Transactions of the Korean Nuclear Society Spring Meeting
Gyeongju, Korea, May 29-30, 2008

Effects of the Chromium and Molybdenum on Precipitation behavior and Mechanical Properties in SA508 Gr. 4N Low Alloy Steel

Sang Gyu Park[a], Min Chul Kim[b], Bong Sang Lee[b], Dang Moon Wee[a]
*a KAIST, Advanced High Temperature Materials Lab., Guseoung-dong, Yuseong-gu,Daejeon, 305-701, Korea**
b KAERI, Nuclear Materials Research Center., 150 Deogjin-dong, Yuseong-gu, Daejeon, 305-353, Korea
sg121243 @ naver.com

1. Introduction

Low carbon low alloy steels, applied as nuclear pressure vessels, steam generators and so on, hold a great part of materials for nuclear power plants, and they are very important materials because they determine the safety and the life span of nuclear power plants. In addition, they are used for a long period under extremely severe conditions such as a high pressure, high temperature, neutron irradiation and corrosion, so they require a good combination of strength and toughness, a superior weldability and an good neutron irradiation resistance and so on[1]. SA508 Gr.3 low alloy steel reveals the upper bainite microstructure, which is a fewer tough, so the steel is more difficult to acquire good toughness than to have high strength. And then, if a loss of toughness due to a neutron irradiation during a operation is considered, improving the toughness is very important when a pressure vessel is manufactured.

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 microstructure observation and mechanical test 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 precipitation behavior changes with alloying elements (such as Cr, Mo) after a tempering process of the steel with a mechanical test, fundamental information for an alloy design have been discussed.

2. Experimental Procedure

Five types of pressure vessel steels with different alloying elements were selected for this study. The chemical compositions of the steels are given in Table 1. A model alloy with a typical composition of the SA508 Gr. 4N steel was arranged as a reference alloy (within ASME specified composition). It was planned to alter the coarse cementite into the fine needle type carbide M_2C of SA508 Gr. 4N, by changing the molybdenum content[2]. It was also intended to compose the cementite precipitates become substituted by $M_{23}C_6$ type carbides by increasing the chromium content. Model alloys were austenitized at 880℃ for 2 hours followed by an air cooling, and then tempered at 660℃ for 10 hours.

The observations of the precipitates were conducted using transmission electron microscope (TEM). Metallographic specimens for these observations were prepared by a grinding and polishing up to 0.25 μm thin foil then jet thinned in 10% perchloric acid at -40℃. 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 and 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
KL4-Cr1	0.2	0.3	3.5	1.0	0.5
KL4-Cr2	0.2	0.3	3.5	2.5	0.5
KL4-Mo1	0.2	0.3	3.5	1.8	0.1
KL4-Mo2	0.2	0.3	3.5	1.8	1.0
KL4-Ref	0.2	0.3	3.5	1.8	0.5

3. Experimental Results and Discussion

Fig. 1 shows the distribution of the precipitates in thin foil specimens with a Cr contents variation. Relatively

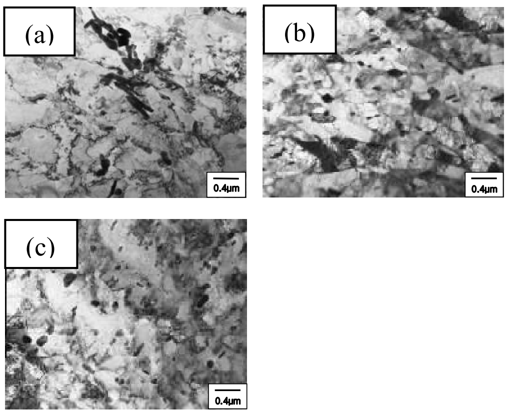

Fig. 1 TEM images of (a) KL4-Cr1, (b) KL4-Ref. and (c) KL4-Cr2.

coarse carbides were observed in the KL4-Cr1(1.0wt% Cr) and they were not distributed evenly, while small carbides were distributed homogeneously in KL4-Ref(1.8wt% Cr) and KL4-Cr2(2.5wt% Cr).

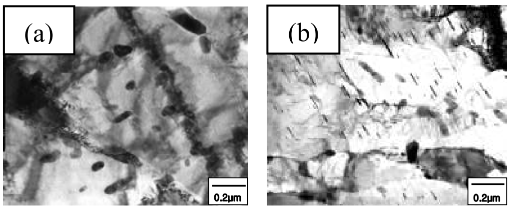

Fig. 2 TEM images of (a) KL4-Mo1, (b) KL4-Mo2.

Fig. 2 shows the distribution of the precipitates in the thin foil specimens of KL4-Mo1(0.1wt% Mo) and KL4-Mo2 (1.0wt% Mo). KL4-Mo1(0.1wt% Mo) showed a similar precipitation behavior to KL4-Ref (0.5wt% Mo). However, fine needle type carbides are observed in KL4-Mo2(1.0wt% Mo). Based on the diffraction pattern from TEM observationand prior research work[3], this type of precipitate with an HCP structure is M_2C, which is molybdenum carbide observed in a commercial nuclear pressure vessel steel.

Fig. 3 shows the tensile test results of the model alloys. In the case of the Mo addition, the strength was increased with an increase of the Mo content due to the solid solution hardening effect and precipitation of M_2C. On the contrary, there are no significant changes of the yield strength with a different chromium contents. In the thin foil observation result, it is clear that the carbide precipitate distribution depends on the amount of chromium. However, the tensile test results shows that the change of the chromium carbide distribution is not affected by the strength of the alloy.

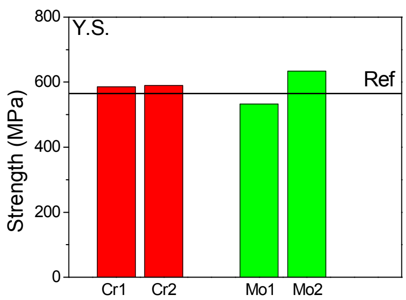

Fig. 3 Tensile properties of steels.

Fig. 4 shows the Charpy impact test results. It is seen that KL4-Cr1 shows the highest transition temperature and lowest Charpy energy. On the contrary, Charpy impact property of the KL4-Cr2(2.5wt% Cr) was improved when compared with KL4-Ref(1.8wt% Cr). This result might be caused by a difference of the carbide distribution behavior. In the low chromium alloy, relatively large carbides are observed in the TEM image. These chromium carbides could affect a

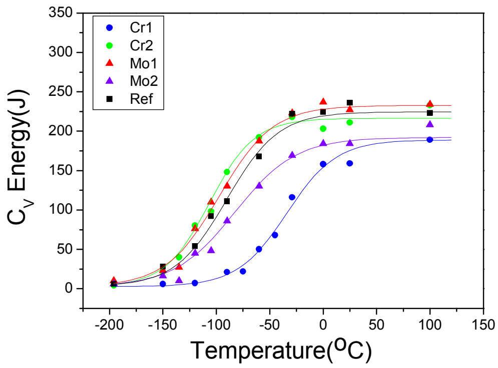

Fig. 4 Charpy transition curves of steels.

deteriortion of the Charpy impact property[4]. In the case of the model alloys with different molybdenum contents are also shown in Fig. 4. Charpy impact properties of KL4-Mo1 and KL4-Ref are similar, which revealed the similar carbide distribution. On the other hand, in the case of the KL4-Mo2, USE(Upper Shelf Energy) was decreased due to the strengthening effect of the M_2C precipitate.

4. Summary

In this study, evaluation of the precipitation behavior and mechanical properties were performed on SA508 Gr.4N low alloy steel with different chromium and molybdenum contents. The carbide distribution is changed by varying the chromium contents. Also, in the KL4-Cr1, relatively large carbide is observed which causes a drop of the charpy impact property of SA508 Gr.4N low alloy steel. In the case of the alloys with different molybdenum contents, KL4-Mo2(1.0wt% Mo) shows the highest tensile strength. This result is caused by a precipitation of the needle type molybdenum carbide M_2C.

Acknowledgement

This study is carried out under the Nuclear R&D program by the Ministry of Knowledge Economy in Korea.

REFERENCES

[1] Young-Roc Im, Yong Jun Oh, Journal of nuclear materials 297 (2001) 138-148
[2] Dieter, GE, Mechanical Metallurgy. McGraw-Hill.
[3] L.A. Norstrom, O. Vingsbo, Met. Sci. 13 (1979) 677.
[4] X.Z. Zhang and J.F. Knott, Acta Mater., 47 (1999) 3483