Thermo-mechanical Fatigue Crack Growth Behaviour of STS 347 Base and Weld Material

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1. Introduction

An exact evaluation of the characteristics of fatigue crack growth rate (FCGR) is very important for the life assessment of the cracked components in nuclear power plant piping system. Surge line is one of the components exposed to severe thermal and mechanical fatigue loads caused by the difference of temperatures and the cyclic internal pressure, respectively. There are no standard methods for the case of cyclic thermo-mechanical FCGR test. In some papers [1-4], authors have used their own method to measure the FCGR. In this study an efficient testing system has been developed to measure the FCGR under cyclic thermal and mechanical loads. Using the developed equipment, the FCGR tests were performed for the specimens of STS 347 weld and base material.

2. Experiment and Results

2.1 Specimens

The specimens tested were made of type 347 stainless steel. The 2 mm thick specimen with 3.5 mm length notch was processed by wire cutting. The fatigue pre-crack was mechanically introduced to sharpen the root of the notch. This ESET (Eccentrically-loaded Single Edge Crack Tension) specimen is one of the standard FCGR test specimen specified in ASTM E647.

2.2 Thermo-mechanical Testing Facility

The testing facility used in the present study consists of a mechanical loading device, thermal control unit, and crack growth measurement instruments. Fig. 1 shows a block diagram of entire system. The mechanical loads were applied using a servo-hydraulic controlled MTS testing system and thermal loads using the high frequency induction heating generation system. For the cooling of the specimen, jets of air were blown across the two sides of specimen. A major advantage of this method is that it takes short time to increase and decrease the specimen temperature and the programmed control is available. The cycles of the mechanical loads from MTS controller and the thermal loads from RF induction heat generator can be easily synchronized with in-phase or out-of-phase. Modifications made to the MTS load frame for high temperature testing were high temperature grip and cooling cylinder. The combination of RF induction coil and the elongated ESET specimen provides a sufficient space to measure the crack length clearly. Crack length can be digitally read out using a tele-microscope with 1/100 mm resolution.

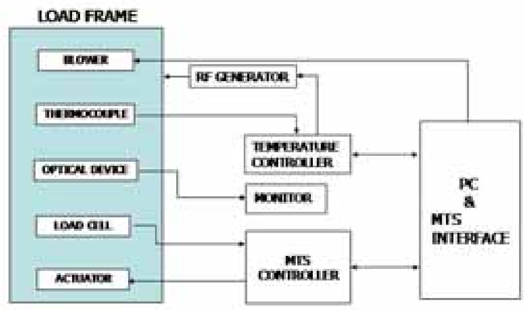

Figure 1 Block diagram of thermo-mechanical fatigue crack growth rate testing system

2.3 Test Procedure and Results

The specimens were prepared in two types; STS 347 base materials and weld materials. Thermal loads are applied in three ways; (a) constant temperature, 167℃, (b) constant temperature, 345℃, and (c) variable cyclic temperature, 167~345℃. The mechanical loading frequency was 10 Hz for conditions (a) and (b). For the condition (c), temperature varies linearly in a cycle per every two minutes. Two different stress ratios were also considered for conditions (a) and (b); R=0.1 and R=0.5. Thermocouples were attached on the center of the specimen using spot welder to control the thermal loads and to record the temperature profiles of the specimens.

The experimental results in Fig. 2 and Fig. 3 show that the higher were temperature and stress ratio, the higher FCGR data were obtained. These results follow the general tendency for the effect of temperature and stress ratio. The corresponding SIFs determined from the equations provided in ASTM E647 have been plotted against crack growth rate. The FCGR data against the small ΔK range at 167 ~345℃ variable temperature loading show somewhat great dispersion comparing to other conditions.

Fig. 4 shows all test data comparing to the reference curves of ASME Boiler and Pressure Vessel Code, Section XI, Appendix C. The FCGR data of weld material were slightly greater than those of base material. As shown in fig. 4, the crack length calculated from the ASME reference curve may give an underestimation in the life time assessment for weld materials. On the other hand, the results indicate that ASME reference curve may give a conservative estimation for the base materials at 167℃ environment temperature.

3. Conclusion

An efficient testing system was set-up to measure the thermal-mechanical FCGR. With constructed testing system, the FCGR data were obtained for STS 347 base and weld material under different temperature and stress ratios. The obtained results in this study can be used for the lifetime assessment.

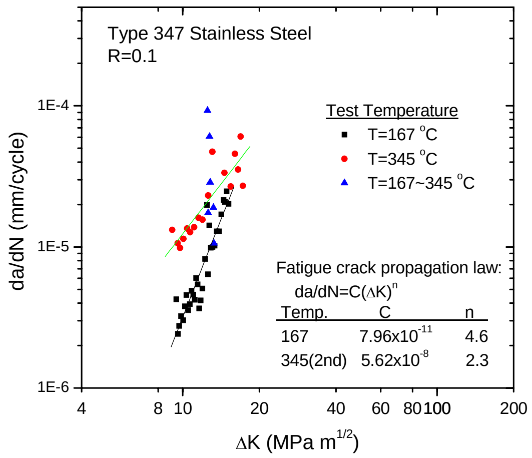

Figure 2 Fatigue crack growth data for STS 347 base material at different temperature

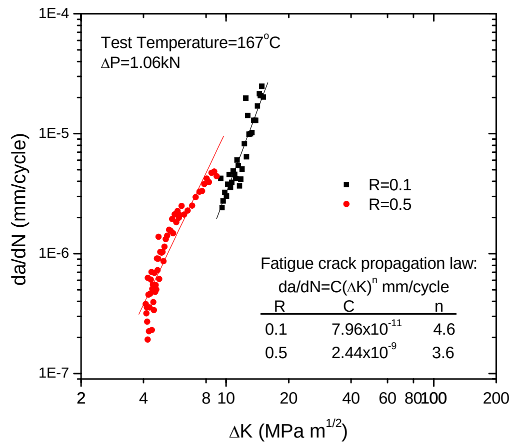

Figure 3 Effect of R-ratio on fatigue crack growth rates for STS 347 at 167℃

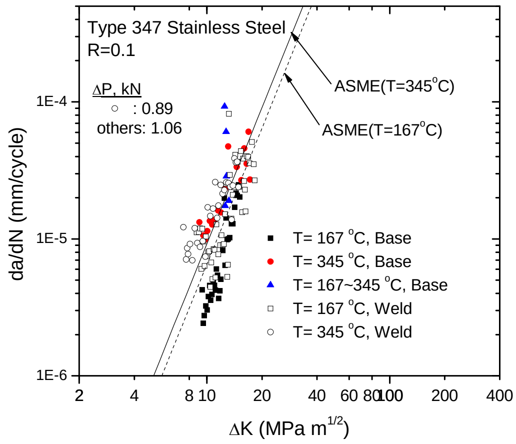

Figure 4 Comparison of the tested fatigue crack growth rates to the ASME reference curves for STS 347 material

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