Effect of Microstructure on the Dynamic Strain Aging Characteristics of Law-alloy Steels

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1. Introduction

SA508 Gr.1a low-alloy steel (LAS) is used as a reactor coolant piping material of nuclear power plants (NPPs). SA508 Gr.1a LAS is made by forging followed by quenching and tempering, and it has a good mechanical properties [1]. Thus, it is considered to be a candidate material for main steam line pipe of advanced NPP. However, it is known that the LAS is typically susceptible to dynamic strain aging (DSA) in the range of operating temperatures of NPPs, and the DSA phenomenon increases strength and decreases ductility and fracture resistance of the materials. Also, it causes abnormal strain rate dependence of LAS [2-3]. Thus, the mechanical properties of SA508 Gr.1a LAS at operating temperature of NPPs are influenced by its DSA characteristic, and it is important to understand the DSA characteristics for ensuring the reliability of mechanical properties of SA508 Gr.1a LAS tested at operating temperature of NPPs. The DSA phenomenon in LAS is known to be caused by the interaction between diffusing atoms, *i.e.*, free carbon and nitrogen atoms, and mobile dislocations [3]. Therefore, the susceptibility and temperature range of DSA are dependent on the amount of free carbon and nitrogen atoms, which is affected by the chemical composition, heat-treatment, and deformation rate of materials. A number of studies have been carried out to understand the parameters affecting the DSA characteristics and to mitigate the DSA susceptibility of LAS [2-3]. In this context, this study investigates the effect of microstructure, which is characterized by manufacturing process, on the DSA characteristics of SA508 Gr.1a LAS pipe material via tensile tests.

2. Experiment

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

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

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

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

that both materials have similar chemical compositions, but heat-treatment conditions are somewhat different. SA508 Gr.1a(D) was tempered at higher temperature for longer time compared to SA508 Gr.1a(I). A round-bar type specimen with a diameter of 5.0mm and a gage length of 25.0mm was used for tensile tests. All specimens were machined from the center and surface of both pipes in L-direction.

Tensile test was conducted at various temperatures ranging from RT to 350^{o}C, including operating temperature of main steam line of NPPs (286^{o}C), under quasi-static strain rate.

3. Results and Discussion

The microstructures at center and surface regions of pipe 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) consists of ferrite-pearlite, whereas it consists of ferrite-bainite-pearlite for SA508 Gr.1a(I). For SA508 Gr.1a(I), the surface microstructure is different from that at center of pipe; the grain size is very fine and the fraction of bainite is apparently high. This indicates that the SA508 Gr.1a(D) was cooled slowly and uniformly during quenching, compared to SA508 Gr.1a(I).

Regardless of test temperature, the strength and ductility of SA508 Gr.1a(D) are lower and larger, respectively, than those of SA508 Gr.1a(I). For SA508 Gr.1a(D), the tensile properties at surface and center of the pipe are almost identical. But, the tensile properties of SA508 Gr.1a(I) are varied along the thickness of pipe; the surface shows a higher strength and a lower ductility compared to the center of pipe. By comparing with their microstructures, it is indicated that the strength and ductility of SA508 Gr.1a LAS pipe materials are dependent on their microstructures, which were characterized by cooling rate during the quenching.

On the other hand, the increase in tensile strength and decrease in ductility are observed at temperature region of 200~316^{o}C for all cases. The temperature region, at which the maximum tensile strength and the minimum ductility appear, is slightly higher for SA508 Gr.1a(D) than for SA508 Gr.1a(I). For a given pipe material, however, the temperature regions are identical at both center and surface, even though the microstructures for both locations are different. It is known that the increase in tensile strength and the decrease in ductility at a certain range of temperature is related to the occurrence of DSA. Thus, the results indicates that the DSA characteristics of both SA 508 Gr.1a LAS pipes are different. Also, it is indicated that the characteristics of DSA are the same for both center and surface regions, where the microstructures are different.

4. Conclusions

The overall mechanical properties of SA508 Gr.1a LAS pipe materials were largely influenced by the microstructure. However, the DSA characteristics of SA508 Gr.1a LAS pipe materials were less affected by the microstructure characterized by the cooling rate during quenching when the tempering condition was the same.

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