Evaluation of the Microstructure and Mechanical Properties in SA508 Gr. 4N Low Alloy Steel with a Nickel and Chromium Contents Variation

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1. Introduction

Low carbon low alloy steels, used as nuclear pressure vessels, steam generators and so on, hold a large portion of materials for nuclear power plants, and they are very important materials since they determine the safety and the life span of nuclear power plants. In addition, they are utilized for a long period under very severe conditions such as a high pressure, high temperature, neutron irradiation and corrosion, so they need a good combination of strength and toughness, a good weldability and an excellent neutron irradiation resistance and so on. SA508 Gr.3 low alloy steel shows the upper bainite microstructure, which is a less tough, so the steel is more difficult to obtain good toughness than to have good strength. And then, if a loss of toughness due to a neutron irradiation during a service is considered, improving the toughness is very important when a pressure vessel is fabricated.

It is known that a higher strength and fracture toughness of low alloy steels could be achieved by increasing the Ni and Cr contents. In this study, we have performed a mechanical test based on the microstructure of SA508 Gr.4N low alloy steel which has higher Ni and Cr contents than SA508 Gr.3 low alloy steel. Based on the microstructure/mechanical property relations obtained from literature research experimental works on SA508 Gr.4N steels, and by observing the micro-structural changes with alloying elements (such as Ni, Cr) after a tempering process of the steel with a mechanical test, fundamental information for an alloy design have been discussed.

2. Experimental Procedure

The chemical compositions of the steels used in this study are given in Table 1. A model alloy with a typical composition of the SA508 Gr. 4N steel was prepared as a nominal alloy (within ASME specified composition). It was intended to increase or decrease the hardenability of SA508 Gr. 4N, by changing the nickel content. It was also intended to make the cementite precipitates become substituted by $M_{23}C_6$ type carbides by increasing the chromium content. Base metal was austenitized at 880℃ for 2 hours followed by an air cooling, and then tempered at 660℃ for 10 hours

Microstructure observations at a low magnification were conducted using optical microscopes and scanning electron microscopy (SEM). Metallographic specimens for these observations were prepared by a grinding and polishing up to 0.25 μm powder then etched in 3% Nital. To investigate overall distribution of carbides and to analyze individual carbide particles in detail, carbon extraction replica technique had been employed. Carbon extraction replicas were examined using JEM-2000FX2 transmission electron microscope.

Tensile properties of a alloys were evaluated using MTS universal static testing machine. Yield strength was determined by 0.2% strain offset stress, or by lower yield stress. Impact transition curves were obtained using standard Charpy V-notched specimens. Impact tests were conducted using SATEC-S1 impact test machine with maximum capacity of 406J in a temperature range of -196℃ to 100℃. The index temperatures were determined from fitted Charpy curves as the temperature corresponding to the charpy energy value of 48J and 68J.

Table 1. Chemical compositions of steels. (wt%)

	C	Mn	Ni	Cr	Mo
Steel 1	0.2	0.3	2.5	1.8	0.5
Steel 2	0.2	0.3	4.5	1.8	0.5
Steel 3	0.2	0.3	3.5	1.0	0.5
Steel 4	0.2	0.3	3.5	2.5	0.5

3. Experimental Results and Discussion

Microstructural features of the steels are presented in Fig. 1. All the steels were presented as tempered martensite structure which is a typical microstructure of SA508 Gr.4N low alloy steel. By comparing steel 1 and steel 2, it is seen that steel 2 (4.5wt% Ni) has much finer

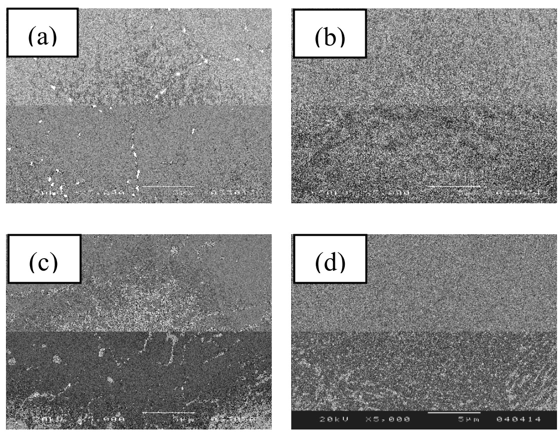

Fig. 1 Microstructure of the specimens (SEM)
(a) steel 1, (b) steel 2, (c) steel 3 and (d) steel 4.

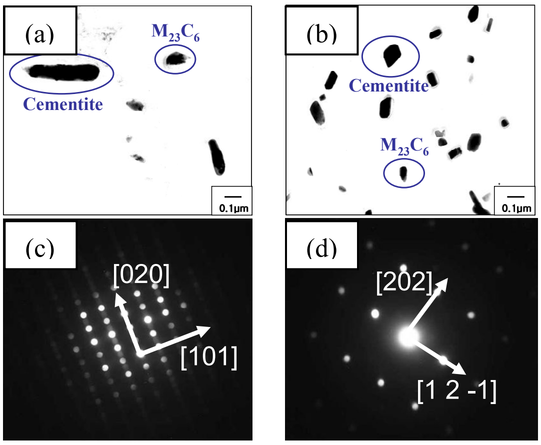

Fig.2 Carbide distribution of steel 3 and steel 4. (a) steel 3, (b) steel 4, (c) cementite D.P. and (d) $M_{23}C_6$ D.P.

structure than steel 1 (2.5wt% Ni), while the structure was less changed with the chromium contents. Fig. 2 shows the examination of the carbon extraction replicas when presence of different carbide morphologies. It is seen that when tempered at 660℃ the small carbides such as $M_{23}C_6$ in steel 4 are homogeneously precipitated while those in steel 3 are less homogeneously precipitated.

Fig. 3 shows the tensile test results of steel 1, 2 and steel 3, 4, respectively. In these results, the strength of the alloy is increased with the nickel contents. In general, it is known that nickel makes a solid solution with a ferrite single phase and brings about a solid solution hardening effect in a steel. Thus the increased strength of a higher nickel alloy steel is caused by solid solution hardening effect[1]. On the other hand, there are no remarkable changes of the yield strength with a chromium contents variation. In the carbon extraction replica observation result, it is clear that the distribution of the carbide precipitate depends on the amount of chromium. However, the tensile test results have shown that the change of the carbide distribution is not affected by the strength of the alloy.

Charpy impact test results are shown in Fig. 4. It is seen that steel 2 shows the lowest transition temperature. In the SEM observation, the grain size of the higher nickel alloy (steel 2) is much finer than the lower nickel

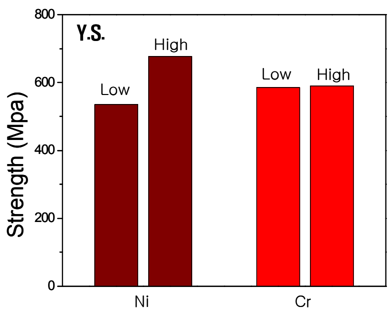

Fig. 3 Tensile properties of steels.

alloy (steel 1). Nickel is also known to be beneficial to a Charpy impact property [2,3]. On the other hand, steel 3 which is a lower chromium alloy shows the highest transition temperature and lowest USE (Upper shelf energy). This result might be caused by a difference of the carbide distribution. In the low chromium alloy, relatively large carbide such as cementite is observed in the transmission electron microscope image. These carbides could affect a decrease of the Charpy impact property[4].

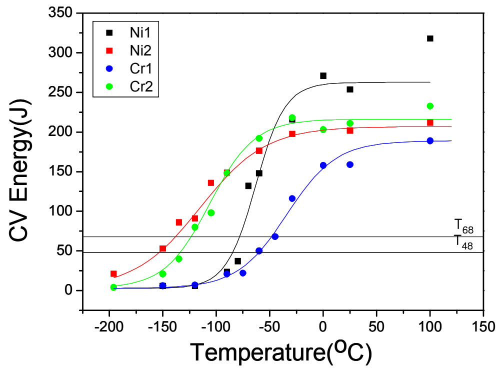

Fig. 4 Charpy transition curves of steels.

4. Summary

In this study, microstructure observation and mechanical tests were performed on SA508 Gr.4N low alloy steel with different nickel and chromium contents. From the mechanical test result, a high nickel (4.5wt %) content steel shows both the highest tensile strength and best Charpy impact property. This result is caused by a solid solution hardening effect and a fine microstructure. The carbide distribution is changed by changing the chromium contents. Also, in the low chromium steel, relatively large carbide is observed in a transmission electron microscope, which brings about a drop of the charpy impact property of SA508 Gr.4N low alloy steel.

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