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INTERMITTENCY IN FATIGUE CRACK GROWTH AND FATIGUE STRIATIONS

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Abstract

The fatigue crack growth rate exhibits apparent self-similarity as it grows as a power of the stress intensity factor (the Paris–Erdogan law). We have studied the fatigue crack growth in two aluminum alloys (Al-1050 and Al-5005) using optical methods and found that the crack tip advances in an intermittent way, characterized by a power-law distribution of crack tip jump sizes. The exponent of the distribution is around two – higher than what is usually observed in avalanching systems – and there is a cutoff that increases with increasing crack velocity. If the generally accepted one-to-one correspondence between the crack tip advancement per cycle and the fatigue striation lines on the fracture surface holds, one should expect a similar distribution for the striation line spacings. We have performed *post-mortem* fractography using scanning electron microscopy and, by automatically tracking the striation spacings, we indeed see a similar power-law distribution with a cutoff and an exponent around two.

1. Introduction

Fatigue failure presents an interesting fundamental science problem as it deals with processes on many different scales. The crack growth rate in a fatigue experiment exhibits apparent self-similarity expressed by the Paris–Erdogan law where the crack growth rate $\mathrm{d}a/\mathrm{d}N$ grows a power-law of the stress intensity factor range ΔK with an exponent m. On small scales the fatigue crack growth has also been observed to occur in intermittent jumps [1,2,3]. Here we take a statistical physics or "crackling noise" approach to fatigue crack growth and try to connect the statistics of microscopic crack advancement jumps – optically observed in-situ [2] as well as using post-mortem fractography [3] – with the macroscopic fatigue crack growth rate. The general view in material science is that the markings observed on the fracture surface of fatigue specimens – fatigue striation lines – correspond to cycle-by-cycle crack advancements, so an intermittent crack advancement should leave some traces of the intermittency also in the spacings of the striation lines.

2. Results

We have performed fatigue crack growth experiments on two different aluminum alloys (Al-1050 and Al-5005) using different loading conditions and while tracking the crack tip position on the sample surface using optical methods. Additionally we have performed *post-mortem* scanning electron microscopy (SEM) imaging of the fracture surfaces, and extracted the spacing between the fatigue striation lines (see Fig. 1a). Our main results can be summarized as:

a. With a constant maximum force an increase in the stress ratio R decreases the Paris exponent m (see Fig. 1b,c). The effect is significantly larger in the more ductile Al-1050 alloy.
b. We observe a fat-tailed distribution of crack tip jump sizes determined by the optical tracking (see Fig. 1d). The distribution can be thought of as a power-law with an exponential cutoff (see fitted line in Fig. 1d).
c. We observe an increase in the cutoff scale with increasing crack velocity, as well as short-range correlations in the large crack jump sizes.
d. The striation line spacing follows a similar distribution as the crack tip jump sizes (see Fig. 1d).

3. Conclusions

The results we have presented here show that the fatigue crack growth rate (in particular the Paris exponent) can be significantly dependent on the loading conditions. By looking at the statistics of the crack tip jumps we observe intermittent crack advancement, characterized by a power-law distribution of crack tip jump sizes. The exponent of the power-law distribution is higher than in normal avalanching systems (around two) and the distribution has a cutoff. The correlations between the cutoff scale and the crack velocity provide a connection between the statistics of microscopic crack tip jumps and observed behavior of the macroscopic crack growth rate. Additionally, we provide a method for extracting the spacing of fatigue striation lines from SEM images, and use this method to show that the distribution of these spacings agrees with the distribution of the crack tip jump sizes. This agrees with the general view of one-to-one correspondence between fatigue striations and loading cycles, even in our case of intermittent fatigue crack growth.

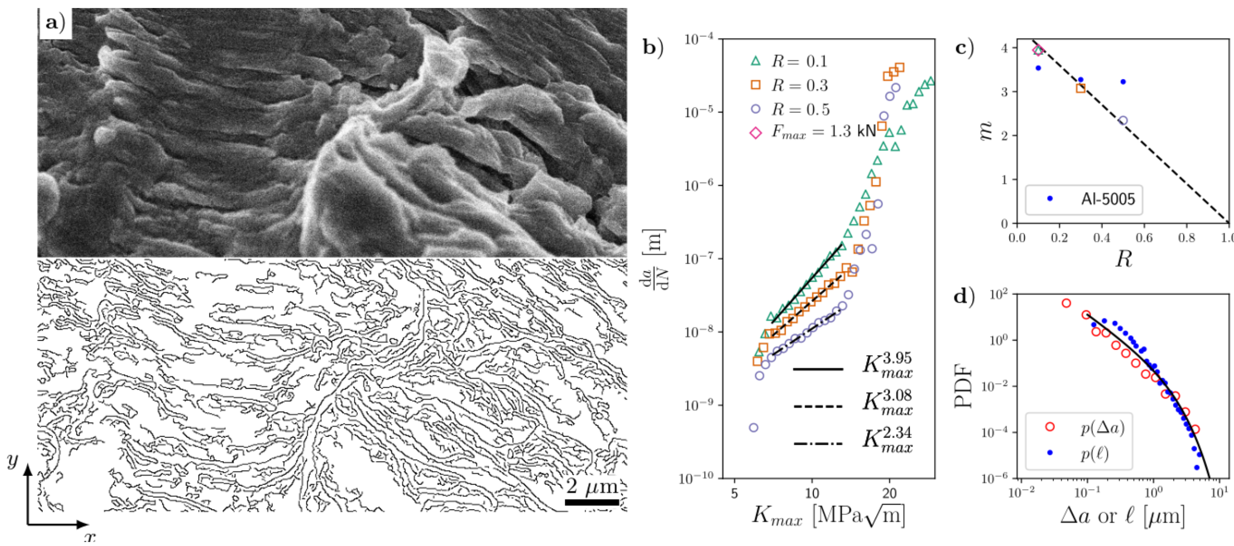

Fig.1 – **a**) Top: a SEM image of the fracture surface of an Al-5005 specimen showing the fatigue striations. Bottom: the result of edge detection used to track the striation lines. **b**) The Paris curves for Al-1050 with a constant maximum force and three different values of the stress ratio *R*. **c**) The decrease in the Paris exponent *m* fitted to the curves in panel a, as well as similar ones for Al-5005. **d**) The probability distribution of the crack tip jump sizes *Δa* as well as the striation spacings *ℓ* for one Al-5005 sample and a fit to the power-law distribution with an exponential cutoff and an exponent two.

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