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Fatigue crack propagation rates in low-density polyethylene as a function of stress intensity factor were found to exhibit a discontinuity in the range $\Delta K = 0.4\text{-}0.6$ MPa$\sqrt{m}$. Within this range the FCP rate decreased with increasing ΔK. Fractographic examination revealed significant differences in the appearance of the fracture surfaces corresponding to values of ΔK below and above the transition range. While the reason for this behavior is not clear, the nucleation and growth of voids was involved throughout--the voids being smaller at low values of ΔK than at higher values.

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A Correlation Between Crack Growth Rate and Fracture Mode Transitions in Low-Density Polyethylene

by

P. E. Bretz, R. W. Hertzberg and J. A. Manson

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A Correlation Between Crack Growth Rate

and Fracture Mode Transitions in Low-Density Polyethylene

P. E. Bretz,[1] R. W. Hertzberg[2] and J. A. Manson[2]

The fatigue crack propagation (FCP) behavior of low-density polyethylene (LDPE) has been described by Andrews and Walker[1] and by Hertzberg, et al.[2] The results published by the former authors showed a discontinuity in the FCP behavior of this material at a crack growth rate of $\sim 10^{-3}$ mm/cycle; on the other hand, no such discontinuity in fatigue response was reported in the latter study. We have since re-examined the FCP behavior of compact-tension specimens of LDPE as a function of ΔK, over a wider range of ΔK (Fig. 1). These data show a decrease in crack growth rates (da/dN) with increasing ΔK between $\Delta K = 0.4$ MPa$\sqrt{m}$ and 0.6 MPa$\sqrt{m}$, followed by an increase in da/dN with ΔK above 0.6 MPa$\sqrt{m}$; the solid lines shown in Figure 1 represent the data reported in reference 2. Thus the absence of any discontinuity in FCP behavior for LDPE reported in the earlier study[2] can be traced to the fact that the entire ΔK test range was above the transition range identified in the present investigation.

Since Andrews and Walker evaluated FCP rates as a function of $\mathcal{T}$, an elastic-plastic surface work parameter, while Hertzberg et al. measured crack growth rates as a function of the elastic stress intensity factor range, ΔK, these results cannot be compared directly. Nevertheless, it is interesting to note that the crack growth rate corresponding to the transition at A (da/dN $\sim 10^{-3}$ mm/cyc) agrees closely with the FCP rate at the discontinuity

[1] Formerly Research Assistant, Lehigh University and currently Engineer, Alcoa Technical Center, Alcoa Center, PA 15069.

[2] Materials Research Center, Lehigh University, Bethlehem, PA 18015

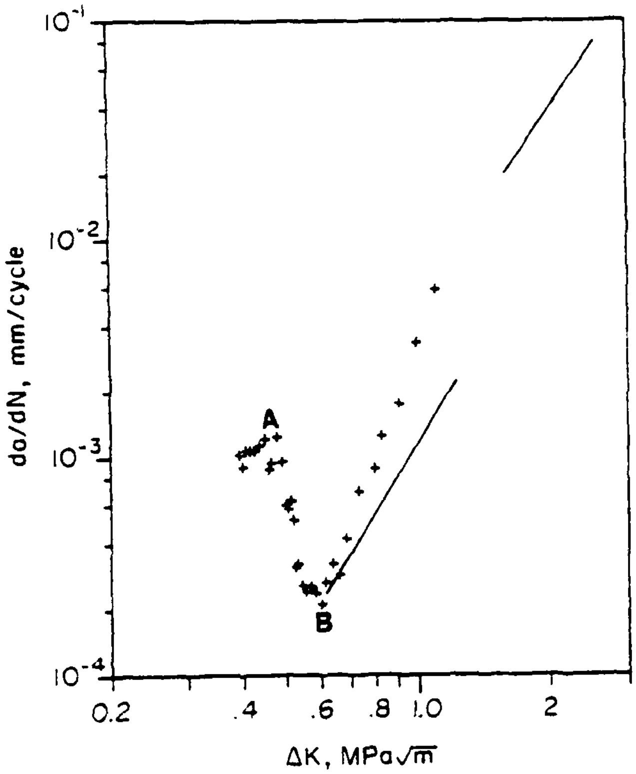
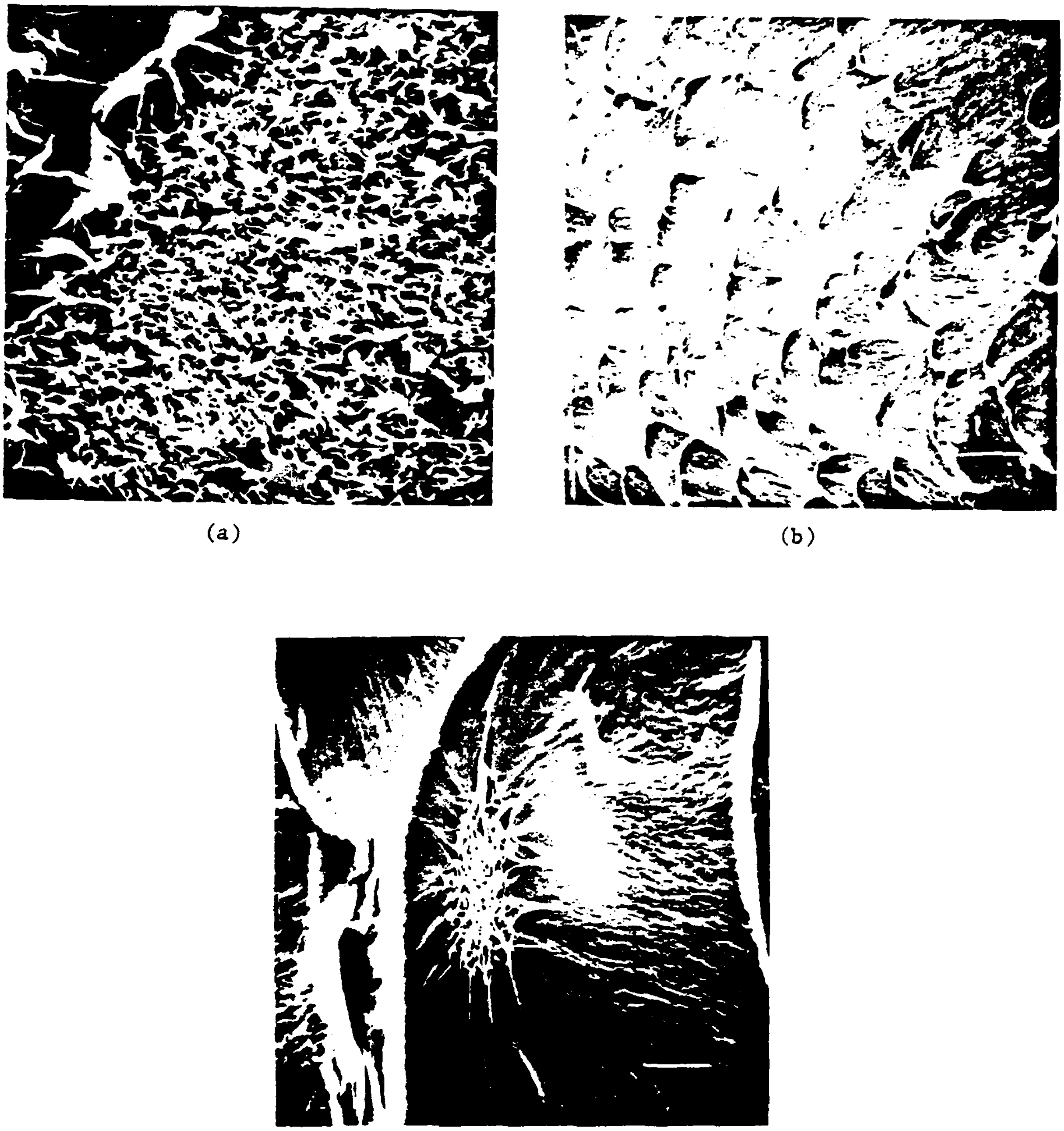


Figure 1 Fatigue crack growth rates as a function of ΔK in LDPE. Note the decrease in da/dN with increasing ΔK between A and B. Solid lines represent FCP data for LDPE from reference 2.

reported by Andrews and Walker.[1] Thus, a phenomenological similarity is apparent between the LDPE data reported by Andrews and Walker and the present results which must reflect an equivalent intensity of the stress-strain field at the advancing crack tip.

An examination of the fracture morphology of LDPE revealed a marked change in the fracture surface appearance at the da/dN-ΔK transition at location B (Fig. 1). Below $\Delta K = 0.6$ MPa$\sqrt{m}$, the fracture surface exhibited a tufted appearance consisting of small voids, while large voids dominated the fracture topography at higher ΔK levels (Figs. 2a and b). This contrast in appearance is very striking, considering the difference in magnification between Figures 2a and b (~ 700X and 20X, respectively). It is believed that both of these fracture surfaces were produced by a void growth mechanism. Above $\Delta K = 0.6$ MPa$\sqrt{m}$, though, there seems to have been a dramatic decrease in the nucleation rate of these voids and an enhanced opportunity for pronounced void growth. Curiously, these large voids appear to have been nucleated by local void clusters whose appearance was quite similar to the smaller voids seen at low ΔK levels (Fig. 2c). The discontinuity in FCP in FCP behavior reported by Andrews and Walker also was accompanied by a change in fracture morphology but was described differently, based on alternate microscopic techniques. Nevertheless, the phenomenological similarity of the two studies is confirmed. Unfortunately, while the correlation between crack growth rate behavior and fracture mode transition in LDPE is striking, the fundamental reason for this behavior remains unclear.

It is not clear why LDPE exhibits FCP discontinuities and high density polyethylene (HDPE) does not.[3] In the latter study, fatigue crack growth rates increased continuously with increasing ΔK values for several molecu-



(a) (b)

(c)

Figure 2 Void coalescence mechanism in LDPE: a) very fine voids at $\Delta K = 0.45$ MPa$\sqrt{m}$, scale bar = 20 μm; b) coarse voids at $\Delta K = 1.0$ MPa$\sqrt{m}$, scale bar = 0.5 mm; c) center of coarse void showing texture similar to that shown in a), scale bar = 30 μm. Crack propagation direction from left to right.

lar weights and thermal histories. Additional complexities become apparent when comparisons are made with regard to fracture surface markings. For example, ultra-high-molecular-weight polyethylene[4] and HDPE[3] reveal various groupings of parallel fatigue fracture surface lines. Though White and Teh[5] reported similar features in LDPE, none were identified in this investigation. Clearly, much additional research on the fatigue behavior of polyethylene is sorely needed.

Acknowledgements

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