Significance of the type of reinforcement on the physicomechanical behavior of short glass fiber and short carbon fiber-reinforced polypropylene composites

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In the present work, short glass fiber (SGF) and short carbon fiber (SCF)-reinforced polypropylene (PP) composites are fabricated using twin-screw extrusion and injection molding techniques. The SGF and SCF are reinforced as a single and hybrid reinforcement into the PP matrix with the same weight percentage (wt%) and the obtained composites are characterized for physicomechanical properties. It is observed that the tensile and flexural strength and modulus of elasticity of PP are improved by increasing the weight percent of reinforcement in the composite. The highest value is observed for composite with 30 wt% of SCF reinforcement; hybrid composite with 10 and 20 wt% of the mixture of SGF and SCF proves to outperform the other composites with the same weight percent of SGF and SCF added individually. The notched Izod impact strength of SGF + PP composite at 30 wt% is found to be the highest amongst all. Furthermore, the increased presence of SCF improved the tensile and flexural properties; however, it was not able to improve the impact strength significantly.

KEYWORDS
hybrid composites, mechanical properties, polypropylene, short carbon fiber, short glass fiber

1 | INTRODUCTION

Polypropylene (PP) is a semicrystalline engineering thermoplastic, widely used in automotive parts, home appliances, extruded profiles, packaging industry, construction, etc., due to its low cost, low density, easy processibility, and well-balanced mechanical, physical, and chemical properties. However, its use is limited in many engineering applications where good mechanical and thermal properties are required, due to its low Young’s Modulus, strength, and thermal conductivity. In order to provide a cost-effective solution, research in the last decade has mainly focused on reinforcing the PP with short fibers to improve its mechanical and thermal properties. The hybridization of fibers in the polymer matrix can increase the mechanical properties of single fiber-reinforced composites and reduce its limitations in many engineering applications. A number of researchers have investigated the effect of glass and carbon fiber (CF) reinforcement on the PP matrix. Unterweger et al. studied the characterization of CF surfaces and their impact on the mechanical
properties of short CF-reinforced PP composites. He reported that the fiber surface properties and coupling agents used in the composite have a major effect on the fiber/matrix interaction, which improves the mechanical properties. Gamze Karsli et al.7 investigated the effect of hybrid carbon nanotube/short glass fiber (SGF) reinforcement on the properties of PP composites. He found that the glass fiber and carbon nanotube-reinforced hybrid composites showed better tensile strength and modulus values compared with only glass and carbon nanotube-reinforced composites. Rezaei et al.10 reported the effect of fiber length on thermomechanical properties of short CF (SCF)-reinforced PP composites; the longer CFs showed better thermomechanical properties than the shorter CFs in CF/PP composites. Fu et al.11 studied the tensile properties of SGF- and SCF-reinforced PP composites. He reported that the mean glass and CF lengths decrease with increasing fiber volume fraction and the combined effect of fiber volume fraction and fiber length determines the final tensile properties of the composites. Aslan et al.15 studied the tribological and mechanical performance of sisal-filled waste carbon and glass fiber composites. Sisal/glass hybrid composites showed similar mechanical properties and better frictional properties than the composites reinforced with glass fiber alone. However, sisal/carbon hybrid composites showed a lower performance during mechanical loading and a higher coefficient of friction than those of the composite reinforced with CF alone. Arao et al.16 investigated the mechanical properties of injection-molded CF PP composites hybridized with nanofillers. The addition of a small amount of nanofillers improved the strength and elastic modulus of the composites; also addition of alumina, silica, and carbon nanotube (CNT) showed a positive effect on the strength of the composites. Evaluation of the effect of hybridizing on the thermomechanical and mechanical properties of calcite/SGF/PP hybrid composites was studied by Senturk et al.17; results revealed that the presence of calcite and SGF in the composite enhanced the bending and tensile properties, but reduced the tensile elongation and impact strength. Aruna Subasinghe et al.18 studied the effect of wool fiber and other additives on the flammability and mechanical performance of PP/kenaf composites; the study revealed that the forced combustion of composite substantially decreased and tensile modulus increased. Strappson et al.19 investigated tensile and impact behavior of PP/low-density polyethylene blends; it was revealed that blending PP with low-density polyethylene significantly reduced the mechanical properties. The tribo-mechanical properties of glass fiber-reinforced PP composites were investigated by Hufenbach et al.20; they showed that the tribo-mechanical properties of PP could be improved with suitable glass fiber reinforcement. Okereke et al.21 carried out a study on the flexural response of PP/E-glass fiber-reinforced unidirectional composites. They concluded that the plastic deformation of the matrix contributes significantly to the flexural response. Kun Zhang et al.22 studied the effect of animated polyphenylene sulfide on the mechanical properties of short CF-reinforced polyphenylene sulfide composites. The results of the study showed that animate polyphenylene sulfide used as compatibilizer could improve the micromechanical properties and bonding between polyphenylene sulfide and CF. Effect of kenaf fiber as a reinforcement on the tensile, flexural strength, and impact toughness properties of recycled PP/halloysite composites was investigated by Suharty et al.23 They found that the kenaf reinforcement in PP increased the tensile strength, flexural strength, and impact toughness. Gabr et al.24 investigated the mechanical and thermal properties of CF/PP composites filled with nanoclay. The addition of nanoclay with plain oven CF in the PP matrix resulted in improving fracture toughness and glass transition temperature by about 67% and 6 °C, respectively. Goulart et al.25 investigated the mechanical behavior of PP reinforced with palm fiber composites; the study revealed that the addition of fibers improved the flexural strength and modulus of PP. Rezaei et al.26 carried out research on the development of SCF-reinforced PP composite for car bonnet. The results have shown that hardness, impact strength, stiffness, and thermal stability of SCF/PP composites increased with increased SCF content.

From the literature, it is found that researchers have tried to improve the mechanical properties of PP by reinforcing with SGF and SCF and also by adding natural and nanofibers, natural, particulate, and nanofillers as hybrid reinforcement and filler materials. The effect of fiber weight percent, fiber-matrix interfacial strength, and fiber length on the mechanical properties are studied. However, comparative investigation of the mechanical behavior of SGF/PP, SCF/PP, and SGF/SCF/PP hybrid composites and the significance of SGF and SCF reinforcement on the performance of PP is limited.

SGFs and SCFs are one of the most widely used reinforcements for PP.15 When compared with glass fibers, CFs exhibit high strength and modulus, low density, excellent thermal and electrical conductivity, but costs much higher. Glass fibers are comparatively ductile and cheaper (over 20 times low priced than SCFs).16,21 SGF and SCF hybrid combinations produce lightweight, high strength, and low cost PP composites maybe with balanced mechanical, thermal, and tribological properties. Thus, it calls for comparing the mechanical behavior of these individual and hybrid composite systems and investigate the significance of SGF and SCF as single and hybrid reinforcement on the mechanical behavior of PP composite.

In the above context, the present work is taken up. In this investigation, SGFs and SCFs were reinforced with PP as single and hybrid reinforcement (10, 20, and 30 wt%) using extrusion compounding and injection molding technique.
The significance of the reinforcement on tensile, flexural, and impact performance of these composites is comparatively investigated. The results revealed that tensile and flexural strength and modulus of PP improved with increased weight percent of reinforcement in the composite. The highest value was observed for composite with 30 wt% of SCF reinforcement; hybrid composite with 10 and 20 wt% of the mixture of SGF and SCF proved to be better than the composite with the same weight percent of SGF and SCF added individually. The notched Izod impact strength of SGF + PP composite at 30 wt% was found to be the largest amongst all. The increased presence of SCF improved the tensile and flexural properties, but could not make a significant contribution in improving the impact strength.

2 | METHODS AND MATERIALS

The polypropylene homopolymer (grade: Repole H110MA, Melt flow index: 11 g/10 min and density: 0.9 g/cm$^3$) was provided by Reliance Industries, India. SGF (grade: EC-6 P546) was procured from Owen Corning India and SCF (grade: SYC-TR-PU6) was purchased from Sung Yung Industry, South Korea. The properties of fiber material used are listed in Table 1.

The short fibers and PP were first mixed in a twin-screw extrusion machine (Model: Bearsoft-Ze40) with an extrusion temperature and speed of 230 °C and 280 rpm, respectively. Then, the compounds were injection molded to the desired shape at 190 °C with 60% of the nozzle pressure using an injection molding machine (Model: Ferromatik-Delta80). Table 2 represents the details of the composite samples prepared; these samples were tested at room temperature to characterize their mechanical properties. Tensile and flexural tests were conducted in accordance with ASTM D638 and ASTM D790, respectively, using a Universal testing machine (Model: UTES-10 by Kalpak Instrument and Control, Pune). The tests were performed at 5 mm/min of crosshead speed. Izod impact test was conducted using the Izod impact testing machine (Model: CEAST Resil Impactor) on notched specimens at the impact speed of 3.46 m/s as per ASTM D256 standard. The shore-D hardness test was conducted in accordance with the ASTM D2240. For each type of composite and for all the tests, five samples were tested and an average is taken; these results are tabulated in Table 3. The scanning electron microscopic (SEM) images of fractured composite specimens are taken using Carl Zeiss, Germany, Model: EVO LS 15. Figure 1 shows the composite samples prepared for carrying out the tensile, flexural, and impact tests. The density of PP and its composites are measured using the analytical balance and density measurement apparatus (Make: Essae, Precision: 0.0001 g) according to ASTM D792; the measured values have been listed in Table 4.

| Material | Diameter (μm) | Length (mm) | Density (g/cm$^3$) | Tensile strength (MPa) | Tensile modulus (GPa) |
|----------|---------------|-------------|---------------------|------------------------|-----------------------|
| Glass fiber | 13.5 | 6 | 2.62 | 3800 | 81 |
| Carbon fiber | 6.97 | 6 | 0.56 | 4810 | 225 |

| Material/composite code | PP (wt%) | SGF (wt%) | SCF (wt%) |
|-------------------------|---------|-----------|-----------|
| PP                      | 100     | 0         | 0         |
| 10G                     | 90      | 10        | 0         |
| 20G                     | 80      | 20        | 0         |
| 30G                     | 70      | 30        | 0         |
| 10C                     | 90      | 0         | 10        |
| 20C                     | 80      | 0         | 20        |
| 30C                     | 70      | 0         | 30        |
| 5G + 5C                 | 90      | 5         | 5         |
| 10G + 10C               | 80      | 10        | 10        |
| 15G + 15C               | 70      | 15        | 15        |
TABLE 3  Mechanical properties of PP composites with different wt% of SGF and SCF reinforcement

| Material/composite code | Tensile strength (MPa) | Tensile modulus (GPa) | Flexural strength (MPa) | Flexural modulus (GPa) | Elongation at break (%) | Impact strength (kJ/m²) |
|-------------------------|------------------------|-----------------------|-------------------------|------------------------|-------------------------|------------------------|
| PP                      | 29.24                  | 2.89                  | 50.20                   | 2.78                   | (600)                   | 1.92                   |
| 10G                     | 27.27                  | 5.13                  | 63.22                   | 5.34                   | 1.34                    | 4.38                   |
| 20G                     | 41.66                  | 8.52                  | 92.80                   | 7.95                   | 1.04                    | 4.04                   |
| 30G                     | 49.11                  | 10.60                 | 93.72                   | 8.28                   | 0.76                    | 4.65                   |
| 10C                     | 32.15                  | 5.31                  | 67.82                   | 5.14                   | 1.83                    | 3.08                   |
| 20C                     | 39.08                  | 13.28                 | 77.81                   | 6.90                   | 0.9                     | 3.09                   |
| 30C                     | 50.91                  | 15.06                 | 104.66                  | 10.16                  | 0.74                    | 3.8                    |
| 5G + 5C                 | 35.35                  | 9.59                  | 76.39                   | 5.03                   | 1.13                    | 3.98                   |
| 10G + 10C               | 44.20                  | 10.97                 | 82.05                   | 8.76                   | 0.67                    | 3.68                   |
| 15G + 15C               | 46.28                  | 13.82                 | 96.60                   | 9.16                   | 0.67                    | 4.11                   |

FIGURE 1  Fabricated composite specimens for tensile, flexural, and impact test

| Material/composite code | Density (g/cm³) | Shore-D hardness number |
|-------------------------|-----------------|-------------------------|
| PP                      | 0.9053          | 74                      |
| 10G                     | 0.9828          | 78                      |
| 20G                     | 1.0421          | 79                      |
| 30G                     | 1.1268          | 82                      |
| 10C                     | 0.9654          | 81                      |
| 20C                     | 0.985           | 81                      |
| 30C                     | 1.0402          | 83                      |
| 5G + 5C                 | 0.9723          | 79                      |
| 10G + 10C               | 1.0406          | 80                      |
| 15G + 15C               | 1.0496          | 82                      |

TABLE 4  Density and Shore-D hardness values of PP and its composites
3 | RESULTS AND DISCUSSION

The variation of density of matrix PP, SGF, and SCF-reinforced PP is shown in Figure 2. The density of PP increased with increased weight percent of reinforcement; the largest value is observed for SGF/PP composite with 30 wt%. Shore-D hardness test results are represented in Figure 3; these values suggest that the reinforcing SGF and SCF into PP matrix increased the hardness. SCF/PP composite at 30 wt% reinforcement showed the maximum value.

The tensile stress-strain relationship of PP sample alone and reinforced with different wt% of SGF and SCF is presented in Figures 4A,B and 5A,B, respectively. The characteristic behavior of all the reinforced PP and PP alone appears to be the same; neat polymer exhibiting a definite linear portion initially and appears to be the stiffest of all followed by SCF- and SGF-reinforced polymers. Glass fiber-reinforced polymer is showing the minimum stiffness and the stiffness of hybrid composites is comparable to it. Figure 6 shows the tensile strength and tensile modulus of plain PP and its composites with different wt% of SGF and SCF reinforcement. From the figure it is seen that reinforcing PP with glass fiber increased the tensile strength, with the composite having 30% SGF by weight showing the maximum value; an exception was observed with the composite having 10% SGF by weight, where a small reduction in strength is observed compared to plain PP. This could be attributed to the insufficient flow of matrix material around the fibers causing the fiber to pull out at low loads.27

There is a 68% increase in tensile strength for 30 wt% SGF content in PP matrix; tensile modulus also showed a similar trend, with neat PP showing the least value and for 30 wt% SGF-reinforced PP, the tensile modulus was increased by 266%. The addition of SCF and a mixture of SGF and SCF by various weight fractions showed a similar increase in both

![Figure 2](image2.png)  
FIGURE 2  The density of PP and its composites

![Figure 3](image3.png)  
FIGURE 3  Shore-D hardness values of PP and its composites
tensile strength and modulus values. Of all the composites including neat PP, composite with 30 wt% SCF is exhibiting the maximum value of both tensile strength and modulus with a 74% rise in tensile strength.

The tensile strength of the composite with 30 wt% of SGP and 30 wt% of the mixture can be comparable to that of the composite having 30 wt% of SCF. For obvious reasons, the maximum value of tensile modulus was found with 30 wt% SCF-reinforced composite.

Figure 7 shows the maximum percent elongation at break for PP and its composites. It is obvious that neat PP showed the maximum elongation; incorporation of any percent of fiber in the PP decreases its fracture toughness strength resulting in the occurrence of early failure. Lower the percentage of fiber content, better would be the elongation before it breaks; it is interesting to observe that CF-reinforced PP (10 wt%) showing increased stretching in comparison with SGP and hybrid fiber composites.
The flexural strength and modulus of neat PP and PP reinforced with SGF and SCF and a combination of these two is represented in Figure 8. It is seen from the figure that the addition of fibers resulted in increased flexural strength and modulus. For SGF-reinforced PP, the presence of 20 wt% of glass fiber showed the maximum flexural strength and modulus values. Increasing the fiber content to 30% by weight did not improve the strength further; whereas for SCF-reinforced PP, both strength and modulus increased linearly with increasing wt% of fiber and 30 wt% SCF-reinforced PP showing the maximum value of all the composites.

This can be attributed to the high strength of CFs. The variation in flexural strength and modulus for hybrid composites showed a similar trend as that of SGF-reinforced PP. Increasing the wt% of hybrid reinforcement to 30 wt% (15SGF + 15SCF) from 20% did not improve the situation.

The influence of adding the reinforcement to PP on notched Izod impact strength values is depicted in Figure 9. It is observed that the impact strength of all the composites is greater than that of neat PP and composite with 30 wt% SGF showing the maximum value of all. Increasing the wt% of individual and hybrid reinforcement showed a mixed response on impact strength. For glass fiber-reinforced PP, increasing SGF content from 10 to 20% decreased the impact strength, but further increase by another 10% improved the strength; these variations in the strength are not substantial.
For SCF-reinforced PP, presence of 10 and 20% by weight of fiber showed the same value of impact strength, further increase in SCF content by another 10% improved the strength; but this improvement is only marginal. The hybrid composite also showed similar variation.

The SEM images are helpful in analyzing the mechanism of failure during the characterization of mechanical properties. Figures 10A, B, 11A, B, and 12A, B show the SEM images of the fractured surfaces of PP composite failed during the tensile test with 10 wt% and 30 wt% of SGF, SCF, and hybrid reinforcement, respectively. Matrix and fiber cracking, fiber-matrix interfacial debonding, pulling out of fibers, and fracture of fibers seem to be the major modes of failure of these composites during testing. Figure 10A, B represents the morphology of the tensile fractured surfaces of PP composite containing 10 wt% and 30 wt% of SGF reinforcement. Fiber-matrix cracking (marked A), fiber pullout (marked B) can be observed; also seen is the fractured fiber (marked C). Matrix fracture is initiated at the surface, propagates along with the thickness on either side of the adjacent fibers simultaneously. Increased fiber content results in good bonding, and the same is reflected in Figure 10B, where reduced fiber pull out can be observed; also matrix cracking and fiber fracture can be observed.

Reinforcing PP with CF improved the matrix-fiber bonding resulting in increased strength of the composite; this has also been substantiated in the SEM images of the fractured surface (Figure 11A, B) for SCF-reinforced composite (10% and 30% by weight) after tensile testing. Matrix cracking and fiber fracture are limited, but fiber pull out can be observed.

This is due to the presence of randomly distributed low strength glass fiber and high strength CF resulting in stress concentration at the interface. The pull out of glass fiber was relatively more; also seen is the random distribution of glass and CF in the matrix. Matrix cracking, fiber debonding, and the pull out are the major causes of composite failure.

These findings are in agreement with the observations made by Zhao et al. Figure 12A, B shows the fractured surfaces of hybrid composite having 10% and 30% by weight of reinforcement, where severe matrix cracking can be seen (marked D), unlike other composites.
4 | CONCLUSIONS

The influence of adding SGF and CF as individual and hybrid reinforcement in PP homopolymer on the physiomechanical properties was investigated. The tensile and flexural strength and modulus of PP improved with increased weight percent of reinforcement in the composite. The highest value was observed for composite with 30 wt% of SCF reinforcement; this enhancement is due to the high strength of CFs. The hybrid composite with 10 and 20 wt% of the mixture of SGF and SCF proved to be better than the composite with the same wt% of SGF and SCF added individually.

The notched Izod impact strength of SGF + PP composite at 30 wt% was found to be the highest amongst all. The increased presence of SCF improved the tensile and flexural properties, but could not make a significant contribution in improving the impact strength. The hardness of PP improved with the addition of SGF and SCF, the largest value of hardness was observed for the composite with SCF reinforcement at 30 wt%. The density of PP increased with increased weight percent of reinforcement; the peak value is observed for SGF/PP composite at 30 wt%. Matrix cracking, fiber fracture and pull out, and debonding at the interface are the major failure modes during testing for mechanical properties. From the above, it can be concluded that the type of reinforcement and its weight fraction in the composite significantly influences the mechanical properties.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this research article.

AUTHOR CONTRIBUTIONS

Sridhar Doddalli Rudrappa contributed to the investigation, methodology, writing of the original draft, review, and editing. Varadarajan Yellampalli Srinivasachar contributed to the supervision, writing of the original draft, review, and editing.
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