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ON MICROSTRUCTURAL CONTROL OF NEAR-THRESHOLD FATIGUE CRACK GROW--ETC(U)

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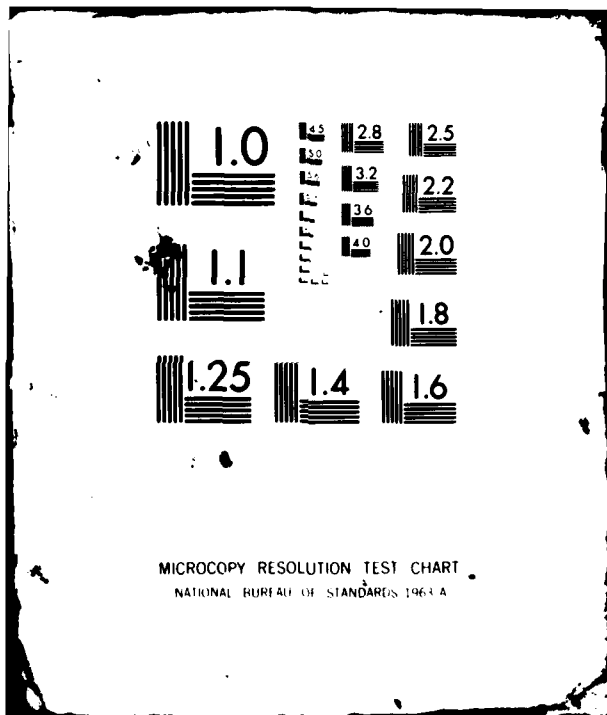
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<p>Fatigue crack growth rate data for 7000-series aluminum alloys can be approximated with a multilinear form, when plotted in conventional logarithmic coordinates over a sufficiently broad spectrum of ΔK.</p> <p>Each transition point in the growth-rate curve appears to be associated with a specific microstructural feature that can serve as a barrier to slip-band transmission, in accord with the cyclic plastic zone model of fatigue crack growth. Evidence strongly suggests that transition to the threshold for fatigue crack growth is controlled by dispersoid particles.</p>		

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ON MICROSTRUCTURAL CONTROL OF NEAR-THRESHOLD
FATIGUE CRACK GROWTH IN 7000-SERIES ALUMINUM ALLOYS

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Introduction

A number of recent studies have been conducted to ascertain the influence of microstructure on fatigue crack growth behavior in aluminum alloys [1-8]. Nonetheless, a comprehensive understanding of microstructural effects in these alloys has yet to emerge—owing at least in part to the large number of microstructural features that may potentially affect the growth of fatigue cracks. Not only are there grain boundaries and subgrain boundaries that might serve as barriers to the transmission of slip-band cracks, but the roles of constituent particles, dispersoids and the primary hardening precipitate must also be considered in this regard—whether for the underaged, peak-aged or overaged conditions.

On the other hand, from recent work with other families of structural alloys—viz. steels and α/β titanium alloys [9-14], a unified picture of material effects on fatigue crack growth has begun to emerge. In particular, a cyclic plastic zone model of fatigue crack growth has been developed that can explain large differences in fatigue crack growth rates (da/dN) observed for different alloy microstructures. These differences can be 2-3 orders of magnitude in da/dN , for a constant set of cyclic loading conditions—viz. stress-intensity range (ΔK) and stress ratio (R), etc. The predictive capability of this

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model, which contains no disposable parameters, depends solely on the knowledge of a material's yield strength (σ_{ys}) and mean free path between microstructural barriers to slip-band transmission (\bar{l}). For a broad range of α/β titanium alloys and steels, \bar{l} is simply the effective grain size; in the case of quenched, high-strength steel, retained austenite in martensite lath boundaries appears to truncate the mean free path for slip-band transmission, which would otherwise be the lath packet dimension.

Naturally, the question begs as to whether the crack growth rate behavior for different microstructural conditions in aluminum alloys is also in quantitative agreement with the predictions of the model. The intent of this communication is to report preliminary findings in this regard. For this purpose, the excellent data sets reported recently by Bucci et al. [15] for 7000-series aluminum alloys are analyzed together with the counterpart microstructural evidence reported by Sanders, Jr. et al. [16]. The da/dN data, obtained over a very broad spectrum of ΔK , characterize the near-threshold growth-rate behavior unusually well.

Predictions of the Model

The cyclic plastic zone model of fatigue crack growth is especially useful for analysis of near-threshold growth rate behavior where microstructural dimensions are of the order of the cyclic plastic zone size for plane strain conditions [17-19],

$$r_f^c = 0.033 (\Delta K / \sigma_{ys})^2. \quad (1)$$

In particular, it has been found that when the condition $r_f^c = \bar{l}$ is attained, a transition point is observed in the growth-rate curve, illustrated in a bilinear form in Fig. 1. In the hypotransitional branch, where $r_f^c < \bar{l}$, a "structure-sensitive" mode of crack growth occurs that is often characterized by "facets" or "crystallographic bifurcation." By contrast, in the hypertransitional branch, where $r_f^c > \bar{l}$, a "structure-insensitive" or continuum mode of crack growth results, often characterized by broad, relatively flat bands of striations. Of prime importance, the model predicts that the da/dN vs ΔK curve will translate along the abscissa according to:

$$\Delta K_T = 5.5 \sigma_{ys} \sqrt{l} \quad (2)$$

where ΔK_T is the value of ΔK at the transition point.

Analysis of the Data

Fatigue crack propagation data are shown in Figs. 2-4 for 7000-series aluminum alloys in plate form (6.35 mm thickness). These results were determined from compact type specimens in high-humidity, room-temperature air at a stress ratio of $R = 0.33$ [15].

Inspection of the results reveals, first of all, that aluminum alloys can exhibit multiple transitions in the da/dN curve, as compared to the bilinear form in Fig. 1.* This is clearly apparent in the data for 7075-T6 (peak-aged condition) exhibited in Fig. 2, where each of three transition points (T_1 , T_2 and T_3) appears linked to a different microstructural barrier to slip-band transmission. The transition to threshold, T_1 , appears to be controlled by dispersoid spacing, as calculation via Eq. 1 shows (cf. figure) that the cyclic plastic zone at this point, $[r_p^c]_{T_1} = 0.76 \mu\text{m}$, approximates the mean free path between dispersoid particles, \bar{l}_D , as discerned from Ref. [16]. Similarly, for T_2 and T_3 , the cyclic plastic zone dimensions, $[r_p^c]_{T_2} = 1.97 \mu\text{m}$ and $[r_p^c]_{T_3} = 4.4 \mu\text{m}$, appear to correlate with subgrain size (\bar{l}_{GS}) and grain size (\bar{l}_{GS}), respectively.

These tentative identifications are strongly supported by evidence for the 7050 alloy. The case of the peak-aged condition, 7050-T6, is illustrated in Fig. 3. Here again, T_1 appears to be controlled by dispersoid spacing, as calculation gives $[r_p^c]_{T_1} = 0.71 \mu\text{m}$ which approximates \bar{l}_D in Ref. [16]; similarly, T_3 appears to be controlled by the grain size [16], $\bar{l}_{GS} \approx [r_p^c]_{T_3} = 4.0 \mu\text{m}$.

Note, however, that any transition T_2 , of the concave type observed in Fig. 2 and linked to \bar{l}_{GS} in the 7075-T6, appears to be virtually absent in Fig. 3. Indeed, such suppression of the T_2 transition is not surprising—for in contrast to the 7075 alloy which contains Cr, the 7050 alloy contains Zr instead.

*Transition to region III behavior [20-21] is not analyzed here, but rather power law behavior [22], as evidenced in bilinear or multilinear forms.

which promotes a higher degree of recrystallization at the expense of subgrain morphology [16]. Consequently, identification of subgrain-boundary control of transition T_2 in Fig. 2 is further reinforced.

If attention is refocused on transition T_1 in Fig. 3, a point of prime importance might be considered: If indeed the transition to threshold (T_1) is controlled by mean free path between dispersoid particles, \bar{l}_D , then the significant shift of T_1 to lower ΔK , observed for the overaged (T7) condition and illustrated in the figure, should be predictable. It is: If one takes $\bar{l}_D = 0.71 \mu\text{m}$ (since dispersoid morphology should be the same for the T6 and T7 conditions), then the shifted transition to threshold can be calculated via Eq. (2), as shown in Fig. 4 with the da/dN data for the 7050-T7 condition. In this figure, comparison shows the calculated value, $(\Delta K)_{T_1} = 2.04 \text{ MPa} \sqrt{m}$, to be in remarkable agreement with the data.

An interesting corollary should be mentioned at this point, as regards the influence of the primary hardening precipitate. From the preceding analysis, it appears that the role of the precipitate on near-threshold fatigue crack growth behavior is indirect (though significant), viz through control of the strength level, σ_{ys} . (It is further noted that spacings between GP zones shown in Ref. [16] appear to be of the order of 0.01-0.02 μm , and thus too small to be linked to the transitions exhibited in the above data.)

Conclusions

From the foregoing, it appears that:

1. Fatigue crack growth rate data for 7000-series aluminum alloys exhibit a multilinear form, when plotted in conventional logarithmic coordinates over a sufficiently broad spectrum of ΔK .
2. Each transition point in the growth-rate curve is associated with a specific microstructural feature that can serve as a barrier to slip-band transmission, in accord with the cyclic plastic zone model of fatigue crack growth.
3. The apparent transition to the threshold for fatigue crack growth is controlled by dispersoid particles.

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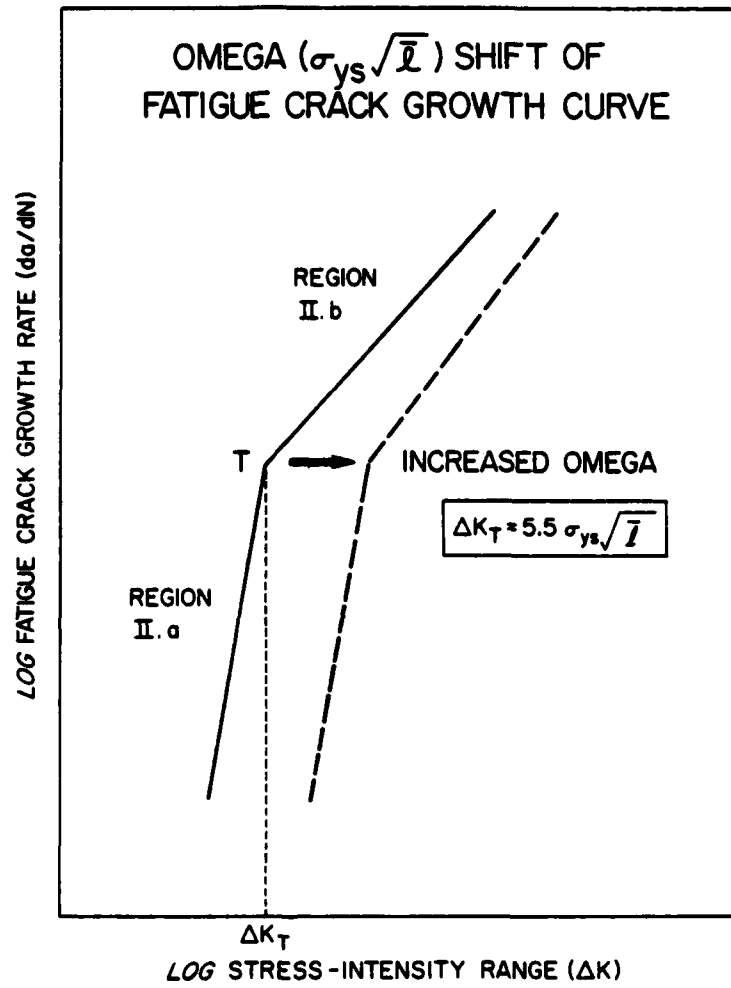


Fig. 1 - Shift in fatigue crack growth rate curve, controlled by microstructure as predicted quantitatively from cyclic plastic zone model

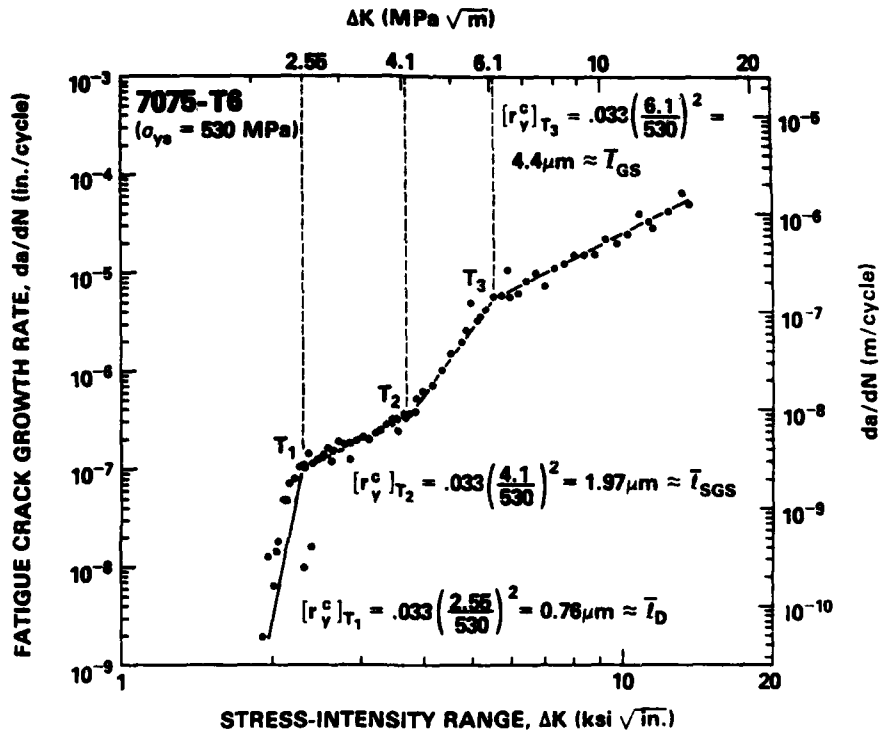


Fig. 2 — Fatigue crack growth rates in 7075-T6 aluminum alloy, after Ref. [15]

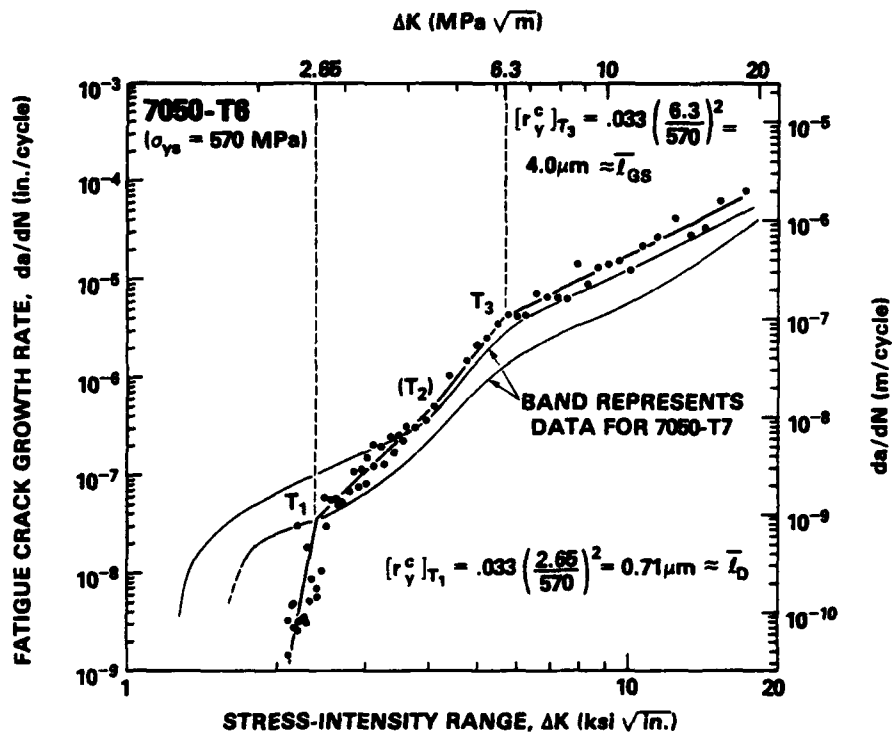


Fig. 3 - Fatigue crack growth rates in 7050-T6 aluminum alloy, after Ref. [15]

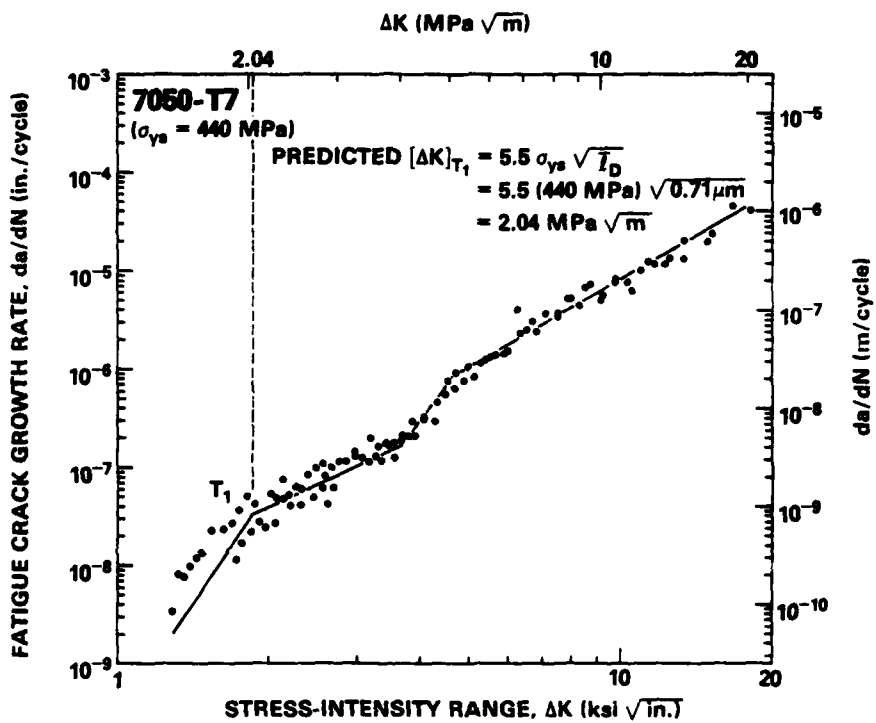


Fig. 4 - Fatigue crack growth rates in 7050-T7 aluminum alloy, after Ref. [15]

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