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FRACTOGRAPHIC ANALYSIS OF FISH-EYE TYPE FATIGUE CRACK IN TWO KINDS OF HIGH STRENGTH STEELS

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ABSTRACT

In order to clarify the influence of the surface treatment on the fatigue behavior of two high strength steels in long life region, cantilever type rotating bending fatigue tests have been carried out by using the specimen to which three kinds of surface treatments were finally performed. The surface treatments tested were grinding, polishing and shot-peening. Many fish-eye type fracture surfaces in long life region were observed in detail using SEM, EDS, and optical microscopy. Two kinds of inclusions were found often in the fatigue crack initiation site of fish-eye cracking. One is alumina for a low alloy steel, another nitride titanium for a bearing steel. Based on the testing conditions, the distance to crack initiation site, the size of inclusions and the size of fish-eye feature, the fish-eye type fatigue initiation behaviors under the condition of three different surface treatments were analyzed using the method of Fracture Mechanics.

KEYWORDS

fatigue, long life, fractography, surface treatment, shot-peening, fish-eye, crack initiation, inclusion

INTRODUCTION

There are a lot of data [1,2,3] on the influence of the surface treatment on fatigue strength of steels in the range up to ten million cycles. Recently, some important researches [4,5,6,7,8,9] that fatigue strength decreases in high cycle range, which exceeds ten million cycles for several steels, are reported.

The purpose of this study is to clarify the influence of the surface treatment on the fatigue behavior of the high strength steel in high cycle region. The fatigue crack initiation behaviors of two kinds of high strength steels were investigated by using the specimens with three different surface treatments. Especially, fish-eye type fracture images at subsurface fatigue crack initiation site were observed in detail using SEM, EDS and optical microscopy to search for the mechanism of fatigue fracture.

EXPERIMENTAL PROCEDURE

A low alloy steel (JIS SNCM439: 0.40C, 0.22Si, 0.78Mn, 0.02P, 0.013S, 0.18Cu, 1.78Ni, 0.83Cr, 0.2Mo, in mass%, 1123K x 1h gas cooled, 1123K x 1h oil cooled and 433K x 1h gas cooled) and a bearing steel (JIS SUJ2: 1.01C, 0.23Si, 0.36Mn, 0.01P, 0.007S, 0.06Cu, 0.04Ni, 1.45Cr, 0.02Mo, in mass%, 8ppmO, 1108K x 40min oil(353K) cooled, 453K x 2h air cooled) were investigated. The notch parts of specimen shown in Fig.1 were finally finished by 100 mesh grindstone, 1500 mesh emery paper a

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RESULTS AND DISCUSSION

Effects of surface treatment on fatigue strength

Figures 2 (a) shows the effects of surface treatment on fatigue strength in a low alloy steel, JIS SNCM439. High stress amplitude loading for rough surface finish promotes surface cracking. The influence of surface treatments on the fatigue life under same stress amplitude is large in short life region. Low stress amplitude loading for all surface treatments promote fish-eye type cracking. The influence of surface treatments on the fatigue limit is hardly admitted in long life region.

Figure 2 (b) shows the results of a bearing steel, JIS SUJ2. Most of the specimens finished by 100 mesh grindstone were surface cracking, and the fatigue life under the same stress amplitude has changed a little depending on the processing lot. Fine finish by 1500 mesh emery paper and surface treatments by shot-peening promote fish-eye type, subsurface cracking. Two open circle symbol data with * marking for the specimens polished by 1500 mesh emery paper show the surface cracking, which the cracking start from the inclusion located on the notch surface. There is a tendency to which the fatigue limit decreases in the range that fatigue life exceeds 10^7 cycles, and the tendency is remarkable in the bearing steel. The fatigue life varies remarkably for the 100 mesh grinding finish, because of the grinding processing damage.

Fractographic analysis of fish-eye type fatigue fracture

Figure 3 shows the typical examples of fish-eye cracking on the specimen finally polished by 1500 mesh emery paper in low alloy steel. In the optical microscope image of the fish-eye as shown in Figure 3 (a), the fatigue crack initiation site is found as a dark area. Y. Murakami et al. [10,11] call this region optical dark area (ODA). Figure 3 (b) is the scanning electron microscope image of the same fish-eye in Fig. 3 (a). The area corresponding to ODA in Fig. 3 (a) is observed in the fatigue crack origin in Fig.3 (b). In this paper, we call this region in Fig.3 (b) granular area (GA).

Figure 4 shows the inclusion observed at the origin of fish-eye cracking on the specimen finally polished by 1500 mesh emery paper in low alloy steel. Figures 4 (a) and (b) show the mating fracture surface images. The image shown in (a) was printed inside out for the convenience of the comparison. Figure 4 (c) shows the Al Kα dot map of the inclusion in (b). It was presumed that this inclusion was an alumina in addition to the information on the shape and size [3,12]., which was grainy and hexagonal. It is a little vague, but GA was also observed in surrounding of the inclusion.

Figure 5 is an unusual observation example in low alloy steel. The inclusion, which was the nucleus of the fish-eye, was presumed as nitride titanium, because of the EDS image, the angular shape and size [3,12]. In this case, GA was remarkably developed in surrounding of the inclusion.

Figures 6 and 7 show the typical inclusions observed at the origin of fish-eye cracking in bearing steel. It was presumed that these inclusions were nitride titanium based on the information of the EDS image, the angular shape and size [3,12]. In Fig.6, GA is hardly observed in surrounding of the inclusion. In Fig.7, GA is remarkably developed in surrounding of the inclusion.

The detailed observation results of the fatigue fracture origin are summarized as follows. The inclusions observed at the origin of fatigue fracture depend on the kinds of steels. Thirteen examples were alumina in the low

alloy steel in the observed inclusion of eighteen samples, four examples was the nitride titanium, and one example
was the manganese sulfides. On the other hand, eleven examples were nitride titanium in the bearing steel in the observed inclusion of sixteen samples, four examples were the alumina, and one example was unknown. In both steels, the fatigue fracture has been initiated at the interface of inclusion and matrix. The peculiar fracture area (GA) formed to surrounding of the inclusion develops remarkably under the low stress amplitude and in the long life region. Y. Murakami [10,11] suggested the high possibility that hydrogen takes part in the formation of this GA, but clear evidence has not been obtained yet.

FRACTURE MECHANICS APPROACH

The stress intensity factor range, ΔK_{ini} , corresponding to the defect size which are evaluated on the square root of the area of inclusion or GA, were calculated using the following expression suggested by Y. Murakami et al.[13].

$$\Delta K_{ini} = 0.5\,\sigma_{at}\sqrt{\pi\sqrt{(area)}}$$

, where σ_{at} is a stress amplitude value which acts on the position of the crack origin. Figures 8 show the relation
between ΔK_{ini} and cycles to failure, N_f for both steels. In both results, the tendency that ΔK_{ini} corresponding to the inclusion size decreases with the increase of N_f is obtained. On the other hand, ΔK_{ini} corresponding to the GA size almost indicates a constant value without depending on the increase of N_f.

CONCLUSION

The influence of the surface treatment on the fatigue behaviors of two high strength steels in long life region was investigated under the cantilever type rotating bending fatigue testing. The surface treatments tested were grinding, polishing and shot-peening. Many fish-eye type fracture surfaces in long life region were observed in detail using SEM, EDS, and optical microscopy. Main results obtained are as follows.

(1) The influence of the surface treatment on fatigue strength of two high strength steels was remarkably large under high stress amplitude and in short life region. But, the influence becomes small under low stress amplitude and in long life region.

(2) The peculiar fracture area (GA) formed to surrounding of the inclusion developed remarkably under the low stress amplitude and in the long life region.

(3) Two kinds of inclusions were found often as nucleus of the fish-eye cracking. One was alumina for low alloy steel, another nitride titanium for bearing steel.

(4) According to the Fracture Mechanics analysis, the tendency that critical stress intensity factors, ΔK_{ini} corresponding to the inclusion size decreases with the increase of N_f ,was obtained. ΔK_{ini} corresponding to the GA size almost indicated constant value without depending on the increase of N_f and the difference of the surface treatments.

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