BIII-8

ANISOTROPY OF FATIGUE CRACK PROPAGATION OF A LOW ALLOY STEEL

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ABSTRACT

To study the stage of fatigue which the anisotropy of fatigue strength of steel occured, the surface of specimens were observed by a microscope under the magnifications of 100 or 400 times and the length of the fatigue crack was measured.

In plain specimen, the anisotropy of fatigue strength occured at both the initiation and propagation stages.

In notched specimen, when the nominal stress is lower than the endurance limit of plain specimen, crack propagation speed does not show the anisotropy. When the nominal stress is higher than the endurance limit of plain specimen, the anisotropy of crack propagation speed is comparatively larger than that of the lower nominal stress.

INTRODUCTION

Many experimental results have shown the anisotropic character of the fatigue properties of forgings and plates. (1, 2, 3, 4, 5) But it is not well known that at which stage of fatigue the anisotropy occurs, that is at the stage of initiation of crack, at the stage of propagation of crack or at final fracture.

MATERIAL

Test material was a 0.3C-3Ni-0.45Mo-0.1V steel forgings which was added 0.090 % sulfur to give anisotropic properties. The forging rate of the forgings was 1.4. The specimens were cut from the surface portion of the 210 mm square forgings. The chemical composition and conventional mechanical properties are given in Table 1 and 2.

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TESTING PROCEDURE

Testing machine used was a fully reversed bending type machine. The plain specimen was 3.5 mm in thickness and 5 mm in width. Notched specimen was 3.5 mm in thickness, 20 mm in width and had a drilled center hole of 2 mm in diameter. The surface of specimen were mirror surface finished by mechanical polishing.

After some reversals of stress the testing machine was stopped and the surface of the specimen were observed by a microscope under the magnification of 100 times or 400 times and the length of fatigue crack was measured.

EXPERIMENTAL RESULTS AND DISCUSSION

S-N diagrams are shown in Fig. 1. Plain specimen shows a distinct anisotropy and the endurance limit of transverse specimen is 88 % of the longitudinal one. But the notched specimens show little anisotropic character on the S-N diagram.

Fig. 2 shows N plotted against the half crack length l measured on the specimens cycled at $\pm$ 45.5 kg/mm^2. In the transverse specimen many cracks start at non-metallic inclusions and the cracks grow longer by joining of the individual crack. In the longitudinal specimen cracks start mainly in the matrix and not at inclusions. Because of the effect of inclusions the initiation of crack in the transverse specimen is sooner and the development of crack is faster than those in the longitudinal one.

Fig. 3 shows N plotted against l measured on the notched specimen cycled at 35.0 kg/mm^2. In this case cracks start in the vicinity of the center hole and when the inclusion is present at the portion the crack initiation is accelerated, especially in the transverse specimen.

The number of stress cycle to grow the crack of about 0.1 mm half length shows comparatively wide range. This is caused by the presence or not of inclusions in the vicinity and that on the transverse center line of the hole.

At all stress levels studied it was seen that dl/dN is nearly constant over the range l/b (b = half width of the specimen) = 0.01 - 0.1. Log dl/dN in this range plotted against the stress level is shown in Fig. 4 for plain specimen and in Fig. 5 for notched specimen.

In Fig. 4 the relation is nearly linear and the difference between the transverse and longitudinal specimen is small at higher stress level. At the higher stress level fatigue cracks have the tendency to initiate not only at inclusions but also in the matrix and join together. Thus the difference between the transverse and longitudinal specimens becomes smaller with the increase of stress level.

In Fig. 5 at the stress higher than 40 kg/mm^2 the crack propagating speed dl/dN of a transverse specimen is a little greater than the speed of a longitudinal one, but at the stress lower than 35 kg/mm^2 the difference is not seen.

The reason of this phenomena is considered as follows. The endurance limit of plain transverse specimen of this material is 36 kg/mm^2, accordingly when the notched transverse specimen is stressed at the higher nominal stress than 36 kg/mm^2 the fatigue damage occurs not only in the vicinity of the hole but also in the whole width of the specimen. At the stress lower than the endurance limit of transverse specimen the first fatigue crack takes place in the vicinity of center hole and propagates outside. It is seen that the crack propagation is accelerated when a fatigue crack approaches a inclusion, but the length occupied by inclusions along the path of fatigue crack is very short than the length occupied by matrix. In the used material which contains so much sulfide the path occupied by inclusions in only 1 % of the total length. Thus the crack propagating speed does not show the anisotropy at the stress lower than 35 kg/mm^2.

SUMMARY AND CONCLUSIONS

To study the stage of fatigue which the anisotropy of fatigue strength of steel occured the longitudinal and transverse bending fatigue specimens were cut from a 0.3C-3Ni-0.45Mo-0.1V steel forgings which contained a large amount of sulfide. The surface of specimens were observed by a microscope under the magnifications of 100 or 400 times and the length of the fatigue crack was measured.

The conclusions are as follows.

1. Plain specimen

In both the initiation and propagation stages the anisotropy is present and this results from inclusions. At the higher stress level fatigue cracks have the tendency to initiate not only at inclusions but in the matrix. Thus the difference between the crack propagating speed of the longitudinal and transverse specimens becomes smaller with the increase of stress level.

2. Notched specimen

2.1 When a inclusion is present in the vicinity of a notch the crack initiation is accelerated, especially in the transverse specimen.

2.2 When a notched transverse specimen is stressed at the higher nominal stress than the endurance limit of the plain specimen, the fatigue damage occurs not only in the vicinity of the notch but in the whole width of the specimen. Thus the effect of inclusion takes place and the crack propagation speed in the transverse specimen is greater than the speed in the longitudinal one.

2.3 When the nominal stress in lower than the endurance limit of the plain transverse specimen the first fatigue crack appears in the vicinity of notch. As the length occupied by inclusion is very short within the total crack path, the crack propagation speed does not show the anisotropy.

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Table 1. Chemical Composition

C	Si	Mn	P	S	Ni	Cr	Mo	V
0.30	0.28	0.66	0.015	0.090	3.02	0.06	0.45	0.09

Table 2. Tensile Properties

Direction of Specimen	Yield Strength (0.2 % offset)	Ultimate Tensile Strength	Elongation %	Reduction of Area
Longitudinal	85	93	20	50
Transverse	85	93	14	22

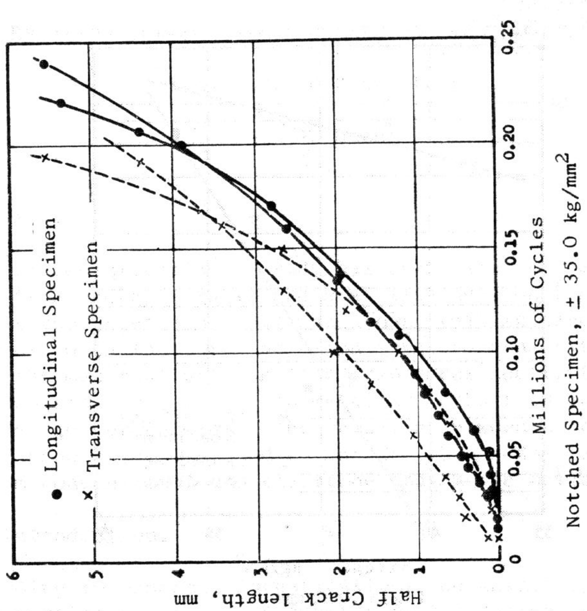

Fig. 3 Crack length vs. number of cycles.

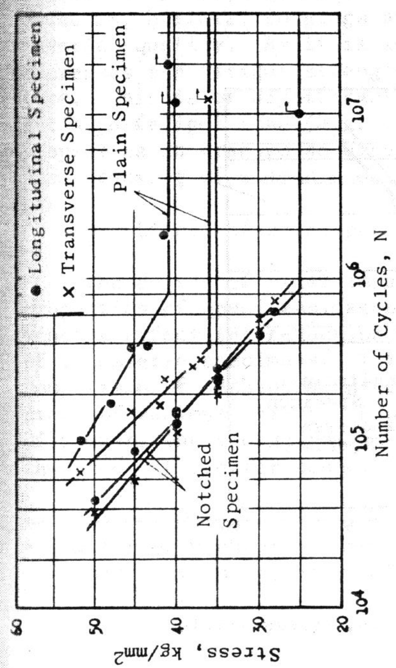

Fig. 1 S-N Curves

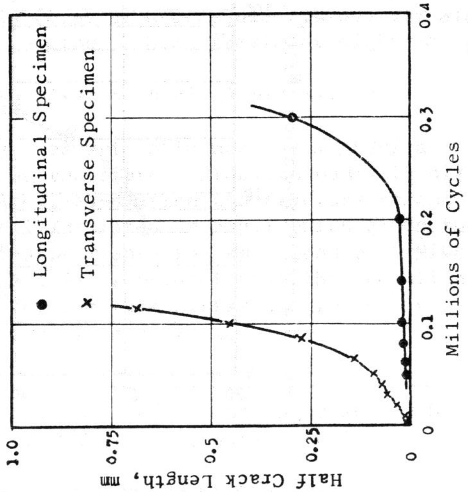

Fig. 2 Half crack length vs. number of cycles.

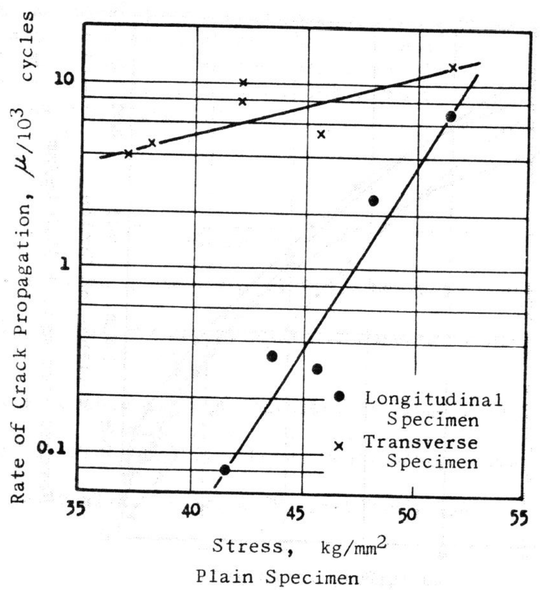

Fig. 4 Rate of crack propagation vs. stress levels.

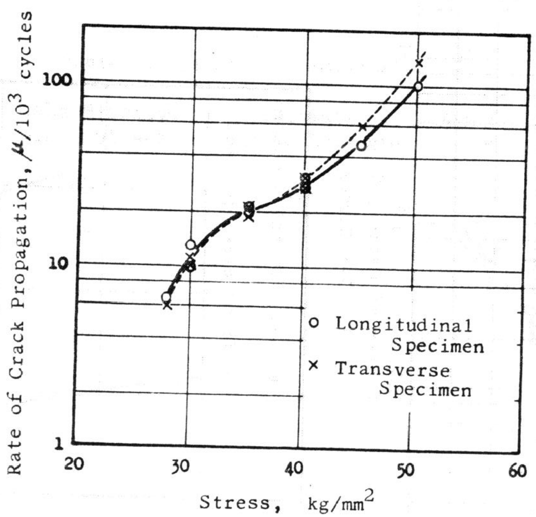

Fig. 5 Rate of crack propagation vs. stress levels.