Study on Fracture Analysis of $(\alpha+\gamma)$ Dual Phase Stainless Steel Using X-ray Diffraction

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ABSTRACT

In this study, X-ray fractography(1)~3) technique was applied to the $(\alpha+\gamma)$ dual phase stainless steel. Effect of the rolling direction on fatigue properties was discussed. Residual stress near the surface was measured by using X-ray diffraction method to the depth direction. Relations between X-ray parameter and fracture mechanics parameter were examined. As the result, distribution of the phase stress in the ferrite phase was related with the maximum stress intensity factor divided by the 0.2% proof stress.

INTRODUCTION

X-ray diffraction observation4) of metal fractures provides us with useful information on the mechanisms and mechanical conditions of fracturing. This method has been developed especially as an engineering tool for fracture analysis. In the present paper, X-ray fractogarphy technique is applied to fatigue fracture surface of dual phase stainless steel which is used for chemical plant and the oil pipes5). Dual phase stainless steel is a composite material which consists of ferrite (α-Fe) and austenite (γ-Fe) phases. This material excels in corrosion-resistance in the chlorinated environment. Many researchers studied the dual stainless steels such as; studies on the influence of the volume fraction of austenite phase6)7), material structure8)9) and aging10) of the material on the fatigue strength; the fatigue strength of the welded section11); the microscopic observation of the initial fatigue crack12); the crack growth property13) 14) under both normal and corrosion conditions15). However, studies using the X-ray fractography technique on dual phase stainless steels have not been done. In this study, fatigue tests of the dual phase stainless steels were conducted by using compact tension (CT) specimens. X-ray fractography technique was applied on the fatigue fracture surface of the material. In addition, influence of rolling direction on the fatigue mechanism of the material was discussed.

EXPERIMENT PROCEDURE

The specimen used are dual phase stainless steel (JIS-SUS329J4L) as rolled. The chemical composition of the material is listed in Table I. The mechanical properties of materials are given in Table II. Optical metallography (Fig.1) shows that specimen has a rolled microstructure. The direction of RD (the rolling direction is parallel to the crack growing direction) and the direction of TD (the rolling direction is perpendicular to the crack growing direction) were used for specimens with two directions to grow the crack. A schematic is shown in the direction, which cuts Fig.1. The volume fraction of γ phase is about 50%.

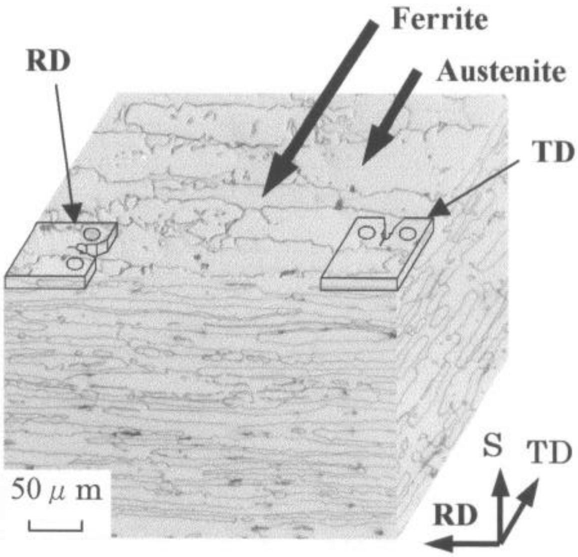


Fig.1 Typical microstructures of test materials and the direction of the crack

A servo-hydraulic closed loop testing machine was used for fatigue tests, and the crack length was measured with a traveling microscope. The fatigue tests were conducted under constant range of stress intensity factors with stress ratios R of 0.5.Figure 2 shows the test specimen which has a starter notch and a pre-fatigue crack of 2 ㎜ in length .The fatigue crack growth test was conducted under the constant R condition. The frequency was 10 Hz.

Residual stress at the fracture surface was measured by using an X-ray diffraction stress analyser. The irradiated area was 2×6 ㎜^{2} and was located on the fatigue fracture surface (made under constant stress ratio) at the middle of the specimen. The conditions of X-ray diffraction are listed in Table Ⅲ . The distribution of the stress in the depth direction was measured by removing the surface layer successively by the electro-polishing.

Table I Chemical compositions.[wt.%]

C	Si	Mn	P	S	Cr	Ni	Mo	Cu	Al	W	N
0.029	0.48	0.88	0.02	0.0004	24.80	7.17	3.02	0.45	0.07	0.30	0.18

Table Ⅱ Mechanical properties of test material.

Code	Structure	0.2% proof stress $\sigma_{0.2}$, MPa	Tensile strength σ_B, MPa	Elongation ε_l, %
JIS-SUS329 J4L	Ferrite+Austenite	625	824	25

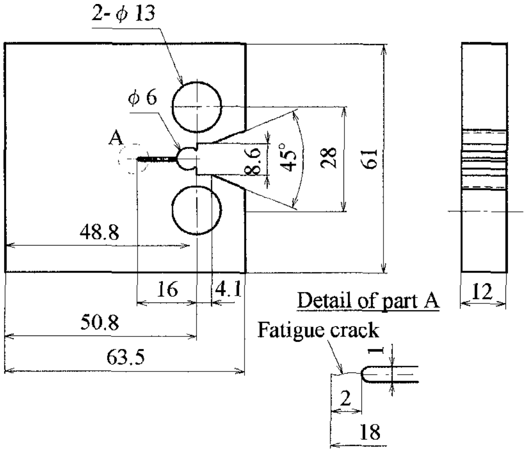


Fig.2 Dimension of test specimen (in mm).

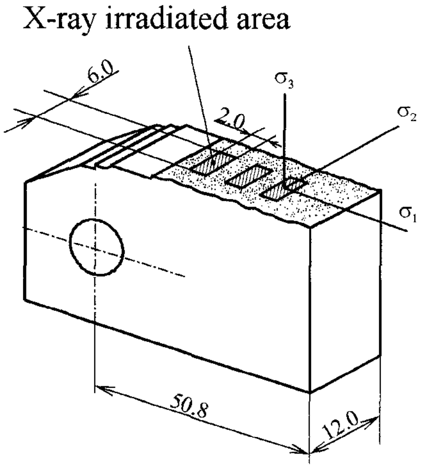


Fig.3 Schematic illustration of X-ray irradiated area on the fracture surface (mm).

Table Ⅲ X-ray condition for stress measurement.

X-ray optics	Ω-Goniometr	
Characteristic X-ray	Cr-Kα	V- Kα
Diffraction plane	α211	γ220
Filter	V	Ti
Diffraction angle, deg.	153.5	157.8

EXPERIMENTAL RESULTS

Fatigue crack growth properties

The crack growth rate, da/dN was plotted against the stress intensity factor range ΔK as shown in Fig.4. The area which da/dN is from 10^{-8} to 10^{-7} indicated the stable fatigue crack growth area under the small scale yield condition and crack grows linearly against the ΔK. Thus for this area Paris law$^{16)}$ which is shown in the following equation are met.

$$da/dN = C(\Delta K)^m \qquad (2)$$

Next, in the case of area where da/dN is under 10^{-8}, ΔK_{th}(indicated as the symbol narrows in Fig.4) of both specimens become about 11～12MPa$\sqrt{m}$ which is higher than other steels and stainless steels. The study on similar dual phase stainless steel$^{13)15)}$ shows ΔK_{th} =6~8 MPa$\sqrt{m}$. Since differences between TD and RD specimens are small, it seems rolling directions did not affect the fatigue crack growth.

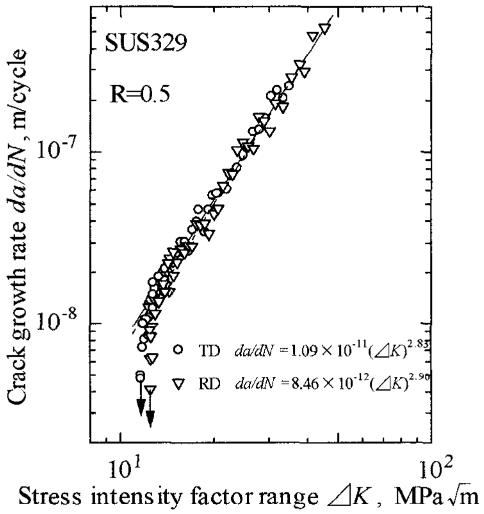
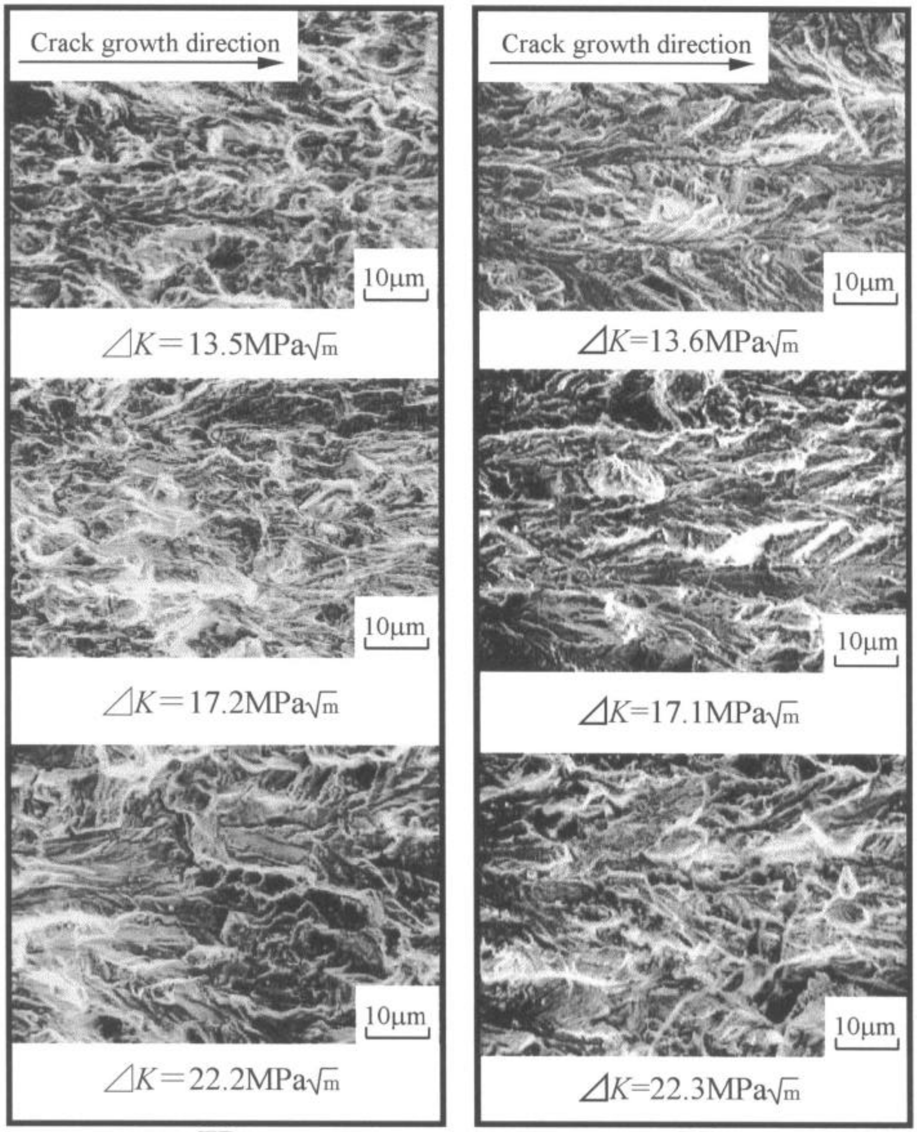


Fig.4 Relation between fatigue crack growth rate and stress intensity factor range under R=0.5

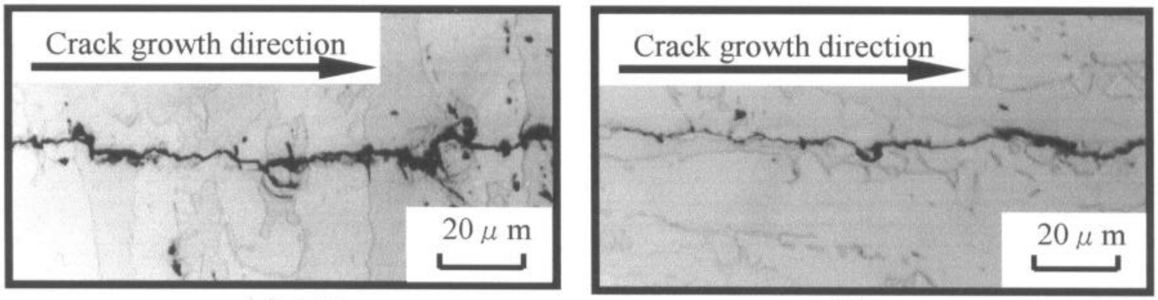
Observation of the fracture and the crack

Fig.5 shows the observation results of fracture surface. Destruction surface is about similar about ΔK . Destruction forms are transgranular fracture on both TD and RD specimens. Fig.6 shows the example of the observation result of the fatigue crack growth behavior. The observation result of the growing conduct of the crack shows that it advances in the ferrite and the austenite phases about the crack irrespective of the rolling direction. A difference by the rolled directions wasn't confirmed from the fracture observation. In addition, a difference by the ΔK was not seen.



TD RD

Fig.5 Fractographs fatigue fracture surface of test material.



(a) TD (b) RD

Fig.6 Optical micrograph of fatigue crack path for SUS329J4L.

X-ray measurement under the fatigue destruction

Fig.7 shows the distributions of residual stress near the surface TD(a) and RD(b) incidentally. For the ferrite phase, as deeper layer were measured, tensile residual stress gradually changed into compressive stress and the stress approached to a constant value at certain depth(which marked on Fig.7). For the austenite phase, tensile residual stress decrease as deeper layer were measured and reached to constant value. Here, the residual stress of ferrite phase remained with the compression inside the material but of austenite phase remained with tensile. Also, the depth where residual stress take local maximum value and the depth where the stress take constant value were deeper in the ferrite phase than in the austenite phase.

Plastic zone depth

The depth where residual stress becomes constant is assumed to be the plastic zone depthω_y (which indicated in Fig.7). Fig.8 shows relationship between plastic zone ω_y and the $K_{\max}/\sigma_{0.2}$. The relation between ω_y and the $K_{\max}/\sigma_{0.2}$ was approximated as straight line in both logarithm plots. The relation can be shown by as follows:

$$\left.\begin{aligned}
\omega_y &= 0.157(K_{\max}/\sigma_{0.2})^2 \quad \text{TD} \quad \text{(ferrite phase)} \\
\omega_y &= 0.076(K_{\max}/\sigma_{0.2})^2 \quad \text{TD} \quad \text{(austenite phase)} \\
\omega_y &= 0.157(K_{\max}/\sigma_{0.2})^2 \quad \text{RD} \quad \text{(ferrite phase)} \\
\omega_y &= 0.104(K_{\max}/\sigma_{0.2})^2 \quad \text{RD} \quad \text{(austenite phase)}
\end{aligned}\right\} \qquad (3)$$

In the case of ferrite phase, both specimens showed the same the value(0.157). From the analysis of failure accidents, the maximum stress intensity factor can be determined from the measurement of the maximum plastic zone determined from the residual stress of ferrite phase and equation (3).

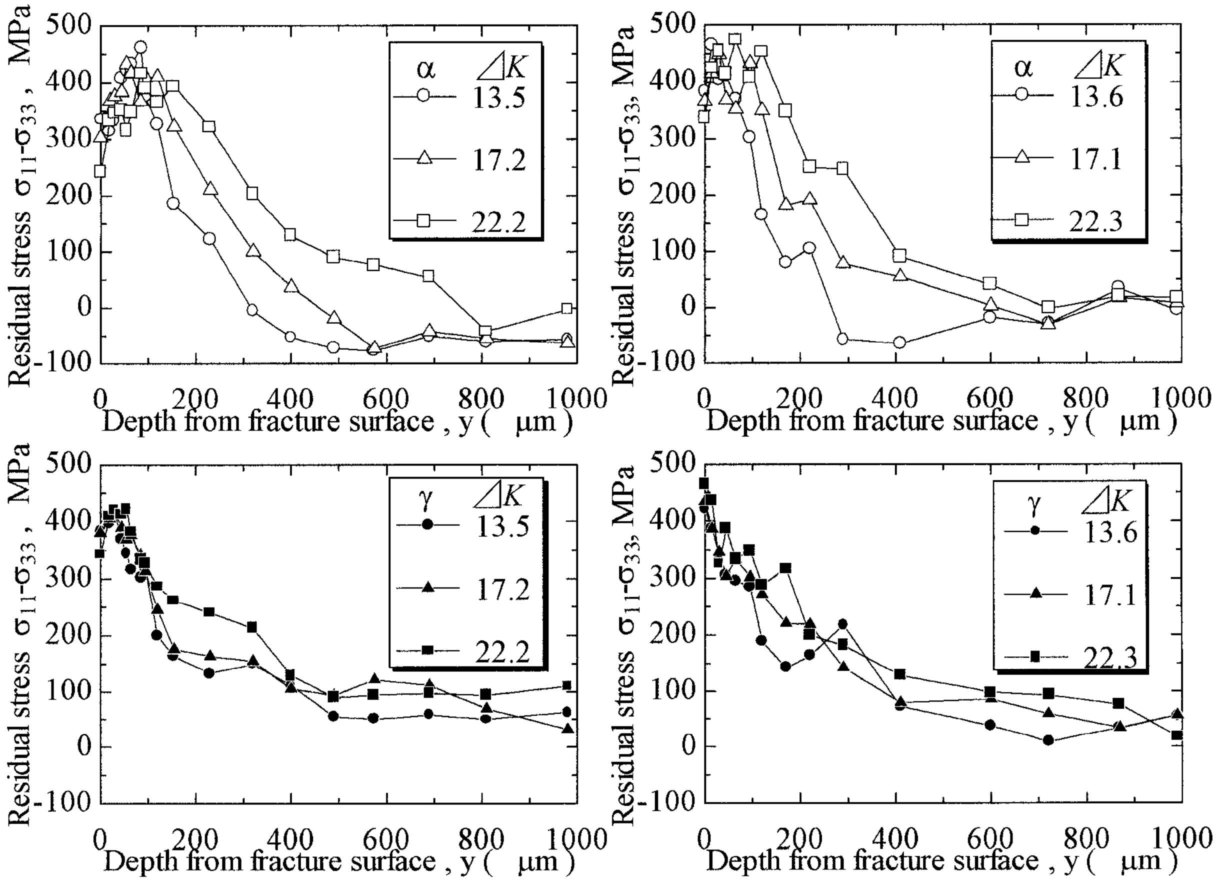
CONCLUSION

(1) The properties of fatigue crack growth do not depends on the rolling direction.

(2) The maximum depth of plastic zone ω_y determined from residual stress was correlated to $K_{\max}$ and the 0.2% proof stress as follows:

$$\omega_y = \alpha'(K_{\max}/\sigma_{0.2})^2$$

where α' is 0.157 for the case of phase stress in the ferrite phase (from calculation using FEM, $\alpha' = 0.15$). In addition, there was no influence of the crack growth direction to the rolling direction.



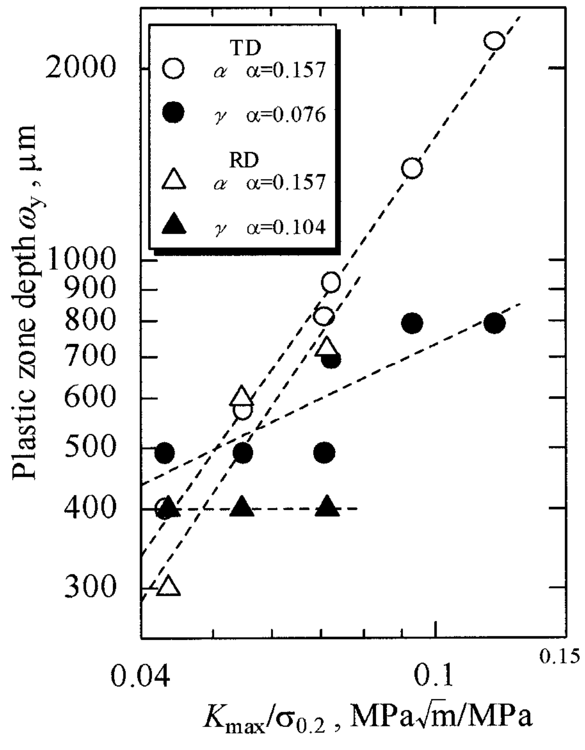


Fig.8 Relation between plastic zone size and maximum stress intensity factor.

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