INITIATION AND SHORT CRACK GROWTH IN FATIGUED 13Cr-6Ni-0.5Mo CAST STEEL

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INTRODUCTION

The initiation and growth of short fatigue cracks in metals attracts considerable interest in recent years (Ritchie and Lankford (1), Miller (2)). The study of surface relief formation and crack initiation on model materials (Polák (3)) revealed the mechanisms leading to crack initiation and early growth. In order to find out wheather the features found on model materials are valid for wider classs of metallic materials, the study was undertaken on 13Cr-6Ni-0.5Mo structural cast steel which is used for the construction of water turbines. Both crack initiation and short crack growth were studied.

EXPERIMENTS

Cylindrical specimens having 10 mm in diameter and 15 mm gauge length were prepared from a large block (750 mm x 750 mm x 250 mm) thermally treated to achieve optimum structure of tempered martensite and a small fraction of residual austenite. A very shallow notch was machined in the centre of the gauge length by grinding another cylindrical surface with the axis perpendicular to the specimen axis into the depth 0.5 mm. to facilitate the observation of the fatigue cracks, the surface of the notch was mechanically polished and the whole gauge length was electrolytically polished. The fine grid was engraved on the surface of the shallow notch in order to help the identification of the individual cracks.

The specimens were cycled in a servohydraulic testing machine under strain control with constant strain rate using axial extensometer. The hysteresis loops were recorded in regular intervals. The cycling was periodically interrupted and the specimen was removed from the testing machine for the inspection using light and scanning electron microscope(SEM).

RESULTS AND DISCUSSION

Considerable density of inclusions was present on the polished specimen surface before cycling. The majority of inclusions were spherical MnS inclusions of the diameter 5 to 20 μm. Larger inclusions of irregular shape were composed of aluminium oxides, silizium oxides and sulphides. When larger inclusions were present

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on the surface or close to the surface, the fatigue crack started from these inclusions. Cycling above the fatigue limit resulted in multiple crack initiation and growth. The inclusions were the preferred initiation sites, however, the initiation on the flat surface without visible surface inclusion could be also detected.

Figure 1 shows the SEM micrograph of the early stage of fatigue crack initiation from the spherical inclusion (MnS). Two persistent slip bands with the extrusion accompanying the crack nucleus are apparent. The persistent slip bands spread in a crystallographic direction. Figure 2 shows the initiated crack which had started from the cracked inclusion. Its total length is about 40 μm. Again, the extrusions accompany the crack nucleation and early growth. In several specimens the surface has been etched after polishing to reveal the microstructure and the specimen was cycled. The crack initiated and grew preferably along the martensitic packets. When the crack grew longer, the irregular crack line approximately perpendicular to the specimen axis was observed.

The crack length was measured using either scanning electron microscope or optical microscope. Figure 3 shows the half of the surface crack a plotted vs the number of cycles for four largest cracks in the specimen cycled with constant strain amplitude $\varepsilon_a = 3.0 \times 10^{-3}$. The crack growth rates were evaluated from these plots. The initial rate of the surface crack was very small and increased rapidly with the crack length. When the crack length reached about 200μm the crack growth rate increased with the crack length only slowly. The crack growth rates for the crack length 200μm were evaluated for several stress amplitudes and exhibited the power-law type dependence with the exponent 3.6 . The value of the exponent was in reasonable agreement with the reciprocal value of the exponent b in the Basquin relation for the fatigue life. The value of 1/b = 4 indicates that the crack growth of short cracks in this steel determines its fatigue life.

REFERENCES

(1) Ritchie, R.O. and Lankford, J., Mater. Sci. Eng., Vol.84, 1986, pp. 11-16.
(2) Miller, K.J., Fatigue Eng. Mater. Struct., Vol.10, 1987, pp. 75-113.
(3) Polák, J., Mater. Sci. Eng., Vol.92, 1987, pp. 71-80.

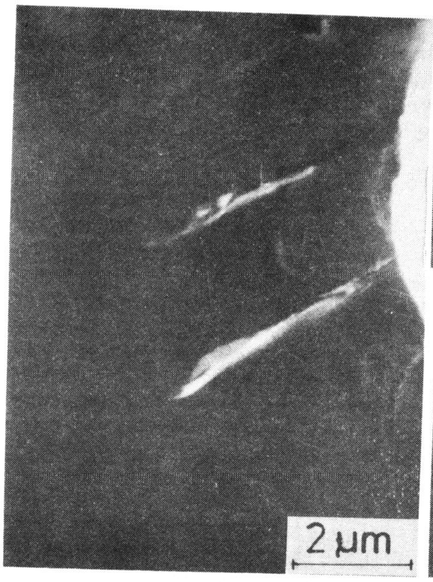

Fig.1 Persistent slip band emanating from the inclusion.

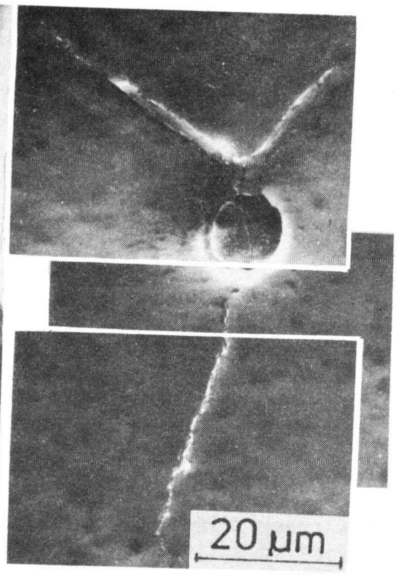

Fig.2 Short crack starting from the cracked inclusion.

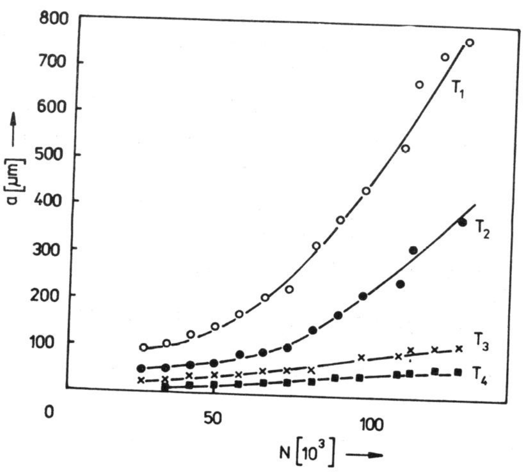

Fig.3 Crack lengths vs number of cycles in specimen cycled with strain amplitude $\varepsilon_a = 2x10^{-3}$.