Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, November 2-3, 2006

Microstructural Changes in SA508 Gr.4N Pressure Vessel Steel with Heat Treatment Conditions

Joung Lim Ko[a], Min Chul Kim[a], Bong Sang Lee[a], Gil Moo Kim[b]
[a] *KAERI, Nuclear Material Technology Div., 150 Deogjin-dong, Yuseong-gu, Daejeon, 305-353, jlko@kaeri.re.kr*
[b] *ChungNam National University Material Engineering department, 220 Gung-dong, Yuseong-gu, Daejeon, 305-764*

1. Introduction

Low carbon low alloy steels, are used for nuclear reactor pressure vessels, which determine the safety and the life span of nuclear power plant. In addition, they are utilized for long period under very severe conditions such as high pressure, high temperature, and neutron irradiation and corrosion, so that they are requested high strength and toughness, weldability, neutron irradiation resistance. These mechanical properties can be affected by grain size and carbide precipitation behavior that depend on chemical composition and heat treatment condition. It is well known that SA508 Gr.4N steel with higher Ni and Cr contents has excellent mechanical properties due to its enhanced hardenability. However more verification is needed, in order to use for the nuclear plant.

This study was initiated to evaluate the effects of metallurgical variables on mechanical properties of SA508 Gr.4N steel as a candidate for the advanced RPV materials. In order to control grain size and carbide morphology, austenitizing and tempering condition were changed. Also SA508 Gr.3 steel was used to compare microstructure and mechanical properties to those of SA508 Gr.4N steel.

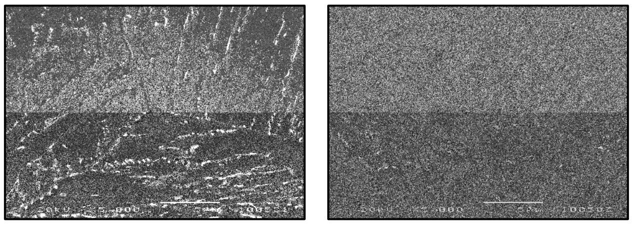
2. Experimental Procedure

The chemical composition of the test specimen is shown in Table 1. The typical heat treatment of the steel includes normalizing at 1200℃, and austenitizing from 810℃ to 880℃ for 2 hours, followed by air cooling. Subsequent tempering treatment carried out during 6 hours at 660℃. For the investigation of carbide precipitation behavior, specimens were tempered during 1 hour, 20 hours, and 50 hours at 660℃ after austenitizing for 2 hours at 860℃, respectively. Microstructural observations at low magnification were conducted using optical and JSM-6300 scanning electron microscopes. Grain size was measured in accordance to ASTM E112. To investigate overall distribution of carbide and to analyze individual carbide particles in detail, carbon extraction replica technique was used. Carbon extraction replica was examined by using JEM-2000FX transmission electron microscope.

Mechanical properties were evaluated by tensile test and Charpy impact test from various heat treated specimens.

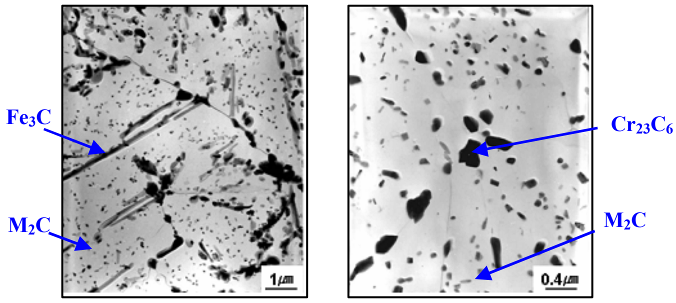
Table 1. Chemical composition of the test specimen

Chemical composition (wt%)					
C	Ni	Cr	Mo	Mn	Fe
0.21	3.6	1.8	0.5	0.3	Bal.



(a) (b)

Figure 1. SEM micrographs of (a) upper bainite microstructure of SA508 Gr.3 steel, (b) the mixture of lower bainite and martensite in SA508 Gr.4N steel.



(a) (b)

Figure 2. TEM micrographs of (a) Fe_3C and M_2C in SA508 Gr.3 steel, (b) Fe_3C, $Cr_{23}C_6$, and M_2C in SA508 Gr.4N steel

3. Experimental Results

SA508 Gr.4N steel shows a mixed microstructure of lower bainite and martensite, because of its higher hardenability by increasing Ni and Cr contents as shown in Fig. 1. It was found that toughness and strength of SA508 Gr.4N steel are higher than those of SA508 Gr.3 steel in our previous work. Coarse cementites existing in lath boundary and grain boundary of SA508 Gr.3 steel were substituted to $M_{23}C_6$ carbide, fine cementite and M_2C carbide as shown in Fig. 2.

We have examined the change of microstructure according to austenitizing temperature. Fig. 3 shows optical micrographs of the specimen with three different austenitizing condition. Austenitizing was done at 840℃, 860℃, and 880℃ for 2 hours. Table 2 shows the grain size measured from the specimens with three different austenitizing temperatures. As the austenitizing temperature decreased, microstructure had a tendency to become finer. Austenite grain sizes were 7.8 ㎛, 16.8 ㎛, and 21 ㎛ after different austenitizing treatment, respectively, as indicated in Table 2.

Precipitation behavior according to the tempering condition was also examined. After austenitizing during 2 hours at 860℃, test blocks were tempered for 1 hour, 20 hours, and 50 hours at 660℃. It was found that changes in tempering condition affect the type of carbide formation, the size, distribution, and chemical composition of the carbides. Fig. 4 shows the SEM micrographs of the specimen with different tempering conditions. According to the increase of tempering time, the sizes of carbides on the grain boundary and the lath boundary were increased.

Detailed TEM analysis and mechanical test results on the heat-treated specimens are under investigation.

Table 2. Grain size of the test specimens with the different austenitizing temperature.

Austenitization condition			
Temperature	840℃	860℃	880℃
Grain size	7.8 ㎛	16.8 ㎛	21 ㎛

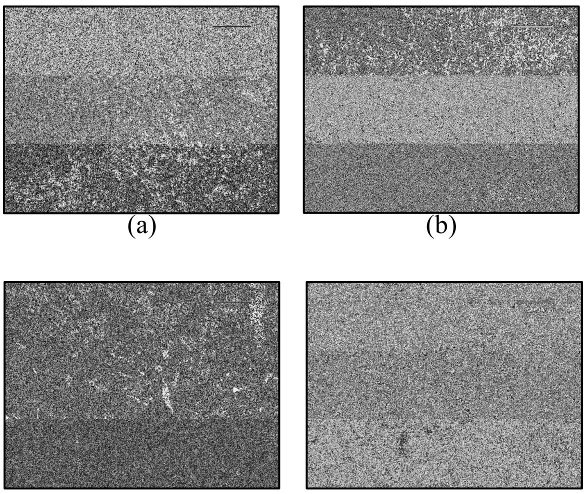


Figure 3. Optical micrographs of SA508 Gr.4N steel by austenitizing heat treatment at (a) 810℃, (b) 840℃, (c) 860℃, and (d) 880℃

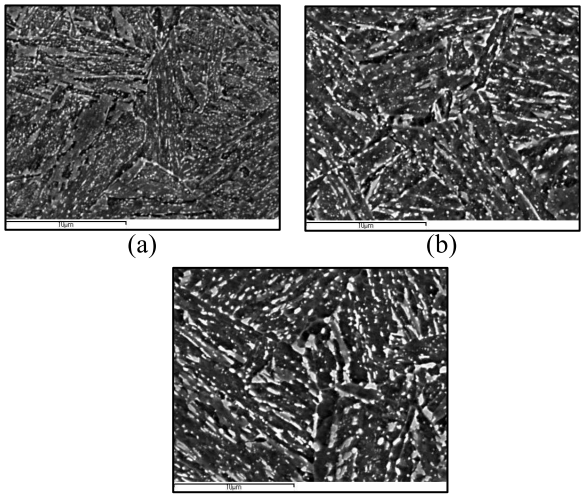


Figure 4. SEM micrographs of SA508 Gr.4N steel with different tempering time at 660℃ (a) 1 hour, (b) 20 hours, (c) 50 hours. All specimens were austenitized at 860℃ for 2 hours.

4. Summary

SA508 Gr.4N steel samples with different grain size and carbide morphology were prepared to investigated the effects of microstructural variables on the mechanical properties. Grain size and carbide morphology were controlled by changing austenitizing and tempering condition. As the austenitizing temperature increased, grain size was increased from 7.8 to 21 ㎛. Carbide sizes on the grain boundary and lath boundary become coarse with increase of tempering time. TEM analysis and mechanical test are currently being carried out.

Acknowledgement

This study is carried out under the Nuclear R&D program by the Ministry of Science and Technology in Korea.

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