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LETTER

Effect of blending sequence on the mechanical properties of ternary blends prepared from recycled poly(ethylene terephthalate)

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One possible approach to produce useful materials from recycled poly(ethylene terephthalate) (r-PET) is by blending with rubber [1–4] or fibers [5, 6]. By blending r-PET simultaneous with rubber and short glass fibers (SGF), it is expected that the resulting SGF/rubber/r-PET ternary blends will possess tailored tensile and impact properties. In the production of multi-component blends, it is known that the blending sequence will has strong impact on the morphology and hence mechanical properties [7]. In this study, SGF/rubber/r-PET ternary blends were produced by two different blending sequences. The morphology and properties of the blends will be reported.

The recycled PET used in this study was supplied in pellet form from a local recycling source. The rubber used is a maleic anhydride grafted styrene-ethylene/butylenes-styrene triblock copolymer (MA-g-SEBS) (Kraton FG1901X, Shell Chemical). The short glass fiber (SGF) used is CRARTEC PLUS 183F (Owens Corning). In the processing of the ternary blends, the weight ratio of SGF/MA-g-SEBS/r-PET was fixed at 20/16/64, and two different blending sequences were used:

One-step compounding

SGF, MA-g-SEBS and r-PET in the designated weight ratio was dry-mixed and then melt blended using a Brabender twin screw extruder. The extrudates were pelletized. The blend so produced will be referred to as C-1 in this work.

Two-step compounding

MA-g-SEBS and r-PET were first melt blended using a Brabender twin screw extruder. The MA-g-SEBS/r-PET binary blend was pelletized and dry-mixed with SGF. The mixture was then melt blended using the Brabender twin screw extruder. The blend will be referred to as C-2 in this work.

The SGF/MA-g-SEBS/r-PET ternary blend pellets were then injection molded into end-gated rectangular plates (150 × 80 × 3.2 mm). The respective pellets were dried in an air circulating oven at 80 °C for 24 h before melt compounding as well as before injection molding. From each injection molded plates, only one rectangular coupons with dimension of 20 × 200 × 3.2 mm were obtained from the middle portion of the plate. These rectangular coupons were subsequently machined into the required geometries for tensile and impact testing.

The tensile strength and Charpy impact strength for the two blends C-1 and C-2 are summarized in Table 1. The standard deviations for the measured values are shown in the brackets. The main observation is that the compounding route (i.e. one-step compounding or two-step compounding) has a strong influence on the tensile strength. Tensile strength for the C-2 blend is only about half of the C-1 blend. On the other hand, Charpy impact strength for the SGF/rubber/r-PET blends is apparently insensitive to the compounding sequence.

Fiber length and fiber orientation are important microstructural parameters to affect the mechanical properties of short fiber reinforced composites. By

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Table 1 Mechanical properties for the blends C-1 and C-2

	Tensile strength (Mpa)	Charpy impact strength (kJ/m^2)
C-1	34.1 (1.0)	6.9 (0.2)
C-2	17.3 (2.0)	7.4 (0.2)

burning off the rubber/r-PET matrix and counting the fiber length distributions, the average fiber lengths for the C-1 and C-2 blends were found to be similar, at 0.31 and 0.36 mm, respectively. In addition, similar fiber orientation patterns were also observed for the two blends. Therefore, both fiber length and fiber orientation are not crucial factors to cause the difference in tensile strengths for the C-1 and C-2 blends.

The force–displacement curves obtained from flexure bending tests (span/width/thickness = 75/12.7/3.2 mm) for the C-1 and C-2 blends are compared in Fig. 1. It can be seen that upon reaching the maximum flexure load, the specimens failed catastrophically. It is important to observe that the flexure bending strength for C-1 is significantly higher than that for C-2. Under flexure loading, maximum tensile stress will be developed at the outer skin of the specimens. Therefore, the maximum bending strength correlates with the tensile strength. The higher flexure strength relates to higher tensile strength. The results shown in Fig. 1 are therefore in agreement with the tensile strength values shown in Table 1.

Specimens with the same dimensions as the Charpy impact specimen were also loaded in quasi-static loading, which will be referred to as single-edge-notched-bend (SENB) tests. Force–displacement (F–δ) curves under SENB test for the C-1 and C-2 blends are compared in Fig. 2. In striking contrast to flexure tests

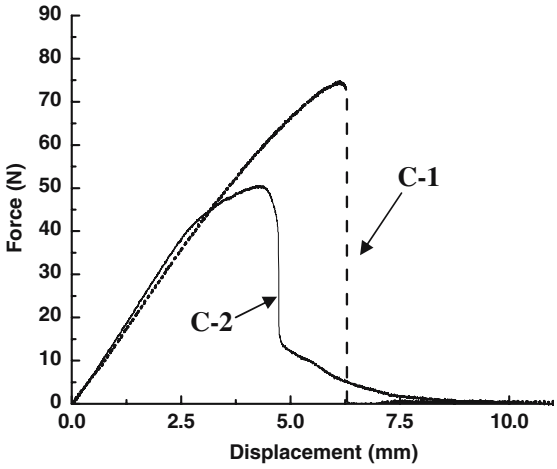

Fig. 1 Force–displacement curves obtained from flexure tests

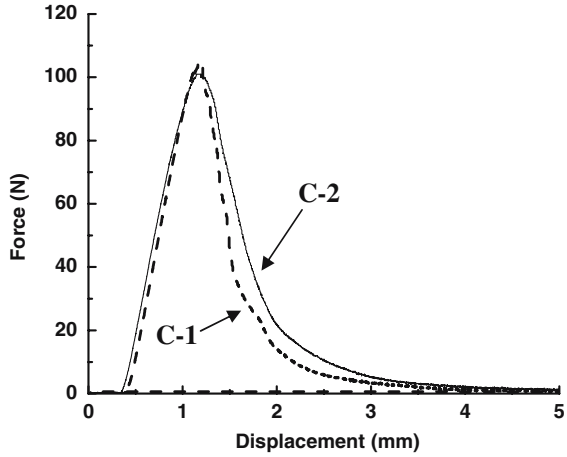

Fig. 2 Force–displacement curves obtained from SENB tests

results shown in Fig. 1, the crack initiated from the initial notches propagated in a stable manner. Such stable crack growth behavior is commonly observed for short fiber reinforced composites [8, 9]. It can be noticed that the SENB F–δ curves for the two blends are nearly identical to each other. When considering fracture toughness as the energy obtained by integrating the area under the F–δ curve, it can be seen that the toughness for both blends are to be the same. This supports the results shown in Table 1 that the Charpy impact strength for the two blends C-1 and C-2 are nearly the same.

Figure 3 shows the microstructures for the C-1 and C-2 blends. In both micrographs, MFD represents the melt-flow-direction. The thickness of both specimens is shown in the horizontal direction. It can be seen that serious rubber agglomeration has occurred in C-2, while the rubber particles are relatively well dispersed in the blend C-1. Two of the dumb-bell tensile bars after tensile testing are shown in Fig. 4. For the C-2 specimen, a high density of crazes was observed throughout the whole gauge length. As for the C-1 specimen, no craze could be detected for the sample loaded up to the final

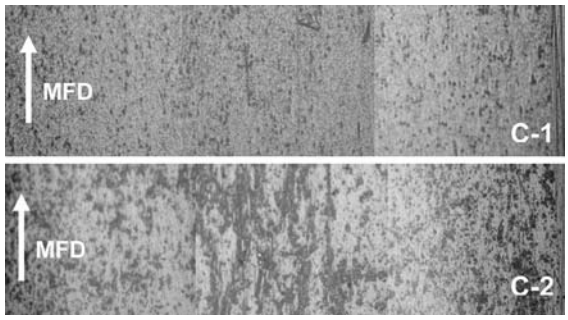

Fig. 3 Optical micrographs showing the microstructures for the C-1 and C-2 blends

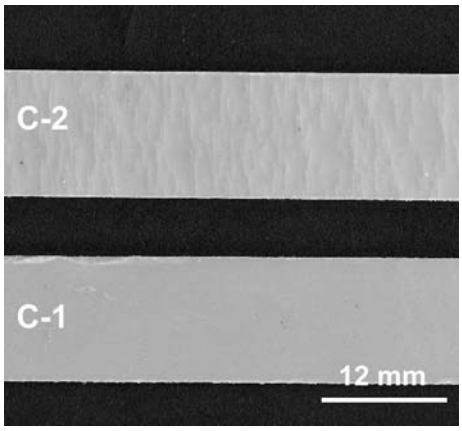

Fig. 4 Sections of tensile fractured tensile bars for a C-2 and a C-1 specimens

fracture point. From the micrographs shown in Fig. 3, it can be understood that the crazes in the C-2 tensile bars were initiated from the rubber agglomerates. As the crazes were initiated at low stress levels, the tensile strength for the C-2 blend is therefore significantly lower than the C-1 blend. On the other hand, in the presence of a notch (such as the Charpy impact and SENB tests), the stress was localized at the notch tip and the crack path. Outside of the crack path ligament, the magnitude of stress was low and therefore not able to cause crazing even for the C-2 samples. Initiation of crack propagation was controlled by the stress at the notch tip rather than the fine details of morphology.

From this study on SGF/rubber/r-PET blend, it can be seen that the melt blending sequence plays an important role on the final morphology, which has a significant influence on the mechanical properties. However, the reasons and hence the mechanisms for developing the two different morphologies in C-1 and C-2 are still unclear. Further research in this direction is definitely needed.

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References

1. Fung KL, Li RKY (2005) Polym Test 24:863
2. Yu ZZ, Yang MS, Dai SC, Mai Y-W (2004) J Appl Polym Sci 93:1462
3. Mouzakis DE, Papke N, Wu JS, Karger-Kocsis J (2001) J Appl Polym Sci 79:842
4. Loyens W, Groeninckx G (2003) Polymer 44:4929
5. Pegoretti A, Penati A (2004) Polymer 45:7995
6. de M Giraldi ALF, Bartoli JR, Velasco JI, Mai LHI (2005) Polym Test 24:507
7. Wang K, Wu JS, Zeng HM (2001) Compos Sci Tech 61:1529
8. Sui G, Wong SC, Yue CY (2001) J Mater Process Tech 113:167
9. Ching ECY, Li RKY, Tjong SC, Mai Y-W (2003) Polym Eng Sci 43:558