Evaluation of crack propagation resistance in intercritically heat-treated SA508 Gr.1A steels

Se-Mi Hyun[a,b], Seokmin Hong [a*], Min-Chul Kim [a], Jongmin Kim[a], Seok Su Sohn[b]
[a] *Materials Safety Technology Development Division, Korea Atomic Energy Research Institute, Deokjin dong, Daejeon, Korea.*
[b] *Department of Materials Science and Engineering, Korea University, Seoul, Korea.*
[*]*Corresponding author: smhong@kaeri.re.kr*

1. Introduction

High-temperature and high-pressure steam moves to the main steam line (MSL) piping of a nuclear power plants (NPPs). In such an environment, the integrity of the MSL piping may be impair, and leakage accidents may occur [1]. Therefore, it is important to improve the safety of the MSL piping, and the LBB concept is applied to the MSL piping to improve the safety of the pipe [2]. LBB safety margin is dependent on the yield strength and J-R fracture resistance [3-4]. SA106 Gr.C steel was used for MSL piping material in Korea standard nuclear power plants (KSNP), but the SA508 Gr.1A steels that have better strength and fracture resistance than SA106 Gr.C steel is being considered [2]. However, further efforts are needed to improve the strength and J-R fracture resistance of the materials to ensure sufficient LBB safety margins.

In general, it is known that fine effective grains improve fracture toughness because the grain boundaries act as obstacles for crack propagation [5]. Also, fine precipitates improve the fracture toughness [6]. Therefore, in this study, IHT was applied to improve the mechanical properties of the material. Also, the correlation between microstructure after IHT and J-R fracture resistance was confirmed.

2. Methods and Results

2.1 Materials and heat treatment

In this study, normal SA508 Gr.1A steel and high strength SA508 Gr.1A steel containing Mo and V were used. Small blocks (size: 130 mm (W) X 160 mm (T) X 35 mm (H)) were taken from the MSL pipes. To improve the mechanical properties of material, IHT was additionally performed to the actual heat treatment process. The IHT condition was carried out at 725℃ for 6 h. For convenience, these samples are referred to as A (normal SA508 Gr.1A steel), B (high strength SA508 Gr.1A steel), AI, and BI (heat treatment sample to which IHT was applied).

2.2 Microstructure

The L-T surfaces were mechanically polished and etched with a 3% nital solution. The microstructure were investigated by an optical microscope (OM, Eclipse-MA200, Nikon, Japan). Several SEM images were selected to analyze the precipitates, the size of the precipitates were quantified using an image analyzer.

The OM images are shown in Figure. 1. The microstructure of A is a composite structure of coarse pearlite (P), ferrite (F), and upper bainite (UB), and that of B consisted of tempered bainite (TB) and ferrite without the formation of pearlite due to the addition of Mo and V and reduction of carbon content.

In the case of AI and BI, coarse pearlite could not be observed because all cementite was decomposed after IHT, and the ferrite and bainite were mainly formed. It showed a tendency to slightly decrease the size of grain and precipitates by suppressing the formation of coarse pearlite after IHT.

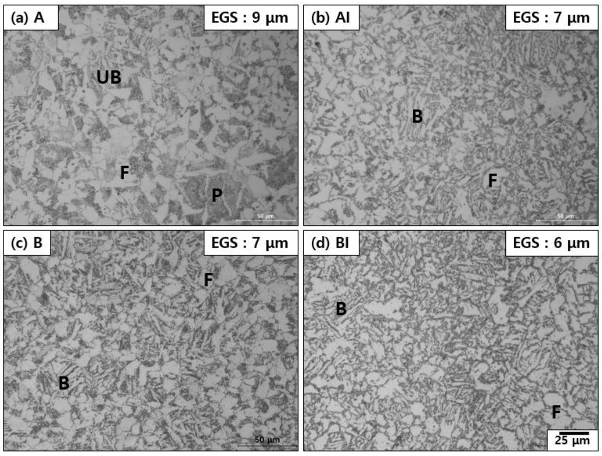

Fig. 1. OM images of SA508 Gr.1A steel before and after IHT.

2.3 Mechanical Properties

Rod type tensile specimens (gage length of 25 mm and gage diameter of 6.25 mm) were prepared in the longitudinal direction according to ASTM E8/E8M [7]. The tensile properties were evaluated at 286℃ using a MTS universal testing machine (MTS 810.24 MTS Systems Corporation, USA). The yield strength was determined by the 0.2% offset method. Tensile properties were summarized in table 1.

In comparison with A, B with the addition of Mo, V improved the strength at 286℃, but the elongation decreased. Also, the yield strength of AI was maintained, but that of BI slightly decreased at 286℃. Although, the strength tent to decrease after IHT, it met the enough minimum requirements in the ASME/ASTM specification [7]. Compared to A, B shows higher strength despite the slight decrease in strength after IHT. The J–R fracture resistance tests were performed according to ASTM E1820-18a [8] using ASTM standard 1T-CT (compact tension) specimens with a T-L orientation. The tests were conducted using a hydraulic material tester (MTS 810.24 MTS Systems Corporation, USA) with a capacity of 100 kN at 286℃. The J-R characterization was performed according to the normalization method in ASTM E1820-18a [8]. From the results, the J-R curve was derived from the load-displacement data for each test specimen. The J_{Ic} values were summarized in table 1. The J_{Ic} value of A and B was similar to each other, but that of AI and BI were greatly improved over 120 kJ/m^2 by IHT. In general, formation of coarse precipitates reduces the fracture toughness [5]. Also, the effective gain size affects the J-R fracture toughness [6]. When a load is applied, a plastic zone occurs at the crack tip. Therefore, J-R estimation model for SA508 Gr.1A steels were established considering the effective grain size, plastic zone size, yield strength, tensile strength. The results of the predicted and tested J_{Ic} values are shown in figure. 2. The predicted values of model were well matched with the values of J_{Ic}. Also, it was confirmed that it appeared linear as a result of verification with the results of the other study.

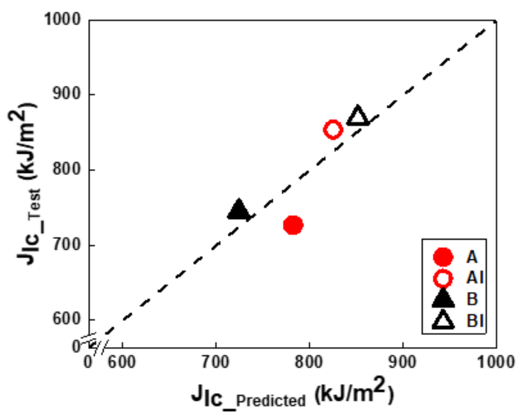

Fig. 4. A results of the predicted and tested J_{Ic} values.

Table 1. Tensile properties and J_{Ic} values of the specimens.

Temp. (°C)	Specimen	YS (MPa)	TS (MPa)	J_{Ic} (kJ/m^2)
286	A	276	539	726
	AI	274	528	846
	B	343	547	727
	BI	333	528	854

4. Conclusions

1. The microstructure of A was composed coarse pearlite, ferrite, and bainite, in case of B, the formation of tempered bainite and fine VC precipitates increased. Therefore, the strength of the B was higher than that of A.
2. In both AI and BI, the J-R fracture resistance was greatly improved, due to the effective grain size was reduced. And, precipitates were refined due to the decomposition of cementite after IHT.
3. J_{Ic} estimation model considering the effective grain size, plastic zone size, yield strength, and tensile strength was established by curve fitting, and predicted J_{Ic} values showed good agreement with the test results.

REFERENCES

[1] Y.S. Chang, M.J. Jung, B.S. Lee, H.S. Kim, N.S. Huh, Hanshouse, 2013.
[2] I.S. Hwang, J.H. Kim, Y.J. Oh, I.S. Kim, Y. S. Kim, J.S. Lee, Report, KINS/HR-250, 1999.
[3] S.M, Hong, K.D. Min, S.M. Hyun, J.M. Kim, Y.S. Lee, H.D. Kim, M.C. Kim, Int. J. Press. Vessel. Pip., 191, pp. 104359, 2021.
[4] M.W. Kim, Y.S. Lee, I.W. Shin, J.S. Yang, H.D. Kim, Trans. of the KPVP., 16, pp. 42-48, 2020.
[5] S.I. Lee, S.Y. Lee, S.H. Nam, B.C. Hwang, Korean J. Mater. Res., 25, pp. 559-565, 2015.
[6] F.B. Picketing, Applied Science, London, 1978.
[7] ASTM E8/E8M-16a, ASTM Int., 2016.
[8] ASTM E1820-18a, ASTM Int., (2016).