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Effect of Manufacturing Parameters on the Mechanical Properties of SA508 Gr.a1 LAS Piping Materials

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1. Introduction

SA508 Gr.1a low-alloy steel (LAS) is made by forging followed by heat-treatment [1], and it is known to have good mechanical properties. For this reason, SA508 Gr.1a LAS is used as a reactor coolant piping material of nuclear power plants (NPPs). Recently, also, it is considered as main steam line piping material of APR+ NPP to improve design margin for LBB (Leak-Before-Break) application. Although SA508 Gr.1a LAS has good mechanical properties, the properties are influenced by various manufacturing parameters, such as chemical composition and heat-treatment condition and procedure. Thus, this study conducted tensile and J-R fracture toughness tests on SA508 Gr.1a LAS piping materials fabricated by two different manufacturers and investigated the manufacturing parameters affecting their mechanical properties from the test results. The investigation results will be applied to develop SA508 Gr.1a LAS piping material having improved mechanical properties in terms of increasing the design margin for LBB application.

2. Experiments

2.1 Materials and Specimens

SA508 Gr.1a LAS piping materials fabricated by two different manufacturers (D and I) were used for the experiment. Two piping materials are denoted as SA508 Gr.1a(D) and SA508 Gr.1a(I). Table 1 and 2 summarize the chemical compositions and heat-treatment conditions. The diameter and the thickness of the pipe are 1075.4 and 102.6mm, respectively.

A round-bar type specimen, designed in accordance with ASTM E8/E8M-09 [2], was used for tensile tests, and 1T-CT specimen, designed in accordance with ASTM E1820-15 [3], was used for J-R fracture toughness test. Fig. 1 illustrates tensile and CT specimens used for the experiment. Tensile specimen was machined from the pipe in L-direction, and CT specimen was machined in L-C direction.

2.2 Test Conditions and Procedures

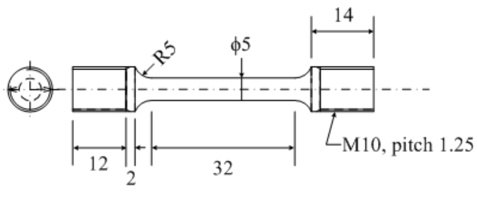
Tensile and J-R fracture toughness tests were conducted on two SA508 Gr.1a LAS piping materials. Tensile test was conducted at various temperatures ranging from RT to 350°C, including operating temperature of NPPs (286°C), under quasi-static strain rate. J-R fracture toughness test was conducted at RT and 286°C under displacement rates of 0.5 and 1000mm/min, corresponding to quasi-static and dynamic loading rates, respectively. In J-R test, the crack extension was determined by normalization method in accordance with ASTM E1820-15 [3].

Table 1 Chemical composition of SA508 Gr.1a LASs used for the experiment (wt%)

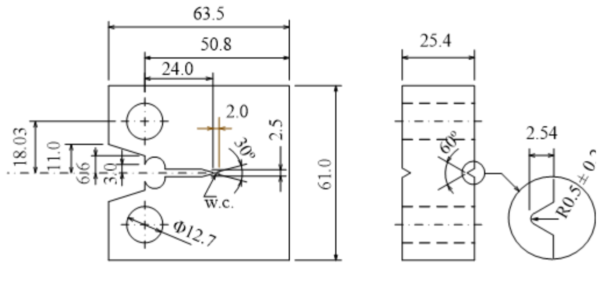
Mater.	Elements					
SA508 Gr.1a (D)	C	Si	Mn	P	S	Ni
	0.25	0.28	1.22	0.007	0.001	0.34
	Cr	Mo	V	Cu	Al	N
	0.20	0.06	0.007	0.05	0.02	-
SA508 Gr.1a (I)	C	Si	Mn	P	S	Ni
	0.25	0.24	1.09	0.004	0.002	0.32
	Cr	Mo	V	Cu	Al	N
	0.15	0.06	0.002	0.06	0.018	0.0043
	Nb:0.001, Ti:0.0014, Sn:0.006, Ca:0.0004, W:0.002, Co:0.01, B:0.0001					

Table 2 Heat-treatment conditions of SA508 Gr.1a LASs used for the experiment

Mater.	Heat-treatment
SA508 Gr.1a (D)	Austenitized @ 880℃ for 10h & W.C./ Tempered @ 660℃ for 8 h & A.C.
SA508 Gr.1a (I)	Austenitized @ 905℃ for 3h & W.C./ Tempered @ 640℃ for 6h & A.C.



(a) Tensile specimen



(b) 1T-CT specimen

Fig. 1 Specimen used for experiment

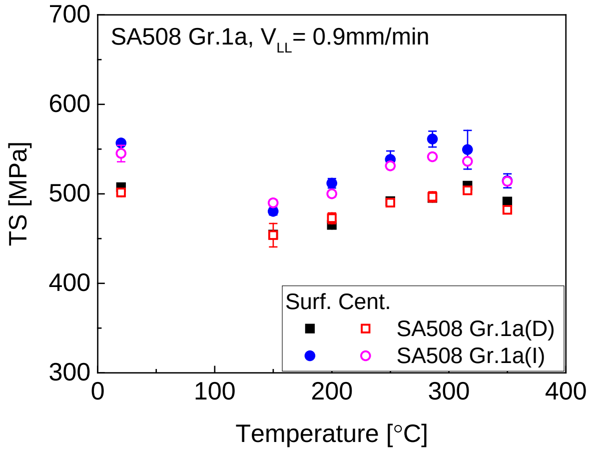


Fig. 2 Variations of tensile strength of two different SA508 Gr.1a LAS pipe materials with test temperature

Also, the microstructure of both materials was examined using optical microscope to understand their metallurgical characteristics.

3. Results and Conclusions

As shown in Fig. 2, regardless of test temperature, the strength and ductility of SA508 Gr.1a(D) were lower and larger, respectively, than those of SA508 Gr.1a(I). For SA508 Gr.1a(D), the tensile properties at surface and center of pipe were almost identical. But, the tensile properties of SA508 Gr.1a(I) were varied along the thickness of pipe; the surface showed a higher strength and a lower ductility compared to the center of pipe. In both materials, the increase in tensile strength and decrease in ductility due to dynamic strain aging (DSA) phenomena were observed at temperature region of 200~316 ºC. Also, the temperature range was slightly higher for SA508 Gr.1a(D) than for SA508 Gr.1a(I).

On the other hand, SA508 Gr.1a(D) showed a higher J-R toughness than SA508 Gr.1a(I) regardless of test temperature and displacement rate. The effect of displacement rate on J-R toughness was negligible at RT for both materials, but the displacement rate effect at 286 ºC was dependent on test material. SA508 Gr.1a(I) showed a similar J-R curve at both displacement rates, but SA508 Gr.1a(D) showed clearly higher J-R curve at quasi-static displacement rate than dynamic displacement rate. This is associated with that the DSA phenomenon of SA508 Gr.1a(D) is activated at a relatively higher temperature than that of SA508 Gr.1a(I).

The examination of microstructure showed that the grain size of SA508 Gr.1a(I) is finer than that of SA508 Gr.1a(D). The microstructure of SA508 Gr.1a(D) consisted of ferrite-pearlite, whereas for SA508 Gr.1a(I) it consisted of ferrite-bainite-pearlite. For SA508 Gr.1a(I), the surface microstructure was different from that at pipe center; the grain size was very fine and the fraction of bainite was apparently high. This indicates that the SA508 Gr.1a(D) was cooled slowly and uniformly during quenching, compared to SA508 Gr.1a(I). Therefore, the lower strength and larger ductility of SA508 Gr.1a(D) than SA508 Gr.1a(I) seem to be associated with the slow cooling. Also, the low strength and large ductility cause high J-R toughness of SA508 Gr.1a(D). Compared with SA508 Gr.1a(I), the higher DSA temperature region of SA508 Gr.1a(D) would be associated with the high tempering temperature and the long tempering time, which could reduce free C and N atoms in the matrix. In addition, it is believed that high Mn, Si, V, Cr contents and low N content of SA508 Gr.1a (D) also contributed to the higher DSA temperature region compared to SA508 Gr.1a(I) [4].

REFERENCES

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