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Changes in Charpy impact properties with Post Weld Heat Treatment in the HAZ of SA508 Gr.4N Low Alloy Steel

Yoon Sun Lee*, Min Chul Kim, Bong Sang Lee
*KAERI, Nuclear Materials Research Center, 150 Deogjin-dong, Yuseong-gu, Daejeon, 305-353, Korea**
Kami625 @ hanmail.net

1. Introduction

Microstructural changes, such as a grain coarsening, carbide precipitaion, and martensite formation, generally occur in the heat-affected zone (HAZ) of low alloy steels used for nuclear pressure vessels. It can cause a deterioration of their toughness and increase their susceptibility to a brittle fracture. Metallographic analyses of low alloy steel welds reveal significantly different regions in HAZ microstructures. In the single pass welds, there were four characteristic regions in the HAZ determined by the peak temperature, to which the region was exposed during the weld thermal cycle: a coarse-grained region, a fine-grained region, an intercritical region, and a subcritical region. In 2-pass welds, the coarse-grained region can be categorized into four zones according to the reheating temperature as follows: an unaltered coarse-grained zone (UCGHAZ), a supercritically reheated coarse-grained zone (SCRCG HAZ), an intercritically reheated coarse-grained zone (ICCGHAZ), and a subcritically reheated coarse-grained zone (SRCGHAZ).

In this study, the effect of a Post weld heat treatment (PHWT) on the tensile properties and impact toughness in the heat-affected zone of SA508 Gr.4N low alloy has been discussed using simulated sub-HAZ specimens.

2. Experimental Procedure

The compositions of the steel used in this study are given in Table 1. Base metal was austenitized at 880℃ for 6 hours followed by an air cooling, and then tempered at 660℃ for 10 hours. Welding thermal cycle was obtained from the thermal-flow formula of Rosenthal. Heat input was 30kJ/cm.

$$T - T_0 = \Theta_1 \frac{\Delta t}{t} \exp[-\frac{\Delta t}{et}(\frac{\Theta_1}{T_P - T_0})]$$

$$\frac{1}{\Theta_1} = (\frac{1}{773 - T_0} - \frac{1}{1073 - T_0}) \qquad \Delta t_{8/5} = \frac{q/v}{2\pi\lambda\Theta_1}$$

Where, T_0 is preheat temperature (℃), T_p is peak temperature (℃), e is natural logarithm (=2.718), t is time (s), q/v is heat input (KJ/cm), λ is thermal conductivity.

To simulate the sub-HAZ, thermal cycle simulation conditions were established, based on a theoretically calculated thermal cycle, peak temperature, and cooling time between 800℃ and 500℃ ($\Delta t_{8/5}$). The HAZ was categorized into seven characteristic zones according to the peak temperature from the thermal cycle experienced during a weld: CGCG, FGCG, ICCG, SCCG, FGFG, ICIC and SCSCHAZ. Simulation of the welding thermal cycles was conducted on a dynamic thermal machine Gleeble 3200. Post weld heat treatment (PWHT) was carried out at the 610℃ for 30 hours. Charpy impact tests were carried out using standard Charpy V notch specimens over a temperature range of -196℃ to 100℃. Tensile tests were conducted using plate type tensile specimens with a 6mm gage length at a strain rate of 1.11 X 10^{-3}/s.

The samples were etched using 3 pct nital or martensite etchant and then their microstructure was examined by an optical microscopy and scanning electron microscopy (SEM).

Table1. Chemical compositions of the steel (wt.%).

	C	Mn	Ni	Cr	Mo
KL4	0.20	0.32	3.56	1.78	0.49

3. Experimental Results and Discussion

Tensile test results at R.T are shown in Fig. 1. Before a PWHT, in general sub-HAZ shows higher yield strengths and a lower elongation than the base metal. After a PWHT to the sub-HAZ specimens, the yield strengths were decreased to a similar level of the base metal.

Fig. 2 shows the SEM micrographs of the simulated HAZ after a PWHT. It was observed that the carbide volume fraction had considerably increased.

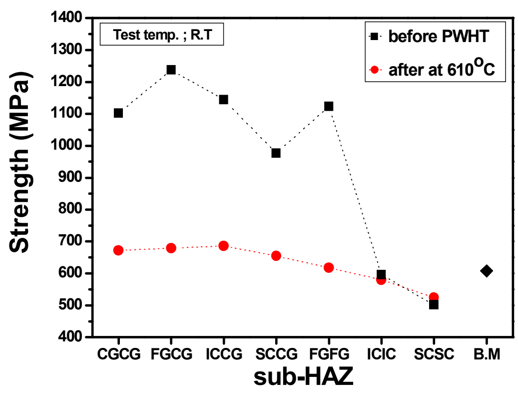

Fig. 1 Yield and tensile strength of simulated HAZ after PWHT.

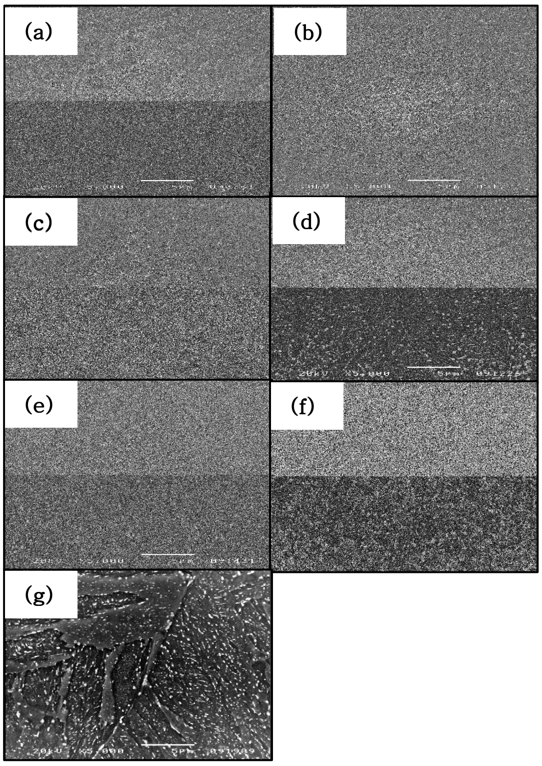

Fig. 2 SEM micrographs of the simulated HAZ after PWHT ; (a) CGCG, (b) FGCG, (c) ICCG, (d) SCCG, (e) FGFG, (f) ICIC, (g) SCSCHAZ.

The Charpy impact test results of various sub-HAZ before a PWHT are shown in Fig. 3. The Charpy impact energies of sub-HAZ were much lower than that of base metal, except in the SCSCHAZ. Especially, SCCGHAZ which the USE (Upper Shelf Energy) and T_{41J} were 55.8J and -3.7℃ respectively has the lowest Charpy impact properties in the CGHAZs.

Fig. 4 shows the effects of a PWHT on the impact

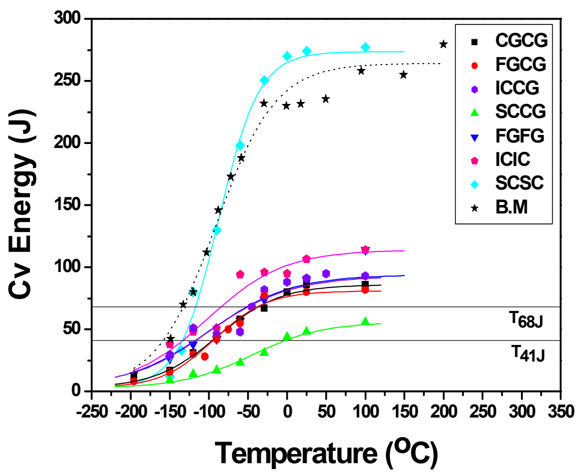

Fig. 3 Charpy impact test results of simulated HAZ before PWHT.

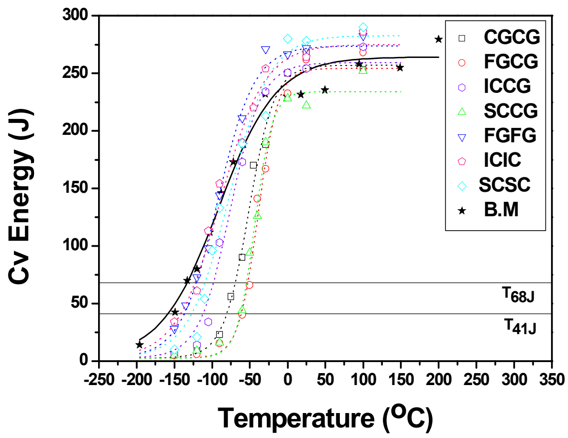

Fig. 4 Charpy impact test results of simulated HAZ after PWHT.

toughness of the simulated HAZ. All the sub-HAZ showed much better Charpy impact properties. Charpy impact energies of the FGFG, ICIC and SCSCHAZ reached a level of the base metal after a PWHT. However, in the case of CGHAZ, the increase of the Charpy impact energy was not sufficient and its transition temperature was consideravely higher than those of other sub-HAZs. Charpy transition curves of 4 types of CGHAZs showed a relatively large deviation.

4. Summary

In this study, the effect of a PWHT on the microstructures and Charpy impact properties in the HAZ of SA508 Gr. 4N low alloy steel was investigated. After a PWTH, The overall microstructures appeared with a tempering effect. Yield strengths were decreased, to a similar level of the base metal after a PWHT. Charpy impact properties of sub-HAZ were improved after a PWHT. However, in the case of CGHAZ, the transition temperature was improved less than the base metal.

Acknowledgement

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