CHARACTERISTICS OF VERY-HIGH-CYCLE FATIGUE FOR A HIGH CARBON LOW ALLOY STEEL

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Summary This paper describes an experimental investigation on the behavior of very-high-cycle fatigue (VHCF) for a high carbon low alloy steel. The results shows that, fatigue failure may occur at relatively low loading capacity with the number of cycles larger than 10^7. At the regime of number of cycles to failure between 10^6 and 4×10^8, fatigue cracks almost initiated in the interior region of specimen. Fish-eye patterns were the main characteristics of VHCF.

INTRODUCTION

Very-High-Cycle Fatigue (VHCF) is the phenomenon of fatigue damage and failure of metallic materials or structures subjected to 10^8 cycles of fatigue loading or beyond. With the advancement of society and the development of technology, a variety of engineering structures and their components, such as air crafts, automobiles, ships, railway, bridges, etc., should be able to endure 10^8 loading cycles or more of safe performance. However, in the traditional fatigue study, research attention was only made on the fatigue process for up to 10^7 loading cycles. Whether a metallic material subjected to a relatively low loading force will suffer fatigue damage, when it is experienced 10^8 loading cycles, remains an unclear issue. This paper attempts to reveal the behavior and mechanism of VHCF for metallic materials. A high carbon low alloy steel was used, as an example, to investigate the behavior of VHCF for such a metallic material.

EXPERIMENTAL PROCEDURE

The test material was a high carbon low alloy steel with the main composition of C 1%, Cr 1.5% and Fe balance. The specimens were heated at 1108K then quenched in oil, followed by tempering at 453K for 2 hours. The yield stress of specimen was 1900MPa. The specimen for fatigue testing was hour-glass type with the minimum section diameter of 3mm as shown in Fig. 1. Fatigue testing was carried out in a rotating loading machine with a cyclic frequency of 52.5Hz. The test was at room temperature in normal laboratory environment.

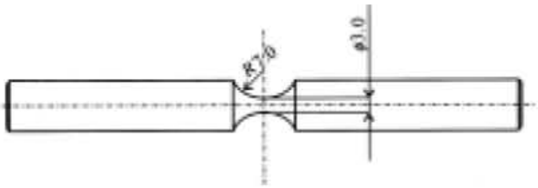

Fig.1 Schematic of specimen (dimensions in mm).

EXPERIMENTAL RESULTS

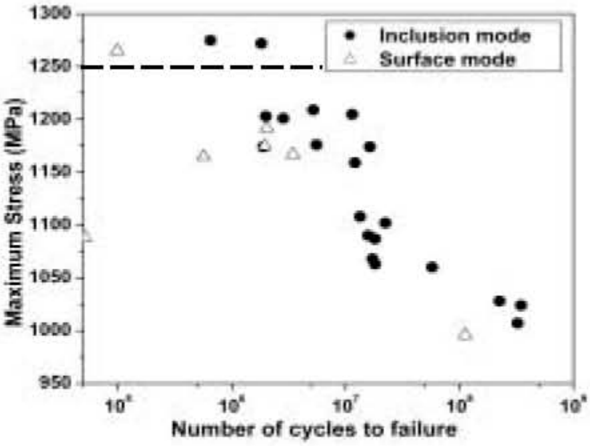

Fig.2 Results of fatigue testing.

Figure 2 is the results of the fatigue tests showing the data of the applied maximum stress versus number of cycles to failure. Note that the nominal fatigue limit of this alloy is around 1250MPa. Most data in Fig.2 are below such limit indicating that fatigue failure occured at the loading capacity lower than the limit based on traditional concept. In such case, the initiation of fatigue crack was at the interior of specimen instead of on the surface. It is seen that, at the same maximum stress of loading, the life time of specimen with crack initiation at the interior is superior in comparison with the specimen with crack initiation at surface area. This suggests that the measures of strengthening surface state and the reduction of the probability for surface crack initiation may shift fatigue damage mode from surface to interior so that to improve the fatigue resistance.

FRACTOGRAPHY OBSERVATIONS

Scanning Electron Microscopy (SEM) was used to examine the fracture surface of fatigue failure specimen. The observations showed that, the inclusion near the surface is very likely the origin of fatigue crack. Figure 3 is an example of "fish-eye" pattern. We may see the morphology in different local regions labeled 1, 2 and 3. Local region 1 is the origin of the "fish-eye" i.e. the source of crack initiation. Figure 4 shows the entire morphology of a "fish-eye". The shape of the "eye" is almost circular. Therefore we measured the equivalent diameter of the "eye". Based on this measurements we are able to estimate the stress intensity factor and the results are given in Fig,5, where A is related to the inclusion area and B is related to dark zone area. The corrected value for A zone is about 30MPam$^{1/2}$, which is comparable to the fracture toughness of the test material. Further analysis obtained that the value of stress intensity factor for fatigue crack initiation is very close to the fatigue threshold of the material (about 6MPam$^{1/2}$).

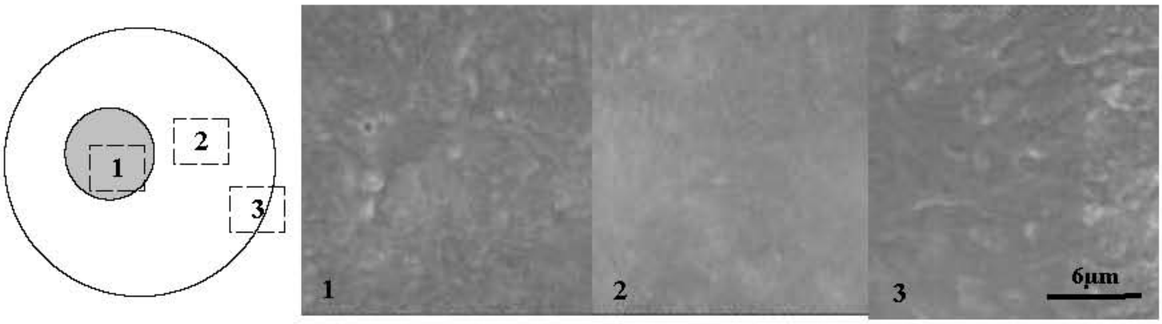

Fig.3 SEM photographs showing morphology of different local regions of a "fish-eye".

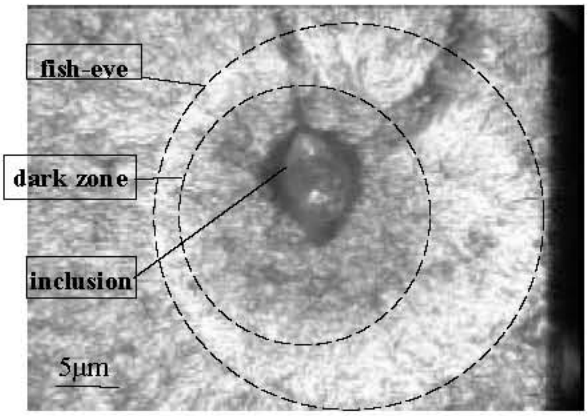

Fig.4 General view of a "fish-eye".

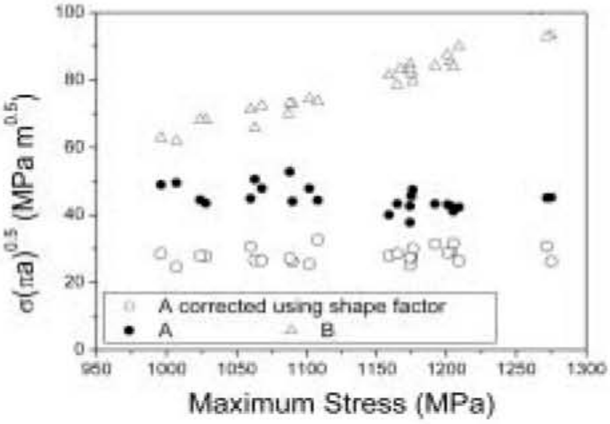

Fig.5 Estimation of fracture toughness vs max stress.

CONCLUSIONS

Fatigue failure may occur below the traditional fatigue limit stress and the life time is larger than 10^7 cycles of loading. Such damage mostly initiates from the inclusion underneath the surface. The formation of "fish-eye" is the main characteristics of very-high-cycle fatigue and it is responsible for the majority of total fatigue life.

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