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# FATIGUE CRACK GROWTH RATE IN LOW △K RANGE ACCORDING TO THE MICROSTRUCTURE AND TEMPERATURE IN P122 ALLOY STEEL

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## ABSTRACT.

There are strong environmental and economic pressures to increase the thermal efficiency of fossil fuel power stations and this has led to a steady increase in steam temperatures and pressures resulting in world wide plans for ultra super-critical power plants. For example, in order to improve the thermal efficiency of power plant, there has been a strong drive to develop heat resistant steels with excellent creep, high temperature fatigue and thermal fatigue resistant properties as well as superior oxidation and corrosion resistant properties. In this study, the test material was P122 alloy which has been developed for ultra super-critical power plant. To measure fatigue crack growth rate in low △K range, fatigue tests were performed by △K decreasing method at three different microstructures (Base metal, HAZ, Weld metal) regions. Also △K increasing tests were performed to investigate fatigue crack growth rate after $\triangle K_{th}$ values were found at each microstructure. Tests were performed with compact tension specimens at 600～700℃ with the loading frequency of 20Hz. Experimental results of the fatigue crack growth rate in low △K range were analyzed to determine the effect of microstructures at different test temperatures.

## INTRODUCTION

High strength, ferritic heat resisting steels are widely studied to increase the steam temperature and pressure of the thermal power plant for better thermal efficiency (1, 2). Cr-Mo steels are extensively used as high temperature components in power plants (3). To improve the thermal efficiency of a power plant, heat resistant steels with excellent creep properties as well as superior oxidation and corrosion resistance properties have been developed (4). The material used in this study was P122 alloy, which was developed as main steam pipe material. Generally, HAZ (Heat Affected Zone) of weldment is reported to be the weakest part of the welded industrial components and serves as frequent crack initiating points (5-8). Also, HAZ was found to have the lowest toughness in welded joints (9). Therefore, the careful inspection must be carried out at the weldment. In this study, fatigue tests were performed to measure fatigue crack growth rate in low △K range using three different microstructures (Base metal, HAZ, Weld metal) regions.

## EXPERIMENTAL PROCEDURE

**Material.** The specimens were obtained from welded joints of main steam pipe in the power plant and the materials were P122 steel. The chemical composition of P122 steel and welding electrode is shown in Table 1.

The first 5paths of welding were carried out by gas tungsten arc welding (GTAW) and rest were shielded metal arc welding (SMAW). Heat treatments of normalizing and tempering were performed on the welded joints and post weld heat treatments were also carried out. The HAZ widths after welding was about 3mm. CT specimens were prepared for fatigue crack growth tests. In the HAZ specimen, the notch tip was located at HAZ.

Table 1 Chemical composition of P122 steel and welding electrode (wt.%)

| Elements | | C | Si | Mn | P | S | Al | Cr | Cu |
|---|---|---|---|---|---|---|---|---|---|
| P122 | Base metal | 0.13 | 0.31 | 0.59 | 0.020 | - | 0.006 | 10.57 | 0.96 |
| | GTAW | 0.07 | 0.32 | 0.48 | 0.006 | 0.003 | - | 10.54 | 1.48 |
| | SMAW | 0.08 | 0.28 | 0.89 | 0.008 | 0.002 | - | 10.05 | 1.44 |
| Elements | | Ni | Mo | V | Nb | N | W | B | Fe |
| P122 | Base metal | 0.34 | 0.33 | 0.21 | 0.06 | 0.06 | 1.79 | 0.002 | Rem. |
| | GTAW | 1.12 | 0.34 | 0.21 | 0.05 | 0.04 | 1.48 | - | Rem. |
| | SMAW | 0.94 | 0.20 | 0.19 | 0.04 | 0.05 | 1.44 | 0.002 | Rem. |

**Observation of microstructure.** To identify the location of the base metal, weld metal and HAZ and confirm the microstructure, etching and microscope observation were carried out.

**High temperature fatigue crack growth test.** Specimens were prepared and the tests were performed according to ASTM E 1457. Fatigue crack growth tests were conducted in accordance with ASTM E 647. The crack length was measured by traveling microscope and the DCPD (direct current potential drop) method. All specimens were pre-cracked at room temperature at a loading frequency of 20Hz up to a/W= 0.23. The sinusoidal loading waveform was employed, and the stress ratio was 0.1 for all tests. To measure fatigue crack growth rate in low $\triangle K$ range, fatigue tests were performed by $\triangle K$ decreasing method at three different microstructures (Base metal, HAZ, Weld metal) regions. Also $\triangle K$ increasing tests were performed to investigate fatigue crack growth rate after $\triangle K_{th}$ values were found at each microstructure. Tests were performed with compact tension specimens at 600～700℃ with the loading frequency of 20Hz.

## RESULTS AND DISCUSSION

**Test results of microstructure and hardness.** The results of microstructural observation are presented in Fig. 1. When checking the microstructures, the base metal showed homogeneous structure and weld metal had nonhomogenity structure in spite of the high hardness.

(a) Base metal (b) HAZ (c) Weld metal

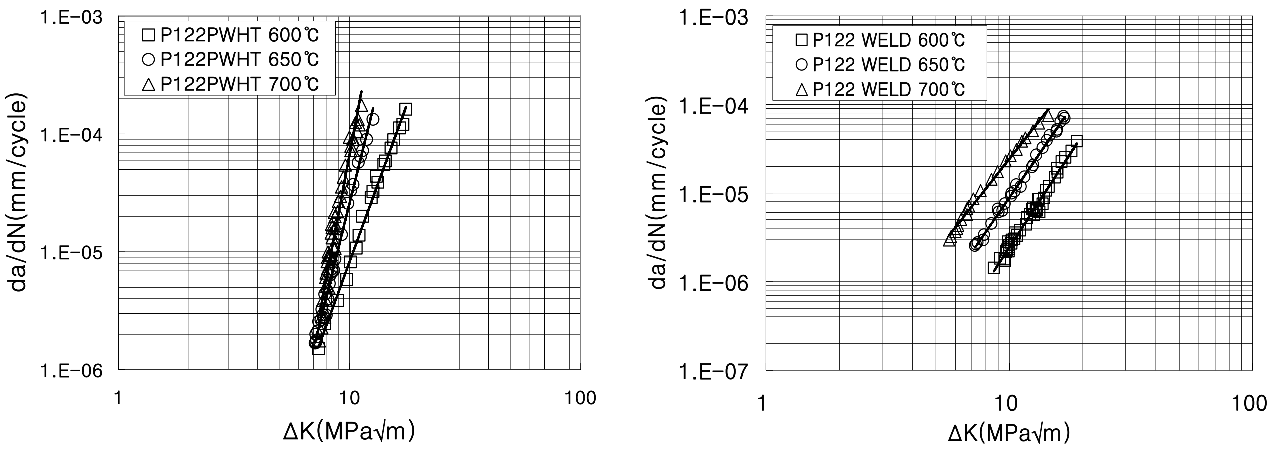
Fig. 1 Microstructure of P122 weldment

**High temperature fatigue crack growth test of P122 weldment.** Fatigue tests were performed using compact tension specimens at various test conditions. Table 2 shows the Paris law of P122 weldment in low $\triangle K$ range for various temperatures.

Table 2 Paris law of P122 weldment in low △K range for various temperatures

| Material | Frequency | Stress Ratio (R) | Temperature | $da/dN = C \Delta K^m$ | |
|---|---|---|---|---|---|
| | | | | C | M |
| Base metal | 20 Hz | 0.1 | 600℃ | $3 \times 10^{-11}$ | 5.375 |
| | 20 Hz | 0.1 | 650℃ | $1 \times 10^{-13}$ | 8.2565 |
| | 20 Hz | 0.1 | 700℃ | $2 \times 10^{-15}$ | 10.429 |
| Weld metal | 20 Hz | 0.1 | 600℃ | $1 \times 10^{-10}$ | 4.2324 |
| | 20 Hz | 0.1 | 650℃ | $9 \times 10^{-10}$ | 4.0014 |
| | 20 Hz | 0.1 | 700℃ | $8 \times 10^{-10}$ | 3.4885 |
| HAZ | 20 Hz | 0.1 | 600℃ | $2 \times 10^{-14}$ | 8.9637 |
| | 20 Hz | 0.1 | 650℃ | $1 \times 10^{-14}$ | 9.3105 |
| | 20 Hz | 0.1 | 700℃ | $8 \times 10^{-14}$ | 9.0087 |

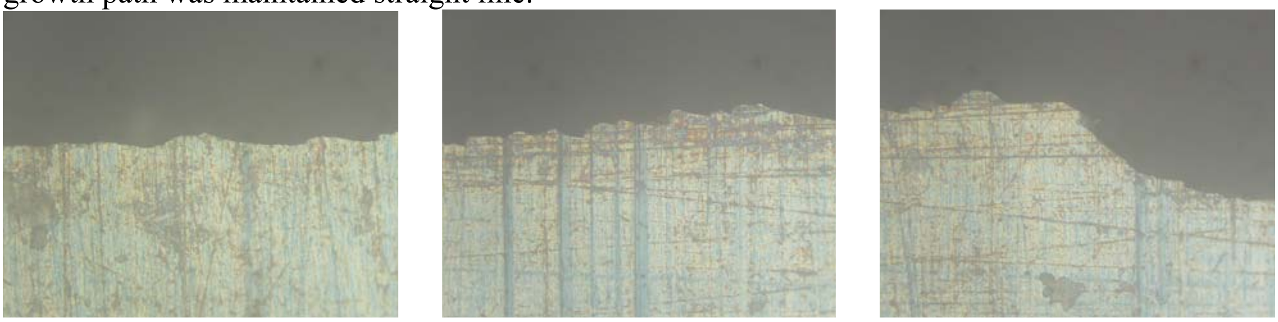
**Fatigue crack growth rate of base metal, weld metal and HAZ as different temperatures.** The results are represented by fatigue crack growth rate (da/dN) vs. stress intensity factor range (ΔK) curves in Fig. 2. Figure 2-(a) shows the fatigue crack growth rate of base metal in the low ΔK range. As the temperature increased, the fatigue crack growth rate increased. The fatigue crack growth rate increment became greater as ΔK increased. Figure 2-(b) shows the fatigue crack growth rate of weld metal in the low ΔK range. As the temperature increased, the fatigue crack growth rate increased.




(a) (b)

Fig. 2 da/dN vs. ΔK curves in low ΔK range of (a) base metal, (b) weld metal

Fig. 3 shows the crack growth path of P122 base metal. In the all ΔK ranges, the surface of crack growth path was maintained straight line.



(a) Low ΔK range (b) Mid ΔK range (c) High ΔK range

Fig. 3 Crack growth path of the P122 base metal

Fig. 4 shows the fatigue crack growth rate of HAZ in the low ΔK range. As the temperature increased, the fatigue crack growth rate increased.

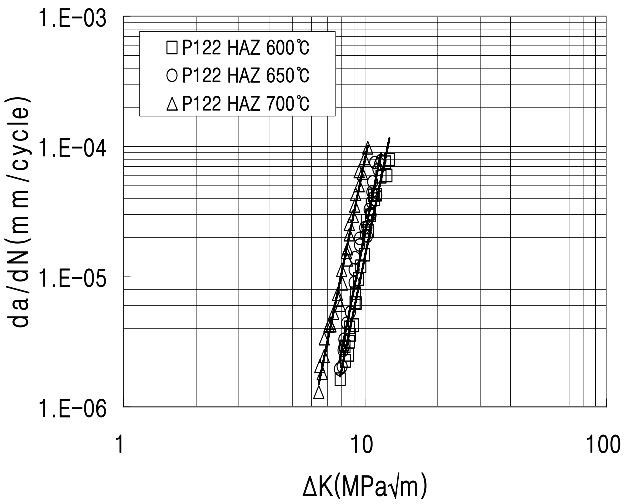
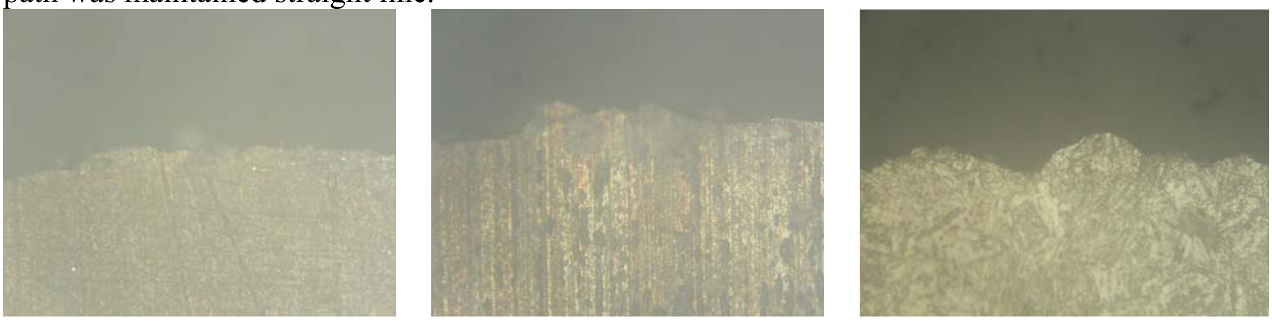



Fig. 4 da/dN vs. ΔK curves in low ΔK range of HAZ

Fig. 5 shows the crack growth path of weld metal. In the all ΔK ranges, the surface of crack growth path was maintained straight line.



(a) Low ΔK range (b) Mid ΔK range (c) High ΔK range

Fig. 5 Crack growth path of the P122 weld metal

**Fatigue crack growth rate of base metal, weld metal and HAZ at same temperature.** The results are represented by fatigue crack growth rate (da/dN) vs. stress intensity factor range (ΔK) curves in Fig. 6 and 7.

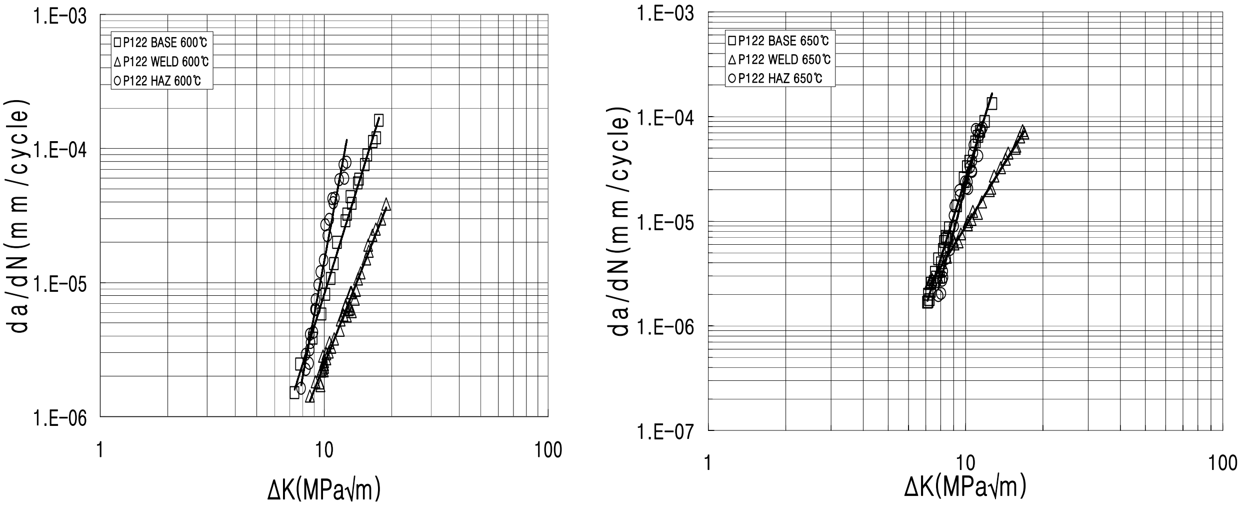



Fig. 6 da/dN vs. ΔK curves in low ΔK range of P122 weldment at (a) 600℃, (b) 650℃

Figure 6-(a) and (b) show the fatigue crack growth rate of P122 weldment in the low ΔK range at 600℃, 650℃ respectively. The fatigue crack growth rate of weld metal is the lowest among three different microstructures, but in the case of base metal and HAZ, the fatigue crack growth rates at 650℃ were similar. Because, in the case of HAZ, the fatigue crack growth rate was affected by the location of machined notch. Fig. 7 shows the fatigue crack growth rate of P122 weldment in the low ΔK range at 700℃. Also, in the case of 700℃, the fatigue crack growth rates of base metal and HAZ at 650℃ were similar.

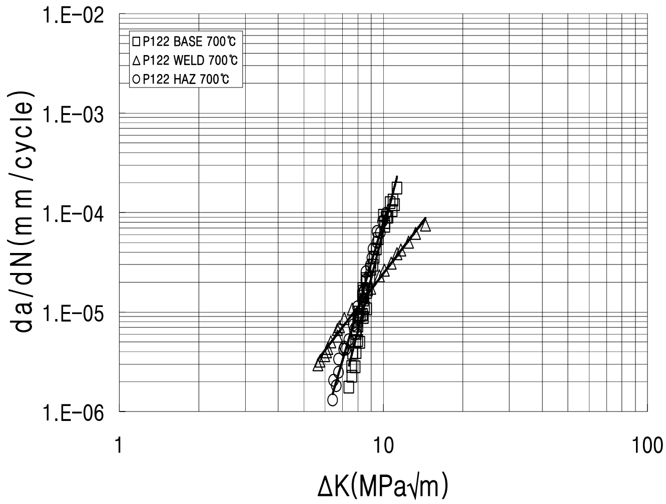
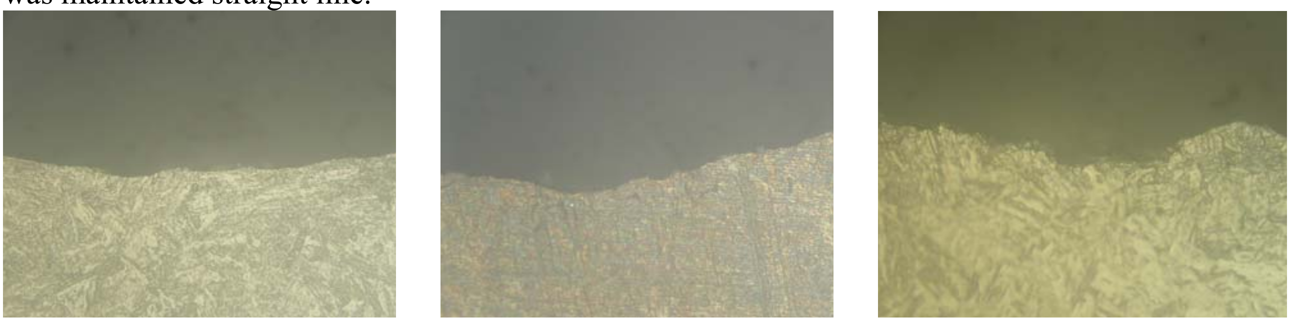



Fig. 7 da/dN vs. ΔK curves in low ΔK range of P122 weldment at 700℃

Fig. 8 shows the crack growth path of HAZ. In the all ΔK ranges, the surface of crack growth path was maintained straight line.



(a) Low ΔK range (b) Mid ΔK range (c) High ΔK range

Fig. 8 Crack growth path of the P122 HAZ

**CONCLUSION**

The fatigue crack growth rates in low ΔK range were investigated through the fatigue crack growth tests on welded joints (Base metal, Weld metal, HAZ) and following conclusions obtained.

(1) The fatigue crack growth rates in the low ΔK range of all materials increased as the temperature increased.

(2) The fatigue crack growth rates of the weld metal in the low ΔK range at all temperature were the lowest among the three materials; therefore, the resistance of the weld metal at high temperature was better than those of the base metal and HAZ.

(3) The fatigue crack growth rate of HAZ was affected by notch location.

(4) In all ΔK ranges for all materials, the crack growth path was observed to maintain straight lines.

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