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Effects of hybrid yarn preparation technique and fiber sizing on the mechanical properties of continuous glass fiber-reinforced polypropylene composites

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Abstract

In this study, hybrid yarns were developed by commingling the continuous polypropylene and glass fibers using air jet and direct twist preparation techniques. The non-crimp fabrics were obtained with $\pm 45^\circ$ fiber orientation from these hybrid yarns. The fabrics were prepared with fiber sizings that are compatible and incompatible with polypropylene matrix to investigate the effect of interfacial adhesion on the properties of the thermoplastic composites. Composite panels were produced from the developed fabrics by hot press compression method and microstructural and mechanical properties of the composites were investigated. It was found that type of the hybrid yarn preparation technique and glass fiber sizing applied on the glass fibers have some important role on the properties of the composites. Composites made of fabrics produced by air jet hybrid yarn preparation technique exhibited better results than those produced by direct twist covering (single or double) hybrid yarn preparation techniques. The highest flexural properties (99.1 MPa flexural strength and 9.55 GPa flexural modulus) were obtained from the composites manufactured from fabric containing compatible sizing, due to better adhesion at the interface of glass fibers and polypropylene matrix. The composite fabricated from fabric with polypropylene compatible sizing also exhibited the highest peel resistance (interlaminar peel strength value of 5.87 N/mm). On the other hand, it was found that hybrid yarn preparation technique and type of the glass fiber sizing have insignificant effect on the impact properties of the glass fiber/polypropylene composites.

Keywords

Commingling, hybrid yarns, polypropylene (PP), glass fibers, sizing, thermoplastic composites

Introduction

Thermoplastic composites are gaining use in many industries such as defense, transportation and marine industries due to the light weight and toughness of thermoplastic composites.[1–3] Thermoplastic composites are considered candidate structural materials for light weight and fuel-efficient automobiles of the future. Potential applications of these materials include floor pans, body side interior panels, bumper beams, etc.[4,5] In aerospace industry, actual applications include missile and aircraft stabilizer fins, wing ribs and panels, fuselage wall linings and overhead storage compartments, ducting, fasteners, engine housings and helicopter fairings.[2,3,6] Thermoplastic composites are used in the construction industry for structural profiles, pipes, concrete rebars and lightweight structural and insulating panels.[3] The materials handling industry benefit from these materials in the form of pallets and cargo containers.

Glass fiber-reinforced thermoplastic materials fall into mainly two categories: aligned thermoplastic composites (ATC) and glass mat thermoplastic composites (GMT). GMTs are non-woven textile technology that are being used as a typical chopped strand mat or a continuous swirl mat form, impregnated typically with polypropylene (PP). ATCs are prepregs fabricated

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from aligned glass fibers, which are suitable for weaving process and impregnation during final forming. ATCs have better mechanical properties than GMTs since glass fiber content is limited up to 40% by mass in GMT's. However, high viscosity of the thermoplastic resin causes to some problems during impregnation into the glass fibers. To overcome this problem, hybrid yarns have been recently developed. They also offer an ideal opportunity to achieve short cycle times.[7] Furthermore, textile preforms manufactured from hybrid yarns are being used in thermoplastic composite manufacturing. These preforms may be in the form of woven fabrics, knitted fabrics, stitched fabrics, braided fabrics or non-woven (non-crimp) fabrics.[8] Current techniques to manufacture thermoplastic composites from these textile preforms and hybrid yarns include: compression molding, filament winding, pultrusion, autoclave molding, inflation molding and injection molding. However, there is very limited work reported in the literature about the development of hybrid continuous fabrics, and the fabrication technologies to prepare composite from these fabrics. The information on the properties of these composites is also relatively limited. Zhao et al.[9] reported tensile and impact properties of glass/PP woven fabrics and Perrin et al.[10] investigated the mode I interlaminar fracture toughness of unidirectional continuous glass fiber/PP composites.

In this study, the effect of processing parameters on the mechanical behavior of continuous glass fiber/PP composites manufactured from hybrid fabrics of glass fiber and PP has been investigated. Three different non-crimp fabrics classified based on hybrid yarn preparation technique were used. Two of them were prepared by direct twist covering technique and one of them was prepared with air jet texturing technique. With direct twist covering technique, two types of hybrid yarns; single (S) twist and the other is double (SZ) twist were produced. In fiber twist technique, it is possible to adjust thermoplastic fiber (i.e. PP) and glass fiber composition by controlling fiber and twist number. In single twist method, hybrid yarn is produced by twisting thermoplastic fiber around the reinforcement fiber by making "S" shape. On the other hand, in double twist method, hybrid yarn is produced by twisting thermoplastic fiber around the reinforcement fiber by making both "S" and "Z" shapes.[11] Air jet texturing is a purely mechanical process that can be used to combine reinforcing and matrix forming filaments. In this process, supply yarn is overfed in the turbulent zone where compressed air is directed mainly parallel to the yarn path, resulting in shifting of the filaments longitudinally together with the formation of filament loops. This action opens up filament bundles, and then builds mingling sections.[8] The hybrid commingled fabrics were used with $\pm 45^\circ$ fiber orientation and non-crimp fabric pattern. Non-crimp fabrics were obtained with various fiber sizings that are compatible and incompatible with PP matrix to investigate the effect of interfacial adhesion on the properties of the thermoplastic composites. Composite panels were produced from these fabrics by hot press compression method. The effect of hybrid yarn preparation technique and type of glass fiber sizing on the mechanical and microstructural properties of thermoplastic composites manufactured from these hybrid non-crimp fabrics were investigated. The microstructural features; mechanical properties (tensile, flexural and interlaminar strength); and impact properties of the composites were examined.

Experimental

Materials

In this study, non-crimp glass fiber/PP fabrics ($\pm 45^\circ$ biaxial) were used to manufacture thermoplastic-based composite material. PP and glass fibers (E-glass) were used as a matrix and reinforcement constituent, respectively and non-crimp fabrics were fabricated in collaboration with Metyx Inc. of Turkey. Properties of fabricated glass finer/PP non-crimp hybrid fabrics and their preparation techniques are given in Table 1. A polyester rope was used for sewing plies of non-crimp fabrics. All of the fabrics were weaved with angle of $+45^\circ/-45^\circ$.

As seen in Table 1, the fabrics named D2, D3, D4 and D5, consisted of glass fibers with polyester resin compatible sizing. The fabric named D8 was prepared with glass fibers containing PP resin compatible sizing. Glass fiber weight ratios were calculated during fabric production and noted in Table 1.

Thermoplastic-based composite manufacturing

Continuous glass fiber reinforced PP-based composites were fabricated by hot press compression moulding of prepared hybrid glass fiber/PP non-crimp fabrics. The composite fabrication was started with cutting the fabrics in to the dimensions of the mould. Then, the mould was transferred to Carver™ hot press; 1.5 MPa process pressure was applied to fabrics, while press was heating up to the lamination temperature of 200 °C. The mould held at 200 °C for 30 min and system was cooled to room temperature under pressure. Glass fiber/PP composites were obtained after removal of the part from the mold.

Table 1. Properties and preparation techniques of glass fiber/PP non-crimp hybrid fabrics.

Fibers	Tex (g/10,000 m)	Composition by weight (%)	Nominal weight (g/m^2)	Glass fiber sizing	Hybrid yarn preparation technique
Fabric ID: D2					
Glass	300	56.0	755	PES resin compatible	Air jet
PP	200	43.2			
PES (E5)		0.8			
Fabric ID: D3					
Glass	300	58.8	834	PES resin compatible	Single twist
PP	200	40.4			
PES (E5)		0.7			
Fabric ID: D4					
Glass	300	73.6	667	PES resin compatible	Single Twist
PP	200	25.8			
PES (E5)		0.9			
Fabric ID: D5					
Glass	300	56.0	755	PES resin compatible	Double Twist
PP	200	43.2			
PES (E5)					
Fabric ID: D8					
Glass	300	59.2	767	PP resin compatible	Air jet
PP	200	40.0			
PES (E5)		0.8			

PES (E5) indicates the polyester rope that was used for sewing plies of the fabrics. The fabrics have + 45°/−45° orientation.
PES: polyethersulfone; PP: polypropylene.

Microstructural characterization

The burnout test method was used to determine the fiber volume fraction of the glass fiber/PP composite panels. In this method, a small sample of composite was burned off in a high-temperature oven at 700 °C. The remaining fiber mass was measured. The volume of the fiber was calculated based on the mass of the fiber and the density of the fiber. The peel and fracture surfaces of tested specimens were examined by scanning electron microscopy (SEM) to investigate the effect of sizing on the interfacial bonding. Optical microscopy was used to examine glass fiber orientations of the fabrics and their composites. For this purpose, a Nikon^{TM} optical microscope was used.

Mechanical characterization

Tensile test technique, ASTM D 3039M-93, was used to determine tensile strength and modulus of the glass fiber/PP fiber composites. Test specimens were sectioned from the panels using a diamond saw. The composites were tested along the longitudinal direction of the fibers. At least five samples were tested for each panel using universal test machine (Shimadzu^{TM}) at a cross-head speed of 2 mm/min. The flexural test technique, ASTM D 790M-86, was used to determine the flexural strength and modulus of the composites. Specimens were tested in three-point bending configuration with a span to thickness ratio of 16. Specimen length and width, span distance and test speed were adjusted according to specimen thickness. The interlaminar peel test, ASTM D 5528-01, was used to determine the peel strength of the laminas. With the aid of this test method, the effect of glass fiber sizing on the adhesion of fiber/matrix interface was investigated. In-plane shear test method according to ASTM D 3518 M was used to measure the maximum shear and offset shear strength of the glass fiber/PP composites. Sectioned test specimens from larger panels were loaded in tension mode using universal test machine along the ±45° direction at a crosshead speed of

5 mm/min. At least five specimens for each set were tested. Charpy impact test machine (Ceast Resil Impactor) was used to determine impact properties of the glass fiber/PP composite materials. This test was performed in accordance with ISO 179 standard.

Results and discussion

Microstructural properties of hybrid fabrics and their composites

Fiber orientation after compression moulding is an important parameter in thermoplastic composite manufacturing from hybrid fabrics. Fiber orientation directly affects mechanical properties of the composite material. Optical microscopy with light source from above and below was used on the hybrid fabrics and composites after lamination in order to investigate the distortions in the fiber orientation. As an example in Figure 1, optical microscope images of fabrics D3, produced by single twist hybrid yarn preparation technique are shown with lightening from above and below.

Based on these images, glass and PP fiber bundles seem to be in order before lamination process. In Figure 2, optical microscope images of the composite produced from the same fabrics (D3) after hot pressing are shown. As seen from these images, the orientation of the fiber bundles is distorted due to the composite manufacturing by hot pressing. So, the alignment of the glass fibers was worse in those composites as compared to hybrid fabrics before consolidation. The melting and flow of the PP fibers cause the disorder of the glass fibers.

Composites fabricated from different fabrics were examined under microscope to compare the glass fiber orientations after lamination. For comparison, optical microscope images of the composites fabricated with fabrics that are prepared with single twist, double twist and air jet hybrid yarn preparation techniques are given in Figure 3. As seen in the figure, the best glass fiber orientations within the composites were obtained from the fabrics prepared with air jet hybrid yarn preparation technique.

Mechanical properties of the thermoplastic composites

Tensile properties. Tensile tests were performed to investigate the effect of the fabric preparation method and type of glass fiber sizing on the tensile properties of

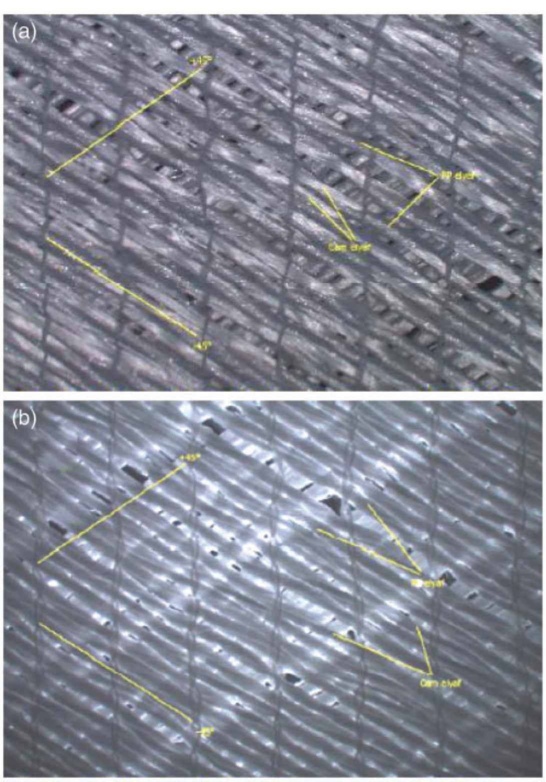

Figure 1. Optical microscope images of glass/PP fabrics (D3) produced by single twist method (a) light source from above (b) light source from below. Magnification 3.2×.

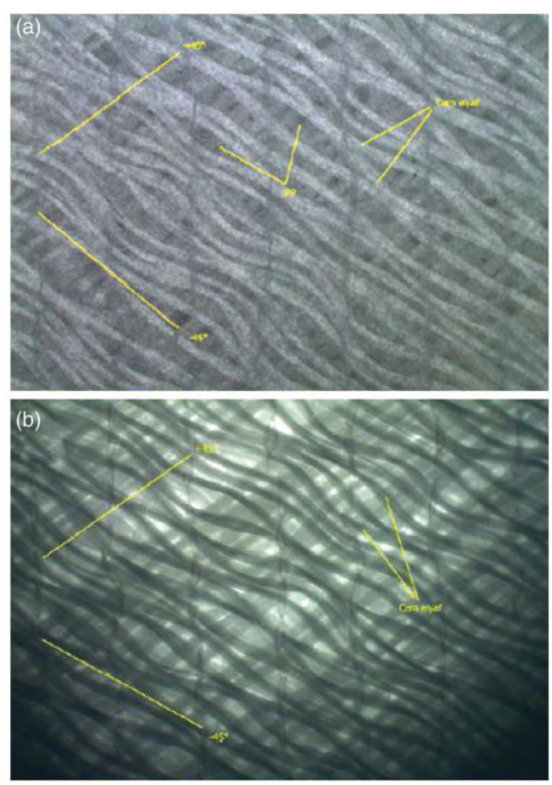

Figure 2. Optical microscope images of composites produced from single twisted fabrics D3 (a) light source from above (b) light source from below. Magnification 3.2×.

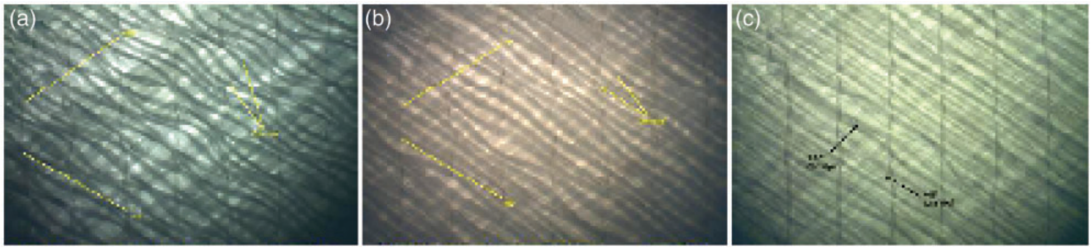

Figure 3. Optical microscope images of composites produced from different fabrics (a) single twist (D3) (b) double twist (D5) (c) air jet (D2). Magnification 3.2×.

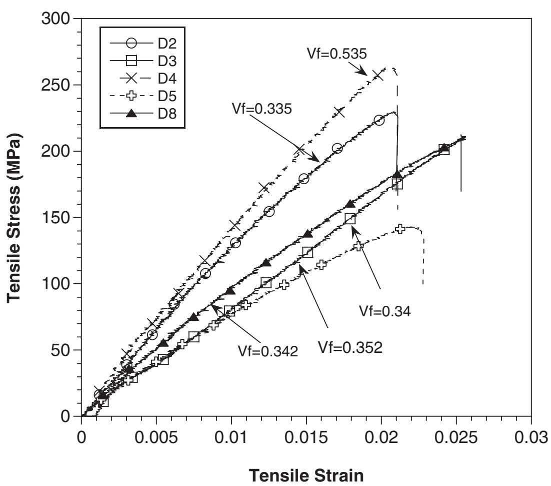

Figure 4. Tensile stress-strain behavior of composites manufactured from various types of hybrid fabrics.

non-crimp glass/PP thermoplastic composites. Figure 4 shows the tensile stress–strain behavior of composites manufactured from various hybrid fabrics laminated at 200 °C temperature and 1.5 MPa compression pressure. The tensile modulus values were obtained from the initial slope of the curve and the tensile strength and strain values were determined at the failure point where the maximum stress was reached. The tensile mechanical properties are listed in Table 2, together with fiber volume fraction values.

As seen in Figure 4 and Table 2, maximum tensile properties were observed from the composite, prepared with fabric D4, as expected. This is due to the highest fiber volume fraction of the D4 coded composites. This composite has an average tensile strength of 262.7 MPa (±15.3 MPa) and an elastic modulus of 13.83 GPa (±0.94 GPa). As the composite panels with the similar fiber volume fractions are compared, the highest tensile properties (with 227.75 MPa (±8.1 MPa) tensile strength and 11.2 GPa (±0.41 GPa) elastic modulus) were obtained from composite that was produced from fabrics named D2 (prepared by air jet hybrid yarn preparation technique).

It was observed that the effect of glass fiber sizing on the tensile properties of the glass fiber/PP composite materials was insignificant. Tensile test results showed that hybrid yarn preparation technique plays a dominant role on the tensile properties of the composites. Composites made of fabrics produced by air jet hybrid yarn preparation technique exhibited better results than those produced by direct twist covering (single or double) hybrid yarn preparation technique. The lowest results (143.75 MPa (±8.46) tensile strength and 8.17 GPa (± 0.59 GPa) elastic modulus) were obtained from the composites made of fabrics produced by double twist covering hybrid yarn preparation technique. The data obtained associates with the findings reported in the literature. Santulli[12] studied tensile properties of commingled E-glass/PP laminates with 60% weight glass fiber content and reported tensile strength and modulus as 225 MPa and 13 GPa, respectively.

Fracture surface SEM images of glass fiber/PP composites fabricated from fabrics D2 and D8 are shown in Figure 5. As seen from SEM images, a more complex failure surface and more extensive matrix deformations were observed for composites prepared with fabric D8. Plastic deformations of the PP matrix around fibers were observed due to better adhesion at the fiber/PP interface. On the other hand, smoother fracture surfaces were observed for composite prepared with fabric D2. Due to weak adhesion at the fiber/PP interface, the failure at the interface occurs at lower matrix deformations.

Flexural properties. Figure 6 shows flexural stress–strain behavior of composites manufactured from various types of fabrics laminated at 200 °C under 1.5 MPa compression pressure by hot pressing. The flexural modulus values were obtained from the initial slope of the curve and the flexural strength and strain values were determined at the failure point where the maximum stress was reached. The flexural mechanical properties are listed in Table 3, together with fiber volume fraction values.

Table 2. Tensile properties of glass fiber/PP thermoplastic composites.

Fabric code	Tensile strength (MPa)	Tensile modulus (GPa)	Tensile strain	Fiber volume fraction	Hybrid yarn preparation technique	Glass fiber sizing
D2	227.75 ± 8.1	11.2 ± 0.41	0.022 ± 0.001	0.335	Air jet	PES resin compatible
D3	211.9 ± 16.1	10.7 ± 0.6	0.02 ± 0.001	0.352	Single twist	PES resin compatible
D4	262.7 ± 15.3	13.83 ± 0.94	0.019 ± 0.0018	0.535	Single twist	PES resin compatible
D5	143.75 ± 8.46	8.17 ± 0.59	0.0215 ± 0.0026	0.34	Double twist	PES resin compatible
D8	208.6 ± 1.98	9.97 ± 0.53	0.023 ± 0.0035	0.342	Air jet	PP resin compatible

PES: polyethersulfone.

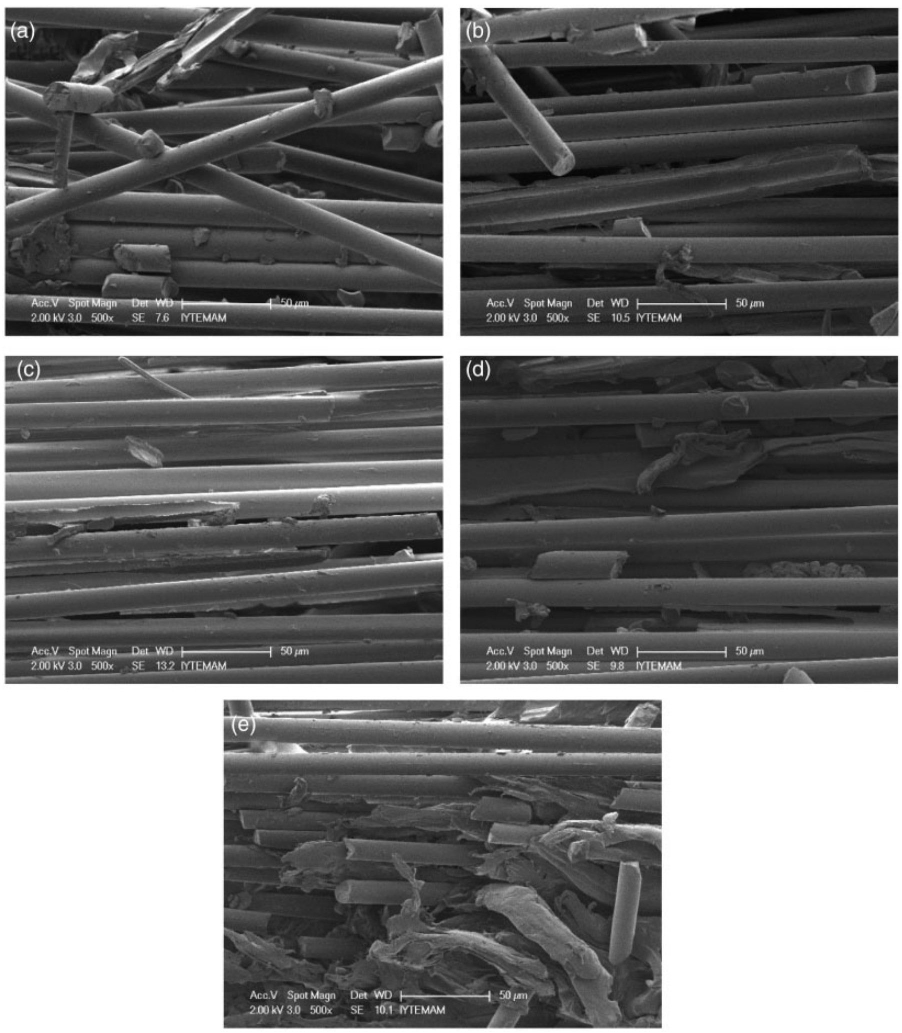

Figure 5. Fracture surface SEM images of the composites fabricated with fabrics coded as (a) D2 (b) D3 (c) D4 (d) D5 (e) D8. Magnification 500×.

Based on the results shown in Figure 6 and Table 3, it is seen that the type of the hybrid yarn preparation technique and glass fiber sizing applied on the glass fibers have some important role on the flexural properties of glass fiber/PP non-crimp composites.

The highest flexural properties (99.1 MPa (±4.2 MPa) flexural strength and 9.55 GPa (±0.293 GPa) flexural modulus) were obtained from the composites manufactured from fabric D8. For these fabrics, PP resin compatible glass fiber sizing

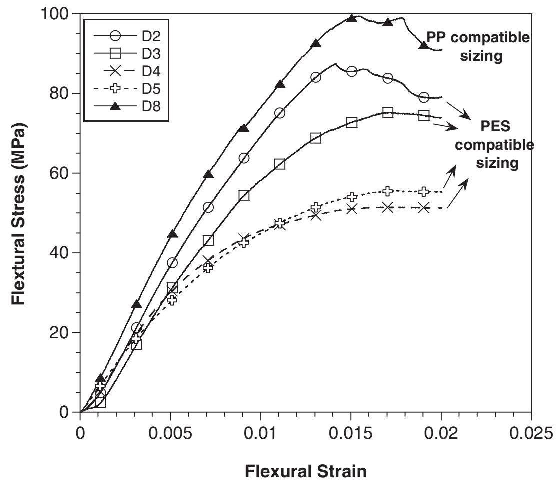

Figure 6. Flexural stress–strain behavior of composites manufactured from different types of fabrics.
PP: polypropylene; PES: polyethersulfone.

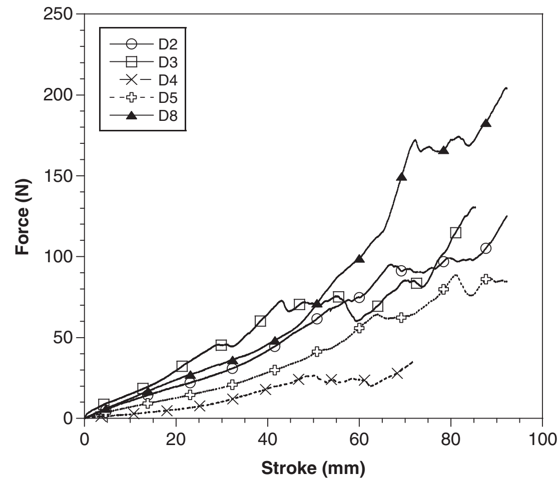

Figure 7. Force vs. stroke values of the composites obtained during the interlaminar peel test.

Table 3. Flexural properties of glass fiber/PP composites.

Fabric code	Flexural strength (MPa)	Flexural modulus (GPa)	Flexural strain
D2	85.2 ± 2.4	7.8 ± 0.4	0.016 ± 0.0028
D3	74.4 ± 5.2	6.6 ± 0.4	0.019 ± 0.0017
D4	48.4 ± 6.5	5.4 ± 0.9	0.023 ± 0.0026
D5	54.8 ± 2.9	5.6 ± 0.4	0.017 ± 0.0034
D8	99.1 ± 4.2	9.6 ± 0.3	0.015 ± 0.0013

was used, and hybrid yarns were manufactured by air jet hybrid yarn preparation technique. It was revealed that the PP resin compatible sizing have some positive effect on the flexural properties of the composites as compared to those with polyethersulfone (PES) resin compatible sizing. This is due to better adhesion at the interface of glass fibers and PP matrix. The results also revealed that interfacial strength has more critical effect on the flexural properties as compared to tensile properties of the composites. The second highest results were (85.2 MPa (±2.4 MPa) flexural strength and 7.83 GPa (±0.41 GPa) flexural modulus) obtained from the composite which was manufactured from fabric D2. Common trait of the fabrics D2 and D8 is the hybrid yarn preparation technique (air jet hybrid yarn preparation technique). Therefore ,it can be concluded that air jet hybrid yarn preparation technique contributes to the better mechanical properties due to relatively better commingling of the glass and PP fibers in the yarn.

As we compare composites which were produced from fabrics via direct twist covering hybrid yarn preparation technique (with similar fiber volume fractions), it was observed that composites manufactured from single twisted hybrid yarns (D3) have better flexural properties as compared to those with double twisted hybrid yarns (D5), as seen in Table 3.

Interlaminar peel properties. Interlaminar peel test was performed to investigate effect of glass fiber sizing on the glass fiber–PP matrix interface. All of the fabrics were hot pressed under 1.5 MPa pressure at 200 °C. Force–stroke values of the composites obtained during interlaminar peel test are shown in Figure 7. The strength values were calculated based on dividing maximum force to specimen width. Fabric properties and interlaminar peel strength values are given in Table 4.

As seen from Figure 7, the composite fabricated from fabric with PP compatible sizing (fabric D8) exhibits the highest peel resistance to delamination than those of the composites made of other fabrics. Composites made of fabric D8 have an interlaminar peel strength value of 5.87 N/mm. The nearest peel strength value (3.97 N/mm) was observed with composites of fabric D2. Based on these results, it can be concluded that PP resin compatible sizing improves adhesion at the interface of glass fiber and PP matrix.

In order to support the results obtained by interlaminar peel test, peeled surfaces of the tested samples were examined with SEM. In Figure 8, peeled surface SEM images of the composites prepared with fabrics D2, D3 and D8 are given.

The images taken from the peeled surfaces are in accordance with peel strength values obtained by interlaminar peel test. As seen in Figure 8, a smoother fracture surface in which fracture occurred along the fiber surfaces or matrix material are observed for the composites prepared with fabrics D2 and D3 (containing incompatible sizing with PP). This indicates lower adhesion at the glass fiber–PP interface. On the other hand, more complex failure modes and deformation of PP matrix are observed for composites with fabric D8. Due to better adhesion at fiber/PP interface, less amount of interfacial debonding and higher extend of plastic deformation of the PP matrix around fibers were observed.

In-plane shear properties. In-plane shear tests were performed to evaluate the in-plane shear properties of the glass fiber/PP composites fabricated from non-crimp fabrics. Figure 9 shows the shear stress responses of the glass fiber/PP composites fabricated at 200 °C process (hot pressing) and under 1.5 MPa pressure. Maximum shear stress and offset shear strength of the glass fiber/PP composites are given in Table 5.

Table 4. Interlaminar peel strength of the composites.

Fabric code	Interlaminar peel strength (N/mm)
D2	3.97
D3	2.58
D4	1.33
D5	2.45
D8	5.87

The highest offset shear strength was obtained from composite fabricated from fabric D8 (10.9 MPa). The second highest offset shear strength was obtained from the composite prepared with fabric D2. Offset shear strength values indicates that the composites made of fabrics fabricated by air jet hybrid yarn preparation technique have higher in-plane shear properties than those fabricated by single twist hybrid yarn preparation technique. Maximum shear stress values of the composites also support this finding.

The thickness of individual plies is an important parameter that influences both the shear stress–strain response and ultimate failure load of the specimen. Fabric D4 has lower nominal weight and ply thickness as compared with other fabrics. Based on the results given in Figure 9 and Table 5, composites made of D4 have the lowest shear strength values due to the lowest thickness of the individual plies of the composite.

Impact properties. Impact properties of the glass fiber/PP composite materials were evaluated with charpy impact tests. Absorbed energies of the composites are given in Table 6.

Based on the results in Table 6, it can be concluded that hybrid yarn preparation technique and type of the glass fiber sizing have insignificant effect on the impact properties of the glass fiber/PP composite. The average absorbed energy values of the composites D2, D5 and D8 are very close to each other and it is in the range of

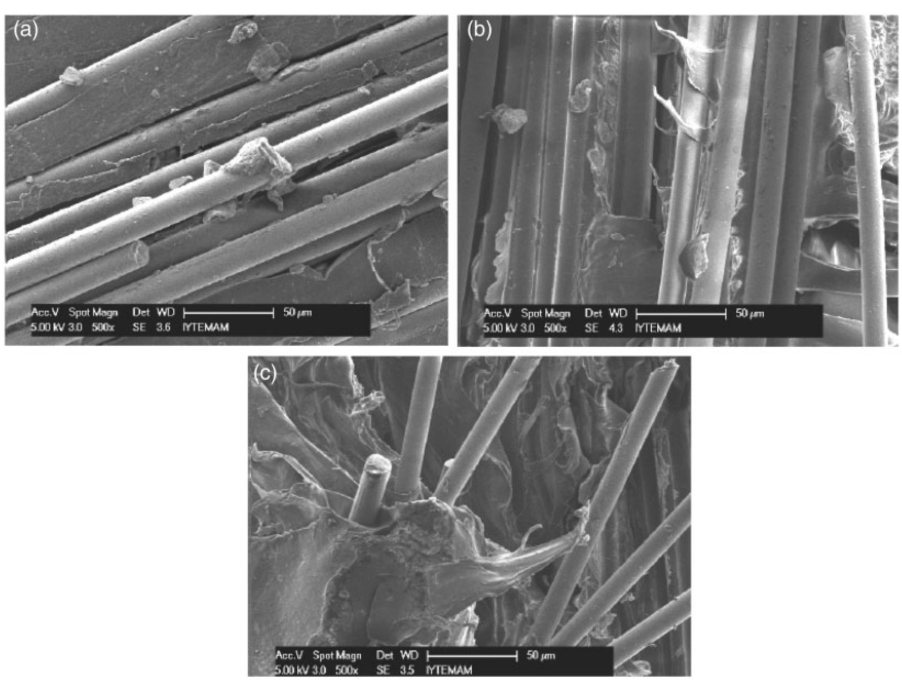

Figure 8. SEM images of the peeled surfaces of the composites coded with (a) D2 (b) D3 (c) D8 Magnification 80×.

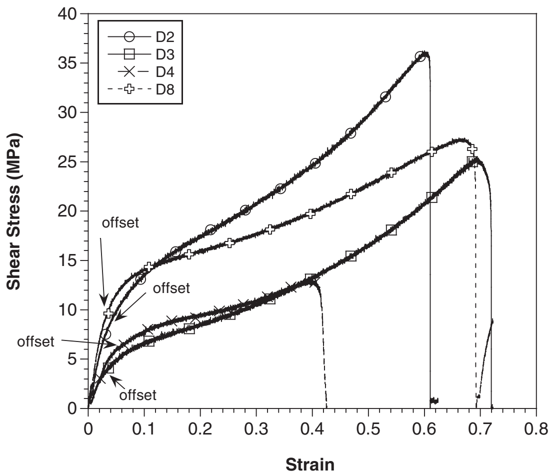

Figure 9. Shear stress vs. strain responses of the glass fiber/PP composites prepared with various type of hybrid commingled fabrics.

Table 5. In-plane shear properties of glass fiber/PP composites.

Fabric ID	Max. shear stress (MPa)	Offset shear strength (MPa)
D2	36.1	7.8
D3	25.1	5.4
D4	13.1	5.7
D8	27.5	10.9

195–198 KJ/m^2. These results are in agreement with the other findings[13] reported in the literature. Santulli studied impact properties of commingled E-glass/PP composites fabricated by compression moulding. They have reported the charpy impact results of glass fiber/PP composites with glass fiber content similar to values used in this study. Similar to the present work, the authors reported the average absorbed energy values of 196.9 KJ/m^2 ($\pm$24.9 KJ/m^2). Composites made of fabric D4 exhibited lower impact properties than those of other composites. It may be due to poor in-plane properties and low thickness of individual plies.

Conclusions

The present study revealed the effects of hybrid yarn preparation technique and type of glass fiber sizing on the mechanical properties of glass fiber/PP composites. Microstructural characterizations revealed that glass fiber bundles appear to be in order before lamination. However, during lamination of the fabrics by compression moulding, it was observed that fiber bundles was slightly disordered due to the melting and flow process of the PP matrix. As hybrid yarn preparation techniques were compared, the best glass fiber orientation was obtained with fabrics produced by air jet hybrid yarn preparation technique. Tensile tests were performed in order to investigate tensile properties of the composites. As composite panels with similar fiber volume fractions are compared, composite panels produced from the fabrics prepared by air jet hybrid yarn preparation technique exhibited the highest mechanical properties than those of composites produced from the fabrics fabricated by direct twist hybrid yarn preparation technique. The lowest values were obtained from the composite panels produced from the fabrics fabricated by double twist hybrid yarn preparation technique. It was observed that PP resin compatible sizing on the glass fibers have positive effects on the flexural and shear properties of the composites as compared to those with PES resin compatible sizing. Based on the flexural test results, it was observed that type of the hybrid yarn preparation technique and glass fiber sizing applied on the glass fibers have some important role on the flexural properties of glass fiber/PP composites. Interlaminar peel test was performed in order to investigate the effect of sizing applied on glass fibers. The best results were obtained from composite containing compatible sizing. Interlaminar peel strength of composite with PP compatible sizing was found to be 1.47 times higher than those of composite with incompatible sizing. Results were supported with SEM images. A relatively lower amount of debonding and higher amount of plastic deformation of the PP matrix around the fibers were observed for composites with compatible sizing. However, for composites with fabrics incompatible sizing with PP, a smoother fracture surfaces with higher amount of debonding were observed. Based on absorbed energy values obtained with Charpy Impact test, it is concluded that hybrid yarn preparation technique and type of glass fiber sizing have insignificant effect on impact properties of the glass fiber/PP composites.

Table 6. Impact properties of glass fiber/PP composites.

Sample ID	Average absorbed energy (kJ/m^2) (SD)
D2	197 ($\pm$32)
D3	175 ($\pm$31)
D4	115 ($\pm$11)
D5	195 ($\pm$35)
D8	198 ($\pm$26)

SD: standard deviation.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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