Polymer Bulletin 15, 271–276 (1986)

Polymer Bulletin

Composites

Some Deformation Features in Mechanical and Electrical Breakdown of Fibrous Polymer Composites

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Summary

Observations have been made for deformational features due to mechanical load or due to electric force for thermoplastic matrix reinforced by short glass fibers. Morphological aspects common for both phenomena have been noted.

Introduction

There have been active researches on mechanical fracture (1-4) and electric breakdown (5-6) phenomena to understand the failure mechanism of fiber-reinforced polymer composites. In this letter certain common features in mechanical and electrical failure phenomena will be mentioned and an explanation will be presented in terms of deformation mechanics of short fiber reinforced polymer composites. A short note on voiding will follow.

Experimental

The injection molded polyethylene terephthalate (PET) or polyphenylene sulfide (PPS) reinforced with short E-glass fibers were provided by Dupont and by Phillips Petroleum Company, respectively. The stress rupture unit (1) has been employed to induce mechanical fracture in air. The microstructure of fractured surface is examined by the scanning electron microscope. The electric breakdown of a composite sample has been conducted by the testing unit mentioned previously (5) and the microstructure of a failed specimen has been investigated by means of polarized light to reveal erosion channels inside the specimen. Occasionally, the ion-milling technique (7) has been employed to investigate the deformed microstructure.

Results and Discussion

As seen in Figure 1 fiber fracture under a tensile load occurs more likely near neighboring fiber ends. Such fiber breakage also appears under a compressive load where the rectangular bar-type specimen tends to buckle prior to failure. Thus, a horizontal compressive load was transformed into a horizontal tensile load by buckling of the sample column.

In these cases, the fiber fracture is induced by the combined action of tensile stress and shear stress. The shear stress from the neighboring fiber tip is transferred through the matrix. There appears to be a critical distance above which the shear stress is not effective in inducing fiber fracture. The net result of the interaction with a neighboring fiber end is the increased tensile force on a plane at 0° to the terminating fiber. Depending on the relative orientation, a certain plane of a fiber will get the maximum increased tensile force. Note in Figure 1 the local debonding at places close to the neighboring fiber end.

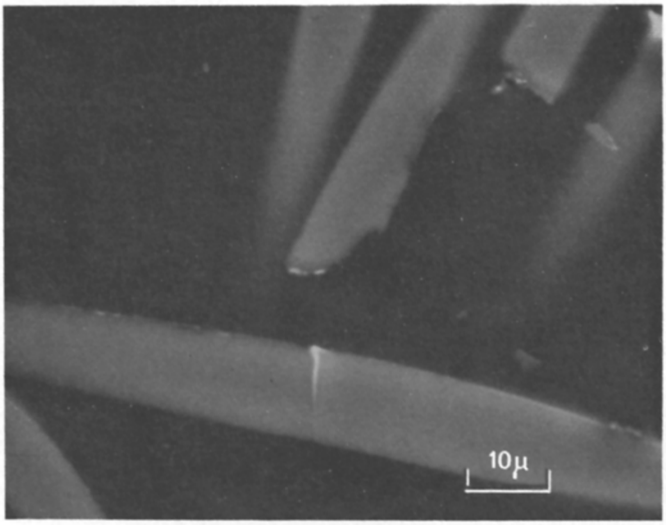

Fig. 1 Localized view of fiber fracture under a tensile load (vertical direction) for (PET/glass) composite.

Polymer failure in a far-field region (1) quite often occurs in parallel discrete cracks for mechanical breakdown under a vertical tensile load. The same kind of parallel crack feature is seen in electrical breakdown (5) in which the applied electric voltage is transformed into a mechanical force by various mechanisms (8), as in Figure 2. The tribological failure in the sub-surface zone also reveals such a parallel feature of discrete deformations, where the external force comes from the combination of normal load and frictional force (9,10). Such a ladder-like parallel feature common to fracture, electric breakdown and tribological failure has its origin in the morphology of semicrystalline polymers (7,11).

The basic building block of semicrystalline polymer structure is a lamellar platelet. The architecture of this platelet for a given polymer can be of three kinds: planar, rigid sheet, and S-shape lamellae (12,13). The initial investigation by TEM and SEM of the mechanical failure process has been recently provided (14), where the (fiber/matrix) interfacial failure mechanism and the interlamellar matrix failure process have been described.

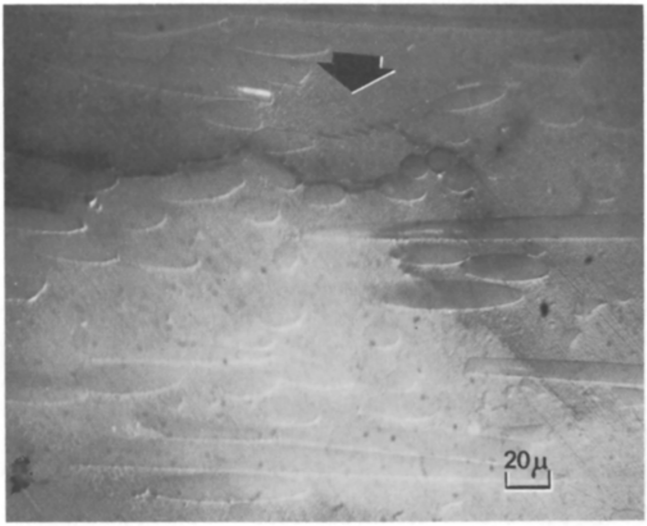

Fig. 2 Discrete matrix failure under electrical breakdown (see the arrow mark) of (PET/glass) composite.

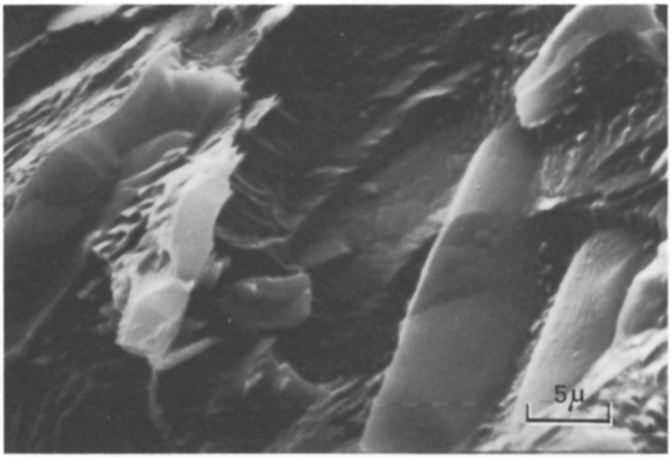

Fig. 3(a) SEM micrograph of deformed (PET/glass) composite.

The SEM micrograph of deformed PET/glass composite is presented in Figure 3(a), in which both planar and ridged sheet lamellae are seen. The deformation causes platelets to be aligned along the stress direction and the interlamellar amorphous phase can be easily etched away by ion-beam bombardment (7). The ridged sheet is a lamellar profile viewed down the crystallographic b-axis. When the b-axis is in the plane of the picture, a curved lamellar profile is obtained as shown in Figure 3(b) revealed in smooth features. Also seen are (fiber/matrix) interfacial microvoids as reported previously (1,14).

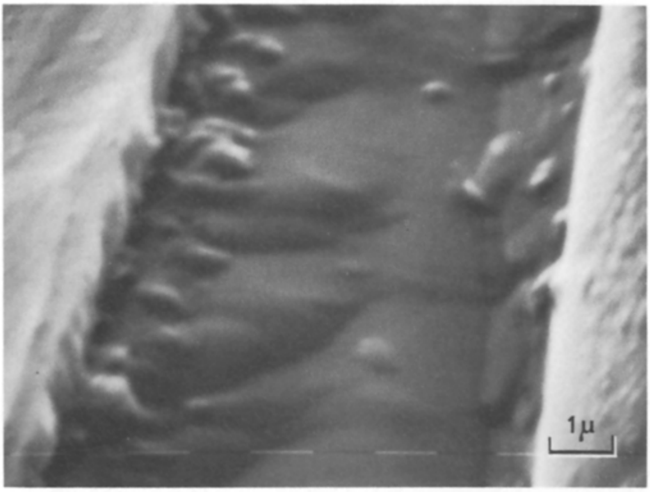

Fig. 3(b) SEM micrograph of deformed (PET/glass) composite when the b-axis is in the plane of the picture.

The fast fracture technique is another way of revealing an intrinsic structural morphology, as shown in Figure 3(c) for a PPS/glass composite. The planar and ridged sheet profiles are seen in the fracture plane, and under a high magnification the interlamellar voiding is seen. Prolific broken craze fibrils are also seen over the whole fracture plane. So, from the previous morphological features, it appears that the ladder-like deformation features are crack failures along the boundary between adjoining planar lamellar platelets.

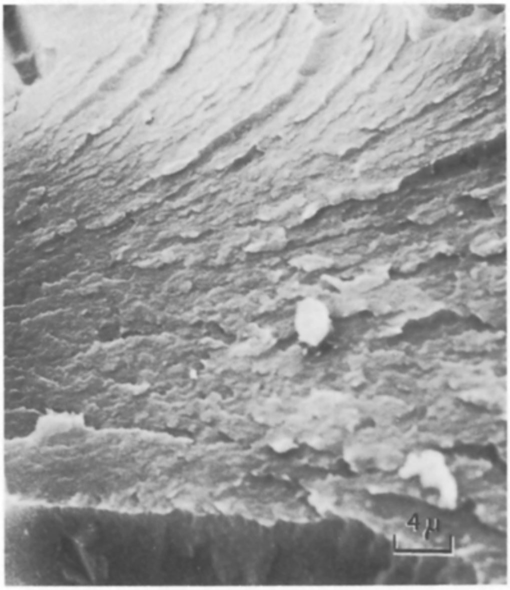

Fig. 3(c) SEM picture of fracture surface of (PPS/glass) composite under a stress rupture.

Voiding is frequently observed prior to macroscopic crack generation/growths. A void can be formed by cumulative breakdown of craze bundles as shown in Figure 4 or shear-like failure along the boundary of local grainy feature. The tensile failure induces a void morphology as on Figure 4 and impact fatigue failure (15) induces a void morphology, where craze fibrils are not seen due to the fast deformation rate in impact. The compressive failure induces a matrix deformation, in which the compressive load is directed horizontally. Because of buckling, a tensile force is induced along the horizontal direction and consequently appears to induce deformation aspects along the boundary of local grainy features in parallel fashion. Voiding occurs at this boundary.

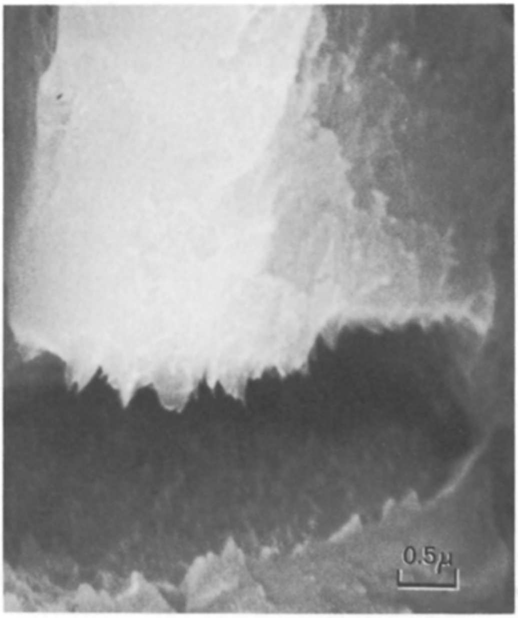

Fig. 4 Voiding of PPS matrix at room temperature and 20 inches per minute strain rate tensile rupture.

Conclusions

(1) The fiber fracture in short fiber composites tends to be enhanced by the presence of neighboring fiber ends due to the reinforced tensile stress applied to the fiber.

(2) The ladder-like crack feature in both mechanical and electrical breakdown appears to be failures along the interlamellar platelet boundaries.

Acknowledgements

The experimental work was partially conducted at Southern Illinois University, Carbondale and at University of Deleware, Newark. The author is grateful to the hospitality of the two institutions. The author would like to thank Dr. A.H. Pulsifer for critically reading the manuscript.

References

1. C. Lhymn, J.M. Schultz, J. Mat. Sci. 18, 2029 (1983).
2. C. Lhymn, J.M. Schultz, J. Mat. Sci. 18, 2923 (1983).
3. C. Lhymn, J.M. Schultz, Polymer Comp. 7, 208 (1984).
4. J.M. Schultz, K. Friedrich, J. Mat. Sci. 19, 2246 (1984).
5. J.M. Schultz and C. Lhymn, Polymer Comp. 7, 215 (1984).
6. C. Lhymn, J. Mat. Sci. Lett. 4, 665 (1985).
7. C. Lhymn, J.M. Schultz, Polym. Comp. 6, 87 (1985).
8. M.T. Shaw, S.M. Shaw, IEEE Tr. on EI, EI-19, 5, 419 (1984).
9. A.R. Rosenfield, "Fundamentals of Friction and Wear of Materials" D.A. Rigney, ed. ASM, Metals Park, OH, 221 (1981).
10. C. Lhymn, K.E. Tempelmeyer, P.K. Davis, Composites 16, 127 (1985).
11. J.M. Schultz, Polym. Eng. and Sci. 24, 770 (1984).
12. D.C. Basset, A.M. Hodge, Proc. R. Soc. Lond. A 377, 25 (1981).
13. D.C. Basset, A.M. Hodge, R.H. Olley, Proc. R. Soc. Lond. A 377, 39 (1981).
14. C. Lhymn, J. Mat. Sci. Lett. 4, 1244 (1985).
15. C. Lhymn, J. Mat. Sci. Lett. 4, 1221 (1985).

Accepted March 14, 1986

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