Comment on "Low temperature crack propagation in an epoxide resin"

Scott *et al.* [1] have recently published a very interesting investigation into the dependence of the fracture behaviour of four amine-cured epoxy resin systems on temperature at constant testing rate, and on testing rate at constant temperature. The results show some interesting contrasts with previous work which seem worthy of further discussion.

The initiation toughness of the four resin systems was found to increase with increasing hardener chain length and also correlated reasonably well with decreasing hardness as measured with a "Barcol" impressor. This is consistent with the crack blunting mechanism proposed by Scott *et al.* since Barcol hardness is related to the yield stress and hence to the amount of plastic flow around the crack tip during loading. The upper transition temperature, where the fracture behaviour changes from being unstable to being stable, T_H, was found to decrease with increasing hardener chain length, as would be expected from the change in yield stress with hardener chain length. So these results, in general, provide excellent confirmation of the correlation between yield stress and fracture behaviour, which has also been observed by other workers [2].

However, lowering the hardener ratio or the post-curing temperature with the ethylene diamine-cured resins was found to reduce the testing rate required to produce stable crack-growth at room temperature. Lowering the hardener ratio could conceivably increase the yield stress by, for example, promoting the secondary amine-curing reaction or reducing plasticization due to unreacted hardener, but it is difficult to conceive of any mechanism that would lead to an increase in yield stress with decreasing post-cure temperature. Hence, these results appear to be inconsistent with the crack-blunting hypothesis. Barcol results, or preferably yield stress data as a function of strain rate, for these materials would be of great interest.

The simple correspondence which was found to exist between increasing hardener chain length and increasing initiation toughness is of relevance to the current debate regarding the existence of high and low cross-link density regions in the macrostructue of epoxy resins [3, 4]. While a simple correspondence between cross-link density and toughness may be expected for a homogeneous network, such a correspondence is surprising if deformation occurs largely in a low cross-link density matrix, as has been postulated by previous authors [5]. It may be premature to relate the toughness directly to the expected cross-link density without further characterization of the resins and their deformation mechanism.

The transition from stable to unstable propagation observed in all of the resins as the temperature was reduced below $-100°$ C is also an interesting result. As the authors suggest, some interaction with the environment must be suspected and, in view of the reported effect of water on the stability of fracture [6], it may be worthwhile to consider whether liquid water could account for the low-temperature instability. Unless the measurements were made on specimens in a totally dry nitrogen atmosphere using, the experimental arrangement as described it would appear that there is a high possibility of water condensing on the specimen. If the temperature was at equilibrium, any liquid water would quickly freeze, however, it may still be able to permeate and plasticize the crack-tip region or may melt at some stage during the test due to temperature rise at the crack tip. Comparison of the fracture surfaces produced at low temperature and in the presence of water could be of value.

Finally, although Yamini and Young [6] have indeed reported a trend towards instability when fracture occurred in the presence of water at the crack tip, we would note that, previously, the opposite effect has also been reported [7, 8] and a mechanism was proposed to explain this result. The effect of water on crack stability may well prove to vary depending on the epoxy system, the testing rate and the temperature.

References

1. J. M. SCOTT, G. M. WELLS and D. C. PHILLIPS, *J. Mater. Sci.* 15 (1980) 1436.
2. A. J. KINLOCH and J. G. WILLIAMS, *ibid.* 15 (1980) 987.
3. J. MIJOVIĆ and J. A. KOUTSKY, *Polymer* 20 (1979) 1095.
4. K. DUŠEK, J. PLEŠTIL, F. LEDNICKÝ and S. LŮNÁK, *ibid.* 19 (1978) 393.

0022–2461/81/051435–02$02.20/0

5. R. J. MORGAN and J. E. O'NEAL, *J. Mater. Sci.* **12** (1977) 1966.
6. S. YAMINI and R. J. YOUNG, *Polymer* **18** (1977) 1075.
7. B. W. CHERRY and K. W. THOMSON, in "Fracture Mechanics and Technology", edited by G. C. Sih and C. L. Chow (Sijthoff and Noordhoff, Alphen aan den Rijn, The Netherlands, 1977) pp. 723–736.
8. *Idem,* in "Adhesion 4" edited by K. W. Allen (Applied Science Publishers, London, 1979) pp. 103–111.

Received 22 September
and accepted 13 October 1980

K. W. THOMSON
Department of Materials Engineering
Monash University,
Clayton, Victoria, 3168,
Australia