Study on the propagation characteristic of the Thermal Fatigue Crack by cyclic thermal load in the STS 304 tube

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1. Introduction

Thermal fatigue crack is one of the life-limiting mechanisms in nuclear power plant conditions. During the operation of a power plant thermal fatigue cracks can initiate and grow in various components (straight pipe sections, valve bodies, pipe elbows, and collector head screw holes). Causes for this are mixing, striping or stratification of hot and cold water. A typical component, where thermal fatigue cracking occurs, is a T-joint where hot and cold fluids meet and mix. The turbulent mixing of fluids with different temperatures induces rapid temperature changes to the pipe wall. The resulting uneven temperature distribution prevents thermal expansion and gives rise to thermal stresses. The successive thermal transients cause varying, cyclic thermal stresses. These cyclic thermal stresses cause fatigue crack initiation and growth similar to cyclic mechanical stresses [1]. In order to fabricate thermal fatigue crack similar to realistic crack, successive thermal transients were applied to the specimen. In this study, in order to identify propagation characteristic of thermal fatigue crack, thermal fatigue crack specimens of 4000cycle, 6000cycle, 9000cycle were fabricated. Thermal transient cycles were combined with heating (60sec) and cooling cycle (30sec). Destructive testing and scanning electron microscopy were carried out to identify the crack propagation characteristic and fracture surface morphology.

For example, Fig. 1 shows thermal fatigue crack from the outlet pipe of shell side of regenerative heat exchanger (Tomari Power Station Unit-2, Japan) [2].

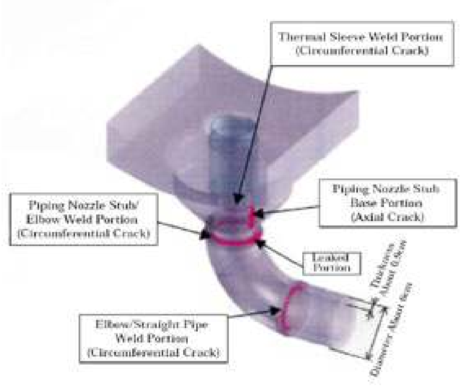


Figure 1. Outlet pipe of shell side of regenerative heat exchanger

2. Methods and Results

2.1 Experimental Method

2.1.1 Block diagram of thermal fatigue crack producing apparatus

The test material was austenitic STS 304, which is used as pipelines in the Reactor Coolant System of a nuclear power plants (O.D.= 89mm, t=7.7mm). The fabricating mechanism of thermal fatigue crack formation is shown Fig. 2. Thermal fatigue loading was applied with high frequency induction heating and water cooling in order to achieve high heating and cooling rates. Thermal transient cycles were combined with heating (60sec) and cooling cycle (30sec). In order to prevent intergranular crack by Cr carbide precipitation at the grain boundaries [3], the maximum temperature was restricted to 450℃.

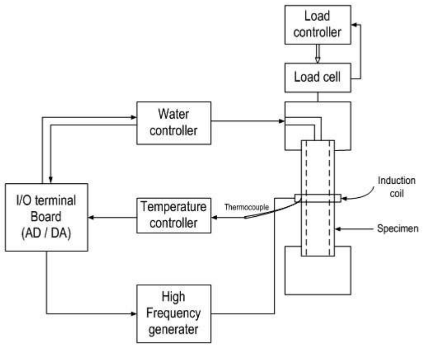


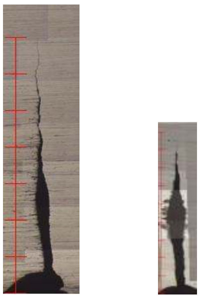
Figure 2. Mechanism of thermal fatigue crack formation

3.2 Experimental results

3.2.1 Cross-section of Thermal fatigue crack

In order to identify propagation characteristic of thermal fatigue crack by cycle, thermal fatigue crack specimens of 4000cycle, 6000cycle, 9000cycle were fabricated in the same condition. By the destructive testing, it was confirmed that thermal fatigue crack initiated and propagated at the boundary of air and cooling water (70°, 290°). For fabricated thermal fatigue cracks, crack depth was measured by optical microscopy. Fig. 3 shows the cross-section of thermal fatigue crack by cycle. In Fig. 3, the crack path is tortuous. And the crack width is narrow and the crack tip radii are small.

70°, 0.8mm 290°, 0.8mm
(a)



70°, 2.8mm 290°, 1.7mm
(b)

70°, 3.2mm

290°, 6.2mm
(c)

Figure 3. Cross-section of thermal fatigue crack:
(a) 4000cycle, (b) 6000cycle and (c) 9000cycle

Fig. 4 shows the maximum crack depth by cycle. In Fig. 4, it was confirmed that propagation rate of thermal fatigue crack was approximately 1~1.1 ㎛*/cycle* in this experimental condition.

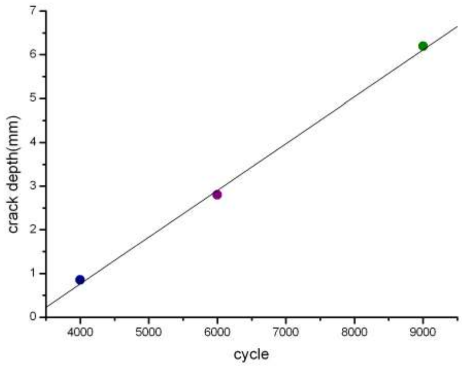


Figure 4. Thermal fatigue crack depth by cycle

3.2.2 Fractographic morphology of thermal fatigue crack

Fig. 5 shows the SEM micrographs from the fracture surfaces due to the thermal fatigue crack (9000cycle) and it's fatigue striations on the fracture surface of thermal fatigue crack. In the SEM micrographs, each striation represents an incremental advance of the crack front during one load cycle. The magnitude of the increment, that is, striation spacing, depends on the stress/strain range [4]. In Fig. 5, thermal striation spacing was measured 0.9 ㎛. And this result is similar to propagation rate by the destructive testing.

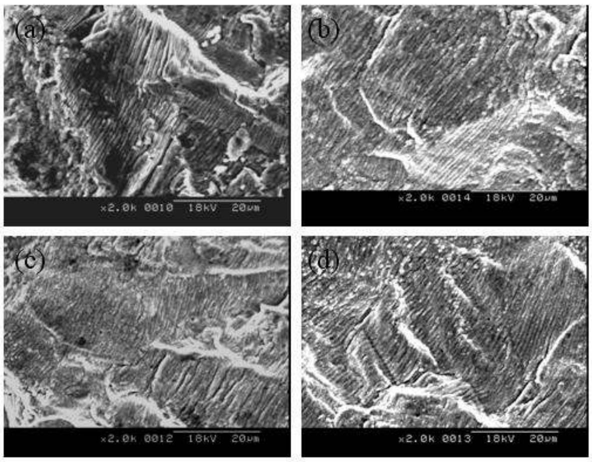


Figure 5. Fracture surface of thermal fatigue crack

4. Conclusion

In this study, in order to identify propagation characteristic of thermal fatigue crack, thermal fatigue crack specimens of 4000cycle, 6000cycle, 9000cycle were fabricated. By destructive testing, it was confirmed that thermal fatigue crack initiated and propagated at the boundary of air and cooling water (70°, 290°). From destructive testing, it was confirmed that propagation rate of thermal fatigue crack was approximately 1~1.1 ㎛*/cycle* and this result was similar to thermal striation spacing (0.9 ㎛) in the SEM micrograph.

5. Acknowledgments

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