Mechanical Characterization of Hybrid Thermoplastic Composites of Short Carbon Fiber

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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. 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 composites. Increase in tensile strength by 77%, 100% 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: Short Carbon fibers Hybrid materials, Mechanical, Blends*.**

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 body of modern cars, bikes, penal of solar boards, automobile accessories, polymer gears, 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 in the form of fibers enhances the mechanical properties of polymer composites.

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. 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. To study 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].

II. MATERIALS AND PROCESSING

A. Materials

The details of materials and their specifications are also tabulated in the same Table 1.

Table 1: Data and details of the materials used.

Materials	**Designation**	**Form**	**Size (μm)**	**Manufacturer**	**Density (g/cc)**
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

B. 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. 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 removed to get the pure composites and to remove impurities from the previous stroke of the extrusion.

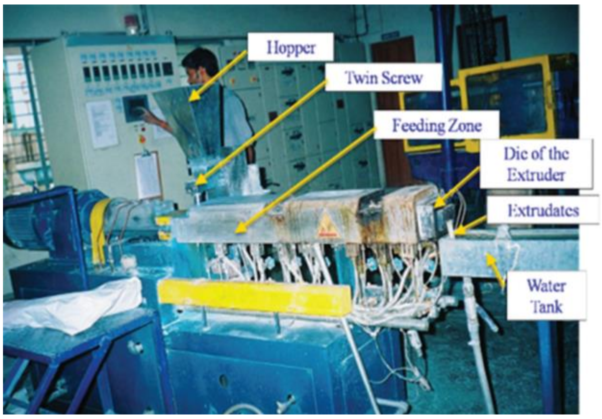

Fig 1: Barbender Co- rotating twin screw extruder.

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

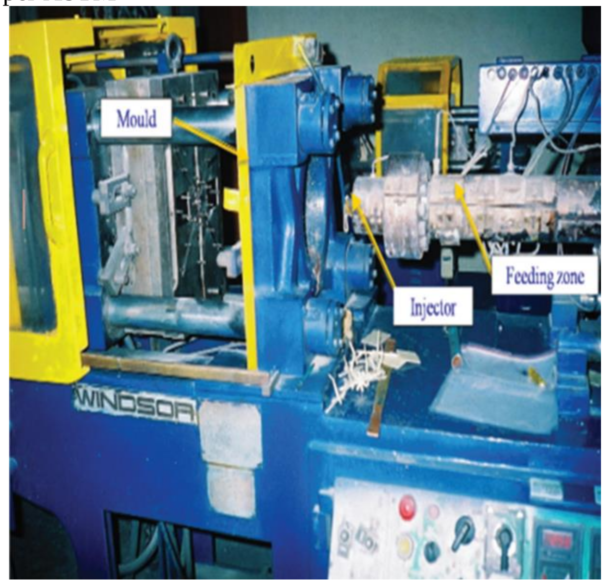

Fig 2: Injection moulding machine (GLS Polymers, Bangalore, India).

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

PP: Polypropylene, SGF: Short glass fiber, SCF: Short carbon fibers

III. 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.

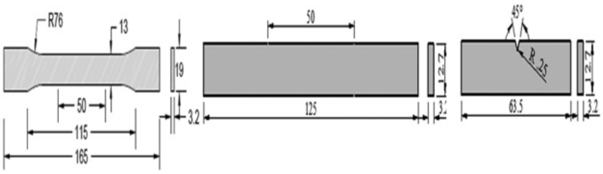

Fig 3: Specimen standards :(a) ASTM D 638 (b) ASTM D790 and (c) ASTM D256

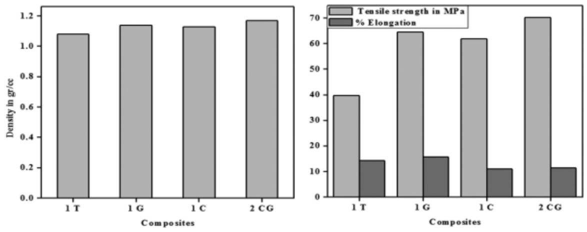

Figure 4: Individual and hybrid effect of fibers on the properties of polyamide 66/polypropylene blend: (a) Density and (b) Tensile strength and % Elongation.

IV. RESULTS AND DISCUSSIONS

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

The effect of fibers on the density of 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.

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 PP blend. Among the studied composites, hybrid composite is most appreciable.

The hybrid effect of fibers on the percentage elongation of PP composites is shown in Figure 4b. The decrease in percentage elongation after the hybrid fiber reinforcement into the blend PP was noticed. The maximum reduction in elongation was noticed for SCF filled 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 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.

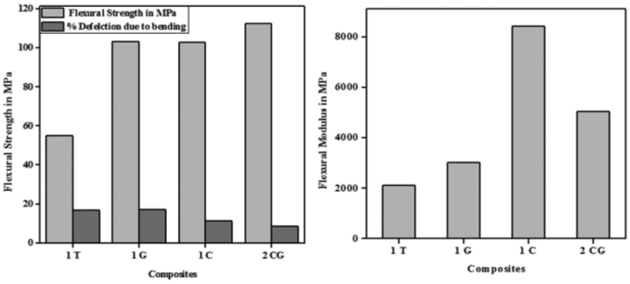

Figure 5: Individual and hybrid effect of fibers on the properties of polyamide 66/polypropylene blend: (a) Flexural strength and % deflection and (b) Flexural modulus

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.

B. 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 5a. 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.

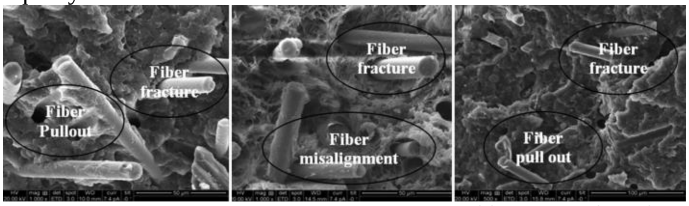

Figure 6: Scanning electron microscopy photographs of fractured surface of 10 wt. % short glass fiber filled polyamide 66/polypropylene blend: (a) Tensile fracture, (b) flexural fracture, and (c) impact fracture.

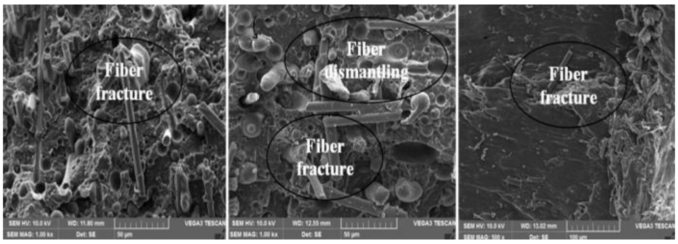

Figure 7: Scanning electron microscopy photographs of fractured surface of 10 wt. % short carbon fibers filled polyamide 66/polypropylene blend: (a) Tensile fracture, (b) flexural fracture, and (c) impact fracture.

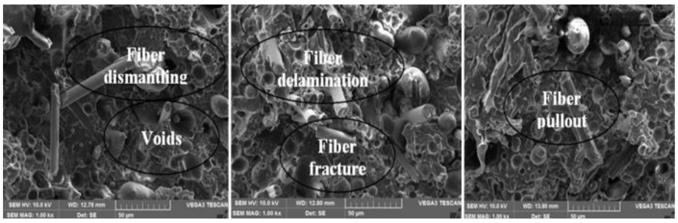

Figure 8: Scanning electron microscopy photographs of fractured surface of 10 wt. % short glass fibers and 10 wt. % short carbon fibers filled polyamide 66/polypropylene blend: (a) Tensile fracture, (b) flexural fracture, and (c) impact fracture.

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 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 PP blend composites possess the better hardness.

V. 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 PP composites are shown in Figures 6-8, respectively. The SEM micrographs of fractured surfaces of 10% SGF filled PP blend is shown in Figure 6a-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 6a. The sizing of the fibers by the matrix blend is uniform and compatible. Less number of voids was seen in Figure 6. The flexure fractured surface of the same composites is shown in Figure 6b. 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 8c, and severe matrix deformation is also seen in Figure 8. The same observation was made with the SCF filled composites (Figure 7a-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 7a). The fibers are misaligned during the flexure test (Figure 7b). 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 7c. 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 8a-c. The tensile fracture is characterized by the brittle fracture with the availability of the voids (Figure 8a). 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 8b). 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 8c). Furthermore, the inner crack initiation by the fibers is seen in Figure 8. On the conclusion, the hybrid composites are characterized by the brittle fracture which is evidenced by the SEM photographs.

VI. 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. % PP blend are the promising composites for the structural applications.
2. The maximum reduction in elongation was obtained for SCF filled PA66/PP composites.
3. 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.
4. The specific strength of the hybrid composite is high. This is due to the high strength of the hybrid fibers.
5. The flexural strength is improved by 104% over the blend by the hybrid effect of fibers.
6. 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.
7. The hybrid effect of the fibers has reduced the strain rate by 20% than that of pure blend during bending.
8. 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%.
9. Fiber fracture, fiber pullout, and fiber misalignment are some of the mechanisms observed during fractographic analysis through SEM.

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