Fatigue Crack Growth Rate and Fracture Resistance of Heat Affected Zone of Stainless Steel Narrow Gap Welds

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1. Introduction

In nuclear power plants, the automated narrow gap welding (NGW) technique has been widely used in joining stainless steel pipes in primary coolant system [1]. As the primary system pipes are subjected to various transients during plant operation, cracks could initiate and propagate that would cause accidents. To prevent the cracking from developing into sudden failure in the primary system, leak-before-break (LBB) design concept has been developed and applied to many nuclear power plants [2,3]. Meanwhile, to apply the LBB design, mechanical properties of the structural materials of piping systems should be evaluated, especially at weld zone and heat affected zone (HAZ), because mechanical properties within those regions show considerable scatter and spatial differences [1,4,5]. In this study, fatigue crack grow rate (FCGR) and fracture resistance of base metal, weld zone, and HAZ of type 316L stainless steel narrow gap welds were performed at plant operating temperature (315°C) and room temperature. In particular, FCGR and fracture resistance of HAZ were evaluated in detail and compared to those of base metal.

2. Methods and Results

In this study, type 316L stainless steel was used for the base metal and 308L for the welding wire. To make narrow gap welds, an automatic gas-tungsten arc welding (GTAW) was used at the speed of 5.1cm/min.

2.1 Specimen preparation

The CT specimens were machined for the FCGR and the fracture resistance tests along with circumferential direction and shown in Fig. 1. Size and shape of specimens were in accordance with ASTM E1820-09 [6]. To measure the HAZ properties, machined notch was located 2mm away from the edge of the weld fusion zone based on the previous results [1].

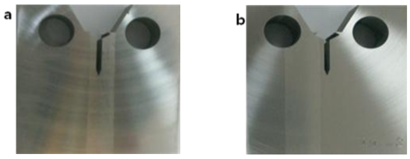

Fig. 1 The schematic of (a) the weld and (b) HAZ specimens.

2.2 Fatigue Crack Growth Rate

The FCGR tests of the base metal, fusion zone and HAZ were conducted at 315°C, and room temperature following ASTM E647-08 [7]. During the FCGR tests, crack lengths were measured by unloading compliance method. The results of FCGR tests at 315°C and room temperature were shown in Fig. 2 and 3. As the figures indicate, the FCGR of the weld fusion zone and the HAZ were greater than that of the base metal at both temperatures.

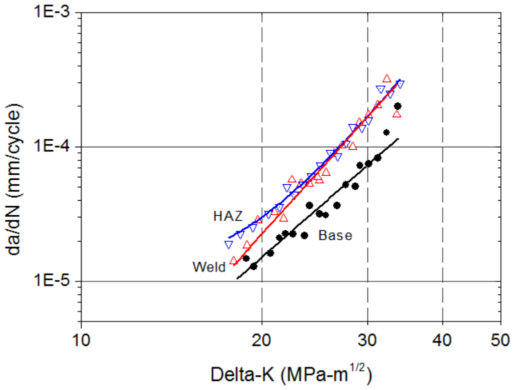

Fig. 2 Results of FCGR tests at 315°C.

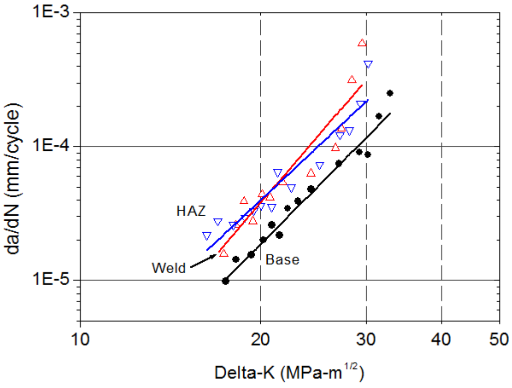

Fig. 3 Results of FCGR tests at room temperature.

In case of the weld fusion zone formed by NGW process, high FCGR was caused by well aligned dendrite structures in the successive weld deposits [1]. The high FCGR in HAZ could have been caused by the microstructural change due to repeated heating and rapid cooling cycle experienced during welding process. As HAZ of SS welds are more susceptible to stress corrosion cracking than weld metals, it is wise to investigate the mechanisms to explain the high FCGR for LBB application.

2.3 *Fracture Resistance*

The fracture resistance of the base, weld fusion zone and HAZ tests were conducted at plant operating temperature, 315°C, and room temperature following ASTM E1820-09 [6]. Crack length was measured using unloading compliance method. The measured fracture resistance curves, J-R curves, are shown in Fig. 4 and 5. The fracture toughness values are summarized in table 1. As shown in the figures, fracture resistance of HAZ was similar to base metal and much higher than that of weld fusion zone. Also as temperatures increased from room temperature to 315°C, fracture resistances of those regions were decreased.

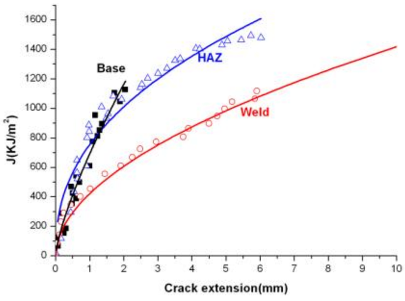

Fig. 4 J-R curves of base, weld, and HAZ at 315°C.

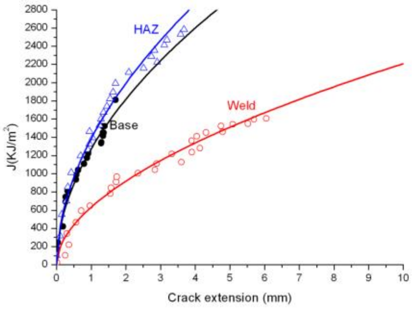

Fig. 5 J-R curves of base, weld, and HAZ at room temperature.

Table I: Measured fracture toughness (J_Q, KJ/m^2)

	Base	Weld	HAZ
315°C	1470	401	1153
25°C	2546	636	2274

The base metal showed similar tendency as previously reported [8]. As mentioned above, the well aligned dendrite microstructure in weld fusion zone was assumed weaker point for fracture resistance [1]. In case of HAZ sizes and shapes of grains depend on the locations [9]. It is surmised that areas which contact on the base metal with the weld zone were melted and re-solidified by heat caused by the process of welding. Because heat transfer of metal is very fast, heated and partially melted base metal cooled down rapidly and then, phase transformations were occurred. Despite the microstructural change, its effects on fracture resistance were not significant.

3. Conclusions

From the mechanical tests on the stainless steel NGW used in nuclear piping system to apply LBB concept, the following conclusions were drawn;

- Fatigue crack growth rates (FCGR) HAZ had similar tendency to weld zone but higher than that of HAZ at both plant operating temperature (315°C) and room temperature.
- Fracture resistance of HAZ was much higher than that of weld fusion zone. Furthermore, as temperature increased from room temperature to operating temperature, fracture resistances were decreased
- Microstructures were changed in the weld zone and HAZ by heat flux which was made from repeated heating and cooling during many welding paths.

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