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OPTICAL MICROSCOPIC EVALUATION OF START OF CRACK GROWTH OF STAINLESS STEEL (SS-202)

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Abstract- *The objective of the present study is to develop a method of prediction to evaluate start of crack growth from persistent slip bands (PSBs) in low cycle fatigue of stainless steel using an optical microscope during the early stages of its fatigue life. Changes in the surface of the material under constant cyclic loading at three different stress amplitude were measured. Upto 10 percent of fatigue life the length of the slip band remains unchanged and then start to increase for all cases of investigation. Increasing the length of PSBs indicates the start of crack growth.*

Keywords: Optical microscopy, Crack growth, Prediction method

1. INTRODUCTION

Fatigue is one of the primary reasons for the failure of the structural components. The life of a fatigue crack has two parts namely initiation and propagation. Dislocations play a major role in the fatigue crack initiation phase. It has been observed in laboratory testing that after a large number of loading cycles dislocations pile up and form structures called persistent slip bands (PSB).The persistent slip bands have a unique stress-strain curve, caused by the backward and forward motion of screw dislocations between the walls. Many authors have worked on these structures, and their main features are widely agreed. Persistent slip bands lead to the initiation of fatigue cracks, because where they intersect the external surface of the material, they cause stress concentrations and generate intrusions, which follow the interface between the persistent slip band and the matrix within which it is embedded [1-6]. In this study we monitor the change in length of PSBs those are appear as a black line under optical microscope.

2. Material and Methods

The material investigated was austenitic, chromium-nickel-manganese alloy stainless steel SS202. The shape of specimen is shown in Fig.1 .The chemical compositions and mechanical properties of tested material are shown in table 2.1 and 2.2 respectively.

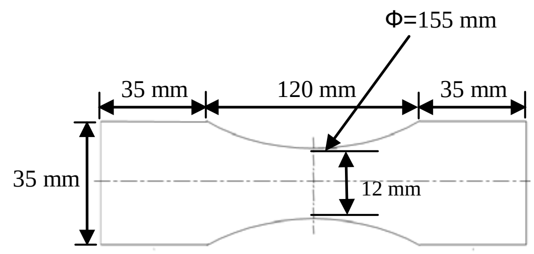

Fig. 1: Specimen configuration

Table 2.1 Chemical compositions (wt%)

C	Cr	Ni	Mn	Si	P	S	N	Fe
0.15	17-19	4-6	7.5-10	0.75	0.06	0.03	0.25	Ba

Table 2.2 Mechanical properties

E (GPa)	ν	σ_Y (MPa)	σ_U MPa)
190	0.27	270	515

Fatigue testing was performed by using MTS810 for plane bending loading at room temperature. The specimens were prepared followed ASTM E606 and fine polished by emery paper of the grade of 800, 1000, 1200, 1500 and 2000. In order to monitoring the start of crack

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growth (start to increase length of the slip band, appeared as a black line on optical microscope), we observed the surface of the specimen by optical microscope. To evaluate the cyclic load at the start of crack growth, the experiment was done very carefully. Determining the length of PSBs before and after loading, the start of crack growth was detected. At first, at the zero cycle the image of fine polishing specimen was taken from optical microscope microstructure. Then the specimen was attached in fatigue testing machine by the fixture. The amount of load applied on the material surface was between the limit of yield strength and ultimate strength as shown in table 2.3. To apply these bending load on the specimen, the handle of spring loaded device was rotated in clockwise direction and immediately again rotated in anticlockwise so that the specimen became in balance position. Thus one cycle was completed. We observe the surface after 100 cycles. The experimental flow chart is shown in Fig.2.

Table 2.3 Experimental stresses

Stress (MPa)	Load (Newton)
275 (σ_Y)	
375	145
400	160
450	180
515 (σ_U)	

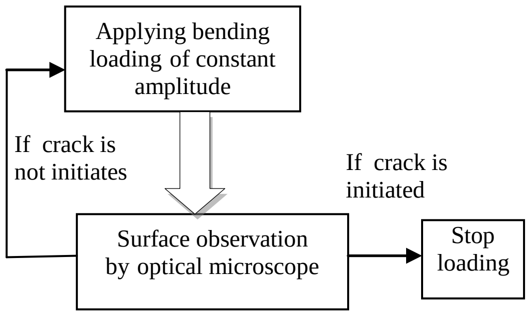

Fig.2 Experimental flow chart

2.1 Optical microscope observation area

The center portion edge (2×2 mm^2) of the test piece is taken into consideration for observation because it is confirmed that around 95% cracks were initiated within this range. Twenty (20) optical microscope images (one picture = 628×468 μm^2) were taken within 2×2 mm^2 area as shown in Fig.3.

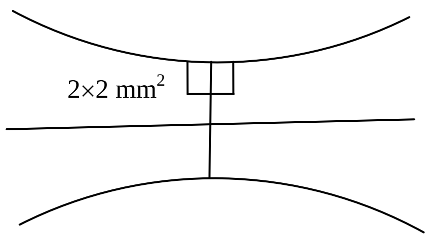

Fig.3 Optical microscope measurement area

3. Experimental Results and Discussion

Figure 4 and 5 show typical optical microscope images of different number of cycles at 400 MPa and 450 MPa respectively. The persistent slip bands (PSBs) (from where crack initiated) are located in the optical images indicated by the arrows. In the optical microscope observations of the same location, the length of the black line (slip band) remains constant during the period (N=1000 to 7000 cycles as shown in Fig. 4 and N=100 to 1500 cycles as shown in Fig. 5). The slip band begins increasing in length at N=7500 cycles and N= 2500 cycles for two stress amplitude (400 MPa and 450 MPa) respectively indicating the start of crack growth from a crack initiated along a PSB. The result in Fig.4 shows that the crack was initiated from PSBs not from scratch (around 5µm width). In comparison to Fig. 4 and Fig. 5, it is found that the PSBs evolution is higher at high stress amplitude. Figure 6 shows the relationship between number of fatigue cycle to the length of the slip band at stress of 450 MPa for three different PSBs location and found a region of crack initiation.

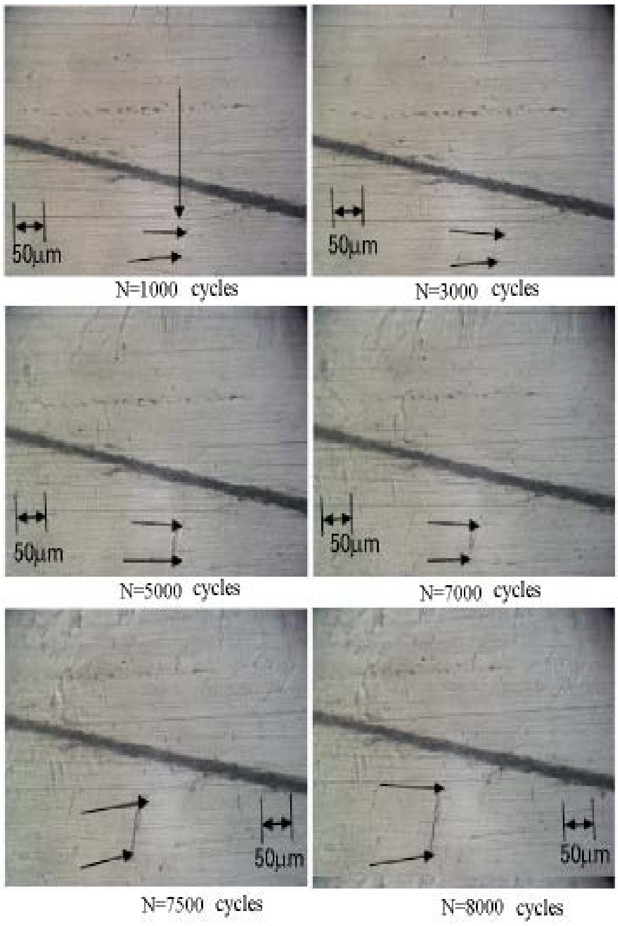

Fig.4 Optical microscope image at 400 MPa

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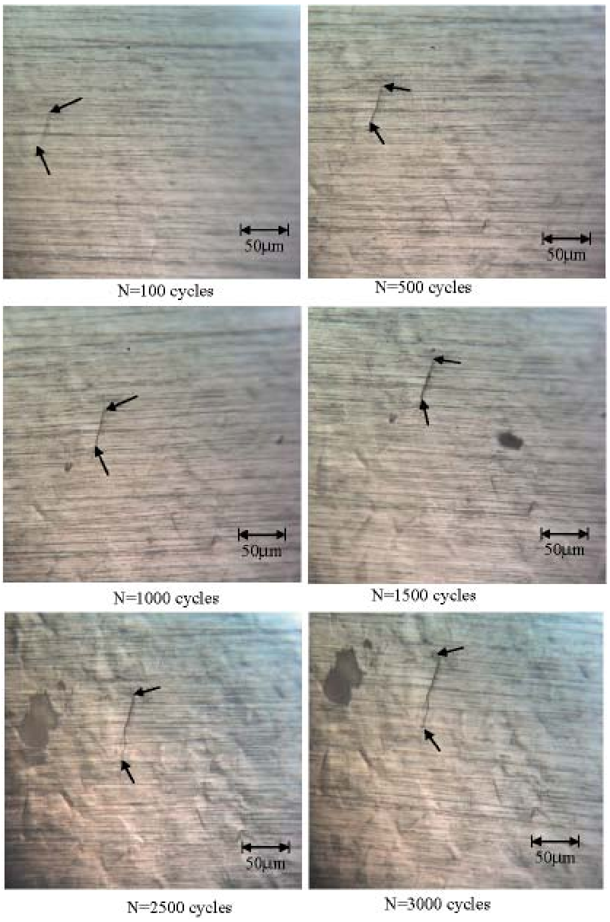

Fig.5 Optical microscope image at 450 MPa

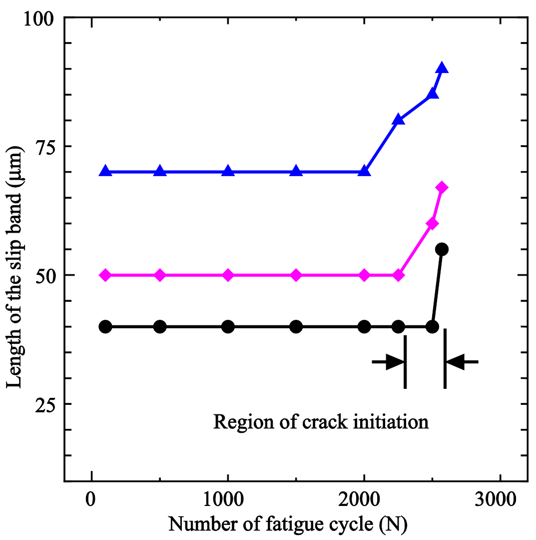

Fig.6 Optical microscope image at 450 MPa

3.1 Fatigue life curves

We can predict the start of crack growth using Basquin law which relates the stress amplitude to number of fatigue cycles are given in Eq. 1.

$$\sigma_a = \sigma'_f \left(2N_f\right)^b \qquad (1)$$

where σ_a is the stress amplitude, N_f I the number of cycle to failure, σ'_f is the fatigue strength coefficient and b the fatigue strength exponent are shown in Table 3.1 [8] . Assuming $\sigma_f = \sigma_i$, $N_f = N_i$ and $\sigma'_f = \sigma'_i$.

Table 3.1 Parameters of the fatigue life curves

Type of cyclic loading	σ'_f (Ref), σ'_i(Exp) (MPa)	b
Constant stress [8]	1163	-0.074
Constant stress [exp]	1063	-0.101

Figure 7 shows the results from ref 8 and experimental value using constant are given in table 3 and found the well agreement of experimental results to simulated results ref. value)

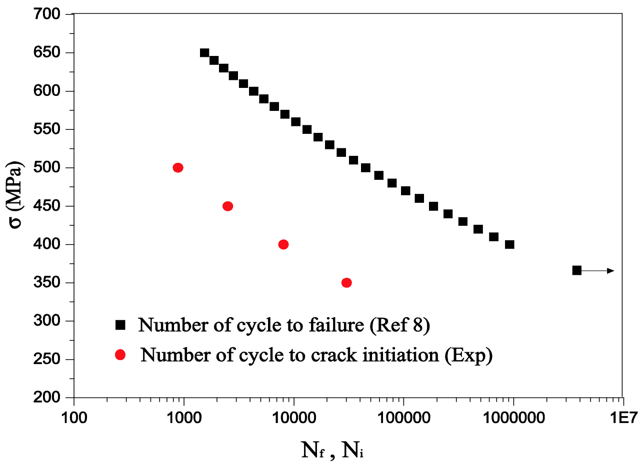

Fig.7 Relation between stress amplitude and number of cycle to failure and number cycle to crack initiation.

4. Conclusion

► Around 10 percent of fatigue life the length of the slip band remains unchanged and then start to increase increasing the length of PSBs indicates the start of crack growth.

► We can predict the start of crack growth within 5% accuracy.

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7. NOMENCLATURE

Symbol	Meaning	Unit
E	Modulus of elasticity	GPa
ν	Poisson ratio	-
σ_Y	Yield stress	MPa
σ_U	Ultimate stress	MPa
σ_a	Stress amplitude	MPa
σ'_f	Fatigue strength coefficient	MPa
b	Fatigue strength exponent	-
N_i	No. of cycle to failure	-
N_f	No. of cycle to crack initiation	-

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