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Enhancement of LBB Characteristic of Main Steam Line Piping in Korean Nuclear Power Plants by using the improved SA508 Gr.1A steels

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1. Introduction

Much effort has been made to apply the leak before break (LBB) design to the secondary system as well as the primary system in nuclear power plants. The sufficient LBB safety margin are need for applying the LBB design. The LBB safety margin is dependent on the J-R characteristic and yield strength of materials. Therefore, increase in J-R characteristic and yield strength of material is important to increase LBB safety margin. In order to improve the LBB characteristic, SA508 Gr.1A steels are considered instead of the SA106 Gr.C steels currently used in main steam line piping of Korea Standard Nuclear Power Plant (KSNP). Toughness of commercial SA508 Gr.1A steels is better than that of SA106 Gr.C steels. Although the change in MSL piping material from SA106 Gr.C steel to SA508 Gr.1A steel, the sufficient LBB safety margin did not secure. Thus, in this study, new SA508 Gr.1A steel with high strength and toughness was developed by the changes of alloy design and fabrication process. When the developed SA508 Gr.1A steels were used as MSL piping materials in APR+, The LBB safety margin were evaluated.

2. Experiment

In this study, advanced SA508 Gr.1A steels were developed by the changes of alloy design and fabrication process. A schematic image of fabrication process of MSL pipe was shown in figure 1. After the mandrel forging, quenching-tempering heat treatment and mechanical milling were performed. The product image of developed SA508 Gr.1A was shown in figure 2. The size of MSL piping was approximately Φ830 x 6850 mm. Rod-type tensile specimens (gauge length: 25 mm, diameter: 6.25 mm) were prepared in the longitudinal (L) direction for tensile test. Standard 1T-CT (compact tension) specimens with and T-L orientation were prepared for J-R test. A fatigue pre-crack was induced such that the initial crack length was approximately 60% of the specimen width. After pre-cracking, the specimens were side-grooved to a depth of 10% of the specimen thickness on both sides. schematic images of tensile and 1T-CT specimens were shown in Figure 3. Tensile tests were performed at room temperature and 286 °C at a strain rate of 5.2×10^{-4} /s according to ASTM E8/E8M [1]. According to the ASTM E1820-16 [2], J-R tests were conducted using unloading compliance methods at a test rate of 0.5 mm/min at 286 °C. The J–R curve was derived from the load-LLD data.

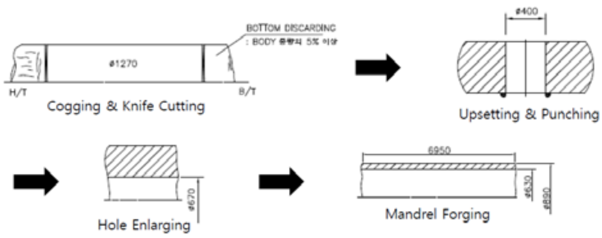
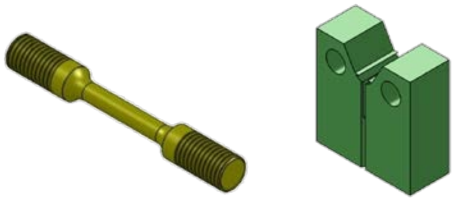


Figure 1. A schematic images of SA508 Gr.1A MSL piping fabrication process.

Figure 2. Image of developed SA508 Gr.1A MSL piping



(a) (b)

Figure 3. Schematic images of (a) tensile and (b) 1T-CT specimens.

3. Results & Discussion

The results of tensile and J-R test of developed SA508 Gr.1A steel at 286 °C were compared with those of commercial SA508 Gr.1A steel as shown in Table 1. Compared with the commercial SA508 Gr.1A steels, the yield strength and tensile strength of developed steel increased by 167MPa and 54MPa, respectively. The J_{IC} increased by 98 kJ/m^2. The developed SA508 Gr.1A steels had better mechanical properties. In particular, yield strength, which affects the LBB safety margin mostly, increased greatly.

Using the mechanical properties of SA508 Gr.1A steels, LBB safety margin were evaluated as shown in Table 2. The geometry and applied load of pipe were the same as those in APR+ [3]. The leakage crack length was calculated using the PICEP (pipe crack evaluation program) [4]. An instability load that unstable crack propagation occurs were calculated using the GE/EPRI equation [5]. The LBB safety margin were 1.273 when commercial SA508 Gr.1A steels was used. When developed SA508 Gr.1A steel was used, the LBB safety margin was 1.528. It is approximately 25% higher LBB safety margin. If the newly developed SA508 Gr.1A steel applied to the MSL piping and other piping in NPP, it is expected that the safety of pipe lines were greatly improved.

Table 1. Results of tensile and J-R test of commercial SA508 Gr.1A steel and developed SA508 Gr.1A steel.

Specimen	Tensile test			J-R test
Material	YS (MPa)	TS (MPa)	El. (%)	J_{IC} (kJ/m^2)
Commercial SA508 Gr.1A	240	510	30.4	528
Developed SA508 Gr.1A	407	564	26.6	626
Amount of Enhancement	+167	+54	-3.8	+98

Table 2. The LBB safety margin of MSL pipe in APR+ when commercial and developed SA508 Gr.1A steels were applied to MSL pipe material.

Material	LBB margin
Commercial SA508 Gr.1A	1.273
Developed SA508 Gr.1A	1.528

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