SOME ASPECTS OF SMALL FATIGUE CRACKS UNDER VARIABLE STRESS RATIOS

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Recently, the hard unexpected accidents caused by fatigue fracture phenomena have been increased in any field. The fatigue crack mechanism has many obscure organizations for initial crack and micro-rack propagation. An indefinite problem is remaining about the fracture mechanics property from the occurrence of the crack to the short crack area. This paper experimentally clarifies the crack progress property by the difference with the notch shape of specimen and applied load conditions. In order to observe dynamic behavior of micro crack with scale of grain size, the microscope with 1000-times magnification was used. First, the relation between the crack growth rate and the stress intensity factor by the difference with angle of notch is investigated when the stress ratio is positive. Secondly, the opening and closing stress is disputed and the crack growth rate is also investigated when the stress ratio is changed in the loading condition.

EXPERIMENTAL PROCEDURE

Experiment specimen

The steel material used to experiment is SS400 (Japan Industrial Standards) with 280MPa for yield point. The chemical composition of this steel is 0.16%C, 0.17%Si, 0.63%Mn, 0.013%P, 0.006%S. The shape dimension of specimen is shown in Figure 1. The surface of specimen is ground by water polishing paper #2000 to observe the fatigue crack. In addition, the surface is finished up with alumna solution 0.05 μ m . In order to detect the grain boundary, the etching is processed by 3% nitric acid alcohol.

Experimental methods

The equipment used to experiment is maximum capacity 250KN hydraulic servo fatigue test machine. Load cycle number is 10Hz. Three strain gauges were fastened from the notch point to 1mm, 2mm, and 3mm points for the detection of the crack opening and closing point stress. The dynamic observation technique with 1000-times optical microscope was used in the measurement of the crack length at the crystal grain level. The image of the monitor caused by the cycle load was observed by the stroboscope's synchronizing as a geostationary screen. The crack growth rate was obtained by using the time counter in the monitor.

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EXPERIMENTAL RESULT AND DISCUSSION

Behavior of crack generation

A lot of minute cracks occur near the machine notch point along the grain boundary before the crack occurs. The crack that develops especially in the minute crack becomes a main crack. The crack spreads along the grain boundary in the process zone. The process zone of stripes pattern appears in the front of notch to a direction of 45° and 135° against operation axis of applied load. The crack grows up repeating progress and stopping in the process zone.

Effect of depth and angle of notch in short crack

When the angle in the notch point is made constant, the relation between the crack length and the crack growth rate by the difference of the depth of the notch was investigated here. It is understood that there is an area where the crack growth rate decreases from the speed of the initial crack from this result. The short crack area increases to about 0.5mm-1.2mm from machine notch as the depth of the notch increases to 3, 5, and 6mm. Moreover, the short crack area is located from the notch point within the range of the distance of about 0.7mm-1.4mm, and this area moves to the following stability crack area. The short crack is an area until changing to the stability crack. The stability crack is a monotonous increasing one, and the increasing rate is fixed regardless of the depth of the notch.

On the other hand, when the depth of the notch is made constant, the relation between the crack growth rate and crack length was investigated by the difference of the angle of the notch. The growth rate of the initial crack becomes 10^{-4}-10^{-5} mm/cycle as the angle in the notch increases to 60° , 90° , and 120° . This growth rate decreases within the range of 10^{-5}-10^{-6} mm/cycle as the crack length increases. The crack growth rate increases along with making the angle of notch an acute one. This rate has the decreasing and increasing area on the boundary of the minimum value of the stability crack regardless of the notch shape. The decreasing rate of the crack growth one decreases as the angle of the notch increases when paying attention in the short crack area. Figure 2 shows relation between crack growth rate and stress intensity factor by difference of angle of notch. Thus, it can be seen that the short crack area will be strongly influenced by the angle of the notch.

Relation between angle of notch and crack opening and closing stress

The dynamic stress-strain curves in a short crack area 1mm away from the notch point were achieved by using the dynamic strain gauge. Crack opening and closing stress σ_{COC} becomes each 30MPa, 40MPa, and 60MPa respectively at the value of 60° , 90° , and 120° in angle of the notch. The degree of the stress concentration rises if the angle of the notch has an acute angle. In a word, the load $d\sigma$ ($= \sigma_{max} - \sigma_{COC}$) becomes a driving power of the crack progress directly. Therefore, the crack growth rate quickens if the angle of the notch becomes an acute angle. Thus there is a correlation between the angle of the notch and the crack opening and closing stress.

Crack progress property by difference of stress ratio

The effect to the crack progress behavior by the difference of the stress ratio that contains the positive and both amplitude tests was carefully thought about here. Load condition, stress ratio, and each load type used by this experiment are shown in Table 1.

Table 1 Applied loads and Stress Ratio

Specimen	σ max(MPa)	σ min(MPa)	Stress Ratio R
Case 1	93.7	37.5	0.4
Case 2	93.7	18.7	0.2
Case 3	87.5	1.7	0
Case 4	62.5	-15.6	-0.25
Case 5	62.5	-31.3	-0.5
Case 6	62.5	-46.8	-0.75

The experiment value of crack opening and closing stress σ_{COC} by the difference of stress ratio R were obtained from the dynamic strain gauge fastened from notch's point to 1mm point. As for case 1 and case 2 of stress ratio R>0, about 20% of the amplitude of the total stress occupies to the crack opening and closing stress, and it is understood 80% of the remainder is effective directly as a driving power of crack progress. Next, it can be confirmed that σ_{COC} in case3 of stress ratio R=0 is about 20% of the amplitude of the total stress as well as the case of stress ratio R>0.

On the other hand, it has been understood that σ_{COC} is corresponding to the position of 0 of applied stresses for case 4, case 5 and case 6 in both amplitude tests of stress ratio R<0. Figure 3 shows σ_{COC} in the case of R=-0.75. Thus, the driving power of crack progress is corresponding to all the tension side loads for stress ratio R<0. The relation between the ratio of σ_{COC} /total amplitude of applied stress and stress ratio R is shown in Figure 4. These are almost in a straight line relation. The value of σ_{COC} /total amplitude of applied stress increases like 25% as for case 4, 35% as for case 5, and 42% as for case 6 in stress ratio R<0 region.

The relation between the crack growth rate and the crack length when stress ratio R is a positive and negative were shown in Figure 5(a), (b) respectively. The crack growth rate da/dN decreases as stress ratio R becomes smaller in the case where R is negative. The crack growth rate increases as R does bigger in stress ratio R>0 region.

Image analysis of crack progress by difference of stress ratios

The crack progress behavior can be divided roughly into three items as follows. One is a grain boundary crack that progresses along the grain boundary. The second is a crack in the grain, which penetrates in the crystal grain, and the remains is behavior that stops at the front of certain crystal grain. The distinction whether it was a crack in the grain boundary or the grain was performed from the spread route of the crack collected to the video screen. The crack in grain boundary was 86.5 %, and corresponding one in the grain was 13.5% where the stress ratio was R>0. On the other hand, it has been understood that the crack of grain boundary was 55.0%, and the crack in the grain became 45% where R was negative. The fraction of the crack in the grain increased in the both amplitude fatigue tests. Tracks of the fatigue crack in the case where R is negative are shown in Photograph 1. Black tracks in the photograph show the crack of grain boundary and white marks indicate the crack in the grain. The slip lines caused before the crack were more remarkably observed in the case where R was negative as shown in Photo.1 (b).

Vickers's hardness measurement

After the fatigue tests, the hardness of the crystal particle was achieved by the Vickers's hardness measurement when applied load time was 30sec. The results were 294 at the edge of crack and 163 at the point from the crack edge by 5-6 particles in the case R>0. On the other hand, the corresponding values were 373 and 181 respectively in the case R<0. Thus, Vickers's hardness number of particles in the case R<0 were higher than those of the case R>0 regardless of measurement points. Moreover, the hardness of the neighborhood point of the crack is higher than those of far away point of crack regardless of the stress ratio.

CONCLUSIONS

The conclusion obtained from this research is described as follows.

(1) The crack spreads along the grain boundary in the process zone. The process zone of stripes pattern appears in the front of notch to a direction of 45° and 135° against operation axis of applied load.

(2) The crack growth rate increases along with making the angle of notch an acute one. This rate has the decreasing and increasing area on the boundary at threshold intensity factor of the stability crack heedless of the notch shape.

(3) The crack growth rate quickens if the angle of notch becomes an acute angle. There is a correlation between the angle of notch and the crack opening and closing stress.

(4) About 20% of the amplitude of the total stress occupies to the crack opening and closing stress, and it is understood that 80% of the remains is effective directly as a riving power of crack progress for stress ratio R>0. Conversely, the driving power of crack progress is corresponding to all the tension side loads for stress ratio R<0.

(5) The relation between the ratio of σ_{COC} /total amplitude of applied stress and stress ratio R has almost a straight line relation.

(6) The fraction of the crack in the grain extended in the both amplitude fatigues tests. Vickers's hardness number of particles in the case R<0 were higher than those of the case R were>0 regardless of measurement points.

Acknowledgement

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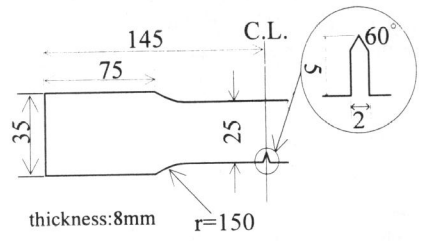


Fig.1 Shape of specimen

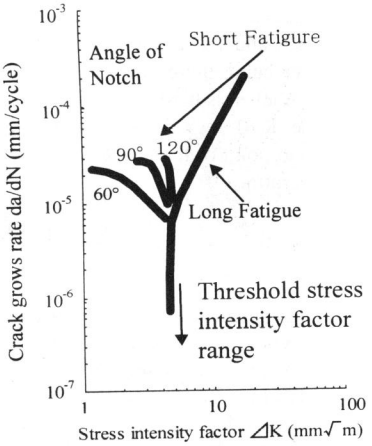


Fig. 2 Relationship between da/dN and ⊿K

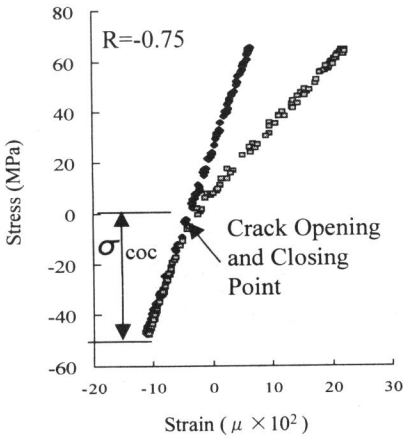


Fig.3 σ_{coc} in the case R=-0.75

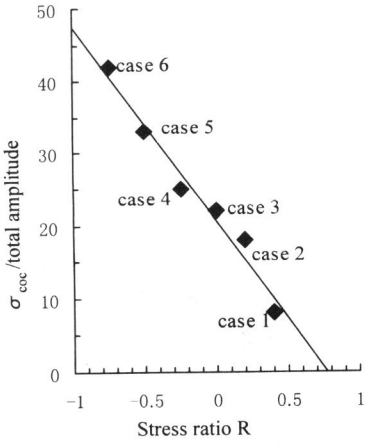
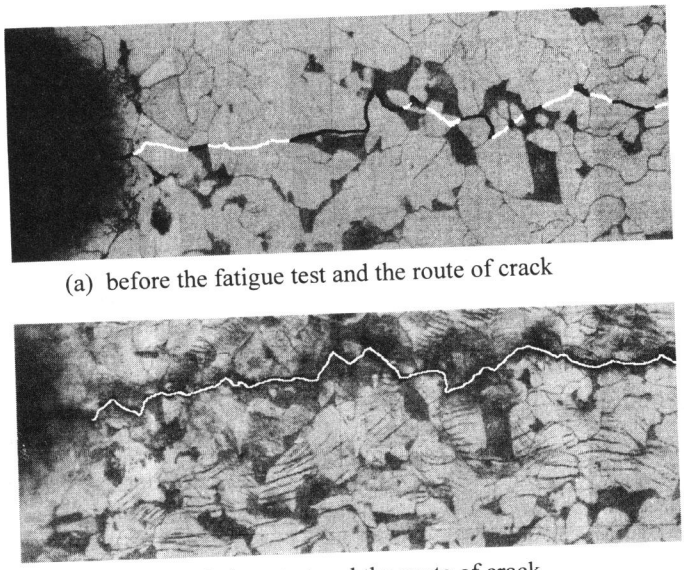


Fig.4 Relationship between σ_{coc}/TA and stress ratio



(a) before the fatigue test and the route of crack

(b) after the fatigue test and the route of crack

Photo.1 Image analysis of crack progress (within 1.7mm from machine notch)

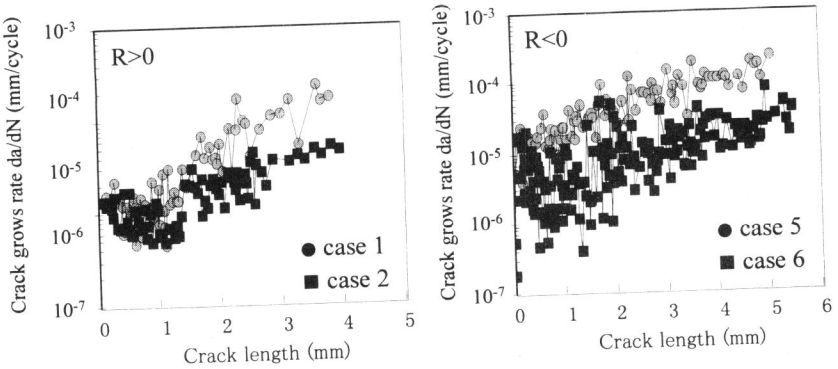


Fig.5 Relationship between da/dN and crack length