CRACK INITIATION AND SMALL CRACK BEHAVIOUR IN A COPPER BASED PM ALLOY

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INTRODUCTION

Short cracks have been frequently reported to grow faster than long cracks when subjected to cyclic loading at the same stress intensity range ΔK. This anomalous behaviour is frequently related to the breakdown of the applicability of LEFM concepts due to mechanical factors (crack closure, plasticity, inadequate stress field analysis...) or to metallurgical factors (role of the crystallographic orientation, grain boundary effects...) ; however it is always difficult to conclude unambiguously, in particular for natural cracks, that there is not a specific behaviour of small cracks compared to long cracks (1).

We have studied the behaviour of small cracks in a PM copper based alloy hardened with a dispersion of fine coherent particles (10 nm) of a complex oxide Cu-Al-O introduced into the copper matrix by an internal oxidation process. The relatively high mechanical properties of this alloy (σ_y = 360 MPa, σ_u = 430 MPa), its stable dislocation structure in fatigue and its fine grain size (2 µm) minimize the causes of small crack behaviour.

EXPERIMENTALS

Fatigue tests were carried out on cylindrical specimens cycled under reversed loading (R = -1) in the elastic domain at a frequency of 40 Hz in laboratory air. Cycling was periodically interrupted for the specimen to be examined in SEM ; crack initiation and the evolution of the surface crack length with the number of cycles was established for different cyclic stress amplitudes. The reference data based on the behaviour of long cracks was established for different loading conditions (R = -1, 0.1 and 0.5) using SEN type specimens. Crack closure was determined by classical load-displacement records to establish effective ΔK values (2).

RESULTS

Fig. 1 gives the evolution of the surface length of the major cracks for specimens cycled under two stress levels $\Delta\sigma/2$ of 260 MPa and 190 MPa. It is clear from these curves that for this metal crack initiation occurs very early in life. The analysis of crack initiation conditions shows that microcracks form at defects

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inherent to powder metallurgy processes in particular at large inclusions (≅ 100 μm) or porosity clusters.

If it is assumed that the crack front adopts an equilibrum semi-circular shape for small cracks, it is possible to establish the curves giving the fatigue crack growth rate (FCGR) as a function of ΔK from the data in Fig. 1. ΔK is evaluated taking into account only the tensile part of the loading cycles. The relation between ΔK and the applied stress and the crack length was based on the solutions given by Rooke and Cartwright (3) and Raju and Newman (4). Fig. 2 compares the FCGR curves corresponding to the short cracks with that corresponding to the reference long crack data. For the long cracks the threshold stress intensity factor ΔK is about 2.7 MPa $\sqrt{m}$. This figure shows that for ΔK greater than 3 MPa$\sqrt{m}$ the short cracks (a ≅ 180 μm for 190 MPa and a ≅ 100 μm for 260 MPa) conform to the predictions based on the long crack data. However for lower values of ΔK there is a breakaway from the long crack curve with the short cracks growing faster than the long cracks, this being so even for ΔK less than ΔK_{th}.

This apparently anomalous behaviour can be explained by the breakdown of the assumption on the stable crack geometry for microcracks less than 100 μm long. In fact the initial geometry of the microcracks is dictated by the geometry of the inclusion at the crack origin. Fig. 3 shows clearly that the initial value of a/c (depth over half surface length) is much more than the assumed value of 1. Fig. 4 however shows that the assumed semi-circular geometry (a/c = 1) is verified for cracks more than 140 μm long. A correction for ΔK based on the extrapolation of the results of Newman and Raju (5) for this initial value of a/c ≅ 4 tends to compress and shift the horizontal portion of the short crack curve into a point on the reference long crack curve, thus resolving the apparent anomalous short crack behaviour.

These results show that in a fine grained material with a relatively high elastic limit, linear elastic fracture mechanics (LEFM) can be applied to small microcracks (≅ 100 μm).

REFERENCES

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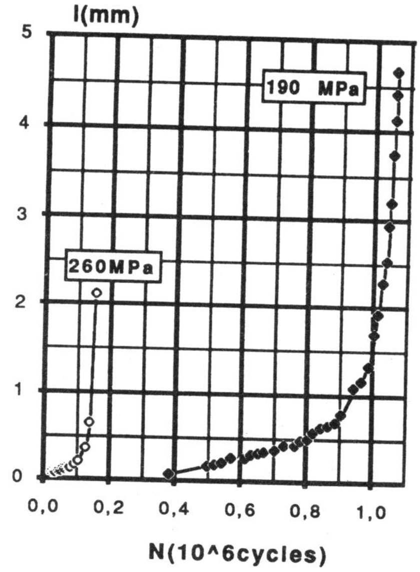

Figure 1 Evolution of the surface length of the major cracks.

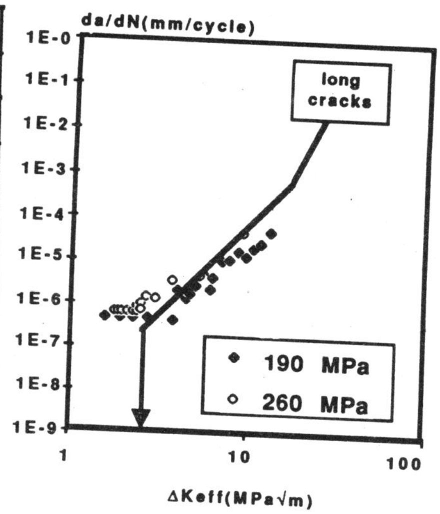

Figure 2 Crack growth curves for short and long cracks.

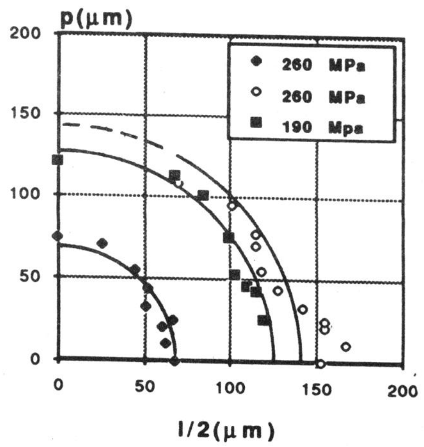

Figure 3 Crack geometry for different secondary cracks.

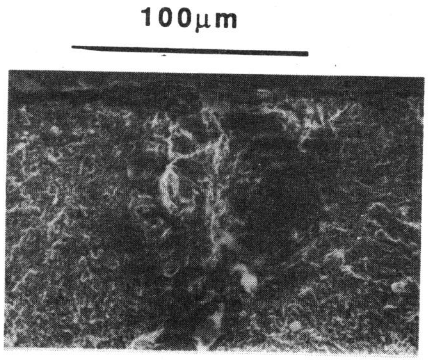

Figure 4 Crack initiation on an inclusion ($\Delta\sigma/2$ = 190 MPa).