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Mechanical Characterization of Hybrid Thermoplastic Composites of Short Carbon Fibers and PA66/PP

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ABSTRACT
The hybrid effect of fibers on the mechanical behavior of thermoplastic composites is the most important for structural applications. This article deals with the individual and hybrid effect of 10 wt. % short glass fibers and 10 wt. % short carbon fibers on the mechanical behavior of 80/20 wt. % PA66/PP blend. These composites are produced by melt mixing method using twin screw extruder followed by the injection molding. The mechanical properties such as tensile, flexure, and impact behavior of the composites are studied as per ASTM method. Further, the hardness and density of the composites were also discussed. Experimental results revealed that the reinforcement of hybrid short fibers into the blend greatly enhanced mechanical behavior of PA66/PP composites. Increase in tensile strength by 77%, 104% flexural strength, and 20.8% reduction in elongation was exhibited by the blend due to the hybrid effect of fibers. Significant improvement in strength of the composites was observed due to individual effect of the fibers. The synergistic effect between the fibers and matrix blend supported in improving the mechanical behavior. The strain rate of the hybrid composites was deteriorated due to the hybrid effect. The impact strength of the hybrid composites is reduced due to the brittle nature of the hybrid filled composites. Fiber fracture, fiber pull-out, and fiber misalignment are the some of the mechanisms observed through scanning electron microscopy photographs.

Keywords: *PA66/PP, Hybrid materials, Carbon fibers,Mechanical, Blends.*

1. INTRODUCTION

Polymer composites are the class of composite materials for structural applications. Polymer composites are often used as the substitute for the metal based ones in the mechanical industries. They are used in the penal of solar boards, automobile accessories, polymer gears, body of modern cars, ratchets of badminton, etc. However, the mechanical performance of the polymer is only the parameter which can hold the strength of them in the field of industries. Homopolymer could not satisfy the demand arising from the situations where the combined effects of mechanical and tribological properties are required. Therefore, it is required to improve the properties of the homopolymer to suit the above mentioned situations. Copolymerization, polymer blending and reinforcing the polymers by fibers and fillers are important methods for the polymer modifications. Polymer blending is fascinating in polymer modification because it has very simple processing and unfolds unlimited possibilities of producing materials with variable properties [1]. Polymer blends are mixtures of two macromolecular species, polymer and/copolymers. Mixing two polymers usually leads to immiscible blends characterized by coarse, metastable morphology, and poor adhesion between the phases. Elongation at break, toughness, and tensile strength are the mechanical properties greatly altered by the phase separated morphology [2]. Therefore, selection of the blend associates determines the effective polymer material. Many researchers have revealed that the addition of fillers and fibers to the polymer matrix has greatly enhanced the mechanical behavior of the composites. A lot of research has been made to improve the mechanical properties using reinforcing the fibers with various neat polymers. The strength and stiffness of the polymer matrix can be effectively improved by reinforcing fibers. Glass and carbon fibers are most widely used reinforcing agents in thermoplastic matrix because of good balancing properties. These fibers are usually sized to permit good bonding with the matrix, producing a material of high flexural, and tensile strength. The addition of reinforcing agents such as glass and carbon particularly

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in the form of fibers enhances the mechanical properties of polymer composites. Manoj Kumar *et al*. [3] studied the effect of banana natural fibers on the mechanical behavior of high density polyethylene and polyamide 66 (HDPE/PA66) blend composites. They stated that the tensile strength of the treated banana fiber composites is better than the non-treated ones. A similar trend was noticed for the flexural behavior and tensile modulus up to 40 wt. % of banana fibers with lowering the value of impact toughness. They revealed that the effect of sizing agent is most appreciable in improving the mechanical behavior of banana fiber filled composites. Bahadur and Cheng [4] studied the reinforcement effect of short glass fibers (SGFs) on the mechanical behavior of polyester composites. The tensile strength, flexural strength, and hardness of the polyester were increased due to the effect of SGF loading. They also revealed that the effect of compatibilizer on the mechanical behavior of the polymer composites. The effect of long glass fibers on the mechanical behavior of polypropylene (PP) composites was studied by Hartikainen *et al*. [5]. They observed that the addition of fiber into the PP improved the tensile strength, fracture toughness, and also tensile modulus of the composites. Palabiyik and Bahadur [2] studied the hybrid effect of polytetrafluoroethylene (PTFE) and copper oxide on the mechanical behavior of SGF filled PA6 and HDPE blends. There is a 60% increase in tensile strength for 15% of SGF in the blend. Further the hardness of the blend was increased in the similar way. However, the addition of PTFE into SGF filled blend PA6/HDPE decreased the tensile strength of the composites. Run *et al.* [6] studied the reinforcement effect of short carbon fibers (SCF) on the mechanical behavior of poly trimethylene terephthalate (PTT/SCF) composites. They revealed that the tensile strength and the rupture strength are increased with increasing content of SCF. The maximum value of the impact strength was obtained for 5 wt. % of SCF in the matrix. Run *et al.* [7] studied the mechanical properties of SCF reinforced PTT/Acrylonitrile-Butadiene-Styrene (ABS) blend. When the ABS content was 5 wt. % in the blend, SCF had significantly improved the flexure, tensile and impact strength of the blends. The SCF has good interface adherence with the matrix. The storage modulus increases as the content of SCF increases in the blend. Fua *et al*. [8] studied the tensile properties of SGF and SCF reinforced PP composites. The results about the composite strength and modulus were interpreted using the modified rule of mixture equations by introducing two fiber efficiency factors respectively, for the composite strength and modulus. It was found that for both types of composites the fiber efficiency factors decreased with increasing fiber volume fraction and the more brittle fiber namely carbon fiber corresponded to the lower fiber efficiency factors than glass fiber. Yuan *et al.* [9] studied the effect of coupling agent on mechanical properties of glass fiber reinforced SCF filled HDPE composites. They showed that increasing coupling agent will improve the bonding strength between glass fibers and the matrix. They proved that the coupling agent will act positively in improving the mechanical behavior of SGF reinforced SCF/HDPE composites. The mechanical behavior of carbon fiber reinforced PA composites is studied by Botelho *et al*. [10]. Two types of composite matrices was studied PA6 and PA66 both reinforced by carbon fabrics and unidirectional carbon fibers. A slight increase of mechanical behavior of PA6/SCF and PA66/SCF was observed. Sahu *et al.* [11] reported the development and characterization of particulate filled glass fiber reinforced hybrid composites. They studied the effect of alumina filler on the 40 wt. % of SGF filled polyester composites. The mechanical behavior of SGF filled composite decreases as the percentage of alumina in the composites increases. Palabiyik and Bahadur [12] studied the mechanical behavior of PA6/HDPE blends reinforced with SGF. They showed that the addition of 5-15 wt. % of SGF into 80 wt. % PA66-20% wt. % HDPE improved the tensile strength of the blend from 20% to 60%, respectively. Yuqin and Junlong [13] reported the mechanical properties of carbon fiber reinforced polyoxymethylene (POM) composites. They reported that the addition of SCF improves the tensile strength of POM. Chen *et al.* [14,15] studied the effect of short glass/carbon fibers on the mechanical properties of PA66/polyphenylenesulphide (PPS) blend. They showed that the addition of 20-30 wt. % of SGF greatly improved the mechanical properties of PA66/PPS Blend. On the other hand, 30 vol. % of SCF had the best mechanical properties of PA66/PPS even though it has negative effect on the same. Experimental investigation on the effect of glass fibers on the mechanical properties of PP and PA6 plastics were reported by Gullu *et al.* [16]. They showed that SGF filled PA6 and PP had exhibited better mechanical properties. Investigation on the mechanical properties of PPS/SCF composites and PA6 filled PPS/SCF composites were studied by Jian and Tao [17]. They showed that better flexural strength was obtained for 25 wt. % of SCF in PPS. Furthermore, they proved that the addition of 6 wt. % of SCF into PA66/SCF exhibited better flexural strength than PPS/SCF composites. Cao *et al.* [18] reported the effect of basalt fiber in ultra-high molecular weight polyethylene. Increase in basalt content in the composite led to decrease in toughness and increase in strength, hardness, and creep resistance. Zhou *et al.* [19] studied the effect of carbon fiber reinforcement on the mechanical properties of PA6/PPS composites. Addition of 15% of SCF into the blend PA6/PPS had greatly improved the mechanical behavior of the composites. There was a 45% increase in tensile modulus of filled composites against the blend. Similarly, the bending stress and bending modulus are also followed the same way. The impact strength of the blend PA66/PPS decreased with the addition of SCF with increase in hardness of the blend. Wu *et al.* [20] studied the mechanical properties of glass fiber and carbon fiber reinforced PA6 and PA6/clay nanocomposites. The results showed that the mechanical properties of polyamode 6/clay nanocomposites are superior to those of SCF or SGF filled PA6 composites in terms of tensile, flexural and modulus without sacrificing the impact strength of the composites. The effect of nanoscale clay on toughness is more significant than that of the fiber. Mouhmid *et al.* [21] experimentally investigated the mechanical behavior of glass fiber reinforced PA66. They studied by reinforcing 15, 30 and 50 wt. % SGF into PA66. They concluded that the glass fiber reinforced PA66 exhibits improvements in its mechanical strengths. Experimental results showed that the studied composite is a strain rate, temperature and fiber volume fraction dependent material. Rudresh and Ravi Kumar [22] studied the effect of SGF loading on the mechanical behavior of PA66/PTFE blend. They showed that the addition of SGF greatly enhanced the mechanical behavior. They studied for 5, 10, 15, 20, 25, and 30 wt. % of SGF effect on 80/20 wt. % PA66/PTFE blend. The improved mechanical behavior continued up to 30 wt. % of SGF in the blend. Obviously, elongation to break decreased due to the brittle nature of PA66/PTFE/SGF composites. PA66 is a high performance thermoplastic polymer. PP is one of the crystalline high performance thermoplastic polymers. Very less data are reported on the PA66/PP blend. The blend of PA66/PP will be the best blend for the polymer matrix. In spite of the fact that polymer composites are used in such structural applications, no data are reported on the influence of PP in PA as blend with hybrid fibers such as SGF and SCF. To design the structural applications with hybrid fibers, keeping this in view, the hybrid effect of SCF and SGF on the tensile, flexural and impact behavior of PA66/PP blend is discussed. Furthermore, the hybrid effect on the specific properties which characterizes the mechanical behavior of the developed composites was.

2. MATERIALS AND PROCESSING

2.1. Materials

The materials used in the present investigation PA66, PP, silane coated SGF and SCF are listed in Table 1. The details of materials and their specifications are also tabulated in the same Table 1.

2.2. Fabrication of Blend and their Composites

The polymers PA66 and PP with proper proportions (Table 2) were dried at 80°C for 48 h before mixing to avoid plasticization, hydrolyzing effects from humidity and to obtain the sufficient homogeneity. The plasticization is a phenomenon of change in thermal and mechanical properties of a given polymer which involves (1) lowering of rigidity at room temperature, (2) lowering of temperature at which substantial deformation can be effected with no too large forces, (3) increase of elongation to break at room temperature, and (4) increase of toughness down to the lowest temperature of serviceability. PA66 and such polymers are very susceptible to moisture, which may deteriorate the mechanical strength of the composites. For this purpose, plasticization and hydrolyzing effects must be avoided before subjecting all the associates of the composites to compounding process and fabrication. The composition of the blend, saline coated sized SGF, and SCF are mixed in proper proportions. The mixed materials were extruded using Barbender co-rotating twin-screw extruder (Make: CMEI, Model: 16 CME, SPL, chamber size 70 cm^3) (Figure 1). The extruder consists of five heating zones and the temperature maintained in these zones were zone 1 (220°C), zone 2 (235°C), zone 3 (240°C), zone 4 (265°C), and zone 5 (270°C), respectively, and the temperature at the die was set at 220°C. The extruder screw speed was set at 100 rpm to yield a feed rate of 5 kg/hr. The extrudate obtained was in the form of cylindrical rod which was quenched in cold water and then palletized using Palletizing machine. During initial stage, around 1 to 1.5 kg of initial extrudate was

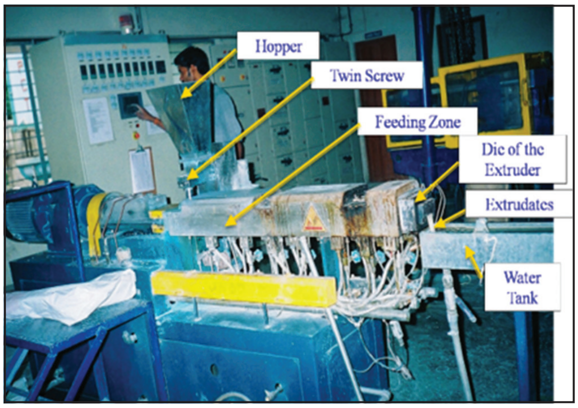

Figure 1: Barbender Co- rotating twin screw extruder.

Table 1: Data and details of the materials used.

Materials	Designation	Form	Size (µm)	Trade name	Manufacturer	Density (g/cc)
Polyamide	PA66	Granules	-	Zytel 101L NC010	Dupontco. Ltd.	1.14
Polypropylene	PP	Granules	12-15	MP1000	Dupontco. Ltd	0.95
Short glass fiber	SGF	Cylindrical	Length=2-3 mm	-	Fine organics, Mumbai	2.5
Short carbon fibers	SCF	Cylindrical	Length=2-3 mm	-	Fine organics, Mumbai	1.25

removed to get the pure composites and to remove impurities from the previous stroke of the extrusion. Before injection molding, all polymer blended composite pallets were dried at 100°C in vacuum oven for 24 h. All specimens were injection molded from the pelletized polyblend material obtained from corotating twin screw extruder. The temperature maintained in the two zones of the injection molding barrel were zone 1 (265°C) and zone 2 (290°C), and mold temperature was maintained at 65°C (Figure 2). The screw speed was set at 10-15 rpm followed by 700-800 bar injection pressure. The injection time, cooling time, and ejection time maintained during injection molding were 10, 35, and 2 s, respectively. All the molded specimens as per ASTM D638 (tensile test), ASTM D790 (flexure test), and ASTM D256 (impact test) were inspected and tested visually and those found defect were discarded for testing.

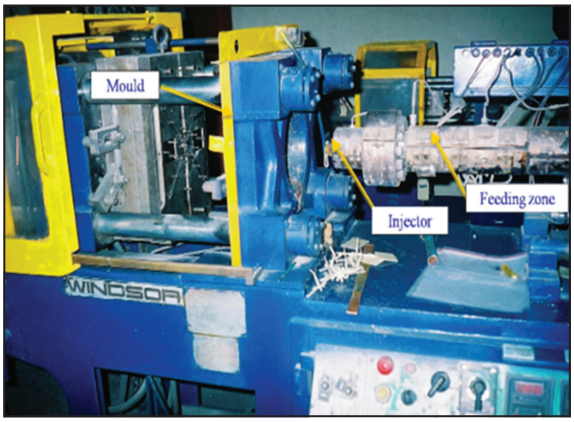

Figure 2: Injection moulding machine (GLS Polymers, Bangalore, India).

Table 2: Formulations of composites in weight percentage.

Material ID	Composition	PA66	PP	SGF	SCF
1T	Blend (PA66/PP)	80	20	-	-
1G	Blend (PA66/PP)/SGF	80	20	10	-
1C	Blend (PA66/PP)/SCF	80	20	-	10
2CG	Blend (PA66/PP)/SGF/SCF	80	20	10	10

PA66: Polyamide 66, PP: Polypropylene, SGF: Short glass fiber, SCF: Short carbon fibers

3. MEASUREMENT OF MECHANICAL PROPERTIES

The mechanical properties such as tensile, flexural, impact strength along with density, and hardness of the composites are measured as per ASTM. The tensile strength and the tensile elongation at break are measured using Universal testing machine (JJ Lloyd, London, United Kingdom, capacity 1-20KN) in accordance with ASTM D638 at constant strain rate of 5 mm/min. ASTM D 638 Type 1 standard dimensions are used (Figure 3a). Flexural strength or three point bending were carried out on the same machine by changing the jaws of the set up and the specimen acts as simply supported beam subjected to point load at the middle. The flexural strength and flexural modulus were determined at the rate of 1.33 mm/min as per ASTM D790. The standard specimen dimensions for the flexural strength is 125 mm×12.7 mm×3.2 mm (Figure 3b). The Notched Izod impact strength was determined using ASTM D256 using Izod impact testing machine at the striking rate of 3.2 mm/s (Figure 3c). The ASTM standards for the mechanical testing are shown in Figure 3. All these tests were conducted at the room temperature. Minimum of three samples were tested for the data representation. On the other hand, the density and the hardness (Shore D) of the composites were determined as per ASTM D792 and ASTM D2240, respectively.

4. RESULTS AND DISCUSSIONS

4.1. Effect of SGF, SCF, and their Hybrid on the Density and Tensile Behavior

The effect of fibers on the density of PA66/PP blend is shown in Figure 4a. The addition of 10 wt. % SGF into the blend increased the density of PA66/PP blend. This is purely attributed to the dense nature of silane coated glass fibers. Further, addition of 10 wt. % SCF into the blend increased the density of the blend but less than that of SGF. This decrease in density is due to the less dense SCF. But inclusion of both the fibers into the blend greatly enhanced the density of blend.

Table 3: Tensile properties of PA66/PP composites.

Properties	Units	ASTM	1T	1G	1C	2CG
Density	gr/cc	ASTM D792	1.08	1.14	1.13	1.17
Tensile strength	MPa	D638	39.78	64.6	62	70.3
% Elongation	%		14.31	15.58	10.98	11.33
Peak load	N		1617	2626	2523	2861
Stiffness	N-mm		98.24	146.54	199.76	219.57
Specific stiffness	N-mm^2/Kg		0.91E+08	1.29E+08	1.77E+08	1.88E+08
Specific strength	N-mm/Kg		3.68E+07	5.67E+07	5.49E+07	6E+07

PA66: Polyamide 66, PP: Polypropylene

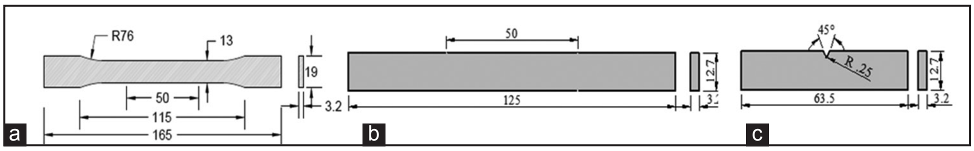

Figure 3: Specimen standards :(a) ASTM D 638 (b) ASTM D790 and (c) ASTM D256

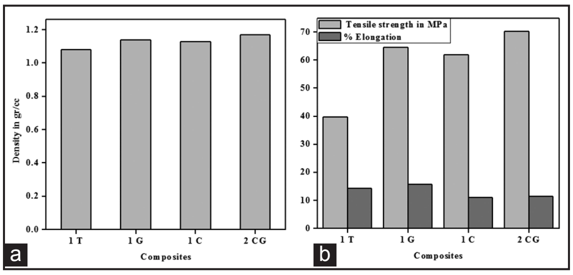

Figure 4: Individual and hybrid effect of fibers on the properties of polyamide 66/polypropylene blend: (a) Density and (b) Tensile strength and % Elongation.

Almost 8% increase in density by the hybrid effect of fibers than that of neat blend. Addition of SGF into PA66/PTFE blend increased the density of the blend [22].

The individual and hybrid effect of fibers on the tensile strength and percentage elongation are shown in Figure 4b. The improvement in the tensile strength was seemed to be the function of fiber reinforcement. The tensile strength of PA66/PP blend is 39.78 N/mm^2 (Table 3). However, the effect of 10 wt. % SGF improved the strength of the blend to 64.6 N/mm^2 which is 62.39% increase. This enhancement of strength is greatly attributed to the silane coated SGF. The silane will act as coupling agent in developing the interfacial bond between the matrix blend and the SGF. The slenderness ratio (l/d) of the SGF also promotes the strength by increasing the surface area of contact with the matrix. The interfacial bond between the SGF and the matrix blend has greatly compatibilized for the effective development of strength of the filled composite. The good elastic modulus of SGF supported the blend matrix in resisting the external load. Further, addition of SCF into the blend improved the strength by 56% than that of neat blend. SCF are good in specific modulus and specific strength. This made the composites to possess high strength. The interfacial bond developed between the blend and SCF is superior. SCF's are rigid and very tough. The results revealed that the incorporation of SCF improves both rigidity and the toughness of the polymer blend. The degree of compatibility between SCF and blend were good for the effective development of the materials. The hybrid effect of fibers on the tensile strength of composite is most appreciable. It is 70.3 N/mm^2 which is almost 77% increase over the neat blend. This shows that the effective interfacial bond and the network between thermoplastics and the fibers were established during the process of polymer blending. The load carrying capacity of the fibers through matrix is very good. Further, the synergistic effect of fibers has contributed a lot to the development of strength in the composites. Furthermore, SCF as a nucleating agent can increase the crystallization rate and decreases the crystal size of the blend [6,7]. Due to the hybrid effect of fibers, a substantial improvement in tensile strength was exhibited by PA66/PP blend. Among the studied composites, hybrid composite is most appreciable.

The hybrid effect of fibers on the percentage elongation of PA66/PP composites is shown in Figure 4b. The decrease in percentage elongation after the hybrid fiber reinforcement into the blend PA66/PP was noticed. The maximum reduction in elongation was noticed for SCF filled PA66/PP composites. This is mainly attributed to the synergistic effect between the associates of the thermoplastic blend and the carbon fibers. The SCF are rigid and toughened in nature. The PA66/PP blend was basically crystalline in nature. However, the addition of 10 wt. % SGF made the material little ductile thereby increasing the ductility of the composite material. Furthermore, the addition of 10 wt. % SCF reduced the elongation of the filled composite. This may be due to the crystalline and brittle nature of SCF. But the reduction in percentage elongation of the blend was exhibited due to the hybrid effect of fibers. Among the studied composites, hybrid composites had the least elongation.

The load versus deflection curve, the stress-strain curve, specific stiffness, and peak load for the hybrid fiber filled PA66/PP blend are shown in Figure 5a-d. Both load-deflection and stress-strain curve followed the linear trend up to the ultimate point. From Figure 5d, the peak load for the blend is 1617 N. However, the reinforcement effect of fibers shifted the peak load to a higher point which is 56, 62 and 77% higher than that of neat blend for SCF, SGF and hybrid fiber filled PA66/PP composites, respectively. The stress-strain behavior of hybrid fiber filled PA66/PP composites is shown in Figure 5b. The hybrid effect of fibers on the stress-strain behavior maintained the linear trend up to the peak point. SGF filled PA66/PP blend initially experienced less stress up to the strain rate of 0.12. But sudden increase in stress was noticed during the final elongation of the composites. This is purely attributed to the brittle nature of the composites. The behavior of the blend is uniform throughout the test. This shows the ductile nature of the composites. Among the studied composites, hybrid composites had the least strain rate. The individual and hybrid effect of

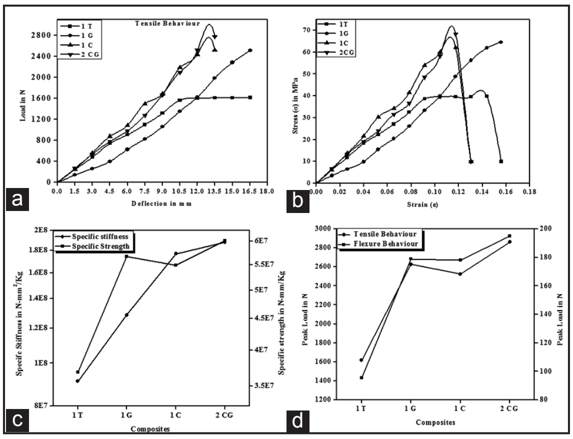

Figure 5: Individual and hybrid effect of fibers on the properties of polyamide 66/polypropylene blend: (a) Load versus deflection, (b) Stress – strain curve, (c) Specific stiffness and specific strength, and (d) peak load.

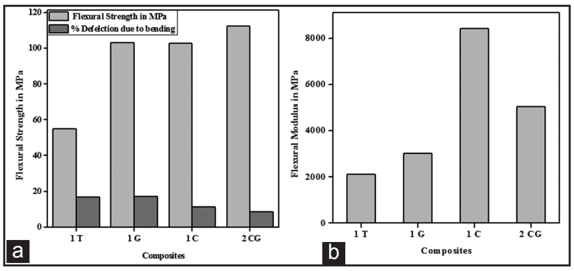

Figure 6: Individual and hybrid effect of fibers on the properties of polyamide 66/polypropylene blend: (a) Flexural strength and % deflection and (b) Flexural modulus.

fibers on the specific strength and specific stiffness of PA66/PP blend composites is shown in Figure 5c. The mechanical characterization of any composite material is measured by its specific stiffness and specific strength. The specific strength is the measure of ratio between the ultimate tensile strength and the density of the composite materials. For the composite materials, this ratio should be high. The specific stiffness of the composites followed the linear trend. This is due to the increase in the tensile load of the composites. Among the studied composites, hybrid effect of fibers improved the stiffness of the hybrid composites. Similar observations are made with the specific strength. The specific strength of the hybrid composite is high. This is due to the high strength of the hybrid fibers. Among the strength analysis of the composites, it is clear that the compatibility of the hybrid fibers with that of the thermoplastic composites are superior when compared with the individual effect of the fibers. The higher specific stiffness of the composites is due to SGF whereas, the higher specific strength is due to SCF. The high stiffness and high specific strength fibers developed the interfacial bonding between the matrix blend and the fibers to improve the strength of the hybrid composites PA66/PP/SGF/SCF.

4.2. Individual and Hybrid effect SGF/SCF on the Flexural Behavior of PA66/PP Blend

The individual and hybrid effect of SGF and SCF on the flexural strength and % deflection due to bending of PA66/PP blend is shown in Figure 6a. The flexural strength of PA66/PP blend is 55 MPa. SGF (10 wt. %) reinforcement into PA66/PP blend promoted the flexural strength by 87%. Same observation was exhibited by the 10 wt. % filled SCF. The improved flexural strength of the blend is attributed to the good balancing flexural behavior of the short glass and carbon fibers. The load carrying capacity of the composite is very good. This has proved by the effective transformation of the load through the fibers into the matrix. This shows that the fiber failure is only by fiber pullout and not by fiber fracture. During the flexural test, outer fibers are in tension and inner fibers are in compression. The outer fibers may pull out from the matrix material resulting in no loss of strength. However, the fibers transformed the load to the matrix which is surmounting them thereby effectively receiving the load. Fiber rupture and fiber pull-out are the major failures noticed during the performance. The hybrid effect of SGF and SCF improves the bending strength of the composites by 104%. This shows that the fibers have a very good interfacial bond with the thermoplastics. Among the studied composites, hybrid fiber filled PA66/PP blend had the better flexural strength. Thus, the effect of fiber properties is of great importance for the structural applications. The effect of fiber reinforcement on the percentage deflection of PA66/PP blend is shown in Figure 6a. Reduction in percentage deflection due to bending was observed during reinforcement of fibers into the blend. Reinforcing SCF into the blend had reduced the percentage deflection by 51% against the blend. Blend had the good percentage of deflection due to the ductile effect of blend. However, the addition of fibers into the blend made the material brittle and reduced the deflection of the blend. SCF had the great effect in reducing the deflection of the blend. This is due to the good compatibility between fibers and matrix. The adhesive bond developed between the fibers and the blend is very good. The hybrid effect of fibers on the deflection of the blend is very severe. Very less deflection due to bending was obtained by the hybrid fiber filled blend. This shows that the hybrid fiber effect made the material strong to support the bending load. The coupling agent of SGF (Silane) and SCF has sized uniformly during blending to contribute equally with that of matrix blend.

The effect of fibers on the flexural modulus of the studied polymer blend is shown in the Figure 6b. The significant improvement over the flexural modulus was noticed by reinforcing the fibers into the blend. The flexural modulus was increased by 3 times that of neat blend by reinforcing SCF. This is purely due to the good modulus and strength of SCF. A slight decrease in flexural modulus was observed by the effect of SGF on the SCF filled PA66/PP blend. Inclusion of SGF into the SCF filled polyblend increased the brittleness of the composite. The hybrid fiber filled composites make the blend to develop voids which can initiate the crack in the polyblend.

The load v/s deflection and the S-S curve for the flexural behavior of hybrid composites are shown in Figure 7a and b. The bending load carrying capacity of the polyblend is less when compared to the studied composites. This is due to the absence of the fiber. However, the inclusion of fibers made the polymer blend stiffened and strengthened to carry the maximum load (Figure 7a). Among the studied composites, hybrid composites have the significant load carrying capacity. The bending stress and strain behavior of the composites are shown in Figure 7b. All the composite materials studied have followed the elastic behavior up to the breaking point. PA66/PP blend has the highest strain rate. The hybrid effect of the fibers has reduced the strain rate by 20% than that of pure blend. The range of strain rate for the break load of all the composites studied is in the range of 0.10-0.25.

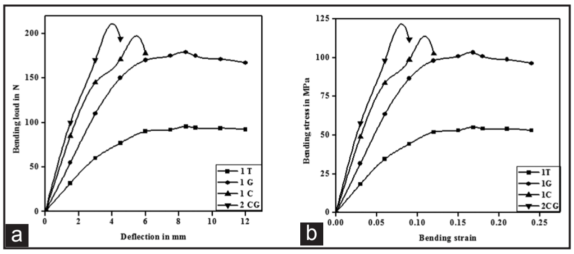

Figure 7: Individual and hybrid effect of fibers on polyamide 66/polypropylene blend: (a) Load versus deflection curve and (b) bending stress and strain curve.

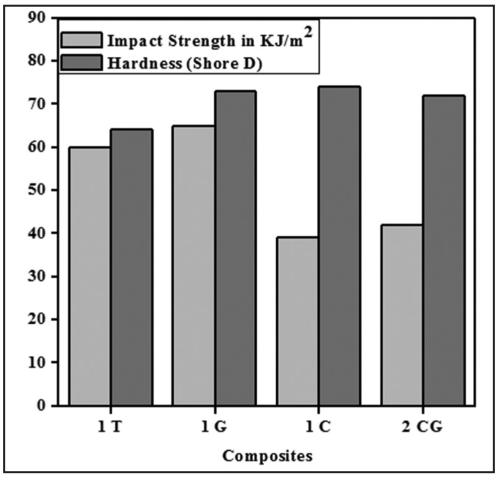

Figure 8: Individual and hybrid effect of fibers on the impact strength and hardness of polyamide 66/ polypropylene blend.

4.3. *Hybrid effect of Fibers on the Impact Strength and Hardness of PA66/PP Blend*

The individual and combined effect of short fibers on the impact strength and hardness of the blend is shown in Figure 8. The impact strength of pure polyblend is 60 KJ/mm^2. Inclusion of 10 wt. % SGF into the blend increased the impact strength by 8%. Furthermore, the effect of 10% SCF on the same has impaired the impact strength by 35%. However, the hybrid effect of fibers had slightly improved the impact strength above SCF filled one but below the impact strength of SGF filled polyblend. The decreased impact strength of SCF filled polyblend is due to the counterbalance of increased surface fracture energy increased sizes of the voids or SCF aggregates in the polyblend [23]. Influence of hybrid fibers increases the size of the voids and also the number of aggregates of the short fibers. Glass fiber improved the brittle nature of the polyblend. This may lead to the introduction of voids in the blend and also the reinforcement effect initiates the crack development in the polymer blend and thereby reducing the impact strength. This will lead to the weak reinforcement effect simultaneously building the strong bridge for the development of internal crack due to the hybrid fiber effect. The high impact strength of the polymer blend is due to the effect of PP. The polymer PP modified PA66 requires more energy to break. This will increase the impact strength of the blend.

Hardness of the polymer blend and their composites are shown in Figure 8. The hardness of the polyblend

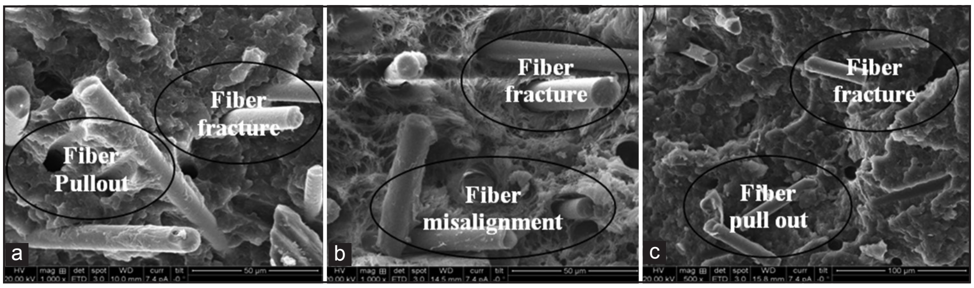

Figure 9: Scanning electron microscopy photographs of fractured surface of 10 wt. % short glass fiber filled polyamide 66/polypropylene blend: (a) Tensile fracture, (b) flexural fracture, and (c) impact fracture.

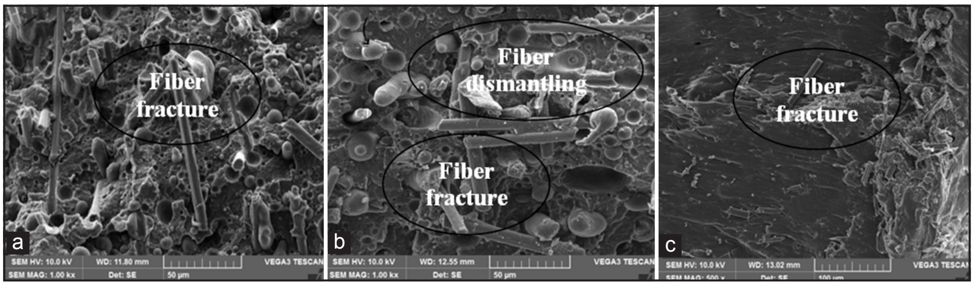

Figure 10: Scanning electron microscopy photographs of fractured surface of 10 wt. % short carbon fibers filled polyamide 66/polypropylene blend: (a) Tensile fracture, (b) flexural fracture, and (c) impact fracture.

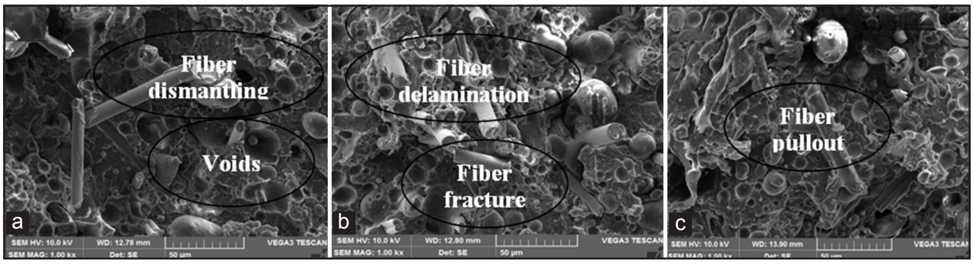

Figure 11: Scanning electron microscopy photographs of fractured surface of 10 wt. % short glass fibers and 10 wt. % short carbon fibers filled polyamide 66/polypropylene blend: (a) Tensile fracture, (b) flexural fracture, and (c) impact fracture.

is increased due to the effect of SGF. This can explained due to the hard nature of SGF. Further, slight improvement in hardness was noticed due to the SCF effect on the blend. The hybrid effect of the fibers on the hardness of the polymer blend PA66/PP marginally reduces. This can be attributed to the brittle nature of fiber filled polymer blend. But the hardness of the hybrid composite was retained above the value of the pure blend. Among the studied composites, SGF filled PA66/PP blend composites possess the better hardness.

5. FRACTOGRAPHY OF THE SURFACES USING SCANNING ELECTRON MICROSCOPY (SEM)

The SEM photographs of fractured surfaces subjected to tensile, flexure and impact test of fiber filled PA66/PP composites are shown in Figures 9-11, respectively. The SEM micrographs of fractured surfaces of 10% SGF filled PA66/PP blend is shown in Figure 9a-c. It is clear from the graph that SGF filled composites characterized by the brittle nature. The fiber fracture and the fiber pull out are seen in Figure 9a. The sizing of the fibers by the matrix blend is uniform and compatible. Less number of voids was seen in Figure 9. The flexure fractured surface of the same composites is shown in Figure 9b. The effective fiber-matrix interface is seen in the graph. However, the matrix blend seemed to be strained much. More number of fiber aggregates is seen in the picture. This is the evidence for the fiber fracture. More number of fiber misalignment was seen from the picture. The fiber pull-out is evidenced during the impact behavior of composites. This is shown in Figure 9c, and severe matrix deformation is also seen in Figure 9.

The same observation was made with the SCF filled composites (Figure 10a-c). However, the fiber pull-out is more during the tension test. The impression of the fiber pull out is clearly visible in the SEM picture (Figure 10a). The fibers are misaligned during the flexure test (Figure 10b). But the interfacial bonding between the matrix and the fiber seemed to very good. Moreover, the uniform sizing of SCF by the epoxy made the interaction effective between the blends associate. There is a physical interaction between the SCF and blend during the melt blending process. The impact behavior shows the uniform bonding between the fibers. This is very clearly evidenced in Figure 10c. However, the phase morphology shows that the crystallinity of the blend is more. This will introduce more number of voids and hence less impact strength.

The SEM photographs of fractured surfaces of hybrid composites are shown in Figure 11a-c. The tensile fracture is characterized by the brittle fracture with the availability of the voids (Figure 11a). Fiber facture and fiber pull-out is evidenced from the photograph. The severe matrix deformation was exhibited by the photograph. The impression of fiber pull-out from the matrix is more. This shows the effective bonding between the fibers and the matrix. The bending fractured surfaces exhibits fiber fracture, fiber misalignment, and fibers pull out (Figure 11b). However, the aggregates of SGF and SCF are more due to the fiber failure. The bending fracture occurred due to brittle fracture. The matrix blend seemed to be more strained than the fibers. The impact surfaces of the hybrid composites characterized by the brittle failure (Figure 11c). Furthermore, the inner crack initiation by the fibers is seen in Figure 11. On the conclusion, the hybrid composites are characterized by the brittle fracture which is evidenced by the SEM photographs.

6. CONCLUSIONS

The effect of blend composition with the hybrid fibers is most promising composites for the better mechanical components. The following are the facts emerged from the experimental investigation of hybrid composites.

1. The hybrid composites with 10 wt. % SGF and 10 wt. % SCF in 80/20 wt. % PA66/PP blend are the promising composites for the structural applications.
2. The hybrid effect of fibers on the tensile strength of composite is most appreciable. It is 70.3 N/mm^2 which is almost 77% increase over the neat blend PA66/PP.
3. The maximum reduction in elongation was obtained for SCF filled PA66/PP composites.
4. The reinforcement effect of fibers shifted the peak load to a higher value which is 56, 62 and 77% higher than that of neat blend for SCF, SGF and hybrid fiber filled PA66/PP composites, respectively.
5. The specific strength of the hybrid composite is high. This is due to the high strength of the hybrid fibers.
6. The flexural strength is improved by 104% over the blend by the hybrid effect of fibers.
7. The significant improvement over the flexural modulus was noticed by reinforcing the fibers into the blend. The flexural modulus was improved by 3 times than that of the neat blend by reinforcing SCF into the blend.
8. The hybrid effect of the fibers has reduced the strain rate by 20% than that of pure blend during bending.
9. Inclusion of 10 wt. % SGF into the blend improved the impact strength by 8%. The effect of 10% SCF on the same has impaired the impact strength by 35%.
10. The hardness of the polyblend is increased due to the effect of SGF. Slight increase in hardness was noticed due to the SCF effect on the blend. The hybrid effect of the fibers on the hardness of the polymer blend PA66/PP still reduces. This can be attributed to the brittle nature of fiber filled polymer blend.
11. Fiber fracture, fiber pullout, and fiber misalignment are some of the mechanisms observed during fractographic analysis through SEM.

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Bibliographical Sketch

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