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Effects of a Post Weld Heat Treatment (PWHT) on the Microstructures and Mechanical Properties in the HAZ of SA 508 Gr.4N Low Alloy Steel

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1. Introduction

In the heat-affected zones (HAZ) of low alloy steels used for a nuclear pressure vessel, microstructural changes, such as a grain coarsening, carbide precipitation, and martensite formation, generally occur and cause a deterioration of the toughness and increase in the sensitivity 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 (SCRCGHAZ), an intercritically reheated coarse-grained zone (ICCGHAZ), and a subcritically reheated coarse-grained zone (SCGHAZ).

The purpose of this article is to investigate the changes of the microstructure and mechanical properties with different post weld heat treatment (PWHT) conditions 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 8 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 1500. Post Weld Heat Treatment (PWHT) was carried out at the range of 550~610℃ for 30 hours to evaluate the effect of the PWHT conditions. Charpy impact tests were carried out using standard Charpy V notch specimens over a temperature range of -196℃ to 200℃. 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). Fracture surface of the broken Charpy specimens was also observed with SEM.

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

	C	Mn	Ni	Cr	Mo
KL4	0.20	0.32	3.56	1.78	0.49

* KL4: SA508 Gr.4

3. Experimental Results and Discussion

Tensile test results at R.T are shown in Fig. 1 and Fig. 2. Before PWHT, sub-HAZ shows higher yield strengths and a lower elongation than the base metal. By applying PWHT to sub-HAZ specimens, yield strengths were decreased while the elongation was increased with an increase of the PWHT temperature.

Fig. 3 shows the optical micrographs of the simulated HAZ. Figs. 3 (a) through (d) have large prior austenite

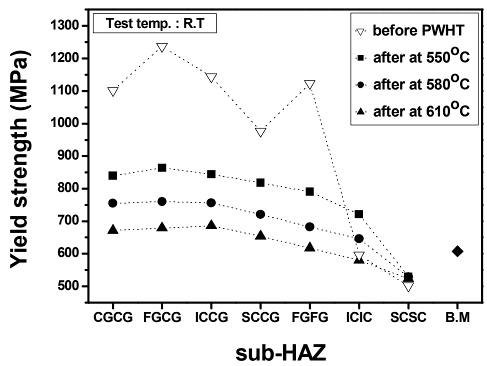

Fig. 1 Yield and tensile strength of simulated HAZ after PWHT.

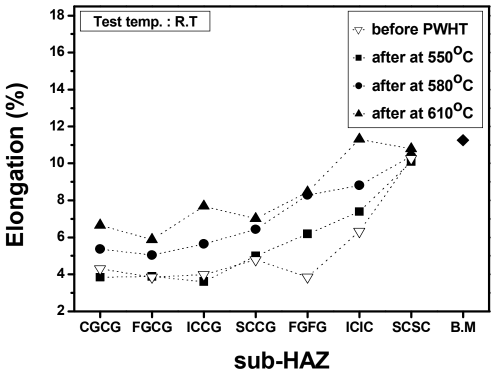

Fig. 2 Elongation results of simulated HAZ

grains and contain lots of martensite. Figs. 3 (e) through (g) do not seem to contain much martensite, showing similar microstructures to the base metal and Fig. 3 (e) has fine prior austenite grains. Fig. 3 (f) and (g) are almost the same as the microstructure of the base metal.

Fig. 4 shows the SEM micrographs of the simulated HAZ after PWHT. The overall microstructures are similar to those before PWHT, it was observed that the carbide volume fraction had considerably increased.

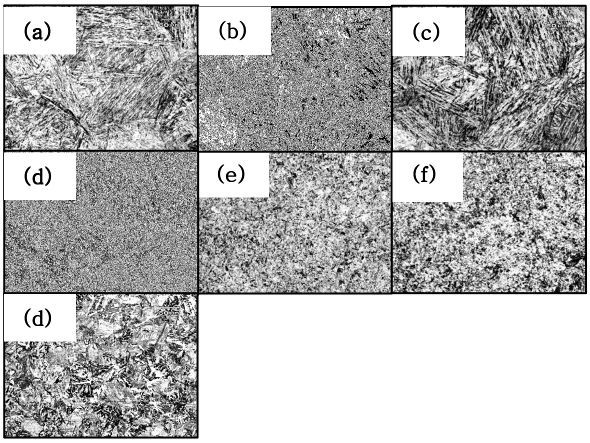

Fig. 3 Optical micrographs of the simulated HAZ (a) CGCG, (b) FGCG, (c) ICCG, (d) SCCG, (e) FGFG, (f) ICIC, (g) SCSCHAZ.

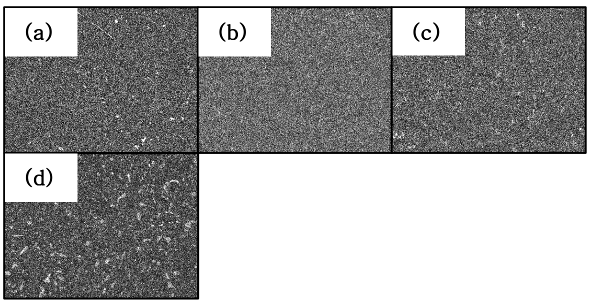

Fig. 4 Optical micrographs of the simulated HAZ after PWHT (a) CGCG, (b) FGFG, (c) ICIC, (d) SCSCHAZ.

The Charpy impact test results of various sub-HAZ after PWHT are shown in Fig. 5. After PWHT, the sub-HAZ showed much better toughness properties regardless of the PWHT temperature. In the case of FGFG, ICIC and SCSCHAZ, Charpy impact energy was recovered up to that of the base metal after PWHT. However, in the case of CGHAZ, Charpy impact energy was not increased as much as the other parts of HAZ.

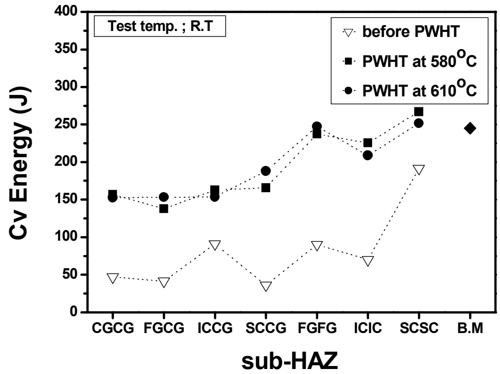

Fig. 5 Charpy impact test results of various.

4. Summary

In this study, the effect of PWHT on the microstructures and mechanical properties in the HAZ of SA508 Gr. 4N low alloy steel was investigated. In various sub-HAZ, four regions of CGHAZ contain lots of martensite, but FGFG, ICIC, SCSCHAZ have similar microstuctures to the base metal. Tensile strength of sub-HAZ was decreased by applying PWHT. However, sub-HAZ shows a better Charpy impact toughness after PWHT regardless of the PWHT temperature.

Acknowledgement

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