INCREASING THE IMPACT RESISTANCE OF SHORT GLASS FIBER REINFORCED VINYL COMPOSITES

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Abstract

The addition of short glass fibers to thermoplastic materials is known to significantly reduce the impact properties of the resulting composites. This paper is the third in a series devoted to understanding and improving the impact strength of short glass fiber reinforced vinyl composites. The first paper characterized the impact behavior and failure mechanisms of these materials. The second paper examined methods of increasing the impact resistance using semi-rigid capstock laminates. The current paper extends this work to laminates using rigid vinyl layers to achieve higher impact strength. Instrumented drop weight impact results demonstrate improvements up to four times that of the original composite.

Introduction

Short glass fiber reinforced vinyl composites are up to three times stronger and stiffer than unreinforced rigid vinyl materials. They also exhibit up to three times the resistance to thermal expansion and contraction. This makes this class of materials good candidates for a wide range of engineered applications. These property improvements are achieved at the expense of the impact properties of these composites, which are significantly lower than those of rigid vinyl formulations[1]. We therefore initiated a series of studies to first understand the impact behavior of these materials and then use this knowledge to develop techniques to improve the impact properties.

The first paper in this series[1] reported the use of Instrumented Impact[2] and Scanning Electron Microscopy techniques to elucidate the damage sequence and failure mechanisms during the impact event. The second paper[3] evaluated the effect of a coextruded, ductile semi-rigid vinyl capstock on the impact of an extruded short glass fiber reinforced vinyl composite. Instrumented Drop Weight Impact measurements showed a small (20%) improvement when the sample was impacted from the capstock side. However, a major (500%) improvement was achieved when the capstock was on the underside of the impacted sample! This was attributed to the delaying of the crack initiation by the presence of the ductile layer on the underside of the sample.

This paper extends this study to laminates of rigid vinyl films and short glass fiber reinforced vinyl composites. The use of rigid vinyl films eliminates the presence of plasticizer and also allows for the preparation of A/B/A laminates where the composite layer is sandwiched between the vinyl layers.

Material and Experimentation

We used 2 mm. thick extruded sheets of Fiberloc ® 80530, a commercially available 30% short glass fiber reinforced vinyl composite, as the B layer for all laminates. The A layer was prepared by milling a commercial white rigid vinyl formulation and pressing the strips into ~ 1mm sheets. The A/B and A/B/A laminates were made by placing the layers in a 15-cm. X 15-cm. mold and bonding them together at high pressure at 204ºC.

All samples were impacted at room temperature on a Rheometrics Drop Weight Tester, RDT 5000, using ASTM D 3763 guidelines. The dart weighed 10 kg. and had a 1.2 cm. diameter hemispherical tup which contained a load cell for data acquisition. All samples were impacted from a height of 18 cm. and the force-deflection and energy-deflection curves were generated. Six specimens were tested for the A and B layers and for each laminate configuration. The resulting curves were analyzed for the force and energy at crack initiation and sample failure. Crack initiation was defined as the point where the first saw-tooth appeared in the force-deflection curve[4]. If there were no saw-teeth present in the curve, crack initiation was taken as the point where the slope of the force-deflection curve reached zero. Sample failure was defined as the point of maximum force. In most cases there was an

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[1] *Rabeh Elleithy and Martin Woods, "Damage and Fracture of Short Glass Fiber Reinforced Polyvinyl Chloride (PVC) Under Impact", ICCE Symposium, 1999.*

[2] *Agarwal and Broutman, "Analysis and Performance of Fiber Composites", John Wiley & Sons, 1980.*

[3] *Rabeh Elleithy and Martin Woods, "Improving the Fracture Resistance of Short Glass Fiber Composites Under Impact", ANTEC '01 Preprints, Vol. 2, 2001.*

[4] *ASTM STP 936, "Instrumented Impact Testing of Plastic and Composite Materials", ASTM, 1986.*

abrupt drop in force beyond this point which indicated a loss in sample resistance to the penetration of the dart.

Results and Discussion

The force-deflection curves for the A (rigid vinyl) and B (composite) layers are shown in Figure 1. The A layer curve increases smoothly up to the maximum and then drops abruptly to zero. This is typical for a semi-rigid material[5]. The curve for the B layer is characterized by a saw-tooth pattern early in the impact process. Prior work[1] has shown that this is due to the initiation of cracks at low strain on the underside of the sample. Table I summarizes the conditions at crack initiation and sample failure for these materials. Since the saw-tooth pattern was absent from the curve for the A layer, initiation and sample failure conditions were the same.

The force deflection curves for the A/B, B/A and A/B/A laminates are shown in Figure 2. The curve for the A/B laminate still contains the saw-tooth pattern at low displacements, indicating that the composite layer, B, is developing cracks early in the process. This is not surprising since the B layer is on the underside of the specimen. However, as shown in Table I, the presence of the A layer on the top of the laminate essentially doubled the force and tripled the energy at the failure point when compared to the B layer control. Even when the results are 'normalized' by dividing by the sample thickness as shown in Table II, the impact values are improved significantly.

The force-deflection curve for the B/A composite does not show the saw-tooth behavior at low displacements. This indicates that the A layer retards the crack development in the B layer. However, once the A layer fails, there is an abrupt drop in the curve indicating that the sample has failed. This is reflected in the data shown in Tables I and II, particularly the energy values.

The force-deflection curve for the A/B/A laminate also does not exhibit the saw-tooth pattern and fails at a much greater force than any of the other laminates. As shown in Table I, the failure energy of this laminate is more than six times that of the B layer alone. When the thickness differences are taken into account, the failure energy is still increased by a factor of about four. This level of impact improvement overcomes most of the impact reduction caused by the presence of the short glass fibers.

Conclusions

Based on the work reported above, we have drawn the following conclusions:

- Laminating a thin layer of rigid vinyl to the top of a glass fiber reinforced composite increases the impact failure energy by about threefold over the composite alone.
- Laminating the same rigid vinyl layer to the underside of the composite eliminates the early crack initiation during impact, but only increases the failure energy twofold.
- Laminating the rigid vinyl layer to the top and bottom of the composite eliminates the early crack initiation and increases the impact failure of the laminate sixfold.
- The A/B/A laminate offers a potential method for obtaining materials with improved strength, stiffness and resistance to thermal expansion, without a major sacrifice in impact properties.

Key Words

Impact, composite, vinyl and laminates.

Table I: Summary of Impact Properties.

Material	Thick, *mm*	Crack Initiation		Failure Point	
		Force *N*	Energy *J*	Force *N*	Energy *J*
A*	0.86	1213	5.8	1213	5.8
B**	2.0	482	0.2	653	1.2
A/B	2.7	658	0.3	1280	3.9
B/A	2.7	1396	2.2	1396	2.2
A/B/A	3.3	2498	7.5	2498	7.5

*Rigid Vinyl Layer
**30% Glass Fiber Reinforced Vinyl Layer

Table II: Summary of Normalized Impact Properties.

Material	Initiation Energy *J/mm*	Failure Energy *J/mm*
A	6.7	6.7
B	0.1	0.6
A/B	0.1	1.4
B/A	0.8	0.8
A/B/A	2.3	2.3

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[5] *Rabeh Elleithy, "Macroscopic Analysis of PVC Fracture Modes Under Impact", ANTEC, 1998, Preprints, Vol. 3, 1998.*

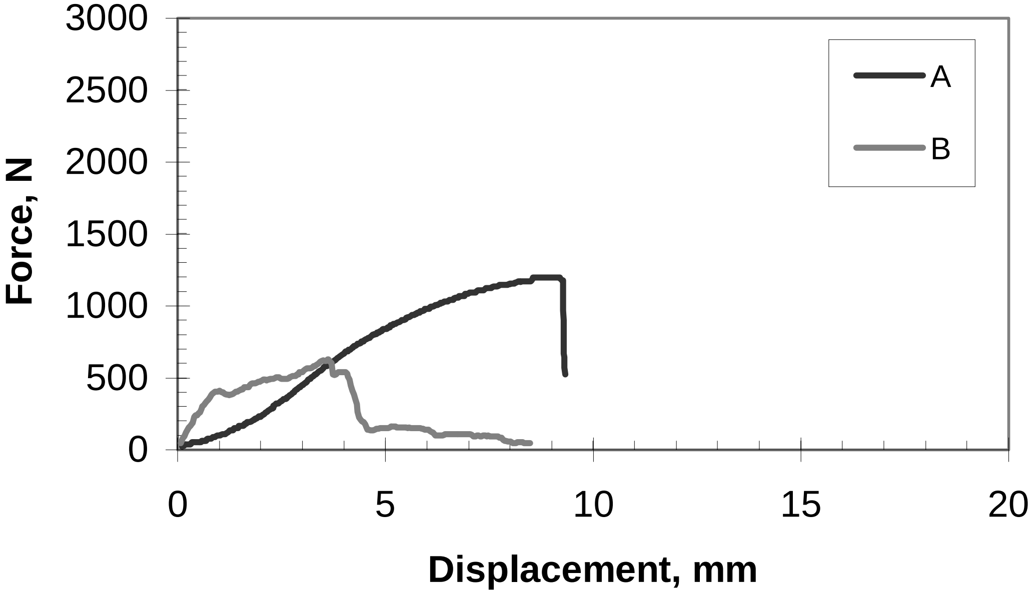

Figure 1: Typical Impact Curves for Individual Layers

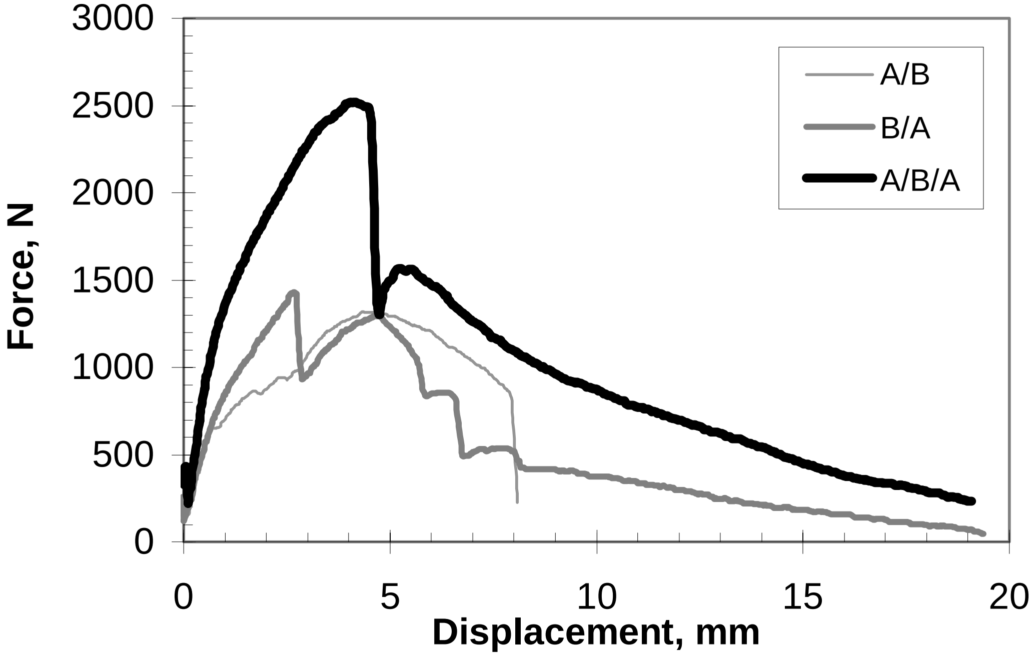

Figure 2: Typical Impact Curves for Laminates