Polymer Bulletin 2, 211–214 (1980)

Polymer Bulletin

The Loading-Rate Dependent Fracture Property of a Toughened Epoxy Polymer

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Summary

The fracture energy of an elastomer-modified epoxy polymer was determined as a function of loading rate. Fracture tests were carried out by using compact tension specimens and standard Izod impact specimens. The fracture energy of the base epoxy was increased by the elastomeric additives. The extent of increase, however, was found to decrease with increasing loading rate.

Introduction

Epoxy polymers are used widely as adhesives and as matrix materials for fiber-reinforced composites. For such applications polymer fracture properties are of great importance because the composite failure mechanism is generally dominated by crack propagation, resulting from the growth of flaws and microvoids inherently present because of the fabrication techniques employed. To mitigate the brittleness of epoxy resins, it is common to add elastomers such as liquid carboxy-terminated-butadiene-acrylonitrile (CTBN) to the epoxy resin for copolymerization and *in situ* formation of a uniformly dispersed phase of small rubber particles (Riew et al, 1976). These particles have been demonstrated to enhance the toughness of unmodified epoxy (Sulton and McGarry, 1973; Bascom and Cottington, 1976). Recently, a commercial epoxy resin formulation, Hexcel F-185 (Hexcel Corporation, Dublin, CA), was developed in which both a liquid and solid CTBN were utilized to achieve a bimodal distribution of particle sizes. This modified epoxy system has been studied to examine the effect of loading rate on toughened glassy epoxy polymers.

Experimental

DGEBA epoxy was modified with the addition of a 8% liquid CTBN (HYCAR 1300, B. F. Goodrich Chemical Company) and a 5% solid CTBN (HYCAR 1472). Cast plates fabricated from both the unmodified and the modified epoxy resins were obtained from the Hexcel Corporation. Compact tension specimens, shown schematically in Fig. 1, were cut from the plates for fracture study. The specimens had the dimensions of $\bar{W}$ = 2.5 cm and b = 0.63 cm. A precrack was introduced at the end of the saw cut by notching with a razor blade. The specimens were fractured in an INSTRON at various cross-head speeds. The fracture failure load was

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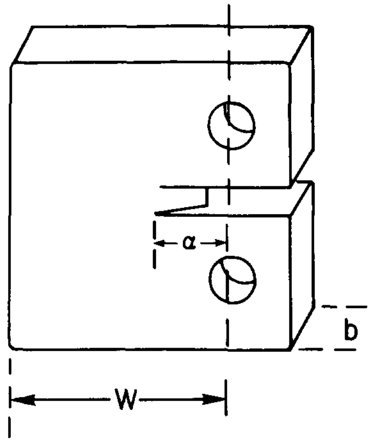

Fig. 1: Compact tension specimen.

measured, and the fracture energy, G_c, determined using the equation of Schutz (1974). In modified epoxy specimens, initial crack propagation from the starting precrack formed a deformation zone, manifested by a stress-whitened area. Since this zone size was a significant portion of the crack length for the elastomer-epoxy material, it was included as part of the crack length, a, shown in Fig. 1.

Standard Izod impact tests were also carried out. Impact load was found to increase linearly with time until fracture. The impact data were used to develop plots of impact energy versus specimen cross-sectional area, as shown in Fig. 2. The slope of the linear plot gave the sample fracture energy at high loading rates, according to the analysis of Plati and Williams (1975).

Results and Discussion

The effect of loading rate on the fracture property of elastomer-modified epoxy polymer is shown in Fig. 3, where the fracture energy, G_c, was plotted against the inverse of fracture time. The lowest rate tested represented a cross-head speed of 0.125 cm/sec in the INSTRON, whereas the highest rate shown corresponded to the impact result. It can be seen that the fracture energy of the base epoxy was greatly increased by the elastomeric additives. At the lowest loading rate, this toughening effect is manifested by an increase in G_c by as much as a factor of 30. This result may be compared with that obtained previously on samples containing liquid CTBN additives alone (Bascom and Cottington, 1976). The addition of a high molecular weight solid CTBN caused further toughening of the base epoxy than was attainable by using liquid CTBN additives alone. However, the improved G_c value for the modified system was also shown to decrease rapidly with increasing loading-rate, although the fracture energy of the base epoxy seemed to be independent of the loading rate. At high loading rates, the fracture energy

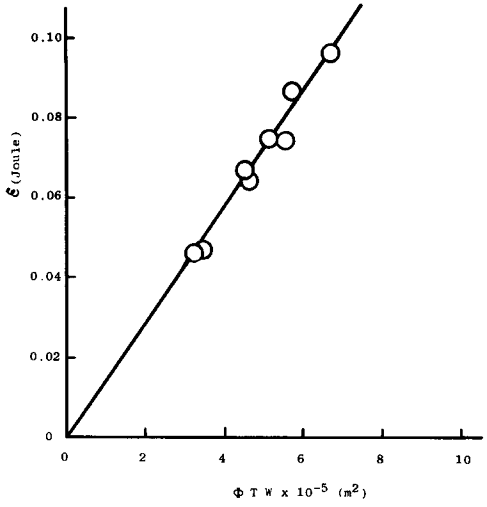

Fig. 2: Impact energy versus specimen cross-sectional area.

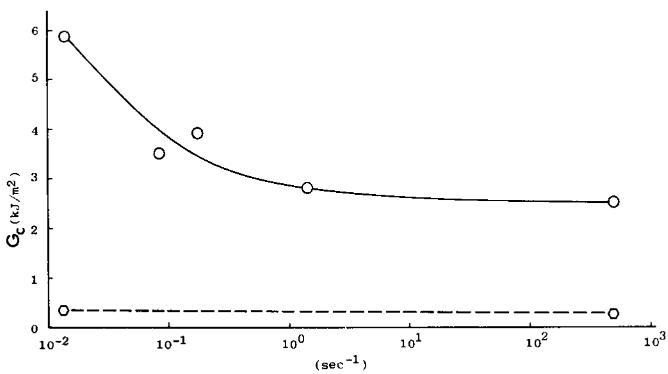

Fig. 3: Fracture energy as a function of loading rate. (O modified epoxy, O unmodified epoxy).

of the toughened epoxy polymer appreared to level off to an asymptotic value approximately eight times of that of the base epoxy. The implication of this loading-rate dependence of the fracture energy of a rubber-toughened epoxy is therefore clear: for high loading-rate applications, such as in an impact failure, the rubber particles dispersed in the brittle matrix become less effective in toughening the epoxies.

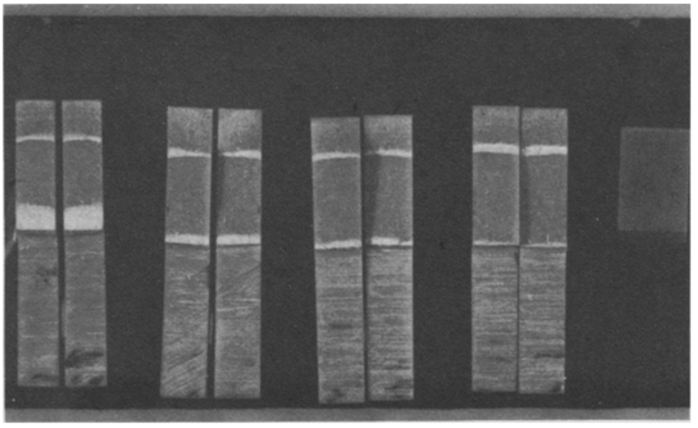

Fig. 4: Photograph of fracture surfaces of specimens tested at different loading rates, from left to right for INSTRON speeds of 0.125, 0.5, 1.25, and 12.5 cm/min and for the impact case.

Figure 4 shows the post-failure appearance of the modified-epoxy specimens tested at various loading rates. The stress-whitened regions developed from the starting crack on the fracture surfaces can be clearly seen. This stress-whitening is associated with the crack-tip damage zone that develops to some critical size prior to catastropic failure. As the loading-rate increased, the size of the stress-whitening zone decreased, and disappeared in the impact case as far as the naked eye could detect. This decrease in the extent of stress-whitening or the critical damage zone size correlated with the decrease in fracture energy with increasing loading rate (Fig. 3), and was in agreement with predictions based on the elastic-plastic theory (Tetelman and McEvily, 1967). This suggests that the elastic-plastic model is useful for analyzing the crack-tip yielding phenomenon in elastomer-modified epoxy polymers.

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Received December 21, 1979