FATIGUE CRACK GROWTH BEHAVIOR OF ARMCO-IRON AT LOW TEMPERATURE

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The fatigue crack growth in the near threshold region has been investigated for ARMCO-iron in liquid nitrogen. The effect of crack closure was studied and compared with the results at room temperature.

The results indicate that the closure stress intensity factor K_{cl} is not only influenced by the geometry of the crack. The plastic deformation of the fracture surface contacts is a further important mechanism which determines K_{cl}.

INTRODUCTION

The temperature can affect the fatigue crack propagation rate and the threshold value ΔK_{th} by both:

- a change of the $da/dN - \Delta K_{eff}$ curve and
- a change of the crack closure behavior.

The purpose of the present study is to investigate the change of the different crack closure mechanisms between room temperature and -196°C.

EXPERIMENTAL PROCEDURE

The experiments were performed on CT specimens (width w = 50 mm, thickness B = 11 mm, notch depth $a_0 \approx$ 10 mm, notch angle 60°.) The specimens were machined in the LT-orientation from the hot rolled sheet. The specimens were annealed for one hour at 960°C in a vacuum furnace. The average grain size after annealing was 70-80 μm.The 0.2% offset yield stress of this material is 150 MPa$\sqrt{m}$ and the ultimate tensile strength σ_{UTS} is 280 MPa.

The pre-cracked specimens were produced with a constant load amplitude in full compression ($R = 20$). The used load amplitude corresponds to a $\Delta K \approx$ 15 MPa$\sqrt{m}$, $5.3 \cdot 10^4$ cycles were used for the production of the pre-crack (measured from the notch root about 0.5 mm).

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During the threshold test the load amplitude was increased in steps until the threshold ΔK_{th} was reached. This technique was proposed by Suresh [1] and Pippan [2,3].

The load ratio R was 0.1. The loading frequency during the threshold test was 80 Hz and for measuring the CTS-curves 50 mHz. The crack length was measured with the direct current potential drop technique or in the case of very low extension of the crack with a stationary optical microscope.

RESULTS AND DISCUSSION

Figs. 2 and 3 show the $da/dN - \Delta K_{eff}$ and the $da/dN - \Delta K_{eff}$ curves tested at room temperature [3] and in liquid nitrogen. The crack growth behavior in the near threshold region is similar at both temperatures. The effect of crack closure is about the same. This was an unexpected result because:

- The roughness of the fracture surface in liquid nitrogen is smaller than at room temperature (see fig. 1). Therefore the roughness induced closure (Minakawa and McEvily [4]) should decrease. (The roughness induced closure is the main mechanism which determines the closure stress intensity factor in ferritic steels (Wasen et al. [5]).

- Since on the fracture surfaces of the specimens tested in liquid nitrogen no oxide debris were observed, the effect of debris induced crack closure (Stewart [6]) should also be small.

- The plastic induced crack closure (Elber [7]), which should be insignificant in the near threshold region) should be also smaller in liquid nitrogen because the yield stress is much larger.

The reason for this unusual behavior is that the yield stress plays an additional important role. It determines the possibility of the plastic deformation of fracture surface contacts.

This is demonstrated in fig. 4, which shows the crack tip strain curves measured in liquid nitrogen before and after a change of the temperature from -196°C to room temperature (where the specimen was unloaded).

After the change of the temperature (curve b) K_{cl} is only 50% of the K_{cl} value of curve a. This reduction of K_{cl} is caused by a plastic deformation of the fracture surfaces contacts at room temperature, where the yield stress of the material is smaller than at -196°C.

After a further extension of the crack in liquid nitrogen the K_{cl} increases to the same value as before the temperature change (curves c,d,e).

CONCLUSION

The closure stress intensity factor is not only determined by the geometry of the crack, the oxide thickness and plastic displacements but also by the possibility of a plastic deformation of the fracture surface contacts.

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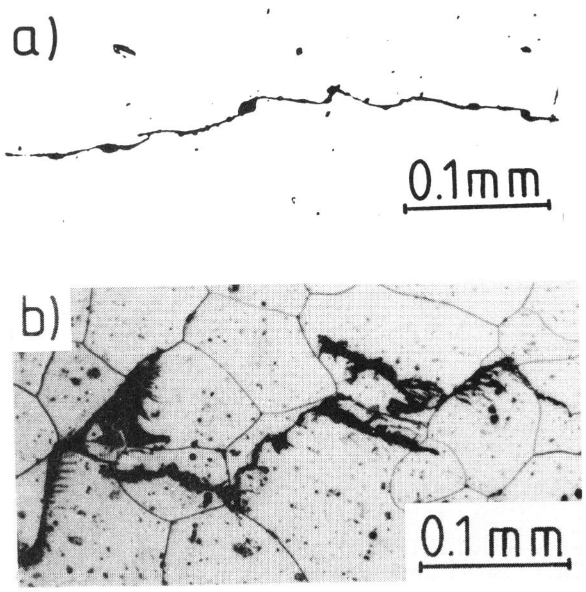

Figure 1: Comparison of the crack profiles in the near threshold region, a) in liquid nitrogen, b) in air

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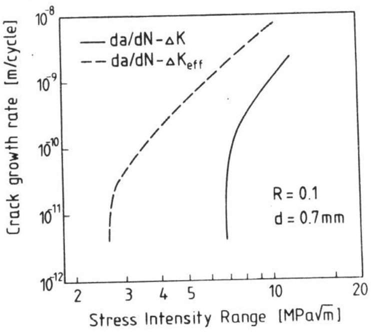

Figure 2: Fatigue crack growth behavior in air [3]

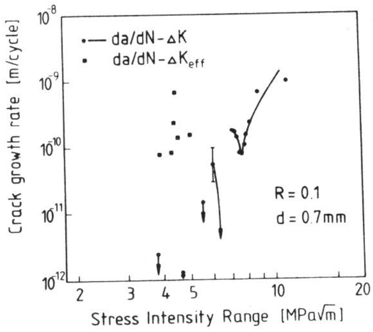

Figure 3: Fatigue crack growth behavior in liquid nitrogen

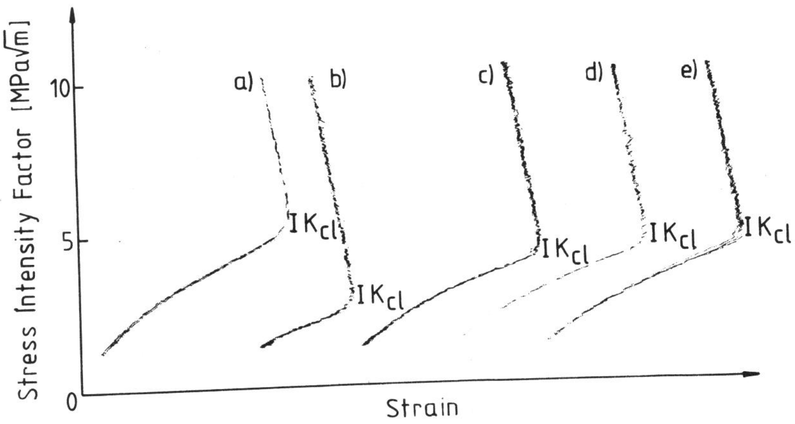

Figure 4: CTS-curves before and after a change of temperature