ENVIRONMENTAL EFFECT ON THE GROWTH OF MICRO-STRUCTURALLY SMALL CRACKS IN STAINLESS STEELS

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Fatigue tests have been conducted on a duplex stainless steel, SUS329J4L, and an austenitic stainless steel, SUS304, in order to clarify the effects of environment and microstructure on early crack growth. The crack initiation sites for both stainless steels were predominantly within austenite phase in room air and 3%NaCl solution, but the initiation in ferrite phase for SUS329J4L and at grain boundary for SUS304 was rarely observed. The fluctuation of crack growth rates was found in the microstructurally small crack region for both stainless steels, and the crack growth rates decreased at phase or grain boundaries. This behaviour was less remarkable in 3%NaCl solution than in room air. Early crack growth immediately after the initiation was significantly enhanced in 3%NaCl solution for both stainless steels.

INTRODUCTION

Most of fatigue life is occupied by crack initiation and early crack growth. Therefore, it is particularly important to clarify crack initiation and small crack growth behaviour. In general, small cracks are classified into three categories (1); that is, microstructurally small crack (2), mechanically small crack (3) and chemically short crack (4). In corrosive environment, while the chemically short crack is well known as the crack size effect of high strength alloys, this short crack is regarded as long crack in microstructural and mechanical sence (4), and the behaviour is considered to be due to the crack size dependence of K_{ISCC} (5). On the other hand, many studies have been conducted on microstructurally and mechanically small cracks in an inert environment. However, the studies in a corrosive environment have not been fully developed. It seems to be due to the difficulty of observation, that is, corrosion debris and surface roughness by anodic dissolution. Moreover, the size of crack emanating from a corrosion defect exceeds generally a region of microstructurally small crack (6). Therefore, it is considered that the microstructurally small cracks in a corrosive environment could be observed only for corrosion resistant alloys, *e.g.* stainless steels and titanium alloys.

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In the present study, fatigue tests for an austenitic-ferritic stainless steel, SUS329 J4L, and an austenitic stainless steel, SUS304, have been conducted in room air and in 3%NaCl solution to clarify the effects of environment and microstructure on crack initiation and early crack growth behaviour.

EXPERIMENTAL PROCEDURES

The materials used were a duplex stainless steel, SUS329J4L, and an austenitic stainless steel, SUS304, whose chemical compositions are listed in Table 1. SUS329J4L and SUS304 were solution treated at 1050℃ for 15*min* and at 1100℃ for 30*min*, respectively. The microstructure of SUS329J4L contained approximately 50% austenite (γ-phase) in volume (7), where austenite islands were in ferrite matrix (α-phase). The microstructure of SUS304 was austenitic. The mechanical properties after heat treatment are given in Table 2. After heat treatment, plate specimens for small cracks were machined in L-direction, which have a shallow notch (depth 0.4*mm*) to restrict the crack initiation site, and its stress concentration factor is about 1.05.

TABLE 1– Chemical compositions (wt.%) of materials.

Material	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	N	Fe
SUS329J4L	0.015	0.41	0.71	0.031	0.0002	0.21	6.71	25.60	3.06	0.15	Bal.
SUS304	0.05	0.46	1.33	0.031	0.003	0.39	8.21	18.25	0.28	0.08	Bal.

TABLE 2– Mechanical properties of materials.

Material	0.2%proof stress $\sigma_{0.2}$ MPa	Tensile strength σ_B MPa	Breaking strength on final area σ_T MPa	Elongation δ %	Reduction of area ϕ %
SUS329J4L	501	731	1625	38	77
SUS304	250	603	1766	63	80

Fatigue tests were conducted using electro servo-hydraulic testing machine operating at a frequency of 10Hz in room air and 1Hz in 3%NaCl solution. Temperature, pH and dissolved oxygen content of the 3%NaCl solution were 30℃, 6.0 and 6.8*ppm*, respectively. Tests were performed at a stress ratio, R, of -1 for small cracks. Crack length was measured using a replication method. Stress intensity factor of small surface cracks was calculated using the analytical solution developed by Newman and Raju (8).

RESULTS AND DISCUSSION

Early Crack Growth in SUS329J4L

The crack initiation sites for SUS329J4L in room air were predominantly at persistent slip bands in γ-phase and uncommon in α-phase. The initiation at phase boundary was not observed. The relationships between crack growth rate, dc/dN, and half crack length on the specimen surface, c, immediately after the initiation are shown in Fig.1. The crack growths in room air are indicated by open symbols in the figure. Remarkable fluctuation of dc/dN is seen in the region of crack size below 200μm. From a close examination of early crack growth, the decrease in dc/dN was found at the phase boundary. The dual-phase microstructure of SUS329J4L contains austenite islands in ferrite matrix, where the interspace of austenite islands is several tens of μm. As shown in Fig.1, the period of variation in dc/dN is coincident with the interspace of phase boundaries, that is, early crack growth is influenced by change of phase. In addition, the decrease in dc/dN is also found at the site other than phase boundaries on the specimen surface. The reason of this behaviour is that, when the crack front encounters phase boundaries in the inside of specimen, the crack growth at surface is influenced by the hesitation of crack in the inside of specimen.

While the crack initiation in α-phase was a rare case in the present study, the crack shown in Fig.1 grew by the length of about 120μm avoiding the austenite islands. However, the growth behaviour of this crack is almost similar to the crack emanated from γ-phase, as can be seen in the figure.

The crack initiation in 3%NaCl solution occurred in γ-phase and at the phase boundary. The initiation in α-phase was not observed. The relationships between dc/dN and c in 3%NaCl solution are also shown by solid symbol in Fig.1. As is evident in Fig.1, dc/dN in 3%NaCl solution is faster than that in room air. Although the fluctuation of dc/dN is also seen in 3%NaCl solution, the decrease in dc/dN is much smaller than in room air.

Early Crack Growth in SUS304

Cracks in room air and in 3%NaCl solution were generated at persistent slip bands in γ-grain and at grain boundary, respectively. The $dc/dN - c$ relationships for SUS304 are shown in Fig.2. While the crack initiation in room air occurred at σ_{max}=200MPa, the crack arrested at the length of 2c=100μm. Subsequently, applied stress was increased to 220MPa, and then the crack began to grow again. The fluctuation of dc/dN is found in the region of early crack growth, and the decrease in dc/dN was observed at the grain boundary.

On the other hand, as shown in Fig.2, dc/dN in 3%NaCl solution is faster than that in room air, and the fluctuation of dc/dN is hardly seen in 3%NaCl solution. This implies that the crack growth in 3%NaCl solution is not accompanied by the small deflection and the hesitation at grain boundary. This tendency is observed more or less for both stainless steels.

Growth Behaviour in Microstructurally Small Cracks

Figure 3(a) and (b) show the $da/dN - \Delta K$ relationships of small cracks for SUS329J4L and SUS304, respectively. For comparison, the results of long cracks are also represented by lines in the figure (7). No appreciable difference of fatigue crack growth behaviour in room air and 3%NaCl solution is observed for long cracks in both steels. As can be seen in Fig.3(a), da/dN in the microstructurally small crack region is enhanced in 3%NaCl solution for SUS329J4L. With increasing crack length, the $da/dN - \Delta K$ relationships of small cracks gradually approach the $da/dN - \Delta K_{\text{eff}}$ relationships of long cracks and then coincide with those of long cracks.

The $da/dN - \Delta K$ relationships of small cracks for SUS304 are shown in Fig.3(b). The lines in the figure represent long crack data for comparison (7). Small cracks in 3%NaCl solution exhibits enhanced crack growth rates in the entire region studied. However, the $da/dN - \Delta K$ relationships of small cracks are not coincident with the $da/dN - \Delta K_{\text{eff}}$ relationships of long cracks. In the previous study (7), the stress level dependence of small crack growth behaviour for SUS304 is observed at σ_{max}=200 and 230MPa, indicating the breakdown in ΔK similitude due to plasticity. Therefore, the application of ΔK seems inappropriate for small cracks of SUS304.

Figure 4 shows schematic illustration which represents an environmental effect in microstructurally small crack region observed in SUS329J4L. In this region, crack growth is enhanced by corrosive media. With increasing crack size, the $da/dN - \Delta K$ relationships of small cracks gradually approach the $da/dN - \Delta K_{\text{eff}}$ relationship of long cracks, and are merged into the $da/dN - \Delta K_{\text{eff}}$ relationship of long cracks in each environment.

CONCLUSIONS

Fatigue tests were conducted on a duplex stainless steel, SUS329J4L, and an austenitic stainless steel, SUS304, in order to clarify the crack growth behaviour immediately after the initiation in room air and in 3%NaCl solution. The conclusions obtained are as follows;

(1) The fluctuation of crack growth rates is observed in the microstructurally small crack region for both stainless steels. The fluctuation in 3%NaCl solution is much smaller than that in room air. Crack growth rates in the microstructurally small crack region are enhanced in 3%NaCl solution for both stainless steels.

(2) The $da/dN - \Delta K$ relationships of small cracks for SUS329J4L gradually approach the $da/dN - \Delta K_{\text{eff}}$ relationships of long cracks with increasing crack length, and then coincide with those of long cracks in each environment. For SUS304, on the contrary, the $da/dN - \Delta K$ relationships of small cracks are not coincident with the $da/dN - \Delta K_{\text{eff}}$ relationships of long cracks.

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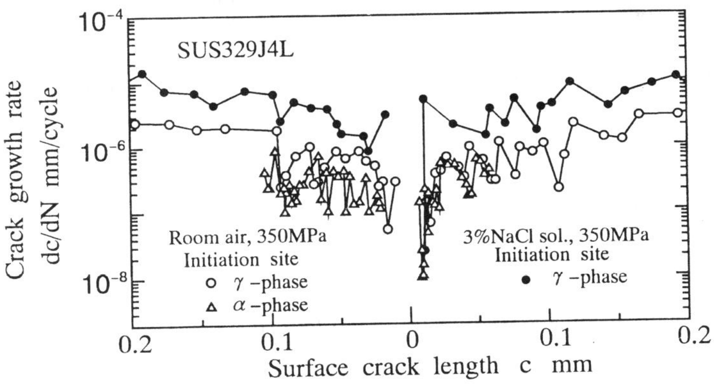


Figure 1 Early crack growth behaviour in room air and in 3%NaCl solution for SUS329J4L

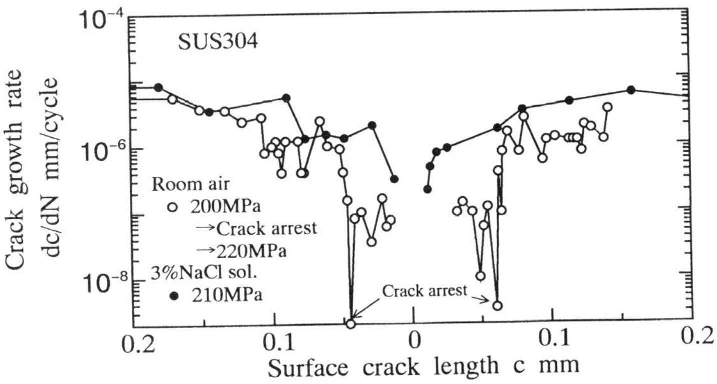
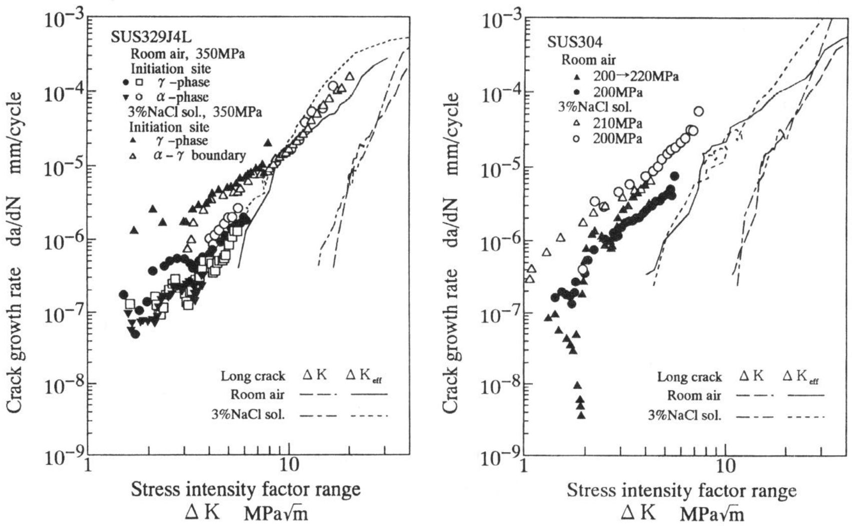


Figure 2 Early crack growth behaviour in room air and in 3%NaCl solution for SUS304



(a) SUS329J4L (b) SUS304

Figure 3 Relationships between da/dN and ΔK for small cracks

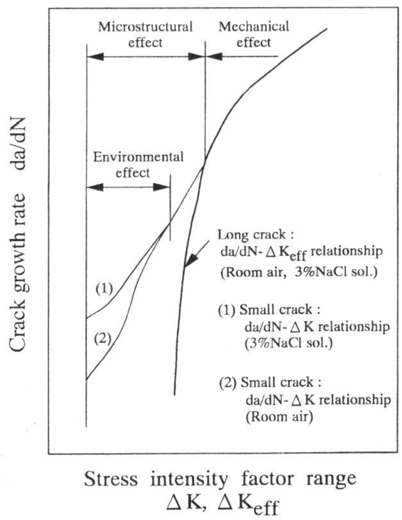


Figure 4 Schematic illustration of da/dN and ΔK relationships for small cracks