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Application of 3 step heat treatment to improve toughness of main steam pipes in NPPs

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1. Introduction

Leak-Before-Break(LBB) methodology has been applied to design for main steam line pipes in nuclear power plants(NPPs) by eliminating the postulation of Double Ended Guillotine Break. From the point of view on material properties in LBB analysis, the premise of LBB is that the materials are sufficiently tough that small through-wall crack would remain stable.

The SA106 Gr.C pipes, however, which was selected for Korea next generation reactor and already used in PWR main steam line pipes. Compared to low alloy steels pipes, those showed low toughness at room temperature, in addition to a substantial reduction in fracture toughness due to dynamic strain aging at the reactor operating temperature. Therefore, safety margins for the application of LBB concept can be reduced.

The purposes of this study are to improve fracture toughness through multiple step thermal treatment and to give sufficient margins for the LBB applicability of main steam line pipes.

2. Methods and Results

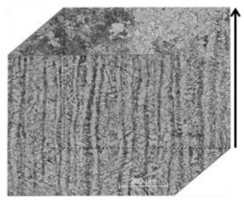
2.1 Material and specimens

The SA106 Gr.C pipes used in this research was received form HANJUNG Co. Ltd, which was the archive material of main steam line pipes of 3 and 4 unites in Young Gwang NPPs. It was fabricated by normal air cooling after hot drawing and then normalized.

The microstructure and the chemical composition of SA106 Gr.C pipes are given in fig. 1. This microstructure is a typical ferrite-pearlite structure with multiple band layers (black line) and arrow denotes hot drawing direction.

The round tensile specimens with 25mm gage length were machined by the ASTM E8M and their tensile axis was parallel to main steam pipes axis. The Standard Charpy specimens were machined in the L-C direction by the ASTM E23 and tested at room temperature.

The specimens for *J-R* test were 0.5 inch thick standard CT specimens machined in the L-C direction, *J-R* specimens were fatigue precracked according to the specifications in ASTM E1152 and were side grooved 10% on each side after pre-cracking.

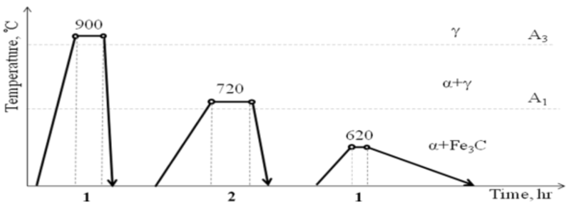


Element	C	Mn	P	S	Si	Cr	Cu	Mo	Ni	V
ASTM Spec.	<0.35	0.29~ 1.06	<0.035	<0.035	> 0.10	< 0.40	< 0.40	< 0.15	< 0.40	< 0.08
Test material	0.218	1.25	0.005	0.003	0.298	0.054	0.181	0.033	0.155	-

Fig. 1 The optical micrograph and chemical composition of SA 106 Gr. C (wt.%).

2.2 Heat treatments

Thermal treatment procedure is shown in fig. 2. All heat treatments are performed in nitrogen gas condition to prevent the surface of test specimens from oxidation and decarburization. In the first stage, specimens were homogenized in the austenite range at 900°C for 1hr and oil cooled. Oil cooling rate was approximately 300°C/sec and then specimens were quenched in the intercritical range (ferrite and austenite) at 720°C again. After intercritcal thermal treatment for 2hrs, tempering was performed at 620°C for 1hr.



· 1st: 200°C/hour, 900°C, 1hour, Oil cooling
· 2nd: 60°C/hour, 720°C, 2hours, Oil cooling
· 3rd: 60°C/hour, 620°C, 1hrous, Furnace cooling

Fig. 2 Schematics of 3 step heat treatment procedure

2.3 Microstructure

Figure 3 shows the microstructure of specimens after heat treatment at each stage. In fig. 3(a), the prior austenite grain boundaries were revealed. The size of the prior austenite grain was about twice as long as that of 20μm martensite grain (b). Formation of martensite in the fine-grained prior austenite was preferred because of the improved mechanical properties such as yield or flow strength [1]. The martensite grains are formed in paralleled arrays called packets which subdivide the prior austenite grain. Each packet can be effectively acted as a grain because most of the laths have the same orientation [2-4].

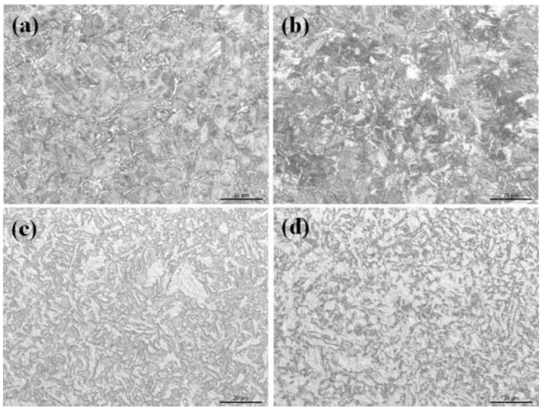
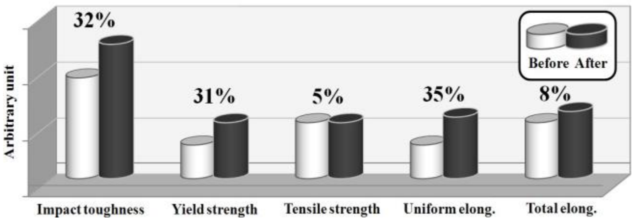


Fig. 3. Microstructure after thermal treatments. (a) etched to show the prior austenite grain boundaries and (b) etched to show lath martensite after 1st TT. (c) and (d) respectively showing microstructure difference after 2nd TT and 3rd TT

The microstructure after intercritical heat treatment at 720°C for 2 hours was shown in fig 3(c). An approach to developing good combinations of strength and toughness in specimens consisted of this heat treatment. Even though the SA106 Gr. C steels are low carbon, the intercritical heat treatment concentrates the carbon in the austenite, another helpful factor for improved hardenability [5-7].

Figure (d) shows changes in the matrix structure that developed during the tempering of specimens. The packet morphology with its parallel sub-units is not clearly visible due to producing coarse and spherical cementite particles at the grain boundaries.



State	Impact Toughness , Joule	Yield strength , MPa	Tensile strength , MPa	Uniform elongation , %	Total elongation , %
As-received	171	340	553	15.5	13.5
After 3 step thermal treatment	224	445	583	21	34

Fig. 4. Summary of Charpy and tensile test

2.4 Test results

As a result of tests, it was clear that physical properties of SA106 Gr.C test materials were improved after 3 step thermal treatment. Figure 4 shows summary of Charpy and tensile test. Specimen after 3 step thermal treatment showed higher both impact toughness and yield strength by over 30% as compared to as-received without decrease in ductility.

The *J-R* test was performed at load-line displacement rates of quasi-static, 0.6mm/minute at 289°C (fig. 5.). *J-R* value of specimen after 3 step thermal treatments increased by about 30% compared with that of as-received.

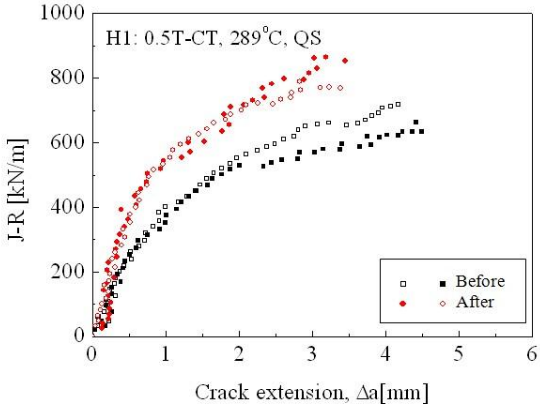


Fig. 5. Variation in the quasi-static J-R curves at 289°C

3. Conclusions

The heat treatment process for manufacturing high toughness SA106 Gr.C steels have been developed by application of 3 step heat treatment to improve toughness. In this process, the intercritical heat treatment(2nd) is added between the conventional quenching(1st) and tempering(3rd). The application of 3 step thermal treatment resulted in the increase of Charpy impact and fracture toughness by more than 30% compared to as-received.

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