Variation of Microstructure and Transition Behavior along Thickness Direction in SA533 B1 Reactor Pressure Vessel Steel

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1. Introduction

SA508 Gr.3 Cl.1 Mn-Mo-Ni low alloy steels, a forging steel, were used for reactor pressure vessels of Korea Standard Nuclear Power Plant(KSNP). However, SA533 Type B Cl.1 Mn-Mo-Ni low alloy steels were used for the reactor pressure vessel from Kori-2 to Hanbit-2, Westinghouse-type nuclear power plants in Korea, which are plate type materials. Therefore, unlike the KSNP, there exist axial welds as well as circumferential welds in the reactor pressure vessel. Compared to SA508 low alloy steel, SA533 B1 low alloy steel shows distinct anisotropy with different mechanical properties depending on the direction of specimen.

In general, reactor pressure vessels are more than 200mm thick. When such a thick material is heat-treated, it has different cooling rates in the thickness direction in the quenching process. This difference in cooling rates leads to differences in microstructure, resulting in differences in mechanical properties[1].

This study quantitatively evaluated the distribution of mechanical properties according to the thickness direction of SA533 B1 low alloy steel for reactor vessel and the anisotropy of mechanical properties according to the orientation of specimen.

2. Experimental Procedure

The tested material was an archive material of SA 533 Type B Cl.1 Mn-Mo-Ni low alloy steel. Test specimens were sampled from 1/10T, 1/4T, 1/2T, 3/4T, and 9/10T of the RPV. Test specimens in the L direction were also taken at 1 / 10T and 1 / 4T positions to evaluate anisotropy. The chemical compositions provided by manufacturer are shown in Table 1.

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[2]. 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 (model: SI-1D3, SATEC, USA) with a 406 J capacity in the temperature range from -120 °C to 150 °C, according to ASTM E23 [3].

Table 1. Chemical compositions of RPV steel [12]

C	Mn	P	S	Si	Ni	Cr	Mo	Cu	V
0.19	1.38	0.009	0.006	0.24	0.62		0.52	0.04	<0.008

3. Results

2.1 Microstructure

Figure 1 shows the microstructure along the direction of the specimen at the 1/10T position. On the LS plane of plate steel, a band structure was formed along the rolling direction, but no distinct band structure was observed on the other side. Figure 2 compares the microstructures at different sampling positions in the thickness direction. Overall, it shows a tempered bainite structure, and a bainite structure with finer lath appears at a 1/10T location close to the surface. However, it was difficult to observe the difference in grain size depending on the location.

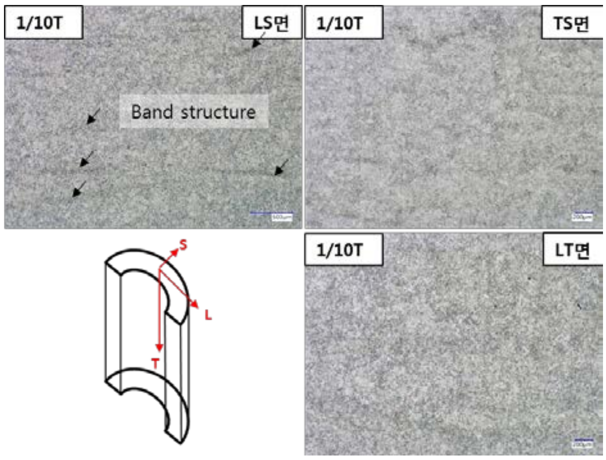

Figure 1. OM images of samples depending on specimen direction

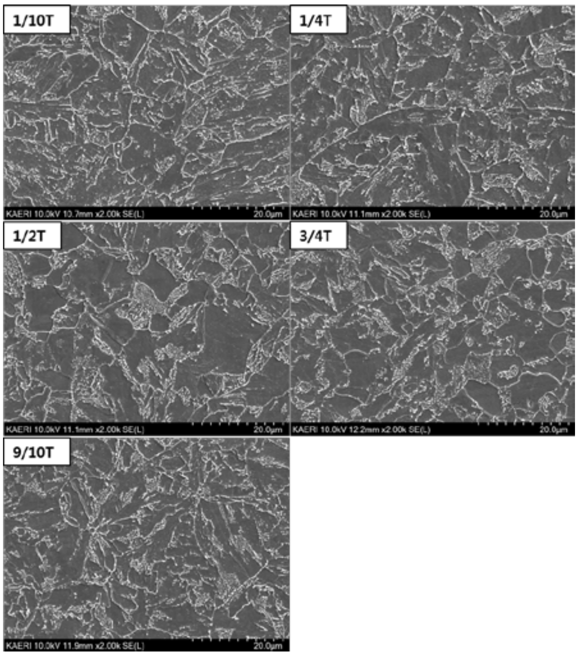

Figure 2. SEM images of SA533 B1 steel according to the sampling depth

2.2 Mechanical Properties

Figure 3 summarizes the tensile properties at room temperature in the thickness direction. It is reported that tensile results obtained from specimens located within the outer one quarter of the thickness are strongly affected by the quenching effect of the steel. Strength properties are increasing in the direction to the surface, while elongation is decreasing[4-6]. However, the difference was not clearly seen in this test, and also the difference in the direction of the specimen was not significant.

Figure 4 shows the Charpy impact transition curves for each position in thickness direction. The transition temperature increased from the surface to the center, and the upper-shelf energy tended to decrease. However, it did not show a complete symmetry trend around 1/2T. 1/10T showed better transition properties than 9/10T. This is thought to be due to the fact that 1/10T has a finer structure than 9/10T as shown in Fig. 2. The

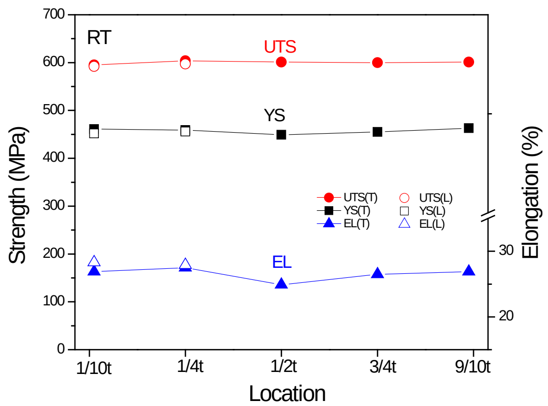

Figure 3. Tensile Properties of SA533 B1 steel according to the sampling depth

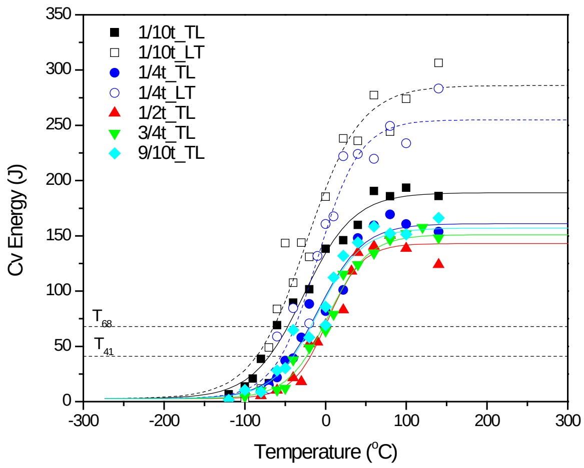

Figure 4. Charpy impact properties of SA533 B1 steel according to the sampling depth

difference in the transition behavior according to the direction of the specimen was obvious, though no significant effect was observed in the tensile properties. As shown in Fig. 4, it is confirmed that the Charpy impact toughness is much better in the L-T direction than in the T-L direction.

4. Summary

SA533 B1 steel shows typical tempered bainite structure. Fine lath bainite structure was formed at surface and coarse lath bainite was formed toward the center. There was no significant difference in tensile properties according to position or orientation. However, in the Charpy impact transition properties, the surface showed better transition properties. Also, the influence of the direction of the specimen was apparent.

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