2]. Those steels as represented by a modified 9Cr-1Mo steel (ASME Grade 91, hereafter Gr.91) are regarded as main structural materials of sodium-cooled fast reactors (SFR) and reactor pressure vessel materials of very high temperature reactors (VHTR). The SFR and VHTR systems are designed during long-term duration reaching 60 years at elevated temperatures and often subjected to non-uniform stress and temperature distribution during service. These conditions may generate localized creep damage and propagate the cracks and ultimately may cause a fracture. A significant portion of its life is spent in crack propagation [3,4]. Therefore, a creep crack growth rate (CCGR) due to creep damage should be assessed for both the base metal (BM) and welded metal (WM). Enough CCGR data for them should be provided for assessing their structural integrities. However, their CCGR data for the Gr. 91 steels is still insufficient.

In this study, the CCGR for the BM and the WM of the Gr. 91 steel was comparatively investigated. A series of the CCG tests were conducted under different applied loads for the BM and the WM at 600°C. The CCGR was characterized in terms of the $C^*$ parameter, and their CCG behavior were compared, respectively.

## 2. Methods and Results

### *2.1 Experimental procedures*

The Gr. 91 steel for the base and weld specimens was used with a hot rolled plate of 32mm thickness. Heat treatment conditions were normalized and tempered at 1050°C/1mim/mm and 770°C/3mim/mm. In welding, a groove shape for the joining of two plates was designed as a single V-groove with 60 degrees. Welded blocks were prepared by using the shielded metal arc welding (SMAW) method. Filler metal was CM-9Cb (brand name) manufactured by Kobe steel as AWS Class, E9016-G (3.2-4.0 mm). Post weld heat treatment was maintained for 255min at 750°C.

To obtain material properties used in $C^*$ equation, the tensile, creep and CCG tests were performed for the BM and WM of the Gr. 91 steel. The tensile specimens were machined with a rectangular cross section of a 2mm thickness, a 6.25mm width, and with a 25mm gauge length. A strain rate was conducted with a slow strain rate of $1\times10^{-4}$ /sec at 600°C. The creep specimens were machined to a cylindrical shape with a 30mm gauge length and 6mm diameter. All the specimens were taken along the rolling direction. The creep tests were carried out with different stress levels at 600°C. Creep strain data with elapsed times was taken automatically by a PC through a high precision LVDT.

The CCG tests were carried out with applied load ranges of 3800N to 4500N at 600°C. Compact tension (CT) specimens were used for a width ($W$) of 25.4mm, a thickness ($B$) of 12.7mm, and side grooves of a 10% depth. Initial crack ratio ($a/W$) was about 0.5, and pre-cracking size was 1.5 mm. Load-line displacement was measured using a linear gauge assembly attached to the specimen and the crack length was determined by the direct current potential drop (DCPD) method. Crack length was calculated using the Johnson's formula from the results of the DCPD. After the CCG testing, the CT specimens were cooled down in a liquid nitrogen solution and fractured to measure the final crack length.

### *2.2 Tensile and Creep properties*

$D$ and $m$ constants were obtained from the tensile tests for the WM and BM of the Gr. 91 steel at 600°C. Plastic constants were obtained by $\varepsilon_p = D(\sigma/\sigma_{ys})^m$. The $A$ and $n$ values were determined from creep tests for the WM and BM at 600°C. The constants were determined by Norton's power law, $\dot{\varepsilon}_{ss} = A\sigma^n$.

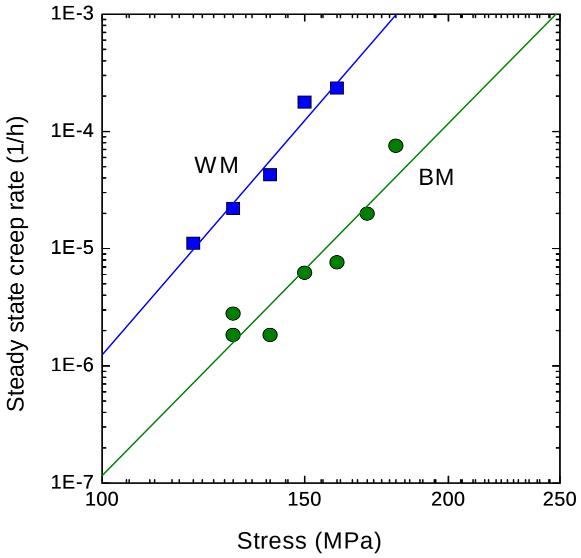

Fig. 1. Comparison of the steady state creep rate for the WM and BM at 600°C.

The WM was about 10 times faster in the steady state creep rate than the BM, as shown in Fig. 1. The *D*, *m*, *A*, and *n* values for the BM and WM were obtained as follows: for the BM, the material constants were obtained as $\sigma_{ys}$=247.5, *D*=0.0017, *m*=6.4, *A*=1.28E-27, and *n*=9.98, and for the WM, $\sigma_{ys}$=298.2, *D*=0.00191, *m*=12.9, *A*=2.28E-29, *n*=11.27.

For the BM and WM, the relationships between steady state creep rate and applied stress followed a good linearity by Norton's power law. The WM was about 10 times faster in the steady state creep rate than the BM, as shown in Fig. 1. This will be significantly attributed to a faster crack propagation rate in the WM.

### *2.2 Comparison of CCGR for the BM and WM*

For the CT specimen, the $C^*$ value was calculated by Eq. 1, and load-line displacement rate ($\dot{V}_c$) due to creep strain was calculated by Eq. 2 [3, 5].

$$C^* = \frac{P\dot{V}_c}{B_N(W-a)}\eta\left(\frac{a}{W},n\right) \tag{1}$$

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

Where: *P* = applied load, *a* = crack size, *W* = width of 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, *m* = stress exponent. Calculating procedures of the $C^*$ values were conducted according to the ASTM E1457 procedures.

Figs. 2 and 3 show the result of the creep crack growth rate vs. $C^*$ parameter obtained for the BM and WM at 600°C. Analysis of the CCG tests on the BM results made it to possible to propose the following creep crack propagation law:

$$\text{da/dt}=1.89\text{x}10^{-2}\text{x}(C^*)^{0.77} \tag{3}$$

(range of validity 0.004 < C* < 2.0 N/mm.h)

Also, analysis of the CCG tests on the WM results made it to possible to propose the following creep crack propagation law:

$$\text{da/dt}=3.62\text{x}10^{-2}\text{x}(C^*)^{0.85} \tag{4}$$

(range of validity 0.025 < C* < 2.5 N/mm.h)

From the results, for a given value of $C^*$, the rate of creep crack propagation can be predicted for the BM and WM of the Gr. 91 steel. It appeared that, for a given value of *C**, the CCGR was about 2.0 times faster than in the WM than the BM. It is suggested that this reason was largely attributed to the high creep rate in the WM, as shown in Fig. 3.

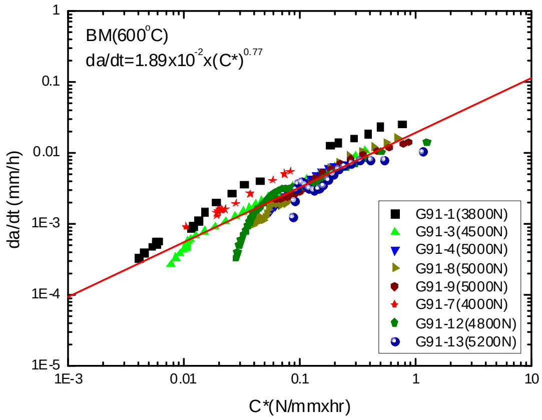

Fig. 2. CCGR law obtained for the BM.

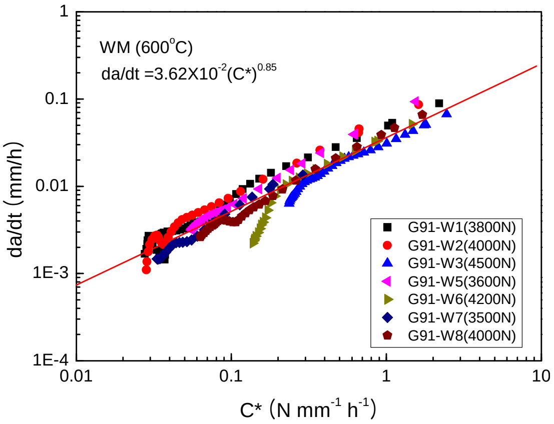

Fig. 3. CCGR law obtained for the WM.

## 3. Conclusions

It appeared that, for a given value of $C^*$, the CCGR was about 2.0 times faster in the WM than in the BM. The reason for this was that the WM was faster in the creep strain rate than the BM. This result can be utilized for assessing the rate of creep crack propagation on the BM and WM of the Gr. 91 steel at 600°C.

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