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# Effect of periodic overloads in particle reinforced aluminum alloys: the near threshold behavior

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**Abstract**

The influence of periodic overloads on the fatigue crack propagation behavior in the near threshold regime of physically (extrinsically) short cracks and long cracks is investigated. The overload ratio and the number of base amplitudes were 1.8 and 1000 cycles, respectively. A 20 vol.% SiC particle reinforced 359 cast aluminum alloy and a 17 vol.% SiC particle reinforced 2124 aluminum alloy are examined. In the Paris regime, the two alloys exhibit a different behavior. In the 2124 reinforced alloy, the overloads induce a reduction of the mean crack propagation rate which is typical for ductile metals. On the other hand, the mean crack propagation rate increases in the 359 reinforced cast alloy which is caused by the generation of micro-cracks during the overload, mainly due to particle fracture.

In the near threshold regime, the behavior of both alloys is very similar. The effective threshold is not affected by the overload, i.e. if the base amplitudes are smaller than the effective threshold they do not contribute to crack propagation.

The initial crack propagation rate of closure free pre-cracks is not influenced by the interaction of the base amplitudes and the overloads. After a relatively short extension of this extrinsically short crack, the periodic overloads begin to dominate the propagation behavior especially for base amplitudes smaller than the long crack threshold of the stress intensity range.


*Keywords:* Overloads; Short cracks; Threshold stress intensity factor range; Metal matrix composites

## 1. Introduction

The effect of variable amplitudes on fatigue crack propagation has been extensively investigated in the Paris regime, see for example [1–5]. However, in the threshold regime as well as in the short crack regime, the number of studies is rather limited [6–11]. Nevertheless, the majority of engineering components are designed for finite life which are subjected to variable amplitude loading with a significant amount of load cycles in the near threshold regime or they are designed for “infinite” life, where cracks should not propagate. The damage tolerant design tools in this field are extremely underdeveloped.

The main reason for this situation is that the knowledge of load interaction effects in the near threshold regime is insufficient. Furthermore, many applications fall into the short-crack regime, where cracks can propagate below the standard measured long crack threshold determined under constant amplitude loading. In the transition regime from these short to long cracks there exists no standard procedure to determine the threshold, and hence, there are no concepts to evaluate the effect of overloads on the non-propagation condition.

To improve this situation, the paper addresses the question, how do extrinsically (physically) short cracks behave under periodic overloads and do periodic overloads influence the effective threshold?

Since the experiments are performed in particle reinforced aluminum alloys, the study will deliver, in addition, information about the effect of periodic overloads in these new types of materials.

In order to answer these questions, fatigue crack growth experiments were performed with periodic over-

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loads in the near threshold regime. Standard fracture mechanics specimens were used and the fatigue crack propagation experiments were started on pre-cracks without crack closure. In other words the fatigue tests were started on extrinsically short pre-cracks [12,13] and the transition to the long crack growth behavior was investigated.

### 1.1. Material and experimental procedure

The materials examined in this study are a 20 vol.% SiC particle reinforced 359 cast aluminum alloy and a 17 vol.% SiC particle reinforced 2124 aluminum alloy in the T6 and T4 conditions, respectively. The micrographs of both alloys are depicted in Fig. 1. The mean size of the particles in the 359 alloy is about 7 μm, the fracture toughness is relatively low 14 MPa√m, Young's modulus and tensile strength are 97 GPa and 247 MPa, respectively. In the 2124 reinforced alloy, the mean size of the particles is about 1.4 μm, the fracture toughness is 23 MPa√m, the Young's modulus, the yield stress and ultimate tensile strength is about 100 GPa, 400 MPa and 590 MPa, respectively.

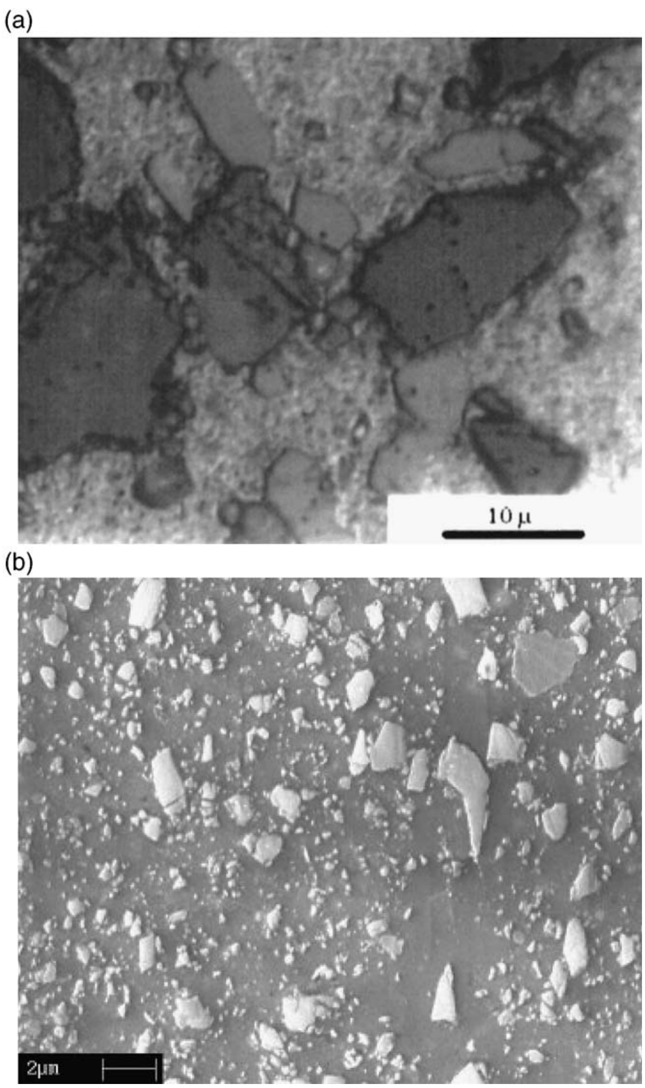


Fig. 1. Micrograph of the investigated 20 vol.% SiC particle reinforced 359 cast aluminum alloy (a) and the forged 17 vol.% SiC reinforced 2124 aluminum alloy (b).

The experiments are performed on standard SENT (width $W$ = 20 mm) and CT-specimens (width $W$ = 40 mm). The notches were machined by spark erosion. Furthermore, a special razor blade cutting technique was applied in order to get extremely sharp notches, with notch radii between 10 and 20 μm. The sharper the notch, the smaller the loads to produce a pre-crack, and the smaller are the effects of the residual stress field generated during pre-cracking [14]. To initiate a crack closure free crack of about 40 μm length measured from the notch root, the specimens were pre-fatigued in cyclic compression (load ratio $R$ = 20) at a $\Delta K$ = 8 MPa√m and 10 MPa√m in the 359 and the 2124 alloy, respectively. The micrograph of a typical notch is shown in Fig. 2. An examination of the effect of the load amplitude during pre-cracking on the $R$-curve for the threshold determined in a stepwise increasing load amplitude test shows that such small $\Delta K$ values for pre-cracking do not influence the following fatigue crack propagation experiment [14].

All periodic overload tests were performed at the same overload ratio and the number of base amplitudes between two overloads was always 1000 cycles. The overload ratio—ratio of the maximum stress intensity factor at the overload to the maximum stress intensity factor of the base amplitudes—was 1.8 and the stress ratio of the base load amplitudes $R$ = 0.1. The experiments were performed at four constant base load amplitudes as depicted in Fig. 3:

- at the smallest load amplitude the base amplitude and the overload correspond to a $\Delta K$ below the effective threshold and between the effective threshold $\Delta K_{effth}$ and the long crack threshold $\Delta K_{th}$, respectively;

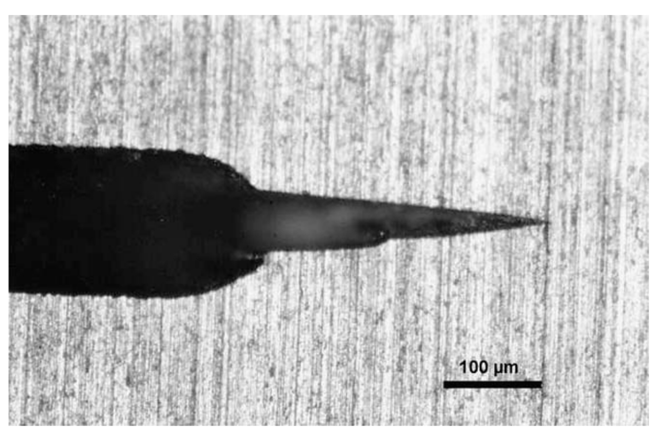


Fig. 2. Optical micrograph of a typical notch.