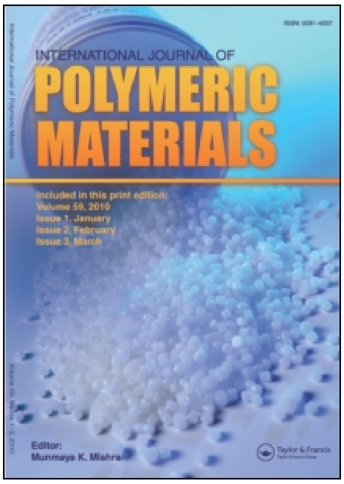

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Scanning Electron Microscopy Studies on Tear and Wear Failure of Short Kevlar Fiber-Thermoplastic Polyurethane Composite

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Scanning Electron Microscopy Studies on Tear and Wear Failure of Short Kevlar Fiber-Thermoplastic Polyurethane Composite

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Tear and wear properties of short kevlar fiber, Thermoplastic polyurethane (TPU) composite with respect to fiber loading and fiber orientation has been studied and the fracture surfaces were examined under scanning electron microscope (SEM). Tear strength first decreased up to 20 phr fiber loading and then gradually increased with increasing fiber loading. Anisotropy in tear strength was evident beyond a fiber loading of 20 phr. Tear fracture surface of unfilled TPU showed sinusoidal folding characteristic of high strength matrix. At low fiber loading the tear failure was mainly due to fiber-matrix failure whereas at higher fiber loading the failure occurred by fiber breakage. Abrasion loss shows a continuous rise with increasing fiber loading, the loss in the transverse orientation of fibers being higher than that in the longitudinal orientation. The abraded surface showed long cracks and ridges parallel to the direction of abrasion indicating an abrasive wear mechanism. In the presence of fiber, the abrasion loss was mainly due to fiber loss.

1. INTRODUCTION

Short fiber-elastomer composites have gained considerable importance in the last two decades because of the advantage of better processing, high anisotropy in mechanical properties and excellent stiffness characteristics in addition to lower cost. Elaborate studies on these composites have been well documented earlier.[1–11] But literature are scanty on the composites from thermoplastic elastomers and short fibers.[12] In an earlier communication[13] the authors have reported the tensile properties of short kevlar fiber-TPU composite along with its dynamic mechanical properties. Tensile strength was improved after an initial drop whereas the impact

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strength was reduced with increasing fiber content and there was drastic reduction in fiber length from 6 mm to approximately 1 mm. Rheology and stress relaxation of these composites have also been reported earlier.[14,15] Since the service life of these composites in many application depends on their resistance to tear and wear a thorough understanding of these modes of failure is essential. Recently scanning electron microscopy (SEM) has been employed successfully to investigate different fracture surfaces of short fiber-elastomer composites.[9,10,13,16] This paper highlights the tear and wear properties of short kevlar fiber-TPU composite and the fracture surface analysis by SEM. Emphasis has been given to the effect of fiber loading and fiber orientation on the tear and wear resistance.

2. EXPERIMENTAL

Ether based Thermoplastic polyurethane (Estane 58311) used in this study was obtained from B. F. Goodrich, USA and kevlar staple fiber (T-970) of approximately 6 mm and length to diameter ratio 500 was obtained from DuPont de Nemours Co., USA. Formulation of the mixes are given in Table I. Both thermoplastic polyurethane and kevlar staple fibers were dried at 105°C for 2 hours to demoisturise the samples before mixing. The mixes were prepared in a Brabender plasticorder, PLE 330, fitted with a cam type mixer at a temperature of 180°C and at a rotor speed of 60 rpm. The torque and temperature were recorded as a function of time. The mixing sequence is shown in Table II. The molten mass from the brabender plasticorder was taken out immediately and sheeted out on a laboratory size (152 mm × 330 mm) open two roll mixing mill at tight nip. Two mm sheets and abrasion resistance test samples were molded in an electrically heated hydraulic press at 180°C for three minutes and quench cooled in cold water. Tear specimens were punched out along and across the grain direction and were tested on Instron universal testing machine, model 1195 according to ASTM D 624-73. Abrasion tests were carried out on a Du Pont abrader as per ASTM D 394-47 A. Schematic representation of fiber orientation in tear and abrasion test samples and the respective scan areas are shown in Figure 1. The fracture surfaces were sputter coated

TABLE I

Formulation of the mixes

Ingredient	Mix No.				
	A	B	C	D	E
TPU	100	100	100	100	100
Kevlar	-	10	20	30	40

TABLE II

Mixing sequence

Ingredient	Time, min	RPM	Ram
1/2 TPU	0	30	up
Fiber	1.5	30	up
1/2 TPU	3.0	60	down
-	9.0	-	dump

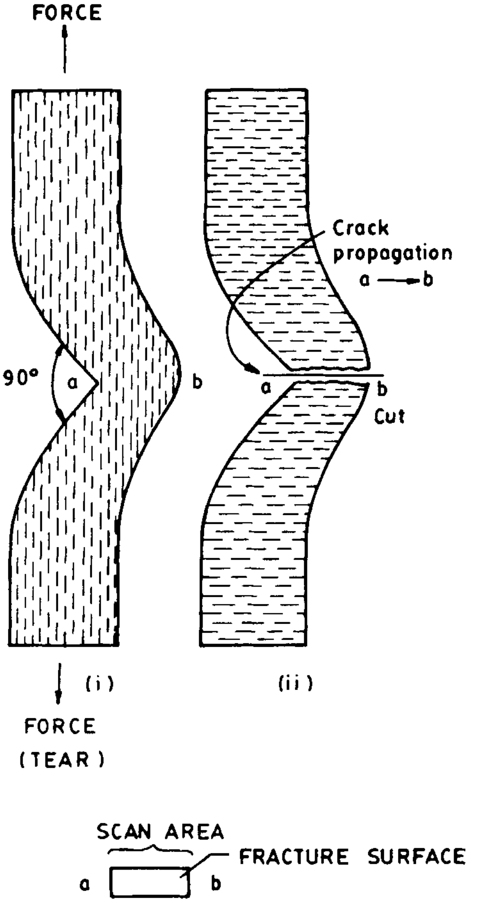

FIGURE 1 Schematic representation of fiber orientation in tear and wear test specimens.

with gold within 72 hours of testing and observed under scanning electron microscope.

3. RESULTS AND DISCUSSION

Table III gives the tear strength and abrasion loss of mixes A–E.

3.1 Tear

Mix A shows the highest tear strength which decreases in the presence of up to 20 phr of short kevlar fibers. On increasing the fiber loading further to 40 phr, the tear strength is improved gradually. A similar trend with respect to fiber loading in the case of tensile strength has been reported.[13] The influence of the direction of orientation of fiber with respect to the direction of application of load becomes prominent beyond a fiber loading of 20 phr. The longitudinal orientation of fiber gives a high tear strength compared to that of transverse orientation of fiber.

The very high tear strength of TPU is arising out of its segmented structure. Thermoplastic polyurethane consists of polyol soft segments and isocyanate rich hard segments which act as thermally labile virtual cross linking sites and also reinforcing fillers.[17] The hard segments are joined to the soft phase, in which they are embedded, through urethane linkage. In tear specimens a large amount of stress is concentrated on its apex producing triaxial stress at the angular region. Thus application of uniaxial stress initiates the failure at the apex and propagates across the sample width. Stress dissipation near the tip of growing crack by viscoelastic process is essential to the development of high strength. Presence of these hard segments in the matrix results in additional mechanism by which strain energy is dissipated. Radok and Tai[18] have studied the mechanical energy dissipation through increased hysteresis resulting from the inclusion of particles in a viscoelastic medium. In addition to causing increased energy dissipation, dispersed particles may serve to deflect or arrest growing cracks thereby further delaying failure.[19]

The SEM photo micrograph of the tear fracture surface of mix A at the tear

TABLE III

Tear strength and abrasion losses of mixes A–E

Property	A		B		C		D		E	
	L	T	L	T	L	T	L	T	L	T
Tear strength, kN/m	106	106	84	86	73	72	90	77	96	75
Abrasion loss x 100 cc/ hr	12.5	11.9	28.0	30.1	34.9	45.9	45.3	61.1	50.9	67.3

initiation region (Figure 2a) shows sinusoidal and straight but unbranched tear lines which tend to die down as the tear propagates. Highly torn and mutilated matrix at the initiation region is also seen. These sinusoidal wave patterns at the tear surface is due to extensive stretching of the matrix under the applied stress which leads to local plastic deformation. Similar results have been reported earlier in the tear testing of semicrystalline thermoplastic elastomers.[20] The presence of sinu-

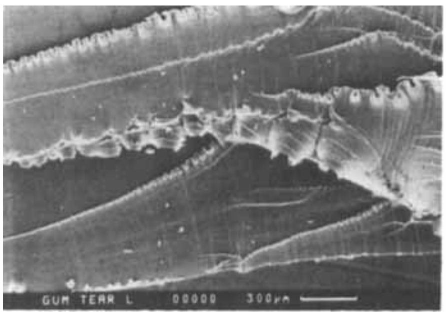

FIGURE 2a SEM photomicrograph of tear fracture surface of mix A—general view.

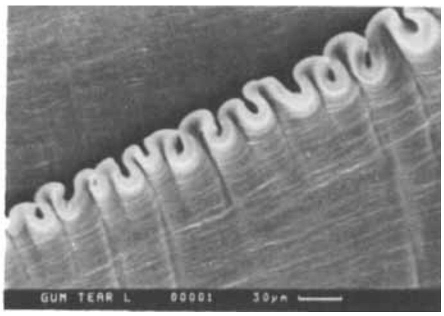

FIGURE 2b SEM photomicrograph of tear fracture surface of mix A—sinusoidal folds.

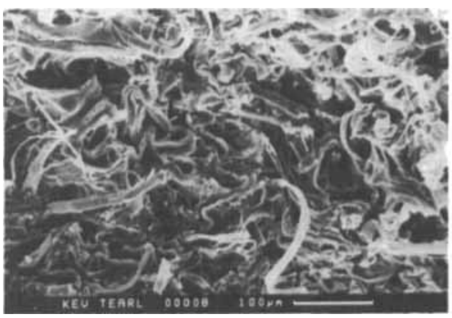

FIGURE 2c SEM photomicrograph of tear fracture surface of mix B. (Fibers in the longitudinal direction)

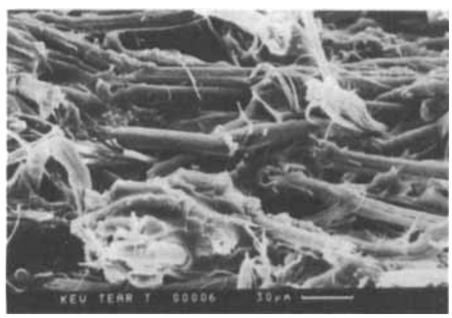

FIGURE 2d SEM photomicrograph of tear fracture surface of mix B. (Fibers in the transverse direction)

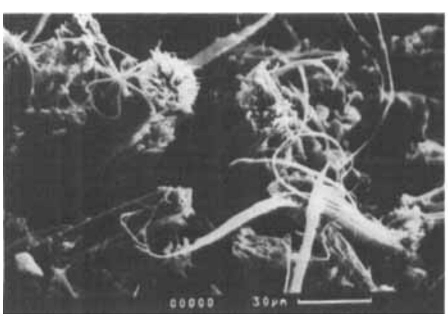

FIGURE 2e SEM photomicrograph of tear fracture surface of mix E. (Fibers in the longitudinal direction)

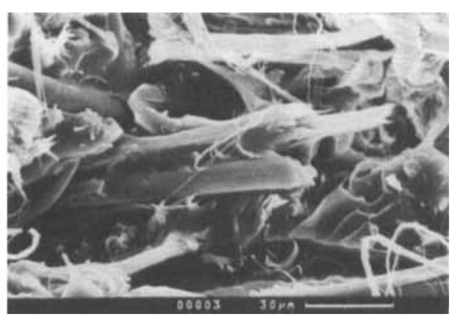

FIGURE 2f SEM photomicrograph of tear fracture surface of mix E. (Fibers in the transverse direction)

soidal folds at the tear failure surface is a characteristic feature of high strength matrices and indicates a periodic stick-slip type of failure. A part of the sinusoidal folds on magnification (Figure 2b) shows microfolds running perpendicular to the direction of propagation of tear and horizontal crazes.

A low fiber loading the reduction in tear strength in longitudinal and transverse directions may be because of insufficient number of fiber to restrain the matrix. Incorporation of short fiber in smaller quantities helps only to dilute the matrix rather than to reinforce it and the load is carried mainly by the matrix. This explains the almost similar tear strengths in the longitudinal and transverse directions. SEM fractograph (Figure 2c) of a low fiber content sample (mix B) with fiber in the longitudinal direction shows the fiber pulled out holes and disgruntled matrix. SEM photomicrograph of the sample with fibers in the transverse direction (Figure 2d) shows exposed fibers—again indicating a fiber-matrix interfacial failure resulting from high stress concentration at the interface. However at high fiber loadings, the reinforcement effect outweighs the dilution effect and hence a gradual increase in tear strength beyond 20 phr is observed. Broken fiber-ends instead of pulled out fibers on the fracture surface of 40 phr fiber loaded sample (mix E) with fibers in the longitudinal direction (Figure 2e) is in agreement with the view. Fracture surface of mix E with fibers in the transverse direction (Figure 2f) also indicates a reinforced matrix. Higher tear strength shown by the mixes D and E in the longitudinal direction may also be due to the fact that the fibers being in a direction perpendicular to the direction of propagation of fracture are better posed to arrest or deflect the advancing crack front compared to transverse orientation where the fibers are aligned parallel to the direction of crack propagation and hence fail to give an effective hindrance to advancing fracture.

3.2 Wear

Figure 3 gives the variation of abrasion loss in the longitudinal and transverse directions, with fiber content. In both the orientations the abrasion loss is found to

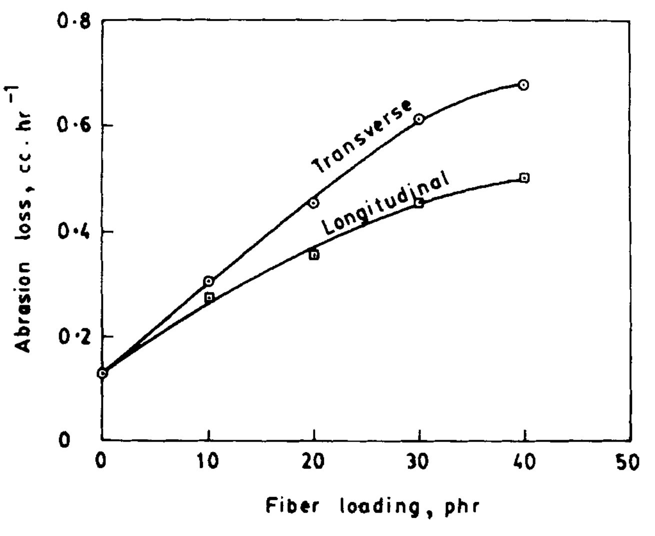

FIGURE 3 Variation of abrasion loss with fiber loading in the longitudinal and transverse directions.

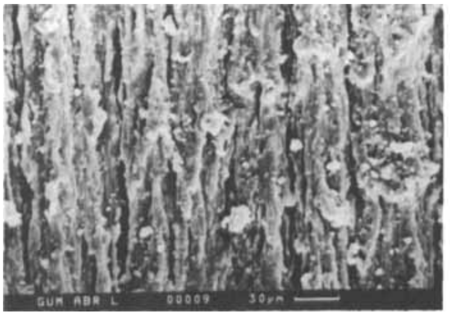

FIGURE 4a SEM photomicrograph of abraded surface of mix A.

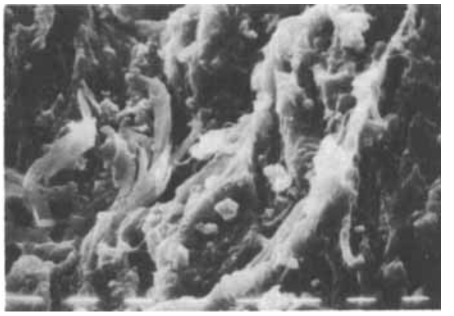

FIGURE 4b SEM photomicrograph of abraded surface of mix B. (Fibers in the longitudinal direction)

FIGURE 4c SEM photomicrograph of abraded surface of mix B. (Fibers in the transverse direction)

FIGURE 4d SEM photomicrograph of abraded surface of mix E. (Fibers in the longitudinal direction)

FIGURE 4e SEM photomicrograph of abraded surface of mix E. (Fibers in the transverse direction)

increase with fiber loading. At all fiber loadings, the abrasion loss in the transverse orientation of fibers is higher than that in the longitudinal orientation and the difference becomes prominent at higher fiber loadings. The low abrasion loss in the case mix A may be arising out of its higher tear strength, as shown in Table III. Southern and Thomas have established that the crack growth plays an important role in abrasion.[21] The abraded surface of mix A (Figure 4a) shows deep fissures and ridges in the direction of abrasion indicating an abrasive wear. Debris of abraded matrix are seen scattered on the surface. The high abrasion loss in the case of fiber filled mixes are due to fiber loss arising out of lower fiber-matrix adhesion at lower fiber loading whereas at higher fiber loading the loss occurs mainly by fiber breakage.

The SEM study of the abraded surface of the fiber-filled mixes also support this view. Figure 4b shows the abraded surface of mix B with fiber in the longitudinal direction. The abraded fiber-ends and long deep fissures in the matrix are visible. As in the case mix A, here also continuous abrasion results in ridge formation. That the fibers are subjected to more abrasive action than the matrix is due to their being pulled partially out of the matrix during early stages of abrasion. In the longitudinal orientation of fibers, the chances of such pull out is less and hence the abrasion loss is less compared to transverse direction. Figure 4c shows the abraded surface of mix B in the transverse direction. The higher amount of fiber breakage is evident from the higher number of abraded fiber ends seen. Long deep cracks and the associated ridges are also seen here indicating that the mechanism of wear is not affected by the presence of fibers. Abrasion loss in the transverse direction is found to increase at a faster rate than in the longitudinal direction with fiber loading. The higher loss in the transverse direction at higher loading may be due to the higher possibility of fiber loss. SEM photomicrograph of the abraded surface of mix E in the longitudinal and transverse fiber orientations are shown in Figure 4d and 4e respectively. The higher extent of fiber loss in the transverse than in the longitudinal direction is evident from higher number of abraded fiber ends seen in Figure 4e as compared to that in Figure 4d.

4. CONCLUSIONS

From this study the following conclusions may be drawn: Tear strength of short kevlar-TPU composite is increased with fiber loading after an initial reduction up to 20 phr. Anisotropy in tear strength is prominent beyond 20 phr of fiber loading. Abrasion loss increases with increasing fiber concentration, the loss in the transverse orientation of fibers being higher than that of longitudinal orientation of fibers at all fiber loadings. SEM study shows good correlation with the observed tear and wear behavior of short kevlar-TPU composite.

References

1. B. E. Brokenbrow, D. Simes and A. L. Stokoe, *Rubber J.*, **151**, 61 (1969).
2. G. C. Derringer, *J. Elastoplast.*, **3**, 230 (1971).
3. G. C. Derringer, *Rubber World*, **165**, 45 (1975).
4. J. E. O'Connor, *Rubber Chem. Technol.*, **50**, 945 (1977).
5. A. Y. Coran, *ibid.*, **47**, 396 (1974).
6. A. Y. Coran, P. Hamed and L. A. Goettler, *Ibid.*, **49**, 1167 (1976).
7. A. Y. Coran, K. Boustany and P. Hamed, *J. Appl. Polym. Sci.*, **15**, 2471 (1975).
8. B. K. I. Ku, Abd. Rahman and C. Hepburn, *Proceedings of the International conference on structure-property relations of rubber, Kharagpur, India*, December 1980.
9. V. M. Murty and S. K. De, *Rubber Chem. Technol.*, **56**, 287 (1982).

10. D. K. Setua and S. K. De, *Rubber Chem. Technol.*, **56**, 808 (1983).
11. S. K. N. Kutty and G. B. Nando, *Plast. Rubb. Proc. Appl.*,
12. S. Akhtar, P. P. De and S. K. De, *J. Appl. Polym. Sci.*, **32(5)**, 5123 (1986).
13. S. K. N. Kutty and G. B. Nando, *J. Appl. Polym. Sci.*, **43**, 1913 (1991).
14. S. K. N. Kutty, P. P. De and G. B. Nando, *Plast. Rubb. Comp. Proc. Appl.*, **15**, 23 (1991).
15. S. K. N. Kutty and G. B. Nando, *J. Appl. Polym. Sci.*, **42**, 1835 (1991).
16. J. L. Andries, C. K. Rhee, R. W. Smith, D. B. Ross and H. E. Diem, *Rubber Chem. Technol.*, **52**, 823 (1979).
17. F. R. Eirich ed., "Science and Technology of Rubber," Academic Press, New York, (1978), p. 532.
18. J R. M. Radok and C. L. Tai, *J. Appl. Polym. Sci.*, **6**, 518 (1962).
19. G. L. Kraus in "Science and Technology of Rubber," F. R. Eirich ed., Academic Press, New York, 1978.
20. S. Thomas, B. Kuriakose, B. R. Gupta and S. K. De, *J. Mater. Sci.*, **21**, 711 (1986).
21. E. Southern and A. G. Thomas, *Rubb. Chem. Technol.*, **52**, 1008 (1979).