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REINFORCEMENT EFFECT OF HYBRID FIBERS ON THE MECHANICAL BEHAVIOR OF POLYAMIDE66 AND TEFLON BLEND

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ABSTRACT

The hybrid effect of fibers on the mechanical behavior of thermoplastic composites is most important for structural applications. This article deals with the hybrid effect of 10wt. % Short Glass Fibers (SGF) and 10wt. % Short Carbon Fibers (SCF) on the mechanical behavior of 80 wt.% PA66 / 20 wt.% Teflon (PA66/PTFE) blend. These composite materials are prepared by melt mixing method by using twin screw extruder followed by injection molding. The mechanical performance of the composite materials is tested as per ASTM method. The experimentally determined mechanical properties are tensile behavior, flexural behavior and impact behavior. Hardness and density of the blend composites are also studied. Experimental results revealed that the addition of hybrid short fibers into the blend greatly enhanced the mechanical behavior of PA66/PTFE composites. Increase in tensile strength by 46%, 45% flexural strength and 47% reduction in elongation was exhibited by the blend due to hybrid effect of fibers. 50% increase in flexural strength is obtained for SCF filled composites. The synergistic effect between the fibers and the matrix blend improved the mechanical behavior. The strain rate of the hybrid composites was deteriorated due to hybrid effect. The impact strength of the hybrid composites is reduced due to brittle nature of the hybrid filled composites. Fiber fracture, fiber pull out and fiber misalignment are the certain mechanisms observed during mechanical performance through Scanning Electron Microscope photographs

Keywords: *PA66/Teflon; Mechanical; carbon fibers; glass fibers; hybrid fibers*.

I. 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. But the mechanical performance of the polymer is only the parameter which can hold the strength of them in the field of industries. Homopolymer couldn't satisfy the demand arising from the situations where the combined effect of mechanical and tribological properties is required. Therefore, it is required to improve the properties of the homopolymr to suit the above mentioned situations. There are three methods to modify the properties of the polymer. Copolymerization, polymer blending and reinforcing the polymers by filler and fibers. Polymer blending is fascinating in polymer modification because it has 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 by means of incorporation of fibers with various neat polymers. The strength and stiffness of the polymers 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 in the form of fibers enhances the mechanical properties of polymers. Manoj Kumar et al [3] studied the effect of banana fibers on the mechanical behavior of High density polyethylene and Polyamide66 (HDPE/PA66) blend composites. They stated that the tensile strength of the treated banana fiber composites is better than the non-treated ones. Similar trend was noticed for the flexural behavior and tensile modulus up to 40wt. % 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 Zheng [4] studied the reinforcement effect of short glass fibers 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. Further, they revealed that the effect of compatbilizer further improved the mechanical behavior of the polymer composites. The effect of long glass fibers on the mechanical behavior of polypropylene composites was studied by Hartikainen [5]. They observed that the addition of fiber into the polypropylene improved the tensile strength, fracture toughness and also tensile modulus of the hybrid composites. Palabiyak and Bahadur [6] studied the hybrid effect of PTFE and Copper oxide on the mechanical behavior of short glass fiber filled Polyamide 6 and HDPE blends. There is a 60% increase in tensile strength for 15% increase in SGF in the blend. Further the hardness of the blend was increased in the similar way. But the addition of PTFE into SGF filled blend PA6/HDPE decreased the tensile strength of the composites.

Run et al [7] studied the reinforcement effect of short carbon fibers on the mechanical behavior of Polytrimethyleneterephthalate (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 5wt. % of SCF in the matrix. Run et al [8] studied the mechanical properties of SCF reinforced PTT/ABS blend. When the Acrylonitrile- Butadiene-Styrene (ABS) content was 5wt. % 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. S.Y.Fu et al [9] 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 more brittle carbon fiber corresponded to the lower fiber efficiency factors than glass fiber.Yuan et al. [10] studied the effect of coupling agent on mechanical properties of glass fiber reinforced short carbon fiber filled high density polyethylene 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 polyamide composites is studied by Botelho et al [11]. 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 [12] reported the development and characterization of particulate filled glass fiber reinforced hybrid composites. They studied the effect of alumina filler on the 40wt.% SGF filled Polyester composites. The mechanical behavior of SGF filled composite decreases as the percentage of alumina in the composites increases. Palabiyak and Bahadur [13] studied the mechanical behavior of PA6/HDPE blends reinforced with short glass fibers. They showed that the addition of 5-15wt. % of SGF into 80wt. % PA66-20% wt. % HDPE improved the tensile strength of the blend from 20 – 60 % respectively. Yuqin and Junlong [14] reported the mechanical properties of carbon fiber reinforced POM composites. They reported that the addition of short carbon fibers improves the tensile strength of Polyoxymethylene (POM). Zhaobin Chen and co-workers [15-16] studied the effect of short glass/carbon fibers on the mechanical properties of PA66/PPS blend. They showed that the addition of 20-30wt. % SGF greatly improved the mechanical properties of PA66/PPS Blend. On the other hand, 30vol. % 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 Abdulkadir Gullu [17].

They showed that SGF filled PA6 and PP had exhibited better mechanical properties. Investigation on the mechanical properties of Polyphenylenesulphide / Carbon fiber (PPS/SCF) composites and polyamide 6 filled PPS/SCF composites were studied by Jian and Tao [18]. They showed that the better flexural strength was obtained for 25wt. % SCF in PPS. Also they proved that the addition of 6wt. % of SCF into PA66/SCF exhibited better flexural strength than PPS/ SCF composites. Shofan Cao et al [19] reported the effect of basalt fiber in Ultra-High Molecular Weight Polyethylene (UHMWPE). Increase in basalt content in the composite led to decrease in toughness and increase in strength, hardness and creep resistance. Zhou et al [20] 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. Han Wu et al [21] studied the mechanical properties of glass fiber and carbon fiber reinforced polyamide6 and polyamide6/clay nano composites. The results showed that the mechanical properties of polyamode6/ clay Nano composites are superior to those of SCF or SGF filled polyamide6 composites in terms of tensile, flexural and modulus without sacrificing the impact strength of the composites. The effect of nano scale clay on toughness is more significant than that of the fiber. Mouhmid et al [22] experimentally investigated the mechanical behavior of glass fiber reinforced polyamide 66. They studied by reinforcing 15, 30 and 50wt. % SGF in to 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 [23] studied the effect of short glass fiber 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 30wt. % of SGF in the blend. Obviously, elongation to break was decreased due to the brittle nature of PA66/PTFE/SGF composites. Polyamide 66 is a high performance thermoplastic polymer. Teflon is a high temperature thermoplastic used as filler for the tribological applications. To fulfill the actual meaning of polyblending, the blend of PA66/PTFE has designed for the structural applications. The blend of PA66/PTFE will be the best blend for the polymer matrix. From the above discussions, no data was reported on using Teflon (PTFE) as one of the blend associate for the structural applications. In spite of the fact that polymer composites are used in such structural applications, no data are reported on the influence of Teflon in polyamide as blend with hybrid fibers such as short glass fiber (SGF) and short carbon fibers (SCF) . Keeping this in view, in order to obtain the balanced mechanical properties, the hybrid effect of SCF and SGF on the tensile, flexural and impact behavior of PA66/PTFE blend is discussed. Also the hybrid effect on the specific properties which characterizes the mechanical behavior of the developed composites are also discussed

II. MATERIALS AND PROCESSING

Materials

The materials used in the present investigation PA66, PTFE, silane coated short glass fibers and short carbon fibers are listed in Table 1. The details of materials and their source are also tabulated in the same table.

Table 1: Data and properties of the materials used

Materials	Designation	Form	Size (μm)	Trade name	Manufacturer	Density (g/cc)
Polyamide	PA66	Granules	---	Zytel 101L NC010	DuPont co.Ltd.	1.14
Teflon	PTFE	Powder	12-14	MP1000	DuPont co.Ltd	3.2
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	1.74

Table 2: Formulations of composites in weight percentage

Formulations of composites in weight percentage					
Material ID	Composition	PA66	PTFE	SGF	SCF
Blend	Blend(PA66/PTFE)	80	20	---	----
Blend /SGF	Blend(PA66/PTFE)/SGF	80	20	10	---
Blend/ SCF	Blend(PA66/PTFE)/SCF	80	20	---	10
Blend/SCF/SGF	Blend(PA66/PTFE)/SCF/SGF	80	20	10	10

Fabrication of blends and their composites

The polymers PA66 and PTFE with proper proportions (Table 2) were dried at 800C for 48 hours 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. Polyamide66 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 and fabrication. The blend of PA66/PTFE is obtained by melt mixing method with the help of extrusion technique.The extrudates which are in the form of cylindrical wires are palletized using palletizing machine. The pallets of PA66/PTFE blend are once again subjected to heating in the oven for 24 hours to remove hydrolyzing effects. The saline coated short glass fibers and epoxy coated short carbon fibers are mixed in proper proportion into the composite mixture of pallets of polymer blend. The materials are mixed and the mixture was extruded using Barbender co-rotating twin-screw extruder (Make: CMEI, Model: 16CME, SPL, chamber size 70cm3) (Figure 1). The extruder consists of five heating zones where the temperature maintained in these zones of the extruder barrel were zone1 (220ºC), zone2 (235ºC), zone3 (240ºC), zone4 (265ºC) and zone5 (270ºC) respectively and the temperature at the die was set at 2200C. The extruder screw speed was set at 100 rpm to yield a feed rate of 5 kg/h. The extrudates obtained was in the form of cylindrical rod which was quenched in cold water and then palletized by using Palletizing machine. During initial stage, around 1 to 1.5 kg of initial extrudate was removed to get the pure blend and to remove impurities of extrudate of previous stroke of the extrusion. Before injection moulding, all polymer blended composite pallets were dried at 1000C in vacuum oven for 24 hours. All test specimens were injection molded from the pelletized polyblend material obtained from co-rotating twin screw extruder. The temperature maintained in the two zones of the barrel were zone1 (265ºC) and zone2 (290ºC) and mold temperature was maintained at 650C (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.

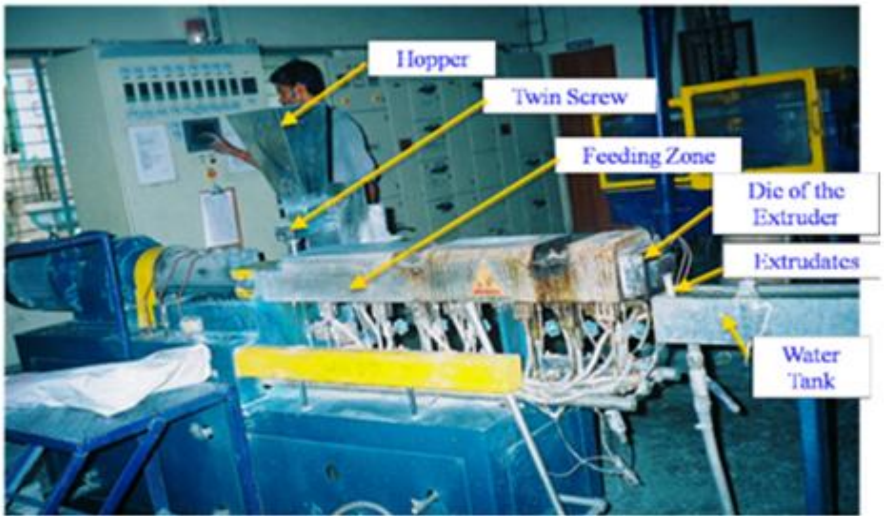


Figure 1: Barbender Co- rotating twin screw extruder (GLS Polymers, Bangalore, India)

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

Measurement of Mechanical Properties

The mechanical properties such as tensile strength, flexural strength, impact strength along with density and hardness of the blends 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 D 638. Tests were performed at constant strain rate of 5mm/min. ASTM D 638 Type 1 standard dimensions are used (Fig.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 2mm/min as per ASTM D790. The standard specimen dimensions for the flexural strength is 125mm x 12.7mm x 3.2 mm (Fig.3b). The notched Izod impact strength was determined using ASTM D256 by using Izod impact testing machine at a striking rate of 3.2mm/s. The ASTM standards for these mechanical testing is shown in the 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 blended composites were determined as per ASTM D792 and ASTM D2240 respectively.

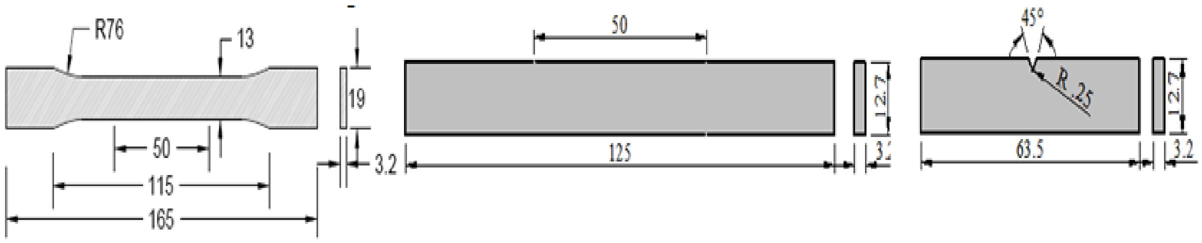


Figure 3: Specimen standards :(a) ASTM D 638(Tensile Test) (b) ASTM D790 (Flexure Test) and (c) ASTM D256 (Impact Test)

III. RESULTS AND DISCUSSIONS

Effect of SGF, SCF and their hybrid effect on the density and tensile behavior

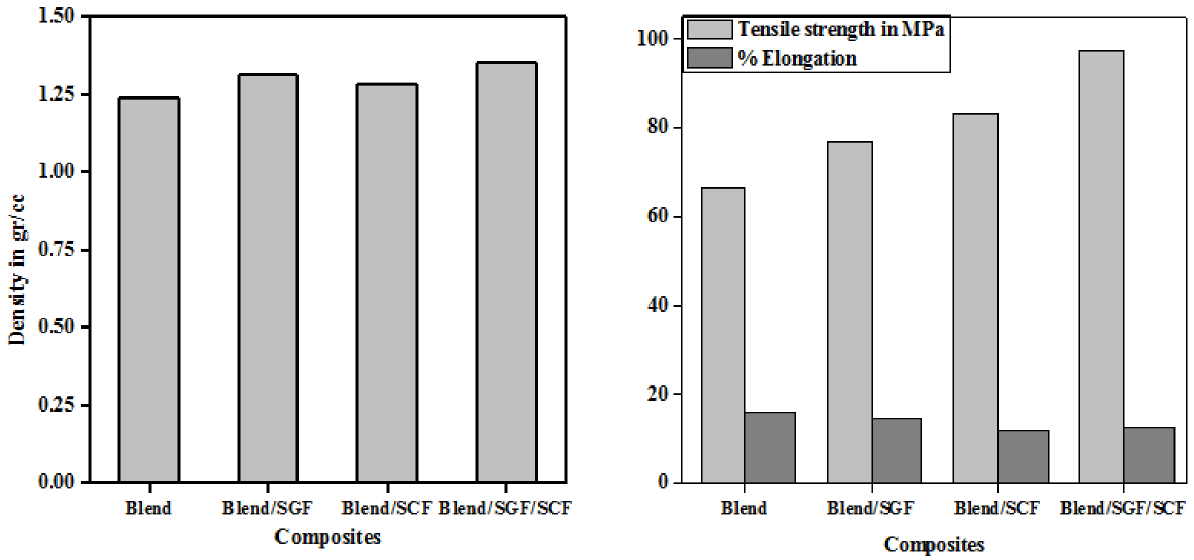
Table 3: Tensile properties of Hybrid fiber filled PA66/PTFE blend

Properties	Units	ASTM Method	Blend	Blend /SGF	Blend/SCF	Blend/SCF/SGF
Tensile strength	MPa	ASTM D638	66.5	76.81	83	97.22
% Elongation	%	ASTM D638	16	14.45	12	12.5
Peak Load	N	ASTM D638	2679	3144	3407	3950
Stiffness	N-mm	ASTM D638	163.55	189.17	241.46	263.33
Specific stiffness	N-mm^{2}/Kg	ASTM D638	1.32E+08	1.44E+08	1.89E+08	1.95E+08
Specific Strength	N-mm/Kg	ASTM D638	5.36E+07	5.86E+07	6.48E+07	7.20E+07

The effect of fibers on the density of PA66/PTFE blend is shown in the fig.4a. The addition of 10wt. % SGF into the blend increased the density of PA66/PTFE blend. This is purely attributed to the dense nature of silane coated glass fibers. Further, addition of 10% SCF into the blend increased the density of the blend less than that of SGF. This demotion is due to the lesser density of SCF than SGF. But inclusion of both the fibers into the blend greatly enhanced the density of blend. Almost 9% 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 [23].

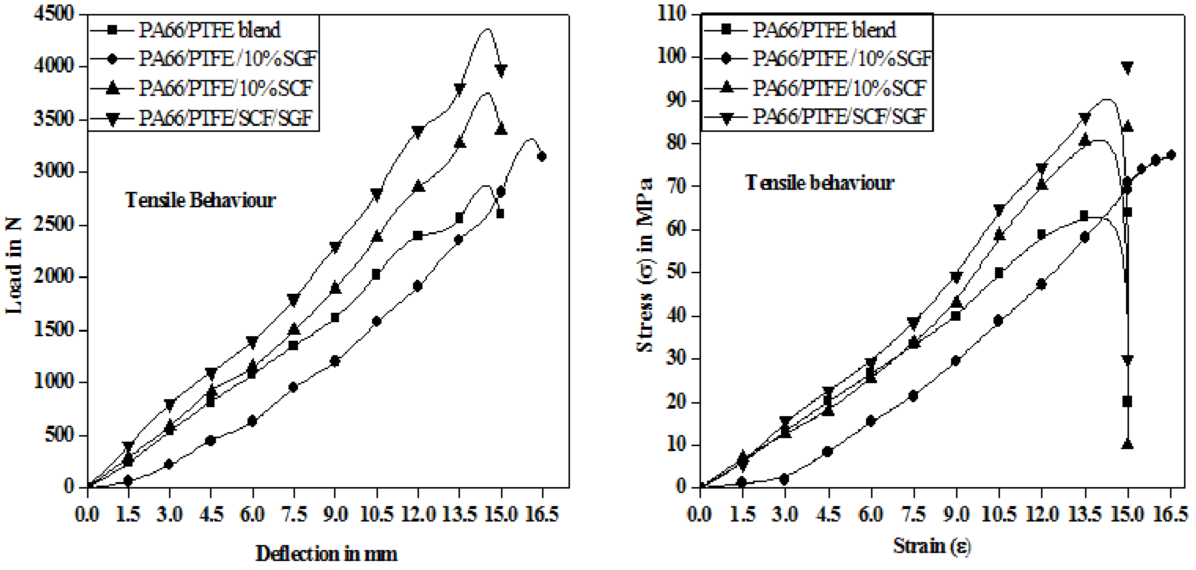
The effect of fibers and their hybrid effect on the tensile strength and percentage elongation are shown in the fig.4b. The improvement in the tensile strength was seemed to be a function of the fiber reinforcement. The tensile strength of PA66/PTFE blend is 66.5 N/mm2 (Table 3). But the effect of 10wt. % SGF improved the strength of the blend to 76.81N/mm2which is 15.5% increase [5, 6]. This promotion 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 surface of 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 almost 25% than that of neat blend [7, 8]. But 8% improvement over the SGF. Short carbon fibers are good in specific modulus and specific strength. This made the composites to possess high strength than that of SGF. The interfacial bond developed between the blend and SCF is superior. SCF 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 97.22 N/mm2 which is almost 46% increase over the neat blend. This shows that the effective interfacial bond and the network between thermoplastic 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 fillers and the fibers has contributed a lot to the development of strength of the composites. Furthermore, SCF as a nucleating agent can increase the crystallization rate and decreases the crystal size of the blend [24]. Therefore, due to this effect, a substantial improvement in tensile strength due to hybrid effect of fibers was exhibited by PA66/PTFE blend. Among the studied composites, hybrid effect of fibers is most appreciable.

The hybrid effect of fibers on the percentage elongation of fiber filled PA66/PTFE composites is shown in the fig.4b. The decrease in percentage elongation after the fiber reinforcement into the blend PA66/PTFE was noticed. The maximum reduction in elongation was obtained for SCF filled PA66/PTFE 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 drastic reduction in the elongation was obtained for hybrid fiber filled PA66/PTFE composites. The blend PA66/PTFE has the good strain rate due to the more percentage of PTFE. The glass fibers reduced the strain rate of blend by increasing the hardness of SGF filled composites. Therefore, the impact strength of the same composites was reduced due to the effect of dense glass fibers. Further, reinforcing SCF into the blend PA66/PTFE reduced the hardness of the blend than the SGF filled composites. But the synergistic effect between the blend and the fibers made the material to become brittle due to the graphite nature of SCF. But the hybrid effect of the fibers made the material brittle and hence significant reduction in elongation was exhibited by the hybrid filled PA66/PTFE composites [13].



(a) (b)

Figure 4: Hybrid and Individual effect of fibers on the properties of PA66/PTFE blend: a) Density and b) Tensile strength and % Elongation



(a) (b)

Figure 5: Hybrid and individual effect of fibers on the properties of PA66/PTFE blend: a) Load v/s deflection, b) Stress – strain curve

The load versus deflection curve and the stress strain behavior for the hybrid fiber filled PA66/PTFE blend are shown in the fig.5 (a and b). Both load- deflection and stress strain curve followed the linear trend up to the ultimate point. From the table 3, the peak load for the blend is 2679N. But the reinforcement effect of fibers shifted the peak load to a higher point which is 17, 27 and 47% higher than that of neat blend for SGF, SCF and hybrid fiber filled PA66/PTFE composites respectively. The stress strain behavior of hybrid fiber filled PA66/PTFE composites is shown in the figure 5b. The hybrid effect of fibers on the stress strain behavior maintained the linear trend up to the peak point. SGF filled PA66/PTFE blend initially experienced less stress up to the strain rate of 13. But sudden increase in stress was noticed during the final elongation of the composites [14]. 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 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 [23]. Among the studied composites, hybrid effect of fibers improved the stiffness of the hybrid composites. Similar observations were 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 in order to improve the strength of the hybrid composites PA66/PTFE/SCF/SGF.

Effect of SGF, SCF and their hybrid effect on the flexural behavior of PA66/PTFE blend

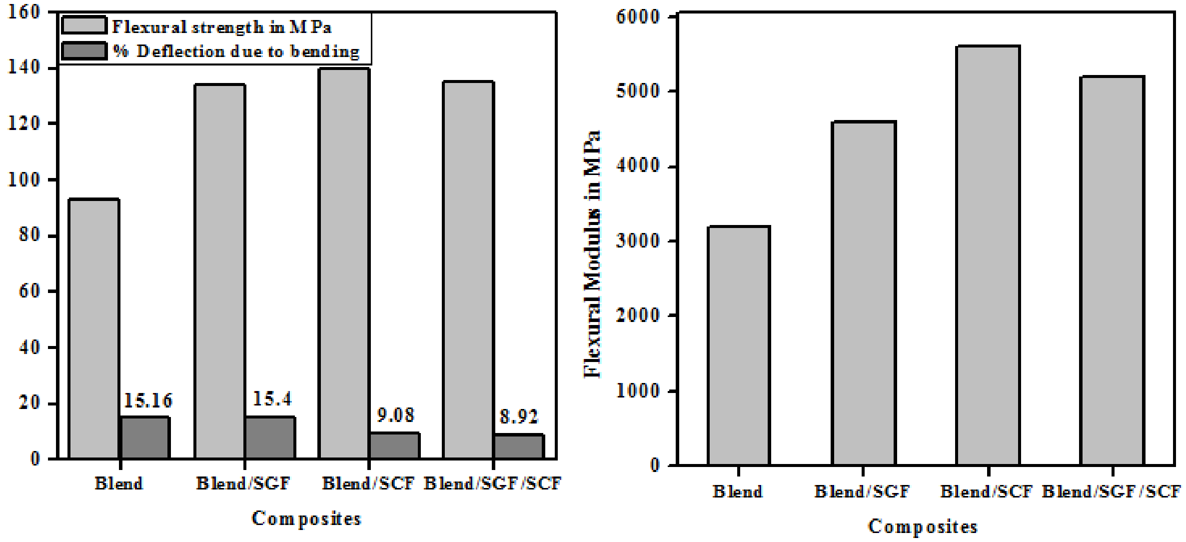
The hybrid and individual effect of SGF and SCF on the flexural strength and % deflection due to flexure of PA66/PTFE blend is shown in the fig 6a. The flexural strength of PA66/PTFE blend is 93 MPa (Table 4). Effect of 10wt. % of SGF reinforcement into PA66/PTFE blend has improved the flexural strength by 44.27% [18, 20]. The improved flexural strength of the blend is attributed to the good balancing flexural behavior of the short glass fibers. The bending strength of the SGF filled Blend is due to the degree of compatibility of the fibers with the thermoplastic matrix material. In addition, PTFE filled PA66 had the better flexural strength. 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 flexural test, outer fibers are in tension and inner fibers are in compression. The outer fibers may pull out from the matrix material resulting no loss of strength. But the fibers transformed the load to the matrix which is surmounting them there by effectively receiving the load. Fiber rupture and fiber pull out are the major failures noticed during the performance.

The effect of 10wt. % SCF on the flexural behavior of the blend has improved the strength by 50%. This shows that the interfacial bond between SCF and thermoplastic blend matrix is most superior [18] . By the same time, SCF has good flexural and specific properties which can characterize the mechanical behavior of the composites. Due to lesser density of SCF, the surface area of SCF with the matrix is more when compared the same with SGF. In addition, SCF develops less interfacial friction with the thermoplastic blend which could develop the effective bond between the fillers of the composites. But the hybrid effect of SGF and SCF deteriorated the bending strength of the composites. This is due to the brittle nature of the composites which was characterized by the loss of impact strength of hybrid fiber filled blend PA66/PTFE. Among the studied composites, SCF filled PA66/PTFE blend had the better flexural strength. But the balanced flexural strength was noticed among the three types of the composites studied. Thus the effect of fiber properties is of great importance for the structural applications.

The effect of fiber reinforcement on the percentage deflection due to bending of PA66/PTFE blend is shown in the fig 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 40% against the blend. Blend had the good percentage of deflection due to the ductile effect of PTFE. But the addition of fibers into the blend made the material brittle and reduced the deflection of the blend [1]. SCF had the great effect to reduce the deflection of the blend. This is due to the good compatibility between fibers and matrix .The adhesive bond developed between the fillers of the blend are 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 in order to contribute equally with that of matrix blend [6].

Table 4: Flexural properties of Hybrid fiber filled PA66/PTFE composites

Properties	Units	ASTM Method	Blend	Blend /SGF	Blend/SCF	Blend/SCF/SGF
Flexural strength	MPa	ASTM D790	93	134.18	139.5	135
% deflection	%	ASTM D790	15.16	15.4	9.08	8.92
Flexural Modulus	MPa	ASTM D790	3198	4590.97	5600	5200
Peak Load	N	ASTM D790	178	240.72	243.08	341.86

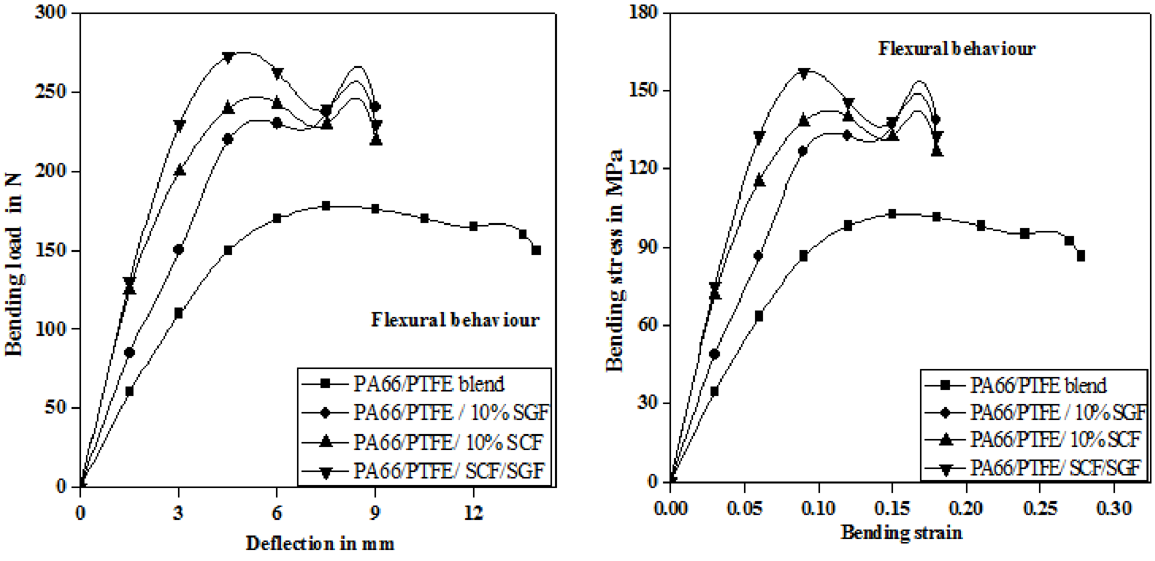


(a) (b)

Figure 6: Hybrid and Individual effect of fibers on the properties of PA66/PTFE blend: a) Flexural strength and % deflection and b) Flexural Modulus

The effect of fibers on the flexural modulus of the studied polymer blend is shown in the fig 6b. The significant improvement over the flexural modulus was noticed by reinforcing the fibers into the blend. Almost double the tensile modulus was noticed by reinforcing SCF into the blend. This is purely due to the good modulus and strength of SCF.A slight decrease in tensile modulus was observed by the effect of SGF on the SCF filled PA66/PTFE 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 the figure7 (a and b). The bending load carrying capacity of polyblend is less when compared to the studied composites. This is due to the absence of fibers. But the inclusion of fibers made the polymer blend stiffened and strengthened to carry a maximum load (Fig.7a). Among the studied composites, hybrid composites have the significant load carrying capacity. The bending stress - strain behavior of the composites is shown in the fig.7b. All the composite materials studied have followed the elastic behavior up to the breaking point. PA66/PTFE blend has the highest strain rate. The hybrid effect of the fibers has reduced the strain rate in bending by 41% than that of pure blend. The range of strain rate for the break load of all the composites under flexural situation studied is in the range of 0.1 to 0.15.



(a) (b)

Figure7: Hybrid and Individual effect of fibers on PA66/PTFE blend: a) Flexural Load v/s deflection curve and b) bending stress and strain curve

Hybrid effect of fibers on the impact strength and hardness of PA66/PTFE blend

Table 5:Impact strength and hardness of hybrid fiber filled PA66/PTFE blend

Properties	**Units**	**ASTM Method**	**Blend**	**Blend /SGF**	**Blend/SCF**	**Blend/SCF/SGF**
Impact strength	KJ/mm^2	ASTM D256	55	45	32	41
Hardness (Shore D)	N/mm^2	ASTM D2240	69	72	70	63

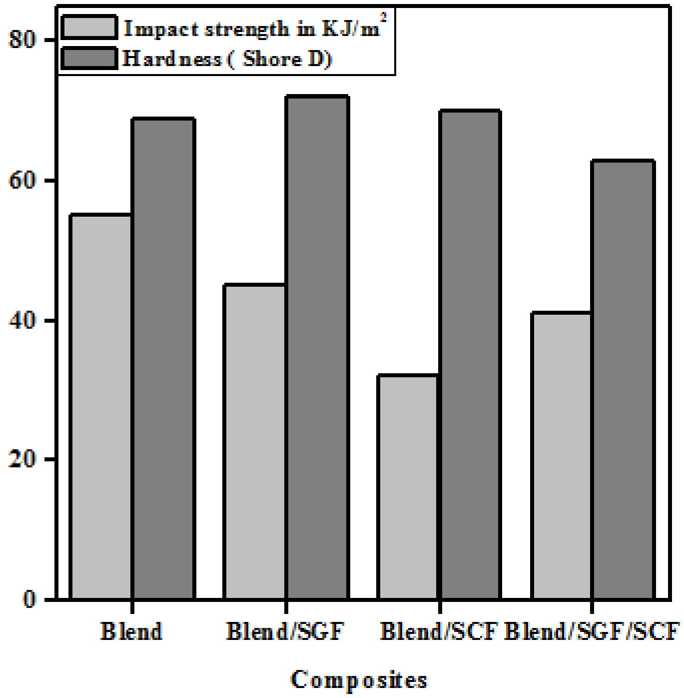


Figure8: Hybrid and Individual effect of fibers on the impact strength and hardness of PA66/PTFE blend

The individual and combined effect of short fibers on the impact strength and hardness of the blend is shown in the fig. 8. The impact strength of pure poly blend is 55 kJ/mm2 (Table 5). Inclusion of 10wt. % SGF into the blend reduced the impact strength by 20%. Furthermore, the effect of 10% SCF on the same has impaired the impact strength by 41.8% more than twice the effect of SGF on the blend [7, 8]. But the hybrid effect of the fibers had slightly improved the impact strength above SCF filled one but below the Impact strength value of SGF filled poly blend. Glass fiber effect 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. The decreased impact strength of SCF filled polyblend is due to the counter balance of increased surface fracture energy, increased sizes of the voids or SCF aggregates in the polyblend [24].Influence of hybrid fibers increases the size of the voids and also the number of aggregates of the short fibers. This will leads 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 PTFE. The polymer PTFE 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 fig.8. The hardness of the polyblend is increased due to the effect of SGF. This can explained due to the hard nature of SGF. Further, slight reduction 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/PTFE still reduces. This can be attributed to the brittle nature of fiber filled polymer blend. But the value of hardness of the hybrid blend was retained above the value of the pure blend PA66/PTFE. Among the studied composites, SGF filled PA66/PTFE blend composites possess better hardness.

IV. FAILURE ANALYSIS USING SEM

The SEM photographs of fractured surfaces subjected to tensile, flexure and impact test of fiber filled PA66/PTFE blend composites are shown in the figure 9, 10 and 11 respectively. The SEM micrographs of fractured surfaces of 10% SGF filled PA66/PTFE blend is shown in the figure 9 (a, b and 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 the fig.9a. The sizing of the fibers by the matrix blend is uniform and compatible. Less number of voids is seen in the figure. The flexure fractured surface of the same composites is shown in the fig.9b. The effective fiber - matrix interface is seen in the graph. But 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. The fiber pull out is evidenced during the impact behavior of composites. This is shown in the figure 9c. Severe matrix deformation is also seen in the figure. The same observations are drawn from SEM photographs of the fractured surfaces of SCF filled composites (Fig. 10a, b and c). But the fiber pull out is more during the tension test. The fibers are misaligned during the flexure test (Fig.10b). But the interfacial bonding between the matrix and the fiber seemed to be very good. But 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 the blend during the melt blending process. The impact behavior shows the uniform bonding between the fibers. This is very clearly evidenced in the picture 10c. But the phase morphology shows that the crystallinty of the blend is more. This will introduce more number of voids and hence less impact strength.

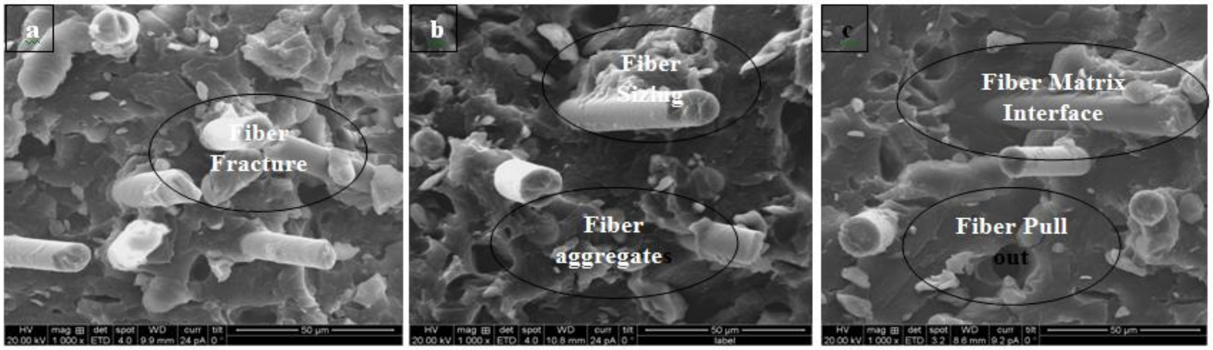


Figure 9: SEM photographs of fractured surface of 10wt. % SGF filled 80/20 wt. % PA66/PTFE blend: a) Tensile fracture, b) Flexural fracture and c) Impact fracture

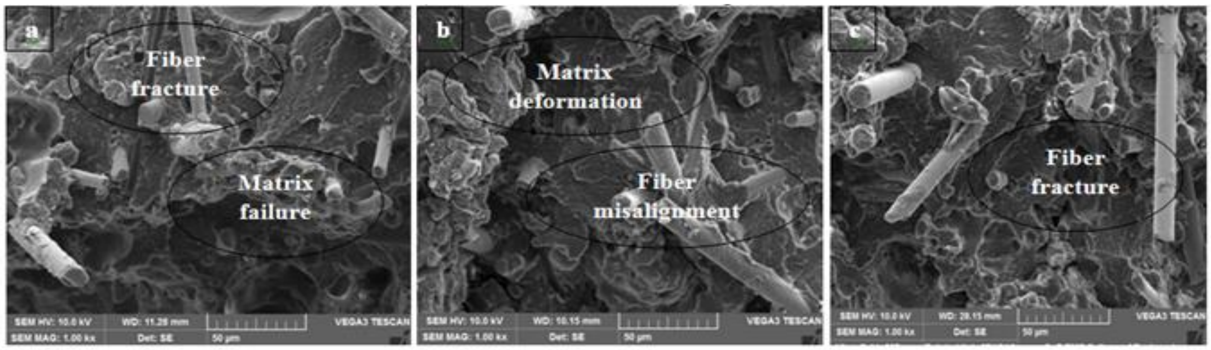


Figure10: SEM photographs of fractured surface of 10wt. % SCF filled 80/20 wt. % PA66/PTFE: a) Tensile fracture, b) Flexural fracture and c) Impact fracture

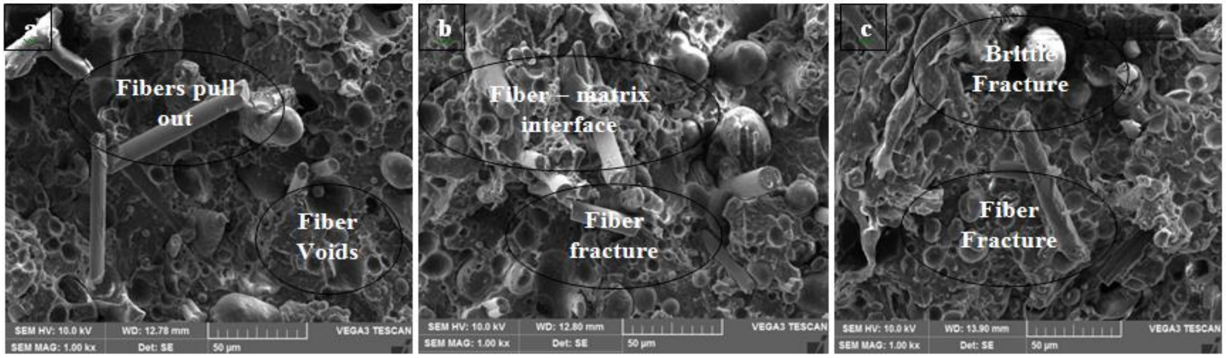


Figure11: SEM photographs of fractured surface of 10wt. % SGF and 10wt. % SCF filled 80/20 wt. % PA66/PTFE blend :a) Tensile fracture, b) Flexural fracture and c) Impact fracture

The SEM photographs of fractured surfaces of hybrid composites are shown in the figure 11(a, b and c). The tensile fracture is characterized by the brittle fracture with the availability of the voids (Fig.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 (Fig.10b). But the aggregates of SCF and SGF 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 (Fig.10c). Also the inner crack initiation by the fibers is seen in the figure. On the conclusion, the hybrid composites are characterized by the brittle fracture which is evidenced by the SEM photographs of hybrid composites.

V. CONCLUSION

The fiber filled thermoplastic composites are the class of composites for structural applications. But the effect of blend composition with hybrid fibers is most promising for the better mechanical performance. The following are the facts emerged from the experimental investigation of hybrid composites:

1. The hybrid composites with 10wt.% SGF and 10wt.% SCF in 80/20 wt.% PA66/PTFE 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 97.22 N/mm2 which is almost 46% increase over the neat blend PA66/PTFE
3. The maximum reduction in elongation was obtained for SCF filled PA66/PTFE composites.
4. The reinforcement effect of fibers shifted the peak load to a higher point which is 17, 27 and 47% higher than that of neat blend for SGF, SCF and hybrid fiber filled PA66/PTFE 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 45% over the blend by the hybrid effect of fibers
7. The effect of 10wt. % SCF on the flexural behavior of the blend has improved the strength by 50%.
8. The significant improvement over the flexural modulus was noticed by reinforcing the fibers into the blend. Almost double the tensile modulus was noticed by reinforcing SCF into the blend.
9. The hybrid effect of the fibers has reduced the strain rate by 41% than that of pure blend during bending.
10. Inclusion of 10wt. % SGF into the blend reduced the impact strength by 20%. The effect of 10% SCF on the same has impaired the impact strength by 41.8% more than twice the effect of SGF on the blend
11. The hardness of the polyblend is increased due to the effect of SGF. Slight reduction in hardness was noticed due to the SCF effect on the blend. The hardness of the blend reduces due to the hybrid effect of fibers . This can be attributed to the brittle nature of fiber filled polymer blend.
12. Fiber fracture , fiber pullout and fiber misalignment are some of the mechanisms observed during fractographic analysis through SEM

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