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SELECTIVE DISSOLUTION AND CORROSION FATIGUE BEHAVIORS OF 2205 DUPLEX STAINLESS STEEL

ABSTRACT

Selective dissolution and its effect on fatigue crack initiation in 2205 duplex stainless steel (DSS) were investigated. In mixed H_2SO_4/HCl solutions, two distinct and separated anodic peaks appeared in the active-to-passive transition region of the potentiodynamic polarization curve. Selective dissolution at each of these characteristic potentials was demonstrated. Under sinusoidal cyclic loading condition, selective dissolution did not assist fatigue crack initiation, instead resulting in the elimination of stress concentration site in the selectively dissolving phase. Microstructural evolution of the corrosion fatigue crack initiation in 2205 DSS in the mixed H_2SO_4/HCl solution and under selective dissolution condition was presented.

***Keywords:** duplex stainless steel, selective dissolution, corrosion fatigue crack initiation*

INTRODUCTION

Both the crystal structure and chemical composition of the constituent phases, namely austenitic (γ) and ferritic (α) phases, in duplex stainless steel (DSS) are different. When exposed in aqueous environment, they may exhibit different electrochemical potentials. Thus, it is expected that selective corrosion will occur within DSS. In fact, several investigations have found the occurrence of selective corrosion in DSSs [1-5]. However, which of the constituent phases is prone to corrosion is controversial and of interest.

Furthermore, it is known that fatigue cracks in many structural materials initiate preferentially in sites where stress concentration occurs or microstructure inhomogeneity exists. In duplex stainless steels (DSSs), fatigue crack initiation was rather complicated. For example, Llanes et al. [6, 7] indicated that fatigue crack would initiate at α phase or at the α/γ interfaces of un-aged 2205 DSS. On the contrary, fatigue crack could initiate at γ phase if 2205 DSS was aged at 475⁰C for 200 hours. Certainly, microstructure has a great influence on fatigue behavior of DSSs, but still in a complicated manner. As pointed out above, selective corrosion may occur in DSSs due to the difference in chemical composition of the constituent phases. Whether selective corrosion affects the

fatigue crack initiation behavior is also of interest and explored in this study.

EXPERIMENTAL

2205 DSS with the form of square bar, 30 x 30 mm, was used. The chemical composition is listed in Table 1. This material was heat treated at 1100°C for 30 min then water quenched before the subsequent tests. The metallographs of three different surfaces, after etching in boiling Murakami reagent, are depicted in Fig. 1. As shown in the left of Fig. 1, the dark phase is ferrite (α) while the white phase is austenite (γ). The volume ratio of α/γ is 53/47. The major alloying elements, namely, Fe, Cr, Ni, Mo and Mn, were analyzed by energy dispersive spectrometer (EDS) with their concentrations also listed in Table 1.

Electrochemical tests

Potentiodynamic polarization test was conducted at a scan rate of 1 mV/sec in the range of -500 to 0 mV_{SCE} from cathodic towards anodic direction. Potentiostatic etching at the anodic peak potential corresponding to selective dissolution of either α or γ was also performed. All potentials were measured with respect to a saturated calomel electrode (SCE). After potentiostatic etching, the surface morphology was examined with a scanning electron microscope (SEM), while major alloying elements were analyzed by EDS.

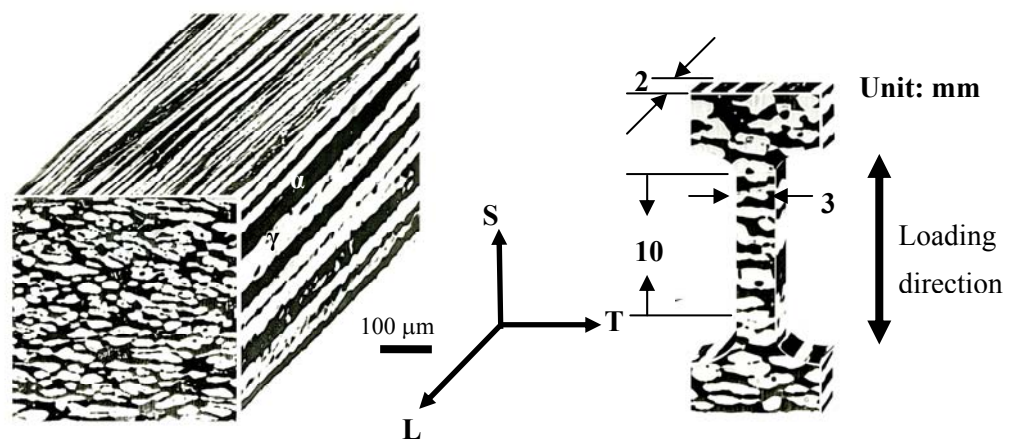


Fig.1. Optical micrograph of 2205 duplex stainless steel, solution heat treated at 1100°C for 30 minutes followed by water quench; and geometry and dimension of fatigue specimen

Table 1. Chemical composition (in wt.%) of 2205 duplex stainless steel and the constituent ferritic and austenitic phases

Element	Fe	Cr	Ni	Mo	Mn	Si	C	Cu	P	S	N
2205 DSS*	Bal.	22.40	5.42	3.24	1.43	0.41	0.014	0.21	0.025	0.004	0.198
α -phase**	Bal.	23.5	4.8	3.5	1.0	--	--	--	--	--	--
γ -phase**	Bal.	20.5	7.2	1.0	2.0	--	--	--	--	--	--

*Glow Discharge Spectrometer (GDS)

**Energy Dispersive Spectrometer (EDS)

Corrosion fatigue tests

Rectangular shape of specimen with the geometric orientation and dimension shown in the right of Fig. 1 was used for fatigue test. A sinusoidal waveform of load with a frequency of 10 Hz was used. The initial maximum stress of $1.2 \sigma_{ys}$ (yield strength) and a load ratio (R) of 0.5 was applied for fatigue test. The loading was parallel to the short transverse (S) direction, as demonstrated in Fig. 1. Fatigue tests were conducted in air and in 2 M H₂SO₄ + 0.7 M HCl aqueous solution at open circuit potential (OCP) and at -300 and -240 mV_{SCE}, respectively, all at ambient temperature. After determining the fatigue life (N_f), some interrupted fatigue tests at certain loading cycles were also performed. The cross section and fracture surface were examined microscopically.

RESULTS AND DISCUSSION

Electrochemical tests

Figure 2(a) presents the potentiodynamic polarization curve of 2205 DSS determined in the air-exposed 2 M H₂SO₄ + 0.7 M HCl aqueous solution. The active-to-passive transition peak consisted of two distinct peaks at -300 and -240 mV_{SCE}, respectively. This characteristic feature of polarization curve has been reported previously [8, 9]. Potentiostatic etching at OCP (-350 mV_{SCE}), -300 or -240 mV_{SCE} for 3 h was performed. The respective surface morphologies are shown in Fig. 2(b)~(d). At OCP and -300 mV_{SCE}, preferential dissolution of α was observed, while that of γ was found at -240 mV_{SCE}.

Fatigue tests

The average fatigue life of 2205 DSS in air was 4.05×10^5 cycles. Interrupted

fatigue test after loading for about $0.6 N_f$ was followed by surface morphological examination. Figure 3 is the SEM micrograph showing the surface morphology of S-L plane after interrupted test. As can be seen in this figure, cracks were formed in α phase rather than in γ phase. The result indicated that α phase was more prone to crack initiation, consistent with that reported by Llandes et al. [6,7]. The high nitrogen content [10, 11] and lower the stacking fault energy [12] in γ phase are all responsible for the increase of resistance to fatigue crack initiation in γ phase.

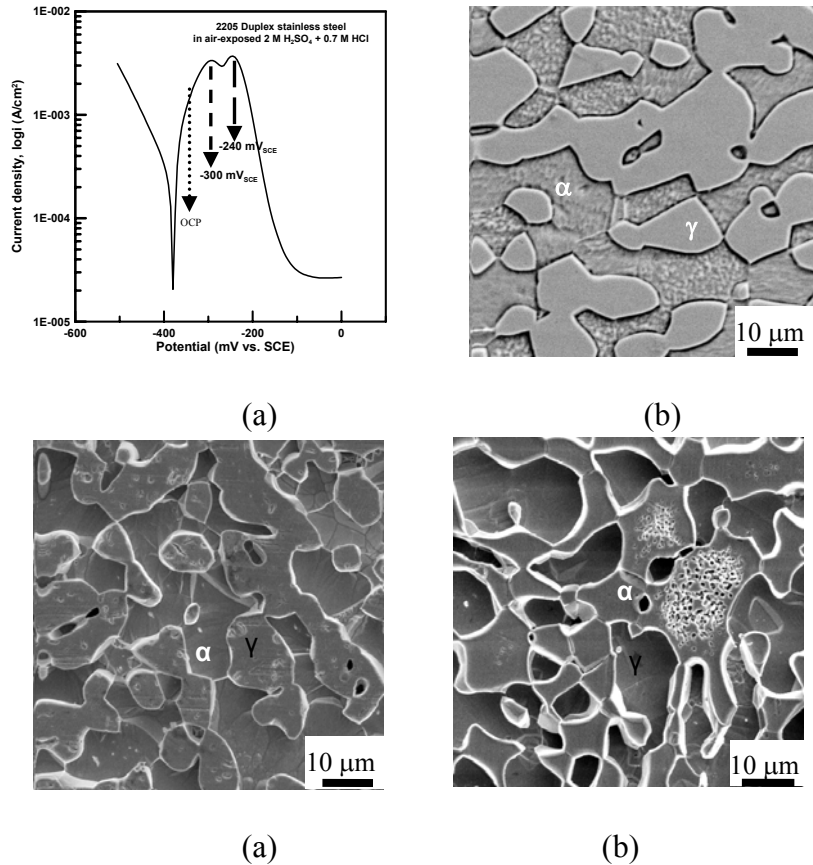


Fig. 2. (a) Potentiodynamic polarization curve of 2205 duplex stainless steel in air-exposed 2 M H_2SO_4 + 0.7 M HCl aqueous solution. Micrographs of 2205 DSS after potentiostatic etching at (b) OCP, (c)-300, and (d)-240 mV_{SCE} for 3 hours, respectively

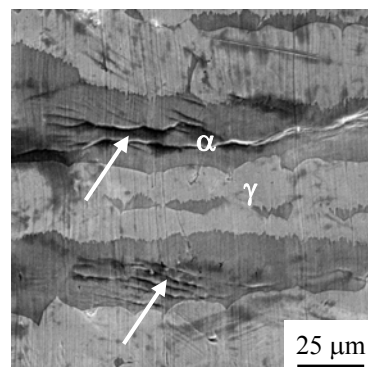


Fig. 3. SEM micrograph showing the surface morphology of 2205 duplex stainless steel after fatigue loading for $0.6 N_f$ cycles

The average fatigue life obtained in 2 M H₂SO₄ + 0.7 M HCl aqueous solution at OCP and at a frequency of 10 Hz was 1.27×10^5 . The substantial reduction in fatigue life as compared with that obtained in air indicated the importance of environmental effect on fatigue behavior of 2205 DSS. Figure 4(a) shows the surface morphology of the specimen fatigued after 0.6 N_f cycles. The SEM micrograph revealed that α phase was preferentially dissolved and the slip bands were concentrated in this phase, which resulted in crack initiation. As revealed in Fig. 4(a), cracks were also formed at the α/γ interfaces. The cross section of the specimen after loading for 0.6 N_f cycles was also examined. As shown in Fig. 4(b), cracks were certainly initiated in α phase and α/γ boundaries. This figure also shows that the cracks propagated in α phase and along α/γ boundaries.

Figure 5(a) shows the surface appearance of the specimen after fatigue loading in 2 M H₂SO₄ + 0.7 M HCl aqueous solution at -300 mV_{SCE} for 0.4 N_f cycles, where $N_f \approx 1.06 \times 10^5$ cycles. Similar to that tested at OCP, selective dissolution occurred in α phase. However, unlike that found at OCP, the cracks were found initiated in γ phase. The cross section of the specimen fatigued for 0.6 N_f cycles are depicted in Fig. 5(b). Cracks mainly initiated and propagated in γ phase. Though the slip bands could be generated in α phase, fast selective dissolution could smooth out these bands easily. Thus, the stress raisers could not be developed in α phase, and crack initiation in this phase was retarded.

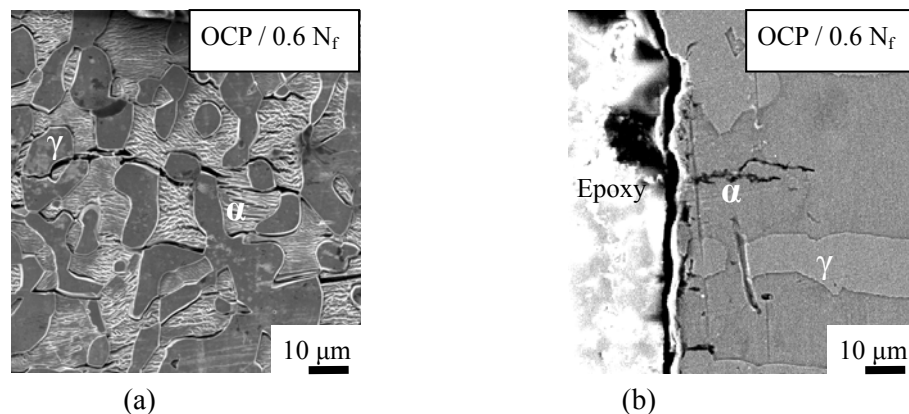


Fig. 4. SEM micrographs showing (a) the surface morphology, and (b) the cross section of 2205 duplex stainless steel after fatigue loading for 0.6 N_f cycles in 2 M H₂SO₄ + 0.7 M HCl aqueous solution at OCP condition

At -240 mV_{SCE}, selective dissolution in γ phase took place during fatigue test in 2 M H₂SO₄ + 0.7 M HCl aqueous solution. Figure 6(a) shows the surface appearance after fatigue loading for 0.4 N_f cycles ($N_f \approx 1.04 \times 10^5$ cycles). Again, selective dissolution did not favor crack initiation in γ phase. Instead, fatigue initiated in α phase and propagated through it, as demonstrated in Fig. 6(b). Though it is generally found that localized corrosion, such as pitting corrosion [13-15], always assists fatigue crack initiation, it is

not the case for selective dissolution in 2205 DSS. It is clear that environmentally-assisted fatigue crack initiation may not be prevailed unless an active stress raiser can be developed by the assistance of localized corrosion.

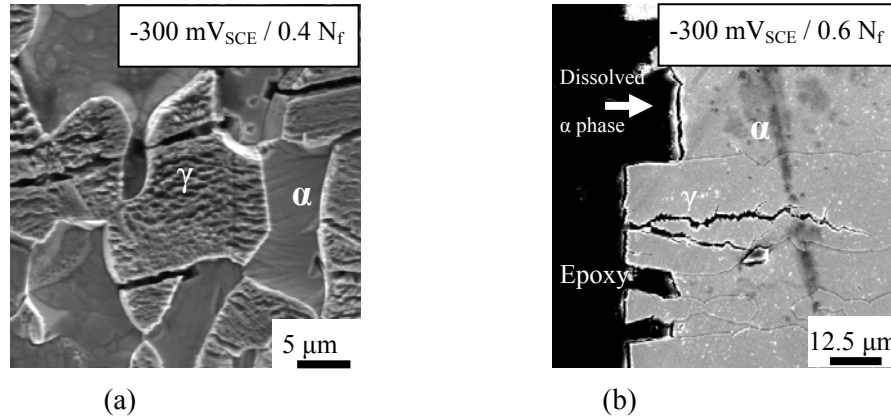


Fig. 5. SEM micrographs showing the surface and cross section morphologies of 2205 duplex stainless steel after interrupted fatigue test at $-300 \text{ mV}_{\text{SCE}}$ for (a) $0.4 N_f$ cycles, (b) $0.6 N_f$ cycles, in $2 \text{ M H}_2\text{SO}_4 + 0.7 \text{ M HCl}$ aqueous solution

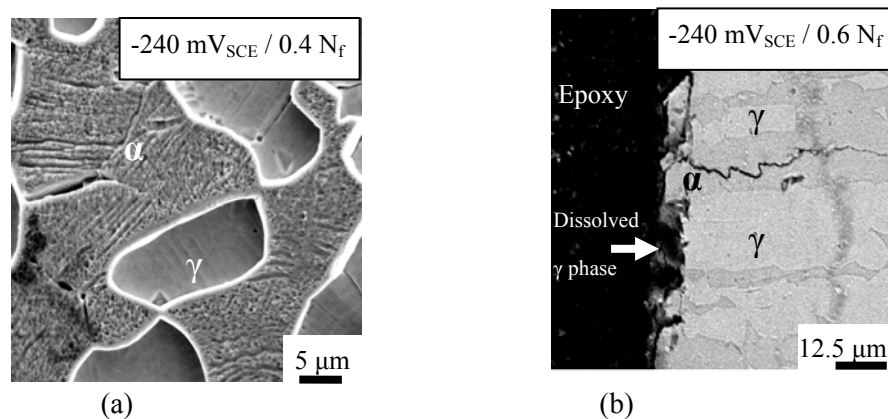


Fig. 6. SEM micrographs showing the surface and cross section morphologies of 2205 duplex stainless steel after interrupted fatigue test at $-240 \text{ mV}_{\text{SCE}}$ for (a) $0.4 N_f$ cycles, and (b) $0.6 N_f$ cycles, in $2 \text{ M H}_2\text{SO}_4 + 0.7 \text{ M HCl}$ aqueous solution

CONCLUSIONS

Preferential dissolution in duplex stainless steel could occur in mixed $\text{H}_2\text{SO}_4 / \text{HCl}$ solution at specific potentials. Selective dissolution affected fatigue crack initiation in 2205 DSS in mixed $\text{H}_2\text{SO}_4 / \text{HCl}$ aqueous solution in a complicated manner. The elimination of stress concentration site by selective dissolution could retard fatigue crack initiation in such acidic solution.

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