JOURNAL OF MATERIALS SCIENCE 26 (1991) 1478–1484

The effect of compatibilizer level on the mechanical properties of a nylon 6/ABS Polymer blend

D. M. OTTERSON, B. H. KIM*
Department of Mechanical Engineering, University of Massachusetts, Amherst, MA 01003, USA
R. E. LAVENGOOD
Monsanto Chemical Company, 730 Worcester Street, Indian Orchard, MA 01151, USA

The influence of compatibilizer on the morphology and mechanical properties of a blend of nylon 6 and ABS has been studied. For this blend, the morphological domain size decreases significantly with increasing compatibilizer level. However, stiffness and tensile stress at yield are unaffected by these changes. Within the range of these experiments, Izod impact strength increases monotonically with increasing levels of compatibilizer, but the resistance to crack initiation (J_c) and the resistance to steady state crack growth (R_p) are both increased by the addition of a small amount of compatibilizer and are essentially independent of further increases.

1. Introduction

The long-term trend in the use of thermoplastic polymers is towards more demanding structural applications. The traditional approach to tailoring such materials to provide the balance of properties required for a specific application has been to start with a conventional plastic and then add lubricants, fillers, reinforcing agents, impact modifiers, etc. This approach is no longer adequate for meeting the needs of the marketplace. The popularity of blends or alloys of different polymers is presently growing because of reduced product development time coupled with property balances that are not achievable by the conventional route [1–3].

Unfortunately, simply mixing polymers with desirable properties will usually not result in a useful end product. Although some polymer pairs are miscible and readily mixed, most are immiscible and blends of them will not have a useful balance of properties [4]. In order to obtain a useful blend of two immiscible polymers, it is usually necessary to add a third material which acts as a compatibilizer. Compatibilizers alter the interface between incompatible materials sufficiently so that the resulting blend has a useful balance of properties [5–8].

Although it is well established that in certain systems compatibilizers can substantially improve the properties of the blend [4], it is not clear what the mechanism behind this improvement is or what properties are most benefitted at different compatibilizer levels.

Work by Howe and Wolkowicz [8] has focused on how the mechanical properties of a compatibilized blend of nylon 6 and ABS are affected by varying the blend structure. Lavengood and Silver [5, 9] have also discussed the influence of structure and morphology on the properties of blends of nylon 6 and ABS. In this work we will show the influence of compatibilizer level on the morphology, tensile properties, Izod impact strength, and fracture toughness of a blend of ABS and nylon 6.

2. Materials

The materials used in this study are blends of nylon 6 and ABS. The proprietary compatibilizer is of the type described by Lavengood *et al.* [10]. The ratio of nylon 6 to ABS was held constant while the compatibilizer levels were 0, 1%, 2%, and 6% of the total blend. All materials were prepared in a twin screw extruder with a screw profile specifically designed to give good mixing. Test specimens were moulded on an Arburg 300 injection moulding machine.

3. Experimental procedure

Scanning electron microscopy (SEM) was used to investigate the morphology and the fracture surface of each blend tested. Photographs were taken of razor-notched surfaces and of fracture surfaces. Sets of specimens were stained with phosphotungstic acid, coated with carbon, and examined in the backscattering mode so the blend morphology could be clearly seen.

---

* Author to whom all correspondence should be addressed.

0022–2461/91 $03.00 + .12

Tensile properties were determined with ASTM Method D-638 using ASTM Type M-II specimens tested at 5 mm min^{-1}. Izod test specimens were prepared from 6.2 mm thick and 12.5 mm wide bars and tested in accordance with ASTM Method D-256.

In preparation for three-point bend crack resistance testing, the samples were given a range of four initial crack sizes by drilling and slotting. Sharp cracks were then introduced by pushing a razor blade into the blunt notch. The total initial crack lengths including the razor notching were 9.3, 7.8, 6.2 and 4.1 mm. It should be noted that the depth of the razor notch varied from 0.6–1.2 mm in order to obtain the proper total initial crack length. The specimens measured 125.0, 12.5 and 12.5 mm for length, width, and thickness, respectively.

An Instron model 1011 tensile testing machine was used to obtain the load versus load-point deflection curves for the crack resistance testing. The machine was fitted with a × 50 magnification microscope which allowed visual observation of crack initiation. The load versus load-point deflection curves were recorded on a strip chart recorder. These curves were then digitized for computer analysis.

Three-point bend testing was chosen due to its mechanical stability. The crosshead speed was 5 mm min^{-1} for all specimens and the span of the test fixture was 76 mm. Temperature was maintained between 22 and 26 °C, and the relative humidity was between 50 and 56% during testing.

4. Results and discussion

As expected from emulsifier theory [11], the morphology of the blend becomes finer as the level of compatibilizer is increased. Fig. 1a–d show the blend morphology as seen in the razor-notched portion of the fracture surface. These views are perpendicular to the general flow direction of the blend during moulding. The compatibilizer acts as a surfactant for the two blend constituents. As the amount of compatibilizer in the system is increased, the amount of interfacial surface area increases which leads to a finer phase size in the blend.

The tensile data given in Table I show that, within the range of these experiments, neither the tensile stress at yield nor the tensile modulus is affected by the compatibilizer level. The difference in the solubility parameters of nylon 6 and ABS is not large and they are both polar. Paul and Newman [4] have shown

TABLE I Tensile data as a function of compatibilizer level

Mechanical property	Compatibilizer level (%)			
	0	1	2	6
Tensile modulus (GPa)	2.12	2.17	2.21	2.18
Tensile yield stress (MPa)	41.1	40.7	41.3	41.0
Ultimate tensile stress (MPa)	35.9	35.8	38.1	35.3
Elongation to fail (%)	90	160	225	135
Range of elongations (%)	67–119	107–201	190–272	102–168

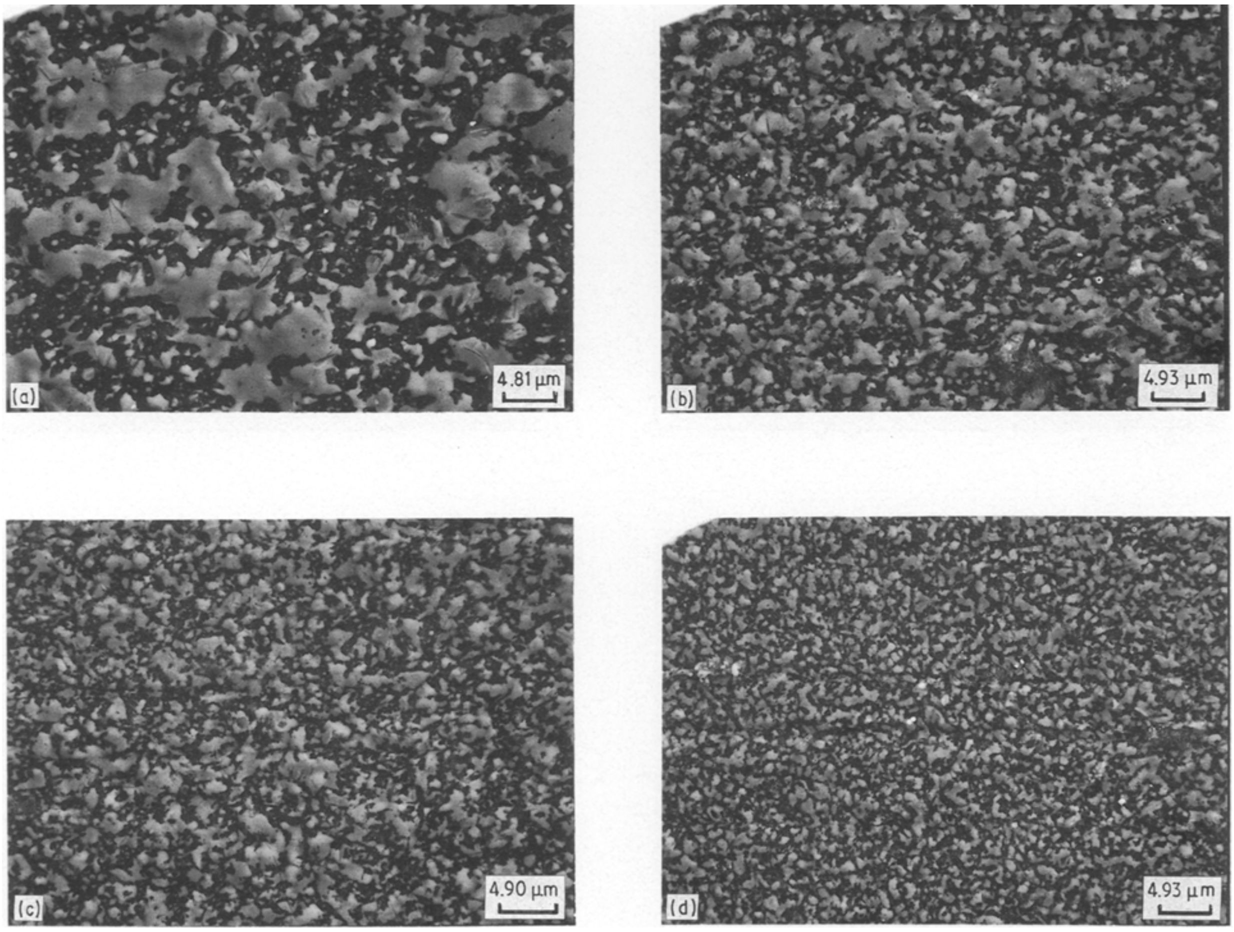

Figure 1 Morphology of the tested samples with (a) 0, (b) 1%, (c) 2%, (d) 6% compatibilizer (× 1300); Surface shown is on a plane perpendicular to flow in the mould.

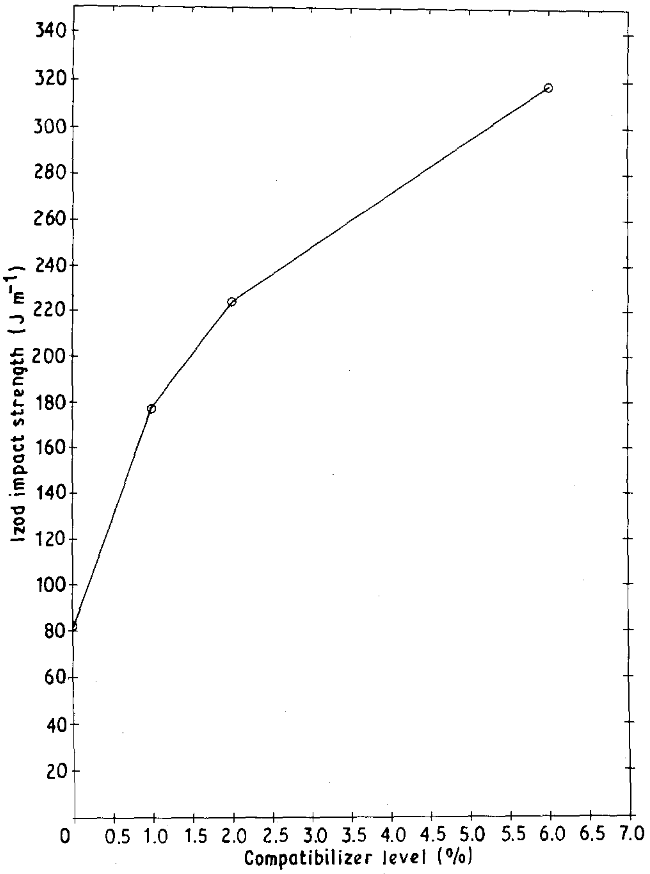

Figure 2 Izod impact strength as a function of compatibilizer level.

that the molecular attraction due to polarity can be quite significant. It appears, based on the yield stress data, that these immiscible polymers have a relatively strong affinity for each other. In contrast, both the ultimate stress and the elongation to fail show a maximum at 2% compatibilizer. The mechanisms responsible for these optima are not obvious.

The Izod impact data, shown in Fig. 2, shows that this measure of toughness increases monotonically with increasing compatibilizer level. The samples containing 6% compatibilizer are nearly four times as tough as the blend without compatibilizer. Fig. 3a–d show scanning electron micrographs of Izod impact fracture surfaces at approximately × 3250 magnification.

The fracture mechanics values were obtained using a technique developed by Kim and Joe [12, 13] which has previously been used successfully on less complex polymeric materials. Their work has resulted in a simple method for determining crack resistance values.

The crack initiation resistance can be found in terms of the critical J-integral value (J_c) utilizing the locus line of crack initiation points on load–displacement records. It has been shown that J_c can be calculated from the following equation [12]

$$J_c = -\frac{1}{B}\frac{\Delta U_c}{\Delta a} \quad (1)$$

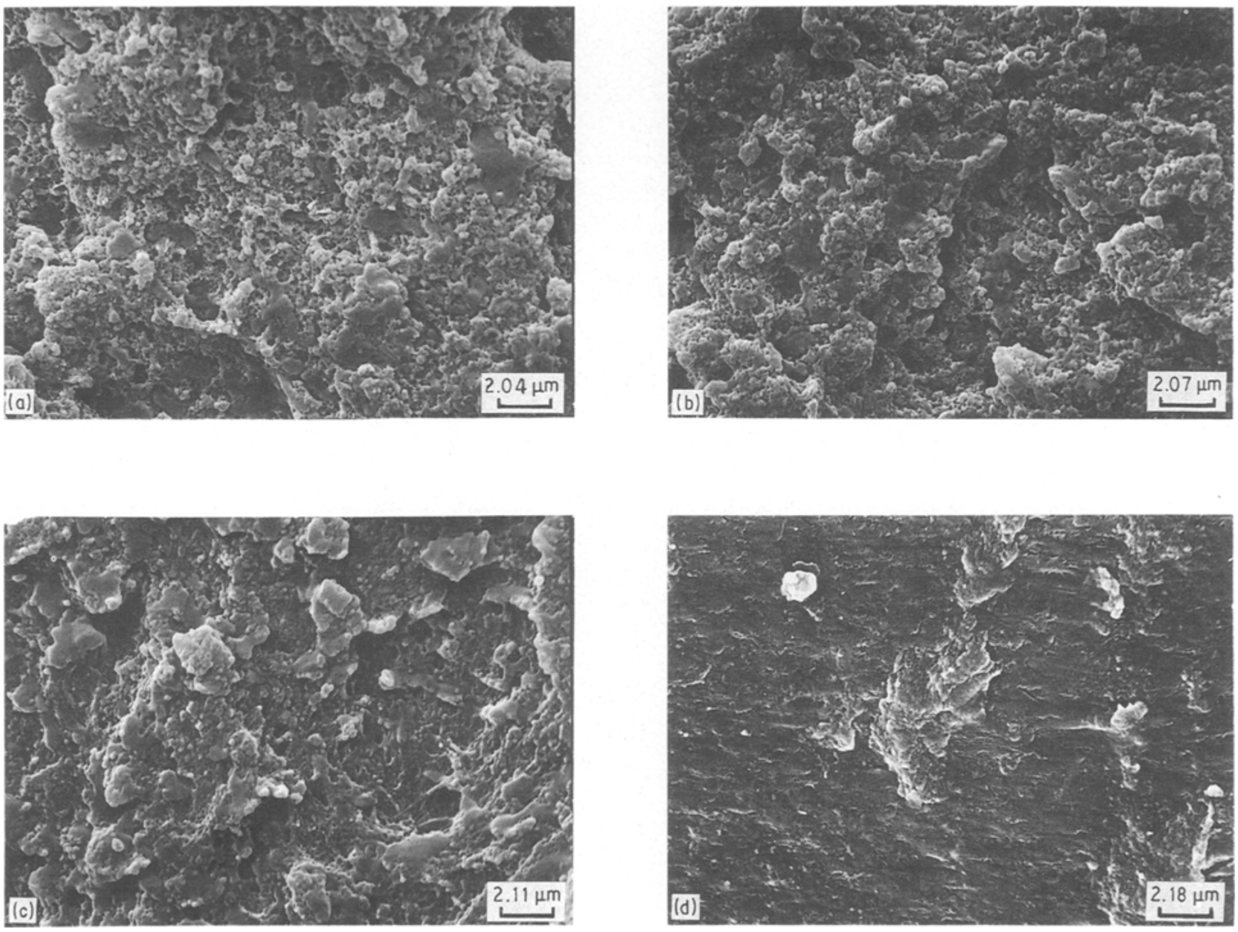

Figure 3 Scanning electron micrographs showing the fracture surface of Izod impact test specimens. (× 3250)

where B is the sample thickness, a is the initial crack length, and U_c is the essential energy required to initiate the crack.

The energy, U_c, can be found from the load versus load-point deflection curves of samples which differ only in their initial crack size. If the crack initiation point is observable and is noted on the load versus load-point deflection curve of each tested specimen, a locus of crack initiation points can be created. U_c is then determined from the area surrounded by the locus line of crack initiation points, the load versus load-point deflection curve, and the x-axis.

J_c may be found by plotting U_c per unit thickness versus a. From Equation 1, it is seen that if U_c varies linearly with respect to a, then J_c is a constant value. The slope of this linear line represents the constant J_c.

The resistance to steady state crack propagation may be obtained in a similar way using the formula [13]

$$R_p = -\frac{1}{B}\frac{\Delta U_f}{\Delta a} \qquad (2)$$

Equation 2 allows the calculation of a resistance value as a function of crack growth if U_f, the total energy for

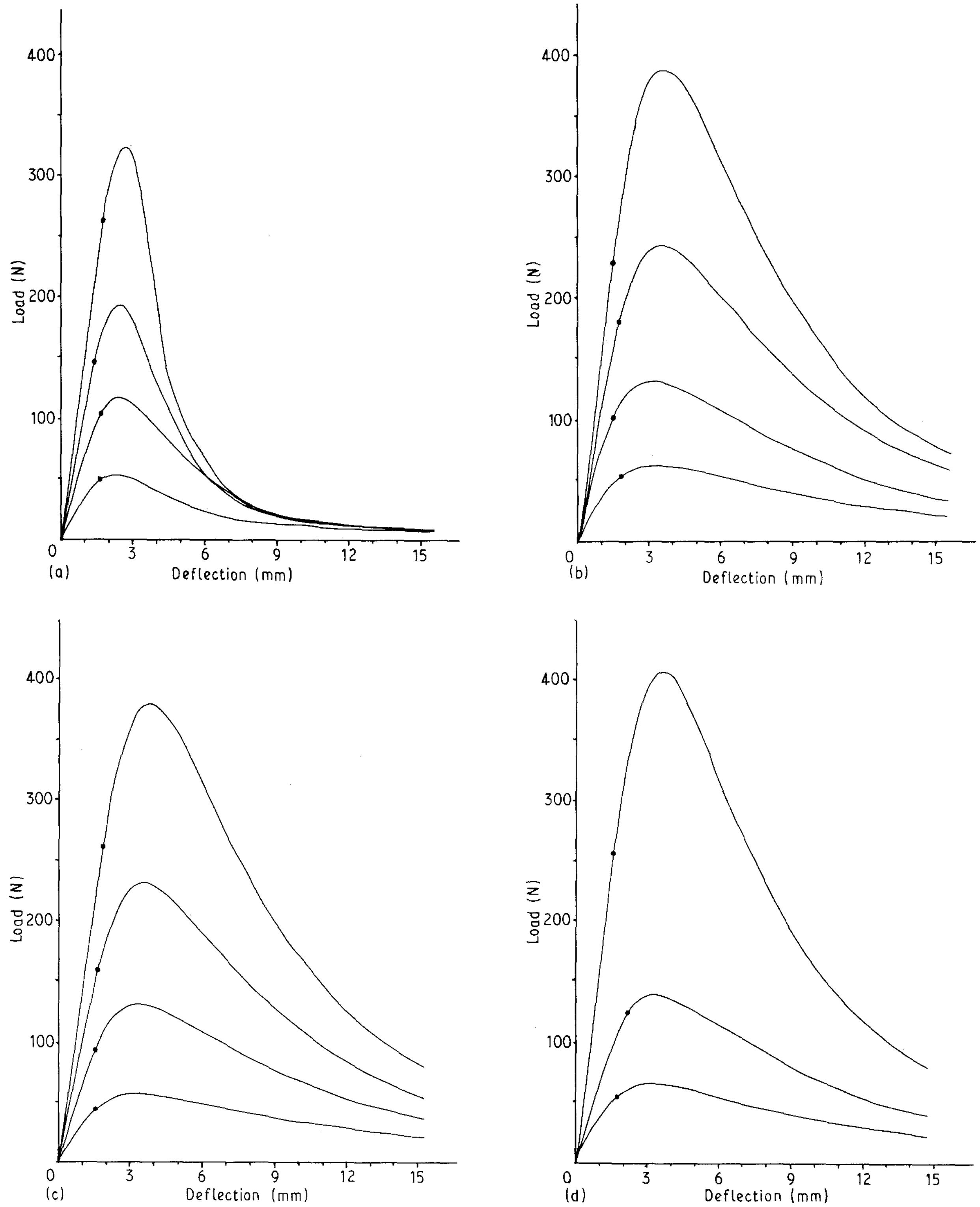

Figure 4 Typical load versus load-point deflection curves for a nylon 6/ABS blend with (a) 0, (b) 1%, (c) 2%, (d) 6% compatibilizer.

fracture, is known. U_f may be determined using each specimen's load versus load-point deflection curve. The total area enclosed by this curve and the x-axis represents U_f.

Once the energy values are determined, they are then plotted as a function of crack extension. If R_p is a constant for steady crack growth, then the plot of energy values with respect to crack extension will be linear. It should then be possible to fit a linear line to this portion of the curve and determine its slope. The slope of this line will yield R_p in accordance with Equation 2.

It may also be possible to determine the resistance to crack growth at maximum load (R_{max}) using the maximum load points on the load versus load point deflection curves as characteristic points. Determination of an R_{max} value depends upon whether or not the complete R curve exhibits a point of sharp curvature between the initiation and steady state resistances [13]

$$R_{max} = -\frac{1}{B}\frac{\Delta U_L}{\Delta a} \qquad (3)$$

If the maximum load point is noted on the load versus load-point deflection curve of each tested specimen, a locus of maximum load points can be created. U_L is then determined from the area surrounded by the locus line of maximum load points, the load versus load-point deflection curve, and the x-axis.

From Equation 3 it is seen that if U_L varies linearly with respect to a, then R_{max} is a constant value and the material's R-curve shows a point of sharp curvature. R_{max} may be found by plotting U_L per unit thickness versus a. The slope of this line yields R_{max}.

Fig. 4a–d show typical load versus load-point deflection curves obtained for the different blends tested using three-point bending. Crack initiation points are shown as black dots on each curve.

Fig. 5a–d are scanning electron micrographs of the fracture surfaces created during three-point bend loading. These fracture surfaces are quite different from the Izod impact fracture surfaces shown in Fig. 3a–d. These fracture surfaces were stained using phosphotungstic acid in order to highlight the nylon 6. Interestingly, samples stained using osmium tetroxide in order to highlight the ABS produced almost identical SEM pictures.

The total energy required to initiate the crack (U_c) was determined and plotted in accordance with Equation 1 for the set of specimens in which crack initiation could be observed. The resulting plots for each compatibilizer level are shown in Fig. 6. The slopes of each of these plots represent J_c for each material and these values are given in Table II. J_c was found to be 2.6, 2.7, 2.9, and 3.6 kJ m^{-2} for blends containing 0, 1%, 2%, and 6% compatibilizer, respectively.

The total energy for fracture (U_t) for each specimen was determined and plotted in accordance with Equation 2. These plots are shown in Fig. 7. The slopes of these plots represent R_p for each material and

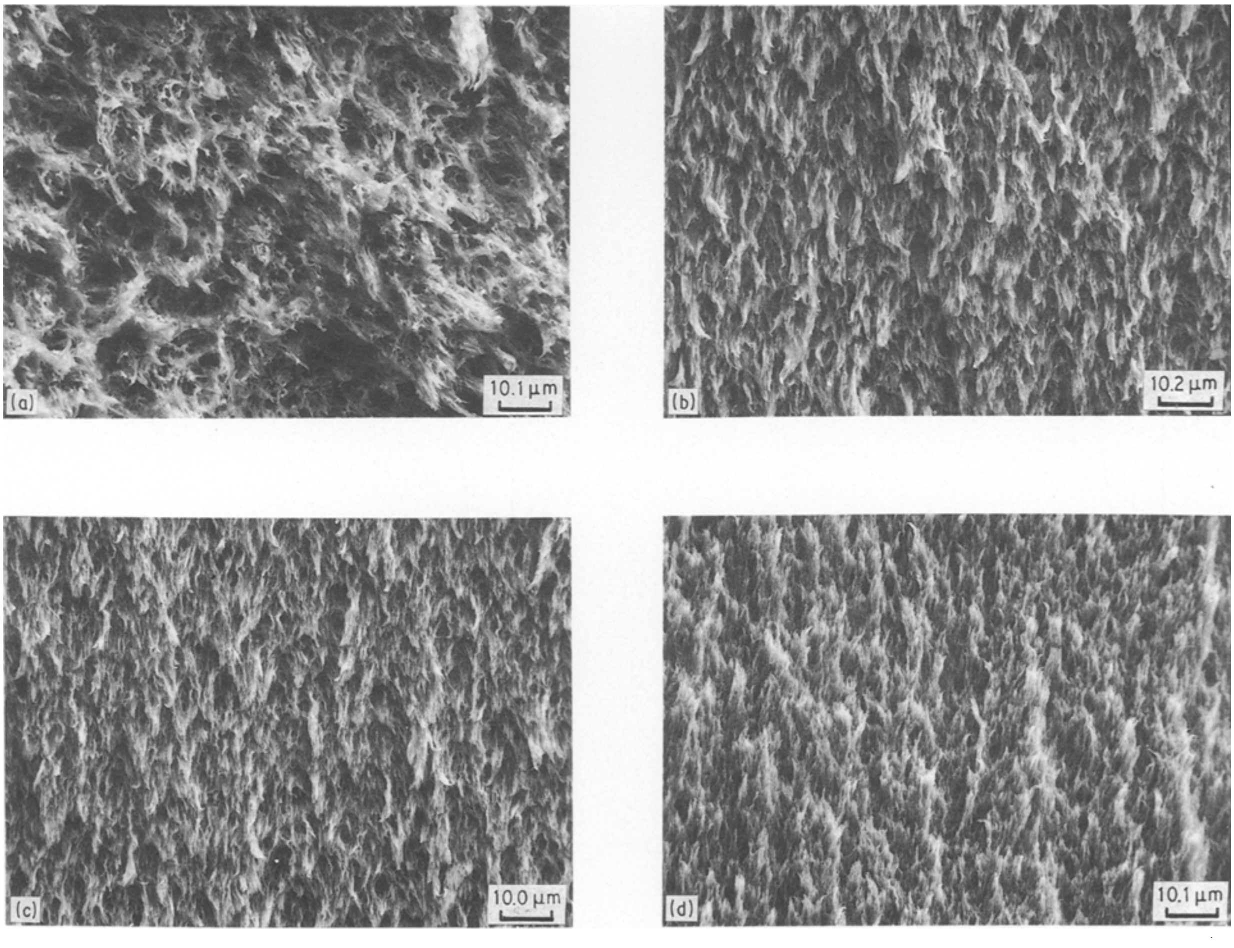

Figure 5 Scanning electron micrographs showing the fracture surface of three-point bend specimens (× 650)

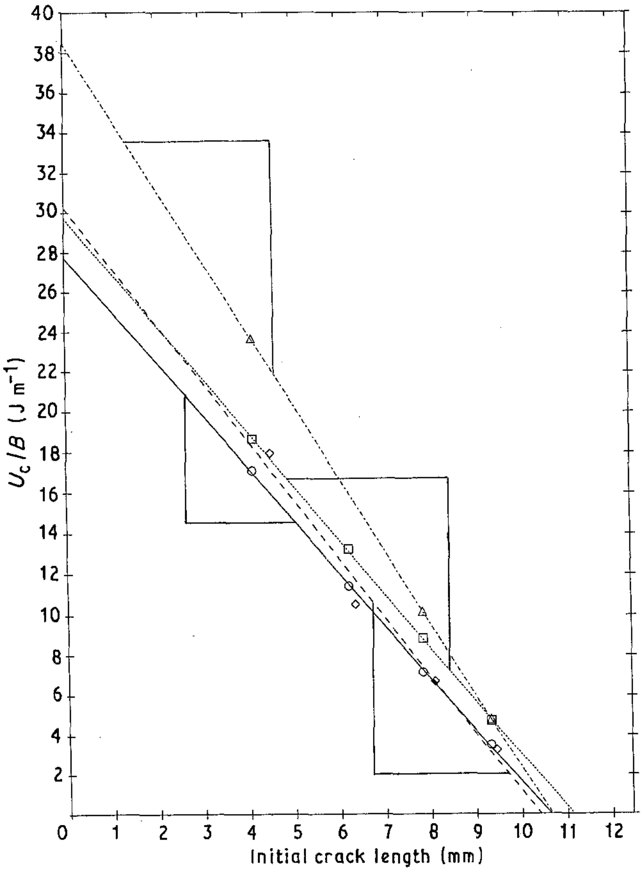

Figure 6 U_c/B versus initial crack length for samples with 0, 1%, 2%, and 6% compatibilizer. The slopes yield J_c (○) 2.6 kJ m^{-2}, (□) 2.7 kJ m^{-2}, (◇) 2.9 kJ m^{-2}, (△) 3.6 kJ m^{-2}.

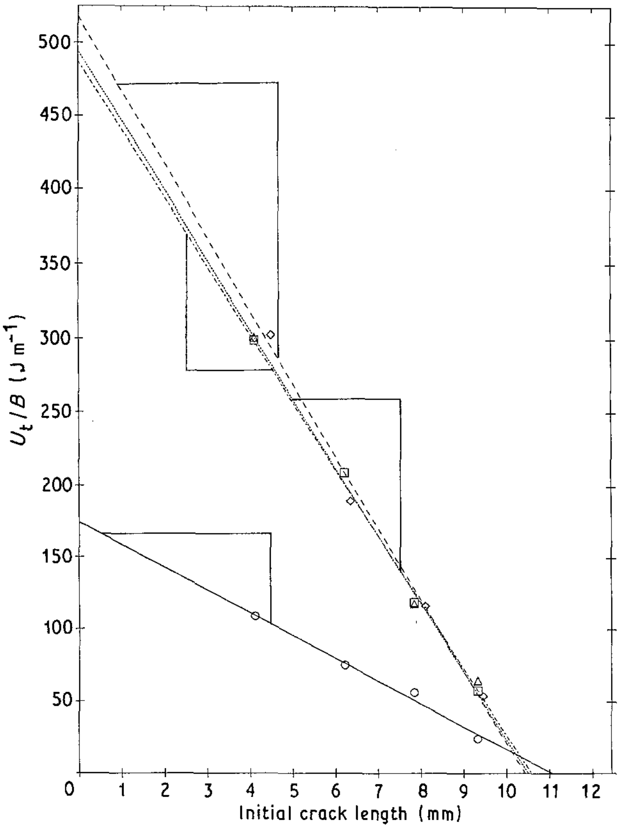

Figure 7 U_t/B versus initial crack length for samples with 0, 1%, 2%, and 6% compatibilizer. The slopes yield R_p (○) 15.7 kJ m^{-2}, (△) 46.1 kJ m^{-2}, (□) 47.1 kJ m^{-2}, (◇) 49.6 kJ m^{-2}.

TABLE II Resistance values as a function of compatibilizer level

Crack resistance	Compatibilizer level (%)			
	0	1	2	6
J_c (kJ m^{-2})	2.6	2.7	2.9	3.6
R_{max} (kJ m^{-2})	6.2	10.5	11.0	11.4
R_p (kJ m^{-2})	15.7	47.1	49.6	46.1

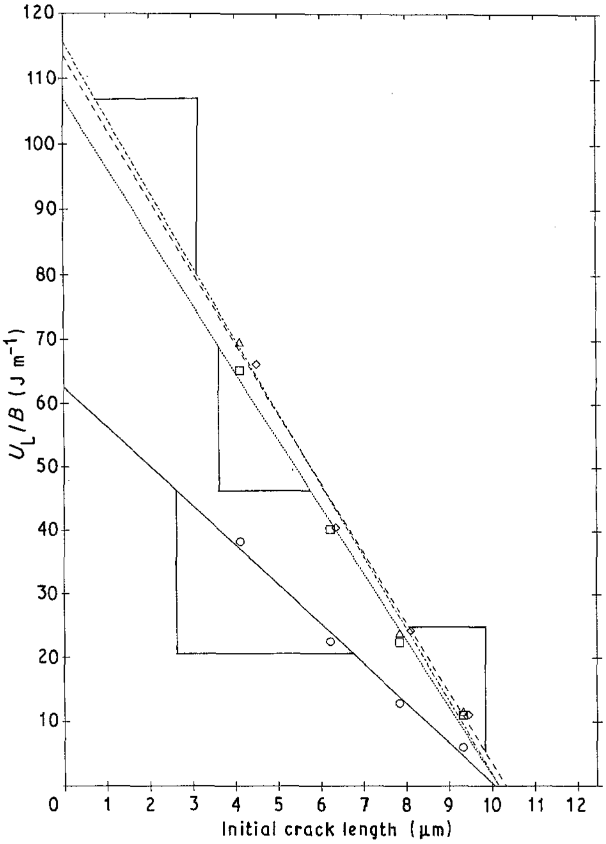

Figure 8 U_L/B versus initial crack length for samples with 0, 1%, 2%, and 6% compatibilizer. The slopes yield R_{max} (○) 6.2 kJ m^{-2}, (□) 10.5 kJ m^{-2}, (◇) 11.0 kJ m^{-2}, (△) 11.4 kJ m^{-2}.

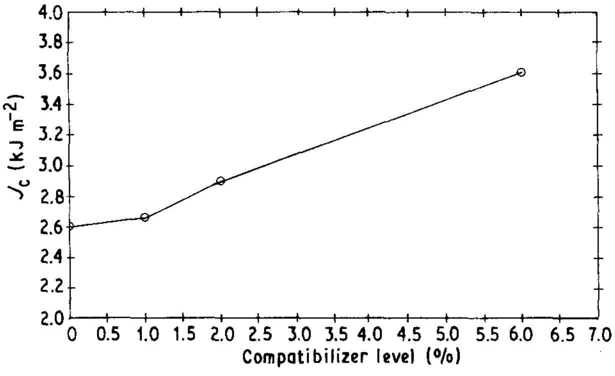

Figure 9 J_c as a function of compatibilizer level.

these values are given in Table II. R_p was found to be 15.7, 47.1, 49.6, and 46.1 kJ m^{-2} for blend containing 0, 1%, 2% and 6% compatibilizer, respectively.

The total energy up to maximum load (U_L) for each specimen was determined and plotted in accordance with Equation 3. These plots are shown in Fig. 8. The

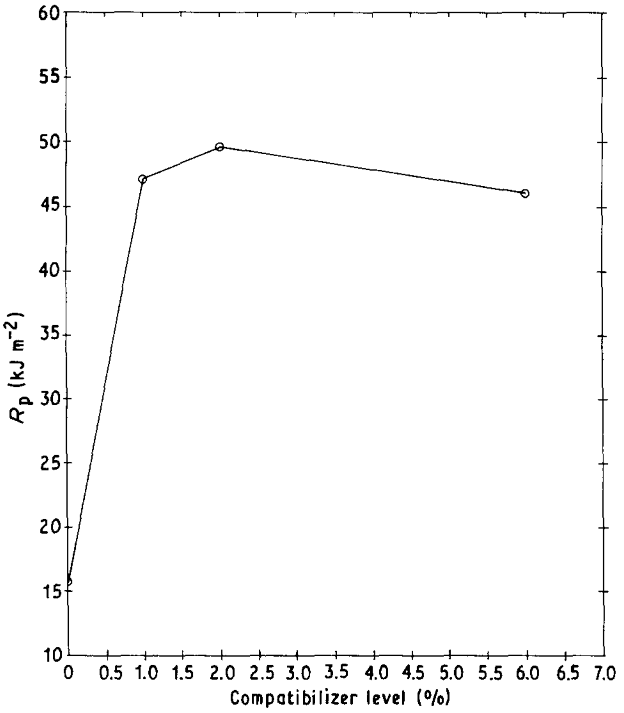

Figure 10 R_p as a function of compatibilizer level.

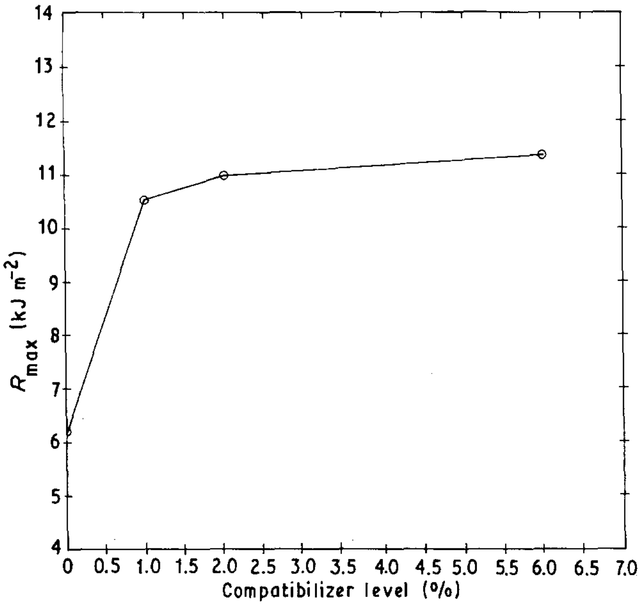

Figure 11 R_{max} as a function of compatibilizer level.

slopes of these plots represent R_{max} for each material and these values are given in Table II. R_{max} was found to be 6.2, 10.5, 11.0, and 11.4 kJ m^{-2} for blends containing 0, 1%, 2%, and 6% compatibilizer, respectively.

Addition of compatibilizer has a dramatic effect on morphology and impact properties but does not appear to have a correspondingly large effect on tensile and fracture properties for the four blends tested. As can be seen in Figs 9–11 and Table II, once compatibilizer has been added, further additions do not affect J_c, R_p or R_{max} values appreciably. For the range of compatibilizer levels tested, it would appear that phase size is of little importance in improving crack resistance.

5. Conclusion

The morphology of these four blends of nylon 6 and ABS is altered by the addition of compatibilizer. The tensile properties at low strains, i.e. modulus and yield stress, of these blends are not affected by compatibilizer in the range of 0–6%, while the stress and strain at failure both show a maximum at 2% compatibilizer. Table I gives all the tensile data.

Within the range of these experiments, Izod impact strength increases monotonically with increasing compatibilizer. The blends containing 6% compatibilizer have three times the impact strength of the uncompatibilized blend.

The four blends have been tested for crack resistance values and the results of these tests are given in Table II. At a low compatibilizer level, properties are significantly better than in material that contains no compatibilizer. However, with further additions of compatibilizer there is little change in the measured crack resistance values. The reductions in phase size caused by further additions of compatibilizer do not have a correspondingly large affect on the crack resistance values for the blends which were tested.

Acknowledgement

The authors thank the Monsanto Chemical Company, for financial support and technical assistance.

References

1. M. T. SHAW, *Polym. Engng Sci.* **22** (1982) 115.
2. L. M. ROBESON, *ibid.* **24** (1984) 587.
3. V. WIGOTSKY, *Plastics Engng* **44** (11) (1988) 25.
4. D. R. PAUL and S. NEWMAN, "Polymer Blends", Vols I and II (Academic Press, New York, 1978).
5. R. E. LAVENGOOD and F. M. SILVER, "New Nylon ABS Alloys: Structure–Property Relationships – Part I", in SPE ANTEC Conference Proceedings, 4–7 May 1987, pp. 1369–74.
6. J. C. ANGOLA, Y. FUJITA, T. SAKAI and T. INOUE, *J. Polym. Sci.* **B26** (1988) 807.
7. C. C. CHEN, E. FONTAN, K. MIN and J. L. WHITE, *Polym. Engng Sci.* **28** (1988) 69.
8. D. V. HOWE and M. D. WOLKOWICZ, *ibid.* **27** (1987) 1582.
9. R. E. LAVENGOOD and F. M. SILVER, "New Nylon ABS Alloys: Structure–Property Relationships – Part 2" in SPE RETEC, Dearborn, MI, 2–4 November 1987, pp. 299–71.
10. R. E. LAVENGOOD, A. R. PADWA and A. F. HARRIS, US Pat. 4 713 415, 15 December 1987.
11. G. I. TAYLOR, *Proc. R. Soc.* **A146** (1934) 501.
12. B. H. KIM and C. R. JOE, *Polym. Test.* **7** (1987) 355.
13. *Idem., Engng Fract. Mech.* **34** (1) (1989) 221.

Received 20 September 1989
and accepted 9 April 1990