Impact Behavior of Unidirectional Polyethylene–Glass Fibers: PMMA Hybrid Composite Laminates

NIRMAL SAHA and AMAR NATH BANERJEE*

Department of Plastics and Rubber Technology, University of Calcutta, 92 A. P. C. Road, Calcutta 700 009, India

SYNOPSIS

Unidirectional (UD) hybrid laminates based on glass fibers (GF) and high performance polyethylene fibers (PEF) were prepared with partially polymerized methyl methacrylate (MMA) at room temperature followed by heating at 55°C (well below the softening point of PEF) for 2 h. Izod impact strength of the composites was then measured. An interesting observation of the study was the change in impact strength that was largely dependent on the position of GF and PEF ply/plies present within the hybrid laminates. When the ply/plies of PEF were at the impacted surface, the impact strength showed a higher value than that of the case when GF ply/plies were at the impacted surface of the hybrid laminates.

INTRODUCTION

Hybrid composites possess some unique features that can be used to meet different design requirements with respect to strength, stiffness, and impact resistance. A key parameter in hybrid composite structures is the arrangement of fibers within the hybrid, as demonstrated by studies on hybrid systems based on carbon, glass, or aramid fibers.[1-5]

A tough reinforceing fiber is polyethylene fiber (PEF), currently produced based on solution (gel) spinning of ultrahigh molecular weight PE, which possesses unique mechanical properties in terms of high specific strength and stiffness.[6] Moreover these PEFs possess a relatively high work to break (i.e., good impact properties) compared to carbon, glass, and aramid fibers. Due to these unique properties, PEFs have high potential for use in composite structures and are suitable for various applications, notably if good impact properties are required.[7-12] Thus it is expected that hybridization of relatively brittle glass fibers (GFs) with tough PEF would be effective in improving the impact properties of GF-reinforced composites. A few workers have used PEF as one of the reinforcing fibers in hybrid composites, but these works are mainly based on thermoset matrix. Composites based upon thermoplastic polymeric matrices potentially offer several advantages compared to those based upon thermosetting resins.[13,14] Thus one could expect a unique structural material based on poly(methyl methacrylate) (PMMA), a thermoplastic polymer, as the matrix in PEF/GF reinforced composite.

The present work was undertaken with the following two objectives: to study impact behavior of unidirectional (UD) laminates cast from MMA–GF, MMA–PEF, and MMA–GF/PEF (hybrid), and to study the role of PEF ply/plies in hybrid laminates toward the impact behavior, depending on the relative position of the ply/plies.

EXPERIMENTAL

Fibers and other reagents used are as follows:

1. PEF (spectra 900, 1200 den) supplied by Allied-Signal Corporation, Petersburg, FL;
2. GF (433 BF-225) supplied by Owens Corning Fiberglas Corporation, OH;
3. MMA supplied by Western Chemical Corporation, Calcutta, India;

* To whom correspondence should be addressed.

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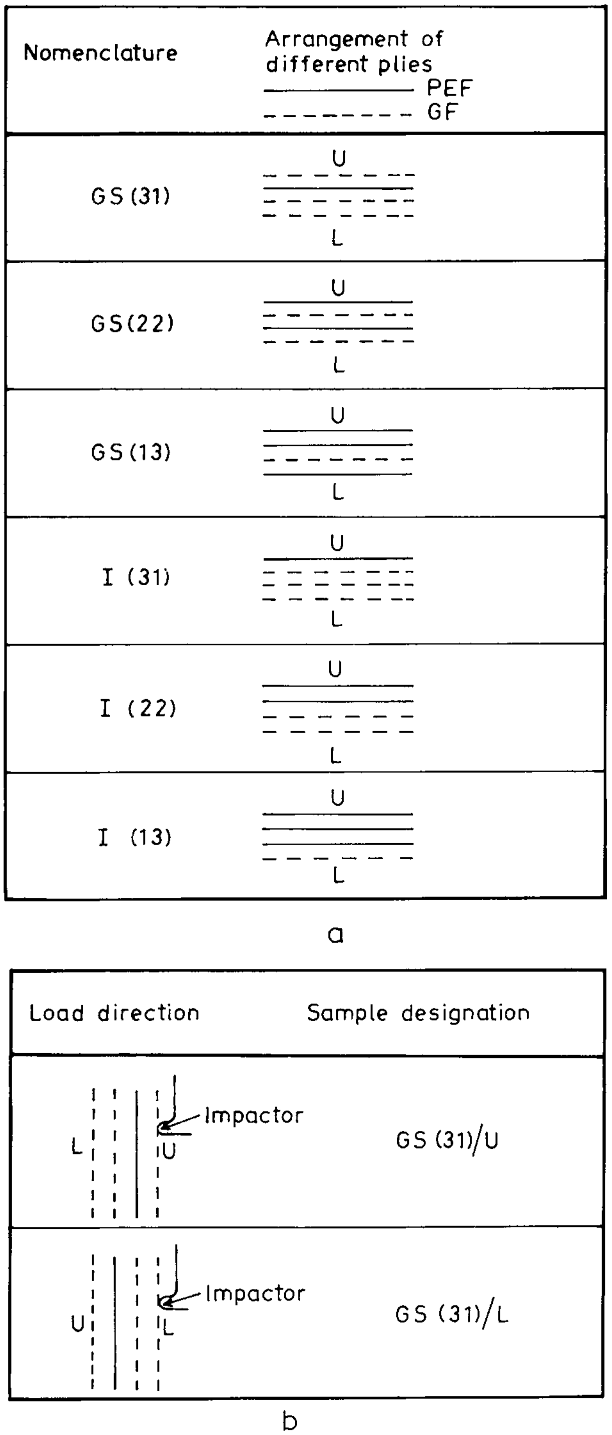


Figure 1 Schematic representation of hybrid laminates: (a) nomenclature and geometry of hybrid laminates and (b) load direction with sample designation.

4. benzoyl peroxide (Bz_2O_2) supplied by Loba-Chemie Indo-austranal Corporation, Bombay, India; and
5. *N,N* dimethyl aniline (NDA) supplied by E. Merck Limited, Bombay, India.

MMA was purified by the standard technique,[15,16] and Bz_2O_2 was recrystallized from chloroform[17] and dried in a vacuum. The purification of NDA was achieved by distillation under reduced pressure before use.

The PEF used for the preparation of composites was treated with chromic acid.[10,18,19] The surface of the GFs were already treated with the standard treatment and used directly for making composites. The wetting characteristics of PMMA on treated and untreated GF and PEF were studied by contact angle determination.[20–22] Improved wetting was found when the treated fibers were investigated.[23]

The UD plies were made in a dust free chamber on a glass sheet using partially polymerized MMA as the resin with an amineperoxide (NDA–Bz_2O_2) initiator system in bulk at room temperature.[24] Laminated structures were prepared by stacking these plies of PEF and GF unidirectionally in the mold, and the composites were made by using the same resin at room temperature until it solidified within the mold. Shrinkage was controlled using extra resin in the mold. Finally the composite was heated to a temperature of 55°C for 2 h to ensure the completion of MMA polymerization. A detailed description of the preparation of laminates is given elsewhere.[23]

UD laminates were prepared in up to four plies for PEF (designated as S_1–S_4, respectively) and GF (designated as G_1–G_4, respectively). The nomenclature and geometry of different hybrid laminates studied are given in Figure 1(a).[23] The first and second digits within the parentheses stand for the number of GF plies and PEF plies, respectively, present in the hybrid laminates. When the striking nose hits the specimen such as GS(31) on U and L side, the sample is designated as GS(31)/U and GS(31)/L, respectively [Fig. 1(b)]. Similar nomenclature is applied for the other hybrid laminates. The unnotched samples for measurements were cut to 70 × 10 × 3 mm dimensions. Izod impact strength was determined using ASTM D256. In all cases, 12 specimens were tested and average values are reported.

RESULTS AND DISCUSSION

Figures 2 and 3 show the variation of impact strength with the volume fraction of the fibers (V_f). As the

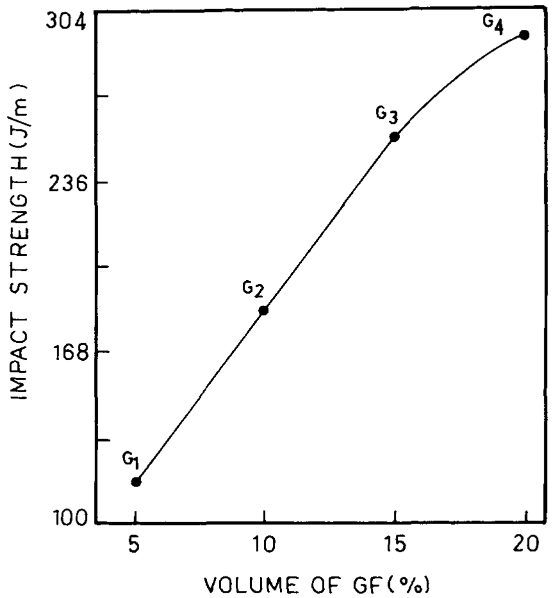


Figure 2 Variation of impact strength with volume of GF (%).

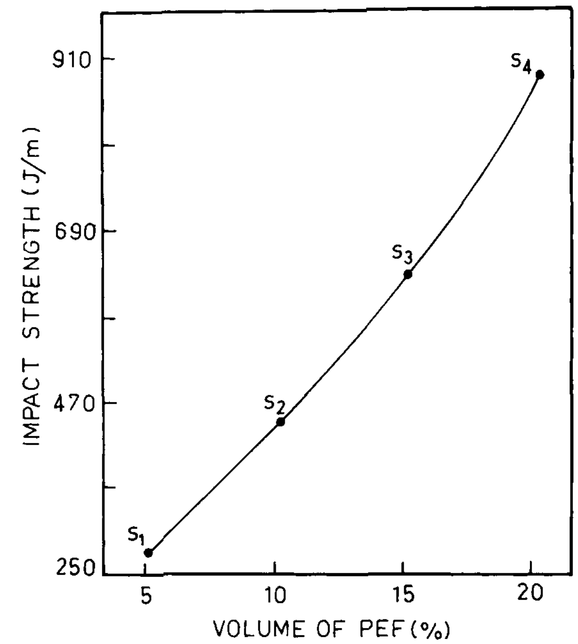


Figure 3 Variation of impact strength with volume of PEF (%).

number of plies is increased from one to four plies, the impact strength gradually increases. The impact strength of PEF-reinforced laminates (PEFRC) 2.5–3.0 times that of GF-reinforced laminates (GFRC) at the same V_f, indicating the superior energy absorbing capability of ductile PEF. The nonlinear variation of impact strength with V_f is observed at higher V_f. The curve tends to flatten for GFRC, but in PEFRC the curve becomes steeper with the increase in V_f. Cracks are generated at the impacted surface (compression side) that contribute to impact failure by crack propagation. In the case of GFRC, the initiated crack is propagated more easily from the impacted surface to the outermost surface (tension surface) due to the brittle nature of GF (i.e., low fracture propagation energy). As a result the curve is found to flatten as V_f increases. But in the case of PEFRC, the PEF absorbed the energy (which is transferred from the striking edge) and also resisted the crack propagation. These facts are more pronounced as the PEF plies increase from one to four plies. Due to these reasons the curve becomes steeper as the V_f increases.

An interesting feature of the present study is that the impact behavior changed remarkably when the position of the PEF and GF ply/plies were altered in the hybrid laminates. In Figure 4 the impact strength is plotted against systems 1–5. All the systems in this figure contain approximately the same total V_f.

When three GF plies and one PEF ply are mixed together (system 2), the impact strength increases from 245 ± 15 J/m [I(31)/L] to 696 ± 17 J/m [I(31)/U]; the samples GS(31)/L and GS(31)/U showed the values of 382 ± 12 and 422 ± 14 J/

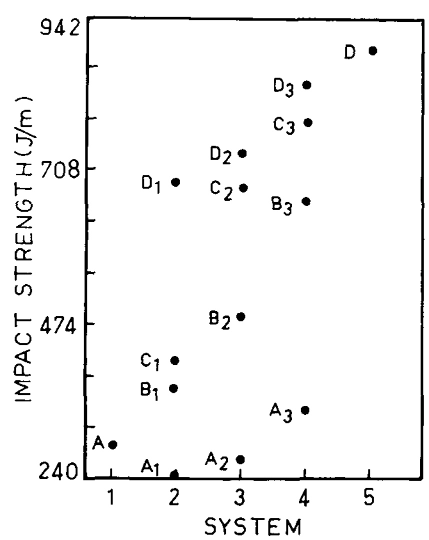
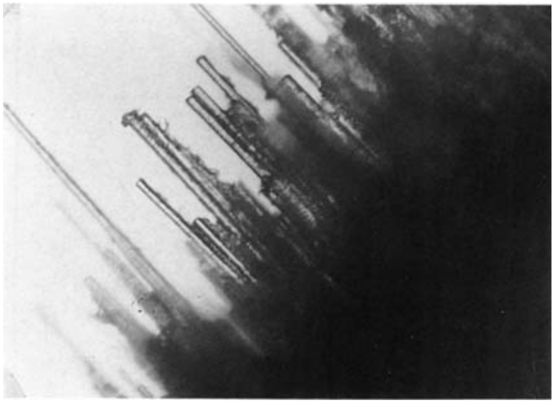
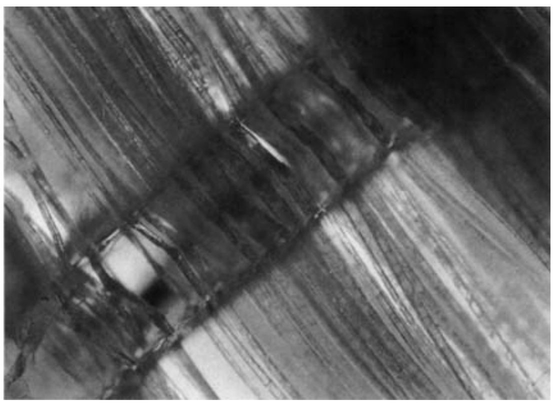


Figure 4 Plot of impact strength vs. systems 1–5. System 1: A, G_4; system 2: A_1, I(31)/L; B_1, GS(31)/L; C_1, GS(31)/U; D_1, I(31)/U; system 3: A_2, I(22)/L; B_2, GS(22)/L; C_2, GS(22)/U; D_2, I(22)/U; system 4: A_3, I(13)/L; B_3, GS(13)/L; C_3, GS(13)/U; D_3, I(13)/U; and system 5: D, S_4.



(a)



(b)

Figure 5 Optical micrographs of the fracture surface: (a) GF at the impacted surface and (b) PEF at the impacted surface.

m, respectively. The same feature is reflected in systems 3 and 4.

From the above studies it may be concluded that when the striking edge hit the side containing PEF ply/plies or ply/plies of the PEF rich side of the hybrid composites, the impact strength was always higher. If the case was just reversed, the impact strength showed a lower value compared to the former one. When the impact shock was applied to the beam, the crack was generated on the compression side, which was transferred to the tension side. The above impact behavior may be due to the superior shock absorbing capability and efficient crack resisting characteristics of the PEF ply/plies compared to the GF ply/plies.

A brittle failure mode was observed in the GFRC, which tended to the ductile failure mode by the incorporation of PEF ply/plies. Almost no PEF fracture occurred in the PEFRC and hybrid specimens. Figure 5 represents the optical micrographs of fracture surfaces of the hybrid laminates. When the GF is at the compression side failure occurs, mainly due to the fibers' failure [Fig. 5(a)]. When the PEF ply is at the compression side, fibers do not fracture but extension and buckling takes place [Fig. 5(b)].

CONCLUSIONS

From the above investigation the following conclusions may be drawn:

1. the impact performance of GFRC can be significantly improved by hybridization with PEF; and
2. the impact fracture mode of GF can be minimized by placing PEF ply/plies at the impacted side of the hybrid laminates.

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