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

Effects of Austenite grain size on Tensile and Charpy Impact Properties in SA508 Gr.1A Low Alloy Steel

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1. Introduction

As safety issues becomes most important in nuclear power plant operation, efforts for applying the leak before break (LBB) concept to the main steam line (MSL) piping in secondary system in nuclear power plant are being made [1]. LBB safety margin is dependent on the mechanical properties (yield strength and toughness) and leak detection facilities. To increase LBB safety margin, increase of yield strength and toughness of MSL piping material is needed. SA106 Gr.C steel was used for MSL piping material in previous Korea standard nuclear power plant (KSNPP). In new KSNPP, SA508 Gr.1A steel is being considered as MSL piping material, and new alloy design and heat treatment conditions of SA508 Gr.1A steel is being developed to improve strength and toughness. Grain size is known to be one of important factor affecting the strength and toughness [2]. In particularly, as prior austenite grain size affects the formation of microstructure, final grain size, and mechanical properties, prior austenite size effects should be studied to improve the mechanical properties [3]. Therefore, in this study, effects of prior austenite grain size on formation of microstructure and mechanical properties of newly developed SA508 Gr.1A were analyzed.

2. Experimental Procedures

2.1 Materials

In this study, improved SA508 Gr.1A prototype steel manufactured by Doosan Heavy Industries was used. Test samples with size of 140mm×140mm×30mm (Length, width and thickness) were taken from the prototype steel pipe line with size of Φ832.6/ Φ696.6 × 6,850 mm as shown in figure 1(a). Actual heat treatment of prototype pipe line steel are composed of austenitizing, quenching, and tempering. Since the size of samples is much smaller than actual piping, it is important to modify the cooling rate during quenching process. To modify the cooling rate during quenching in actual process, air quenching (AQ) process, cooling by blowing the strong wind at upside and down side, is devised. To generate austenite with different grain sizes on SA508 Gr.1A, austenitizing treatment was performed at the different temperature of 880 °C, 960 °C, 1000 °C for 2 hr, and cooled by AQ. Then, the tempering treatment was carried out at same condition. For convenience, these samples are referred to as SS (880 °C), SM (960 °C), SL (1000 °C).

2.2 Microstructure analysis

The longitudinal-short transverse (L-S) planes of the steel were polished and etched with a 3% nital solution, and the microstructures were investigated by an optical microscope (OM; model, eclipse MA 200, Nikon, Japan) and scanning electron microscope (SEM; model, JEOL-6300, JEOL, Japan).

2.3 Mechanical testing

Round bar-type tensile specimens (gauge length 25 mm, diameter 6.25 mm) were prepared in the transverse direction and were tested at room temperature and 286℃ using a universal testing machine with a 10-ton capacity under a strain rate of 5.2×10^{-4}, according to ASTM E8M [4]. The yield strength was determined by a 0.2% strain offset stress. Charpy impact tests were performed on standard Charpy V-notch specimens (standard size; 10 mm × 10 mm × 55 mm, transverse-longitudinal (T-L) orientation) using an impact test machine with a 500 J capacity in the temperature range from -100 °C to 100 °C, according to ASTM E23 [5]. Hyperbolic tangent curve fitting was done for the absorbed impact energy data to obtain the characteristic temperatures [6].

Figure 1. (a) Prototype pipe line steel

Figure 1. (b) Modified cooling method (Air Quenching, AQ)

3. Results and Discussion

3.1 Microstructure

OM and SEM images of the microstructure of the tested materials are shown in Fig. 2. The microstructures is a composite structure of tempered bainite (B) and ferrite (F). By increasing the austenitizing temperature, microstructures consisted mainly of tempered bainite.

3.2 Mechanical properties

Fig. 3 and Table. 1 show the tensile results of three specimens at room temperature and 286 °C. The SL specimen shows the best strengths. The yield strengths at room temperature were 457 MPa (SS), 463 MPa (SM) and 473 MPa (SL). Ultimate tensile strength also tend to increase with increasing the austenitizing temperature. On the other hand, elongations decreased. Samples were composed of tempered bainite and ferrite. At the SL specimen, tempered bainite was mainly observed.

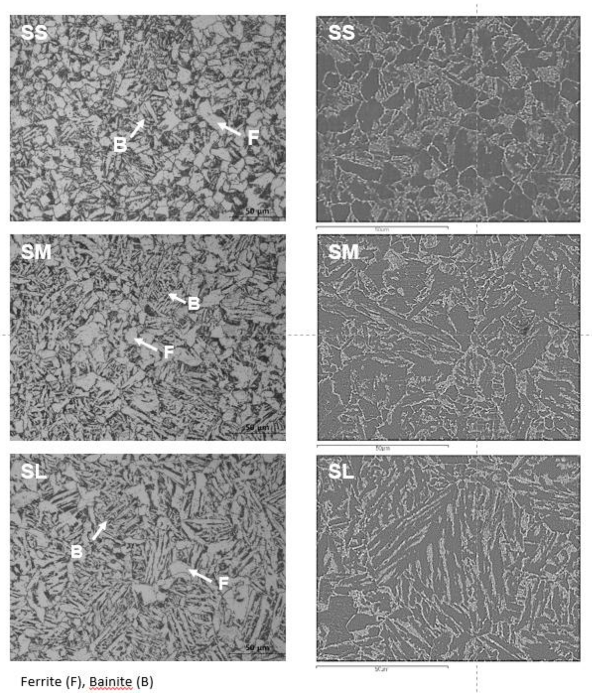

Figure 2. Microstructure of SA508 Gr.1A: SS, SM, SL

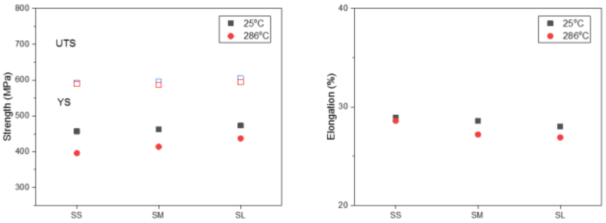

Figure 3. Tensile Properties of SS, SM, and SL

Table 1. Tensile test results of SA508 Gr.1A

ID	RT				286 °C				Remark
	YS (MPa)	TS (MPa)	U.El (%)	T.El (%)	YS (MPa)	TS (MPa)	U.El (%)	T.El (%)	
SS	457	593	11.8	28.9	396	589	12.4	28.6	880°C
SM	463	596	10.9	28.6	414	586	10.9	27.2	960°C
SL	473	605	10.4	28	437	594	10.3	26.9	1000°C

Charpy Impact properties are summarized in Table 2. The Upper Shelf Energy (USE) decreased as the austenitizing temperature increased. The Ductile-Brittle Transition Temperature (DBTT) of SM, SL specimens worse than that of SS specimen.

Table 2. Charpy impact test results of SA508 Gr.1A

ID	USE (J)	T_{41J} (°C)	T_{68J} (°C)	DBTT (°C)
SS	340	-74.5	-60.9	-30.1
SM	327	-67.7	-49.9	-11.1
SL	281	-70.4	-54.0	-24.2

4. Conclusions

In this study, effects of austenitizing temperature on mechanical properties of prototype SA508 Gr.1A steels for MSL piping were analyzed. As the austenitizing temperature increased, the formation of ferrite reduced, grain size increased. In general, it is known that strength increased as grain size decreased according to the Hall-Petch relationship. However in this study, yield strength and tensile strength increased as austenitizing temperature increased. It might be related with the reduction of soft ferrite phase. However, USE decreased and DBTT increased as austenitizing temperature increased owing to the coarse grain size.

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