no stereoregularity has been observed in the product polymer.

Acknowledgements

We wish to thank the authorities of M/S Polyolefins Industries Ltd, Bombay, India for allowing us to carry out experiments with alkylaluminium in their research laboratory and the authorities of Indian Institute of Technology, Kharagpur, India for facilities.

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(Received 3 October 1977;
revised 8 November 1977)

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Correlation between fatigue fracture properties and viscoelastic damping response in engineering plastics

Early fatigue studies of engineering plastics identified a strong dependence of test frequency on fatigue life in unnotched test coupons[1–3]. Numerous investigators identified the onset of adiabatic heating in the gauge section as the primary cause for premature failure. In these cases, the elevated temperature associated with hysteretic heating increased the compliance of the test sample to the point where the cyclic loads could no longer be sustained, whereupon the sample literally melted. Analytical relationships were developed which revealed the temperature increase per loading cycle to be related to the loss compliance of the material, the stress level, test frequency and thermal properties of the polymer as described by equation (1)[4]:

$$\Delta\dot{T} = \frac{\pi f J''(f, T)\sigma^2}{\rho C_p} \qquad (1)$$

where $\Delta\dot{T}$ is the temperature change/unit time; f is the frequency (Hz); J'' is the loss compliance; σ is the peak stress; ρ is the density and C_p is the specific heat. It is pertinent to note that a relationship between fatigue response and viscoelastic properties (i.e. J'') was, therefore, identified for this type of failure.

When the fatigue crack propagation (*FCP*) rate of prenotched samples was examined, however, it was found that the test frequency had the opposite effect on cyclic response in poly (methyl methacrylate) (PMMA). Here, various investigators found that the crack growth rates under cyclic loading conditions decreased with increasing test frequency[5–8]. The implication associated with these earlier fatigue crack propagation studies was that the total crack growth rate was related in some way to a superposition of pure fatigue and pure creep components, respectively[9–12]. On the basis of these results certain crack propagation 'laws' were developed[11–13]. Since that time additional data have been reported which clearly demonstrate these laws to be premature in their formulation[9,14,15]. For example, PMMA, polystyrene and PVC experienced an attenuation in *FCP* rates with increasing test frequency while polycarbonate, nylon-6,6, and others showed no effect. It is worth noting that no material revealed higher crack growth rates with increasing frequency [recall equation (1)]. A number of hypotheses to account for this *FCP* frequency sensitivity have been examined and found wanting to various degrees[9]. One encouraging correlation, however, reported earlier by the authors, has been found between the relative *FCP* frequency sensitivity in several polymers and the frequency of movement of those molecular segments responsible for generating the beta transition peak at room temperature. It was found that the most frequency sensitive materials were those possessing a beta transition-related segmental jump frequency in apparent resonance with the applied machine test frequency. The authors suggested that this resonance condition contributed to a state of adiabatic heating local to the crack tip. This in turn was envisioned to soften the material, thereby blunting the crack tip radius. The more blunt crack tip, being less damaging to the material, would bring about a slowing down of the fatigue crack velocity under cyclic loading conditions.

This hypothesis could be critically examined in two ways. First, frequency insensitive engineering plastics could be made so by altering the machine test frequency range so as to bring the externally applied loading frequency in coincidence with the beta transition-related segmental jump frequency of the material. Since the beta-related jump frequency of materials such as polycarbonate, nylon-6,6 and poly(vinylidene fluoride) are of the order of 10^6 to 10^7, this approach is unreasonable owing to testing machine capability limitations. Alternately materials that were not *FCP* frequency sensitive at room temperature, might be made so at other temperatures if the altered segmental motion jump frequency of the material were now comparable to the mechanical test frequency. Indeed, this has been verified for polycarbonate and polysulphone under low temperature test conditions with maximum frequency sensitivity being found in polycarbonate and polysulphone at approximately 200K and 175K, respectively. Conversely, the very strong frequency sensitivity in PMMA found at 300K was eliminated when this material was tested at 150K. Preliminary results for polystyrene also confirm these trends.

It would appear then that the maximum frequency sensitivity to *FCP* in engineering plastics occurs at a particular temperature unique to that material. In each case that tem-

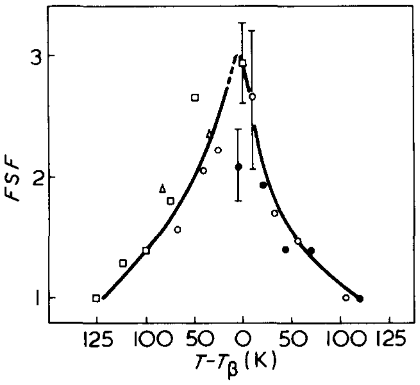

Figure 1 Frequency sensitivity of selected polymers at temperatures relative to T_β. ●, PSF; ○, PC; □, PMMA; △, PS

perature was related to a beta transition segmental jump frequency comparable to the test machine loading frequency. Of great significance, therefore, the overall frequency sensitivity for all the engineering plastics tested, thus far, has been shown to be singularly dependent on test temperature relative to the temperature of the beta damping peak (*Figure 1*). Here the frequency sensitivity factor (*FSF*) is defined as the multiple by which the *FCP* rate changes per decade change in test frequency. The quantity $T-T_\beta$ refers to the test temperature relative to the temperature of the beta peak within the appropriate test frequency range. Note that in all cases the *FSF* parameter is maximized when the test temperature is equal to the temperature of the beta peak. [It is recognized that the precise temperature associated with the β process is, itself, a function of test frequency. We find, however, that the associated error in *Figure 1* (i.e., the quantity $T-T_\beta$) is not significant.]

This observation is of considerable importance as it demonstrates a strong connection between gross mechanical properties (*FCP* response) and fine scale viscoelastic response of a polymeric solid.

Acknowledgements

The authors wish to acknowledge enlightening discussions with Dr E. H. Andrews and support by the Army Research Office, Durham, Grant No. DAAG29–76–G–0336.

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(Received 13 October 1977)

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(Received 13 October 1977)

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