Microstructural Differences in the SCCG, ICCG HAZs of SA 508 Gr. 3 and 4N Low Alloy Steels.

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1. Introduction

Microstructural changes, such as a grain coarsening, carbide precipitaton and martensite formation, in the heat-affected zones (HAZ) of low alloy steels as in a nuclear pressure vessel generally occur and induce a deterioration of the toughness and an increase of the sensitivity to brittle fracture. Metallographic analyses of low alloy steel welds reveal considerably different regions in HAZ microstructures. In 2-pass welds, they could be categorized as seven characteristic regions that are determined by the peak temperature in the HAZ during weld thermal cycle: a coarse-grained region, a fine-grained region, an intercritical region, and subcritical region. The coarse-grained region can be categorized into four regions that are determained by 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 an subcritically reheated coarse-grained zone (SCCGHAZ).

The purpose of this study is to investigate the differences of the microstructure and mechanical properties in the sub-HAZ of SA508 Gr.3 and 4N low alloy steels. Fromr these results, the cause of a toughness degradation in the ICCG, SCCG HAZs of SA508 Gr. 3 and 4N is discussed.

2. Experimental Procedure

The materials used in this study were KL3 and KL4 low allow steels that have a chemical composition as given in Table 1. Specimens were austenitized at 880℃ for 8 hours followed by an air cooling, and then tempered at 660℃ for 10 hours. Welding thermal cycle was determined by the thermal-flow formula of Rosenthal. Heat input is 30KJ/cm. Thermal cycle simulation conditions were established to simulate the sub-HAZ, based on a theoretically calculated thermal cycle, peak temperature and cooling time between 800℃ and 500℃ ($\Delta t_{8/5}$). Simulation of the welding thermal cycles was performed by a dynamic thermal machine Gleeble 3500. Charpy impact tests were conducted using standard Charpy V notch specimens over a temperature range of -196℃ to 200℃. Tensile tests were carried out using plate type tensile specimens with a 6mm gage length at the strain rate of 1.11 X 10^{-3}/s. The hardness measurements were made using a Vickers Hardness tester with a 0.01kg loading for 15s.

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

Table 1. Chemical composition of the steel. (wt%)

	C	Mn	Ni	Cr	Mo
KL3	0.23	1.4	0.9	0.15	0.5
KL4	0.20	0.32	3.56	1.78	0.49

- KL3 : SA508 Gr.3 , KL4 : SA508 Gr.4

3. Experimental Results and Discussion

Fig. 1 shows the optical micrographs of the simulated sub-HAZ. CGHAZ showed different microstructures according to the peak temperature in the 2-pass welds. CGCGHAZ (Fig. 1 (a)) has a coarse-grained martensite. Fig. 1 (b) through (d) has large prior austenite grains and contained lots of martensite. It is generally known that ICCGHAZ has an M-A phase. However, the formation of an M-A phase wasn't observed in ICCGHAZ of KL4. Fig.3 (e)-(g) didn't have much martensite, showing fine prior austenite grains.

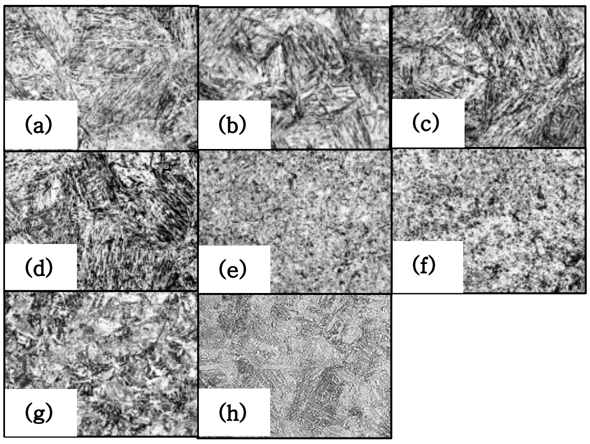

Fig. 1 Optical micrographs of the simulated HAZ (a) CGCG, (b) FGCG, (c) ICCG, (d) SCCG, (e) FGFG, (f) ICIC, (g) SCSCHAZ, (h) base metal.

Tensile test and Charpy impact test results at R.T. are shown in Fig. 2. CGHAZ indicated a higher tensile strength than those of SCHAZ. SCHAZ showed a low tensile strength due to a peak temperature below the transformation temperature during a thermal cycle. Charpy energy at R.T. of all the HAZ was much lower than that of the base metal except for SCSCHAZ. In the

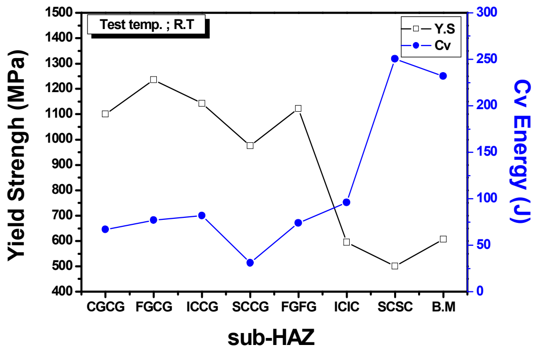

Fig.2 Yield and tensile strength of simulated HAZ (KL3, KL4)

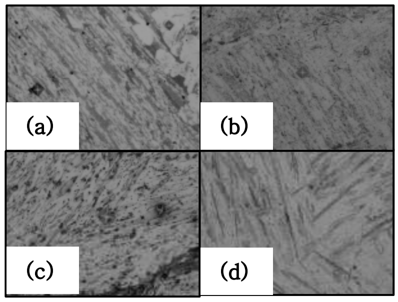

Fig. 3 Optical micrographs of the simulated HAZ after Vickers harness test (a) KL3 ICCG, (b) KL3 SCCG, (c) KL4 ICCG, (d) KL4 SCCG.

case of SA508 Gr. 3, it is known that ICCGHAZ revealed the lowest impact toughness due to a large difference of the hardness between the M-A phase and matrix. However, Charpy energy of SCCGHAZ indicated lower value than that of ICCGHAZ in the KL4 low alloy steel (SA 508 Gr. 4N).

Vickers hardness test was conducted on the ICCG and SCCG HAZs of KL3 and KL4. Vickers hardness test results and the microstructure after the test of simulated sub-HAZ are shown in Table 2 and Fig. 3. ICCGHAZ of KL3 (Fig. 3 (a)) contained isolated M-A phases around the matrix, so the Vickers hardness was widely distributed. However, M-A phase wasn't observed in the ICCGHAZ of KL4 (Fig. 3(a)). And it reveallled uniform hardness results. In the case of SCCGHAZ of KL4 (Fig. 3(d)), martensite partially transformed into ferrite caused by the tempering effect during second pass welding thermal cycle. Therefore, there is a large difference in the hardness between the martensite and tempered martensite. This causes a degradation of the toughness in SCCGHAZ of KL4. More detailed research is ongoing.

Table 2. Vickers hardness of the simulated HAZ

	KL3 ICCG	KL3 SCCG	KL4 ICCG	KL4 SCCG
Average (Hv)	483.79	395.45	336.09	615.56
Standard deviation	129.68	24.41	20.19	88.25

4. Summary

Microstructural differences and mechanical properties in the ICCG, SCCG HAZs of SA508 Gr. 3 and 4N low alloy steels were investigated. The ICCGHAZ of KL3 had a M-A phase that was formed during a second-pass thermal cycle. So, a toughness degradation occurred because of the hardness difference between M-A phase and matrix. However the the M-A phase wasn't observed in the ICCGHAZ of KL4. The SCCG of KL4 had martensite and tempered martensite due to the tempering effect during the second pass welding thermal cycle. As a result, in the case of SA508 Gr. 4N, the SCCGHAZ revealled the lowest impact toughness by the difference of the hardness between the martensite and tempered martensite.

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