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Evaluation of 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 nuclear pressure vessel, microstructural changes, such as grain coarsening, carbide precipitation, and martensite formation, generally occur and cause a deterioration of toughness and an increase in sensitivity to brittle fracture. Metallographic analyses of low alloy steel welds reveal significantly different regions in HAZ microstructures. In 2-pass welds, there were seven 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 subcritical region. 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 (ICRCGHAZ), and an subcritically reheated coarse-grained zone (SRCGHAZ).

It is known that higher strength and fracture toughness of low alloy steels could be achieved by increasing Ni and Cr contents. In this study, the microstructure and mechanical properties in the heat-affected zone of SA508 Gr.4N low alloy steel which has higher Ni and Cr contents than SA508 Gr.3 low alloy steel, have been discussed.

2. Experimental Procedure

The compositions of the steels used in this study are given in Table 1. Base metal was austenitized at 880℃ for 8 hours followed by air cooling, and then tempered at 660℃ for 10 hours. Welding thermal cycle were obtained from the thermal-flow formula of Rosenthal. Heat input is 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 theoretically calculated thermal cycle, peak temperature, and cooling time between 800℃ and 500℃ ($\Delta t_{8/5}$). Simulation of welding thermal cycles was conducted on a dynamic thermal machine Gleeble 3500. Charpy impact 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 6mm gage length at the strain rate of 1.11 X 10^{-3}/s .

The samples were etched using 3 pct natal or martensite etchant and then microstructure was examined by optical microscopy and scanning electron microscopy (SEM). Fracture surface of the broken Charpy specimens were also observed with 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

Tensile test results at R.T were shown in Fig.1 and Fig. 2. In general, yield and tensile strengths of samples from KL4 were higher than those of KL3. But elongation of KL4 was lower than that of KL3 in the HAZ.

Fig. 3 shows the optical micrographs of the simulated HAZ . Fig. 3 (a) through (d) have large prior austenite grains and contain lots of martensite. Fig.3 (e) through (g) do not seem to contain much martensite, showing similar to microstructures of the base metal and Fig.3(e) has fine prior austenite grains. Fig. (f) and (g) are almost

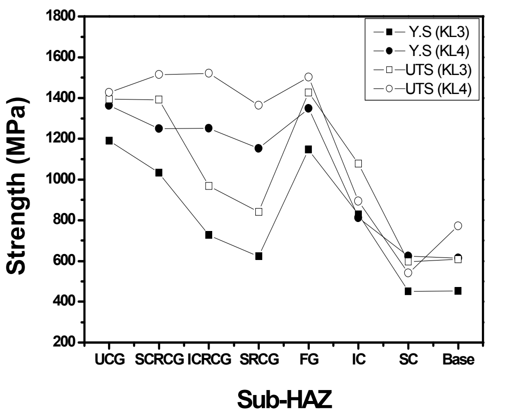

Fig.1 Yield and tensile strength of simulated HAZ (KL3, KL4)

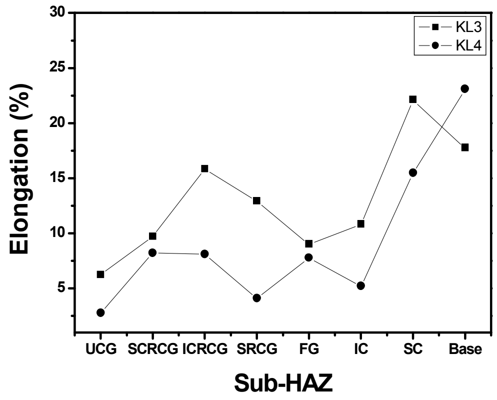

Fig.2 Elongation results of simulated HAZ.

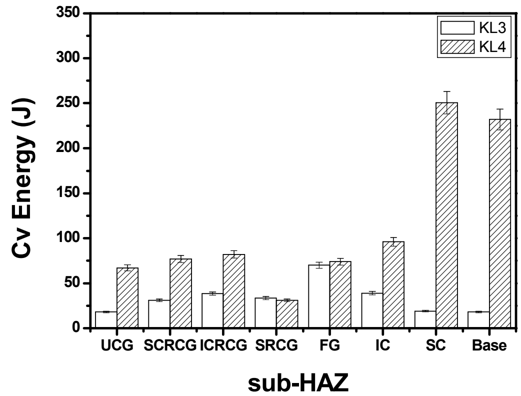

Fig.4 Charpy impact test results of various sub-HAZ at -29℃

the same as microstructure of the base metal.

In the base metal, KL4 showed much better toughness properties than KL3. In base metal, Upper shelf energy(USE) of KL3, KL4 were 184J and 252J, and Index temperature T_{41J} of KL3 and KL4 were 1.1, -151.7 respectively. The improvement of a ductile-brittle transition temperature and tensile properties was taken by changing upper bainite microstructure into martensite which has superior fracture toughness due to increase of Ni and Cr contents.

The Charpy impact test results of various sub-HAZ at -29℃ were shown in fig. 4. The Charpy energy of samples from KL4 were much higher than that of KL3, expect in the SRCGHAZ. Next programs to investigate PWHT are underway.

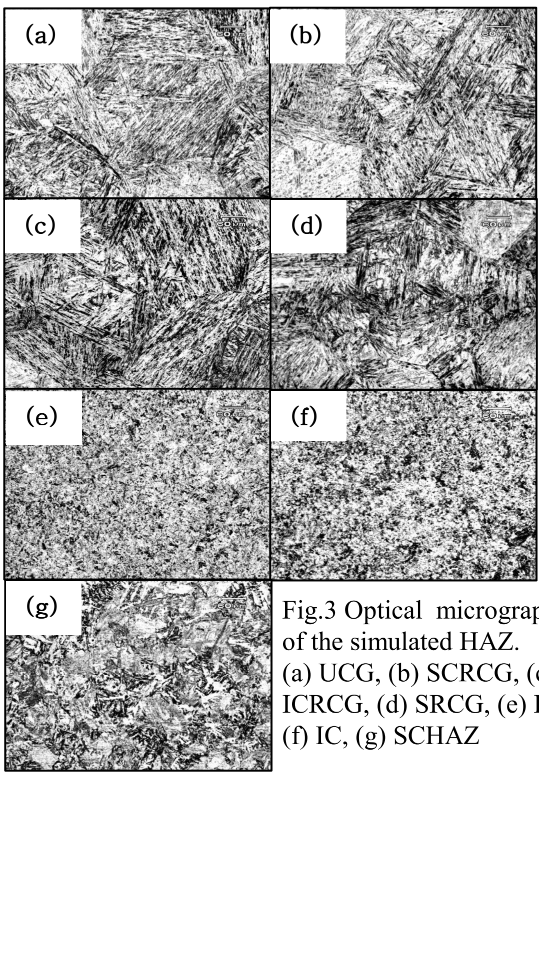

Fig.3 Optical micrographs of the simulated HAZ.
(a) UCG, (b) SCRCG, (c) ICRCG, (d) SRCG, (e) FG, (f) IC, (g) SCHAZ

4. Summary

In base metal, KL3 steel shows the upper bainite microstructure and KL4 steel shows the mixture of tempered martensite and lower bainite. The improvement of a toughness and tensile properties was taken by changing upper bainite into martensite which has superior fracture toughness due to increase of Ni and Cr contents. In various sub-HAZ, four region of CGHAZ contain lots of martensite while FG, IC, SCHAZ shows similar microstuctures to the base metal. Tensile strength and Charpy impact toughness KL4 were higher than those of KL3. The effects of PWHT are underway.

Acknowledgement

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REFERENCES

[1] B.C.KIM, S.LEE, Metall. Trans. A, Vol.22A, 1991, 139

[2] A.Moitra,, P.Parameswaran, Mater. Charcter, Vol.48, 2002, 55-61

[3] C.L.DAVIS, J.E.KING, Metall. Trans. A, Vol.25A, 1994, 563

[4]SANGHO KIM, YOUNG ROC IM, Metall. Trans. A, Vol.32A, 2001, 903

[5] SUNGHAK LEE, BYUNG CHUN KIM, Metall. Trans. A, Vol.23A, 1992, 2803

[6] E23-05 Standard Test Methods for Notched Bar Impact Testing of Metallic Materials. ASTM Standard, 2005