Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 23-24, 2019

Changes in Microstructure and Mechanical Properties of SA508 Gr.1A Low Alloy Steels with Variation of Cooling Rate

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1. Introduction

A series of studies are underway to apply the Leak Before Break (LBB) concept, which was applied in the piping of the primary system of the nuclear power plant, to the main steam line of the secondary system. The LBB concept is a method to improve the safety of piping by detecting the leakage that occurs before the piping breaks, thereby preventing extreme situations such as instantaneous breakage of the piping and taking preemptive measures. The LBB safety margin can be obtained by reinforcing the leakage detection facility of the piping or by improving the strength and fracture resistance of the piping material. However, in order to improve the safety of the piping, it is necessary to use a material having excellent strength and fracture resistance. Therefore, it is considered to replace the existing SA106 Gr.C steel with the SA508 Gr.1A low alloy steel for the main steam piping of the new standard nuclear power plant.

In this study, the effects of microstructure on mechanical properties of SA508 Gr.1A low alloy steel were evaluated. Test specimens having different microstructures were prepared by varying the cooling rate after the austenitizing treatment in the heat treatment process of SA508 Gr.1A low alloy steel. Mechanical properties were evaluated by tensile, CVN impact and J-R fracture resistance tests. In order to evaluate the microstructural factors affecting fracture resistance, fracture surface of tested specimen was analyzed by SEM and EBSD analysis. Based on these results, we considered the material improvement method to improve the safety margin of LBB of SA508 Gr.1A low alloy steel pipe.

2. Experimental Procedure

The tested material was an archive material of SA 508 Gr.1A low alloy steel. The chemical compositions provided by manufacturer are shown in Table 1. The sample blocks in the as received condition were austenitized at 880°C for 2h followed by a cooling in iced water (designated by “WQ”), forced air (designated by “AQ”), and air (designated by “AC”) to induce various cooling rates; they were then tempered at 655°C for 7h.

Samples were polished and etched with a 2% nital solution, and the microstructures were observed using an optical microscope (OM; model, eclipse MA 200, Nikon, Japan) and a scanning electron microscope (SEM; model, JEOL-6300, JEOL, Japan).

Round bar-type tensile specimens (gauge length 25 mm, diameter 6.25 mm) were tested at room temperature using a universal testing machine (model MTS 810, MTS, USA) with a 10-ton capacity under a strain rate of 5.2×10-4, according to ASTM E8M[1]. The 0.2% offset stress method was used to determine the yield strength from the engineering stress-strain curves. Charpy impact tests were performed on standard Charpy V notch specimens (standard size; 10 mm × 10 mm × 55 mm, using an impact test machine with a 500 J capacity in the temperature range from -150 °C to 150 °C, according to ASTM E23 [2]. The J-integral resistance (J-R) tests were carried out using compact tension (CT) specimens with 1T (25.4mm). The specimens were pre-cracked and then side grooved to a total thickness of 20%. The J-R tests were performed using an unloading compliance method with a loading rate of 0.3 mm/min at 286°C according to ASTM E1820 [3].

Table 1. Chemical compositions of SA508 Gr.1A low ally steel used in this study

C	Si	Mn	Ni	Cr	Mo	Cu	Al	Fe
0.21	0.25	1.22	0.25	0.16	0.07	0.05	0.02	Bal.

3. Results

3.1 Microstructure

Figure 1 shows the changes in microstructure with cooling rate. The AQ specimen showed microstructure containing ferrite, perlite and bainite. As compared with the as-received state, the phase change due to the heat treatment was not large. The AC specimen, which had a slower cooling rate than AQ, showed a microstructure consisting of ferrite-pearlite and a larger grain size than the AQ specimen. However, it has a finer grain size than the as-received state. WQ specimens with very fast cooling rates showed tempered martensite microstructure.

3.2 Mechanical Properties

Table 2 shows the tensile properties at room temperature of AC, AQ and WQ specimens. At room temperature, the yield strength and tensile strength increased with increasing cooling rate, but the elongation tended to decrease. These results are attributed to the formation of low temperature transformation phase and grain refinement with increasing cooling rate. The AQ specimen, which is most similar to the cooling rate of as-received sample, showed higher strength and elongation than the as-received sample.

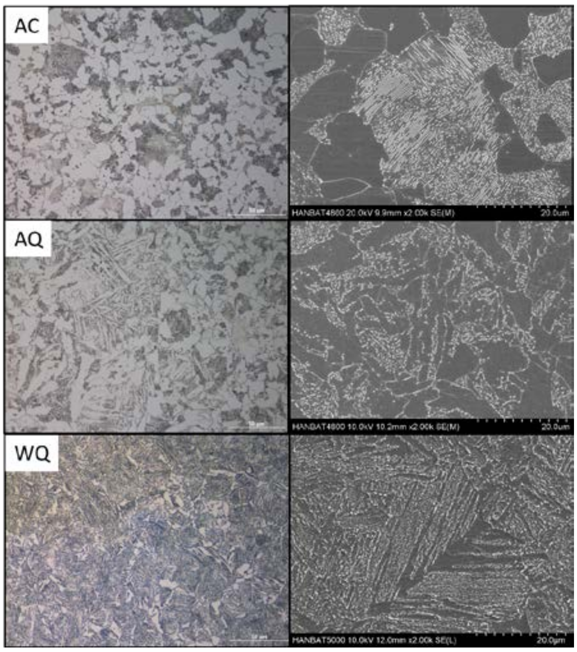

Figure 1. OM and SEM images of samples according to the cooling rates

Table 2. Tensile properties of samples according to the cooling rates.

	YS(MPa)	TS(MPa)	T. El.(%)
AC	325	520	36.3
AQ	359	532	35
WQ	472	609	31

The impact transient curves of the three samples are shown in figure 2. The upper-shelf energy showed no specific trend according to the cooling rate. However, as the cooling rate is increased, the transition temperature is lowered. In particular, the transition characteristics of WQ specimens with a very high cooling rate are greatly improved. In our previous research on SA508 Gr.3 and Gr.4N low alloy steels, similar results were obtained according to the cooling rate[4,5]. In J-R test, crack propagation resistance was improved with higher cooling rate, and WQ specimen with the highest cooling rate showed the best J-R characteristic.

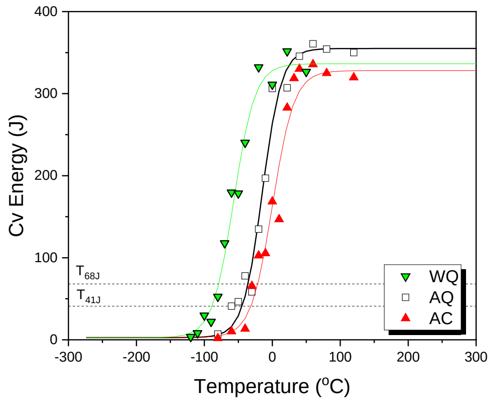

Figure 2. Charpy impact properties of samples according to the cooling rates.

4. Summary

The effects of microstructure on mechanical properties of SA508 Gr.1A low alloy steel were evaluated in this study. Test specimens having different microstructures were prepared by varying the cooling rate after the austenitizing treatment in the heat treatment process of SA508 Gr.1A low alloy steel. It was confirmed that as the cooling rate increases, fine microstructure is formed, and tensile characteristics, impact transition characteristics, and crack propagation resistance are improved. Therefore, it is considered that it is advantageous to maintain the cooling rate after the austenitizing heat treatment as fast as possible in terms of the mechanical properties.

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