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Study on Recycling of Waste Glass Fiber Reinforced Polypropylene Composites: Examination of Mechanical and Thermal Properties

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Abstract: This study presents the preparation of short glass fiber reinforced polypropylene (PP/FG) composites using with waste (post-consumer) polypropylene composite containing long glass fiber (PP/LFG) obtained from the recycling of battery covers of trucks. Waste PP/LFG composite parts were mechanically grinded before adding to PP/FG composites. An injection molding machine was used to produce the PP/FG composite test samples loading with recycled waste PP/LFG composite in the range of 1-20% by weight. Effects of recycled waste PP/LFG content on the mechanical, thermal, and morphological properties of the PP/FG composites were investigated. The following three different tests, at various waste PP/LFG ratios, were conducted: Izod/Charpy Impact test, bending test, and tensile test. Mechanical test results showed that mechanical strength of prepared PP/FG composites were not influenced by content of waste PP/LFG material up to 10 wt.%. Differential scanning calorimetry (DSC) was used for the evaluation of thermal parameters such as melting point and crystallization temperature of the polymer matrix in the composites studied. Furthermore, by analyzing the values of thermal effects determined using the DSC method, it was possible to determine the degree of crystallinity. The DSC results showed that crystallinity %, melting, and crystallization temperatures of PP/FG composites were not influenced to adding waste PP/LFG at different ratios. The morphology of composite materials was investigated by SEM analysis. Good fiber dispersion was observed in the PP matrix for PP/FG composites containing short glass fiber prepared with all ratios of recycled waste PP/LFG material containing long glass fiber.

Keywords: Glass fiber, Polypropylene, Polymer composite, Recycled materials, Mechanical properties.

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1. INTRODUCTION

As examined on the properties of materials (concrete, glass, metal alloys, wood materials, carbon, plastic and etc.) used for general needs in the early days, it is understood that new materials with light, superior and specific properties are needed. Composite materials with desired properties cannot be produced at the expected level due to the high production cost. Despite all these, their usage is rapidly becoming widespread and is expected to increase further. In the 21st century, the demand for thermoplastic polymer composites is increasing, which is due to their superior physical and mechanical strengths. High strength, high rigidity, long fatigue life, low density, and adaptability to the desired properties are the advantages of polymer composite materials over single phase products. Corrosion resistance, appearance, temperature dependent behavior, thermal insulation, thermal conductivity and acoustic insulation can also be significant characteristics arising from their high specific strength and rigidity (1-5).

In terms of mechanical properties, three regions consisting of reinforcement, matrix, and interface are effective in the structure of polymer composite defined as 'material formed by combination of two or more different components along the interface in the macro dimension'. The tasks of these regions are, respectively; to carry the load on the structure, to keep the composite structure together and distribute the loads homogeneously, and to bond the matrix with reinforcement zones. The factors determining the mechanical properties of composite can be listed as the matrix type, the type, and form of reinforcement material. In addition, the compatibility of the reinforcement and the matrix is a requirement for the production of composite with good mechanical strength. Tensile and bending properties decrease when the cavity content of composite materials is above 3-6%. The weakening of the interface bond at high temperatures is one of the main reasons for the production efficiency to be locked. To achieve the good interface interaction, it is reported in the literature that the use of compatibilizers improved the interface adhesion between matrix and reinforcement materials (for example; the use of maleic anhydride modified (grafted) polypropylene for PP composites). Beside this, it is also known that the use of compatibilizers contributes to thermal and mechanical properties of composites (6-8).

Polypropylene (PP) is one of the most widely used thermoplastic polyolefinic material that is most commonly utilized in plastic and automotive industries. PP is determined by its versatile characteristics, chemical resistance, low density, excellent barrier properties, ease of formulation, and good flexibility (9, 10). In contrast, there is a need to cope with some limitations of PP, such as low stiffness and low strength, susceptibility to oxidation (11). Fabrication of PP composites with reinforcing materials is a method of improving their mechanical properties, so the application areas of PP can be expanded through the blending process with the incorporation of various materials. Different reinforcement materials, some mostly preferred inorganic fillers, such as glass fiber (FG), carbon nanotubes, and clays are employed to enhance the properties of the PP polymer. To obtain a high-performance dielectric PP composite, it is reported that an increase in energy storage values is obtained using a blend of maleic anhydride grafted polypropylene (MAPP) and graphene oxide (12). After the increase in use of nanomaterials in the literature, the enhancement of mechanical properties was achieved using PP and 10% nano silica (13). For the fiber addition, a hybrid system was created using basalt fiber on behalf of the environmental approach and therefore an increase in tensile strength was obtained (14). Of these PP composites, glass fiber reinforced PP/FG composites prepared with different types of glass fibers (E-type, S-type so on) are very attractive materials with their ease of fabrication, superior mechanical properties (high specific modulus and strength), and low manufacturing cost (15). PP/FG composites are mostly favored in the developing automotive industry due to the need for lightweight and high mechanical strength. E-type glass fibers are used in a wide range of development studies of PP composites (16-21). In glass fiber reinforced PP/FG composites, the process generally uses E-type glass fibers, long and short fibers in shape depending on their mechanical expectations. In addition, using a MAPP results in a structure with higher mechanical strength in PP composites (17). PP/FG composites are developed as an alternative and stronger structure for bone fracture fixation plates (21).

In the PP/FG composites, it is also important that the polymer matrix has good wetting ability and no chemical bonding on the fiber surface, and the fiber also has surface properties suitable for interaction with the polymer. The low wetting ability of the polymer leads to the formation of voids on the contact surface of the fiber which negatively affects the mechanical properties of the composite structure (22). E-type glass fiber is often preferred for PP/FG composites, taking advantage of its adequate electrical properties compared to other types of glass fibers. In terms of engineering properties, fiber length, and diameter, fiber orientation, and volume ratio are important parameters in the PP/FG composite materials. Among of long (continuous) or short (discontinuous) fibers in length, long fibers are difficult to handle, whereas short fibers are easy to manipulate and process. Also, high elastic modulus and strength are expected properties for fibers. The use of glass fiber increases the mechanical properties of the polymer composite by 2-3 times. Continuous fiber reinforced composites are used for higher values of strength and stiffness, while discontinuous fiber reinforced products are preferred in areas where cost is important (6). In composite preparation with the intended properties, fiber type selection should be made by evaluating the desired properties and cost (23). Continuous fibers are the most durable reinforcing product and increases tensile modulus, dimensional stability, hydraulic stability, and fatigue and impact behavior of composites. The PP/LFG composites used in luggage and load carrier parts of cars have been developed with long fibers with a length of 10 mm instead of short fibers with a length of 0.7-1.5 mm. Recycling of glass fiber reinforced PP composites is an option considering the cost of using it in pure form (3, 24).

Plastic wastes emerge as both daily use and process waste. The recycling of these products is valuable in terms of preventing environmental pollution, saving energy from scratch, reducing the use of pure raw materials. Recycling is a remarkable process in terms of cost and storage. However, considering of only one quarter of the waste is recycled, these products can be used in residential and construction areas. Because of softening and melting properties of thermoplastics, it is possible to produce reusable products from them. Since the recycling of thermoplastics reduces mechanical and other properties, the supplement of recycled waste products should be approximately 10 to 15% on the basis of pure material. In the plastic industry, usually 20% of waste and 80% of thermoplastic polymers are mixed and new plastic batches are formed. The properties of the matrix, fiber, and interface change in each step of composite fabrication, and at this point, the aspect ratio (L/D) of fiber length (L) and fiber diameter (D)) are important parameters for the interface bonding and transferring load. Fracture stress limit is one of the factors which determining the amount of recycling. Thermoplastic products can be recycled by resin dissolving process. Glass fibers separated by dissolution have the same tensile strength as pure glass fibers, but they have 12% less hardness than pure glass fibers. Although there are difficulties for recycled glass fiber reinforced thermoplastic materials obtained by pyrolysis process, researches and calculations are made considering the increasing needs and economic conditions (24-28).

The main objective of this study is to prepare the PP/FG composites with short glass fiber using with waste PP/LFG composites containing with long glass fibers and to recycle the waste PP/LFG composite. For this purpose, PP/LFG composite parts obtained from waste battery covers of trucks was shredded by using mechanical grinder for recycling. Before adding to PP/FG composite, the fiber content and diameter in the waste grinded PP/LFG composites were characterized with burning tests and dimension measurements, respectively. The results of mechanical and thermal tests of PP/FG composites prepared with the adding of waste PP/LFG were compared and evaluated, and determined to the highest amount of recycled waste composite. As a result of the tests, it has been observed that the certain contribution rates of waste PP/LFG composite to produced PP/FG composite structure can be recycled.

2. EXPERIMENTAL

2.1. Material

The raw materials used in this study are glass fiber, polypropylene, and binder material. Table 1 lists the materials' compositions with weight ratios of the constituents and also the symbols which were used in this study. Polypropylene, which is a semi-crystalline polymer and used as a polymer matrix, was purchased from PETKİM in granular form (density: 0.902-0.910 g/cm^3; melting point: 164 °C). As a thermoplastic engineering polymer, PP has superior mechanical properties such as good resistance to stress, low specific gravity, and good impact strength (25, 26).

Table 1: Designation and composition of composites.

Sample	Ratio (wt.%)	Notes
FG	100	Chopped Short Glass Fiber
PP	100	PP granules
PP/LFG (waste composite)	70/30	Waste battery covers of trucks
PP/FG/LFG-X (composite)	70/30/X	Combination of PP, FG, and waste PP/LFG (LFG-X; wt% of waste PP/LFG)

Glass fiber (FG), which is used as a reinforcement material, was purchased from Şişecam Elyaf Sanayii AŞ., in chopped short glass fiber (E-type) form. The length and diameter of the chopped glass fibers is 4.5 mm and at least 14 µm, respectively. The glass fiber diameter distribution (using the Cottonscope device) of the chopped product of short glass fiber is given in Figure 1. Glass fiber consists of silicone, calcium, boron, sodium, iron, and aluminum elements is amorphous and of isotropic material form (27, 31).

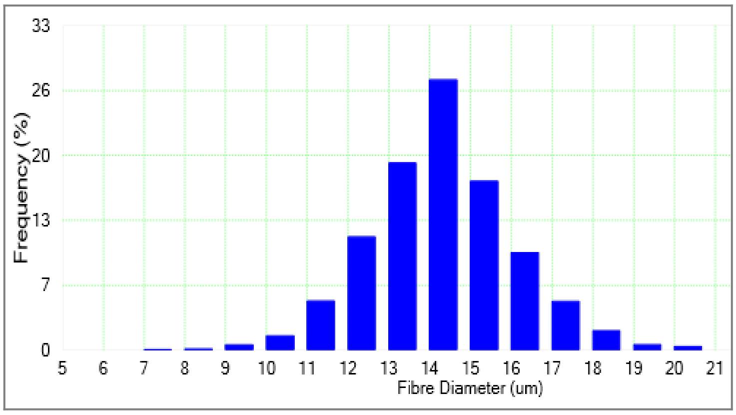


Figure 1: Fiber diameter distribution of the chopped short glass fiber.

Polybond® 3200, a maleic anhydride modified polypropylene, (ρ = 0.91 g/mL, acid value = 6.1 mg/KOH g, MA content = 1.0 wt.%) was purchased from CHEMTURA, USA. It was used as a chemical coupling agent for glass fiber reinforced PP. Polybond® 3200 is used to improve the adhesion strength between glass fiber and PP, and to enhance physical and thermal properties.

The waste PP/LFG material to be recycled is the battery cover for trucks, and this composite material weighs 2500 grams. The fiber diameter distribution of the recycling material is given in Figure 2. The PP/LFG ratio of waste material was found to be 70/30 by burning test.

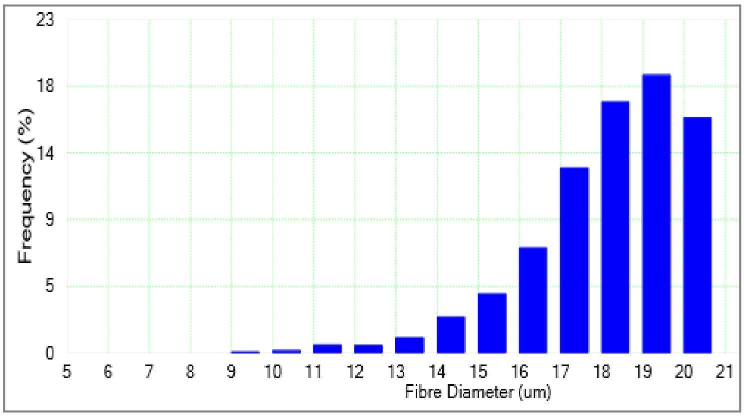


Figure 2: Fiber diameter distribution of the recycling waste PP/LFG composite.

2.2. Preparation, Characterizing and Tests

2.2.1. Sizing of PP/LFG waste composite

Shredding: The waste material for recycling is 60 cm x 40 cm. First, 15-20 large pieces were obtained and then cut to get 2 cm x 2 cm pieces with saw. These parts were transferred to the grinding step.

Grinding: Grinding was performed on IKA WERKE, MF 10 Basic Microfine Grinder Drive. The screen size of the grinder is 0.25 - 0.5 - 1 - 2 mm. 2 mm sieve type was chosen due to the biggest dimensions suitable for in this study. The grinding speed was selected as the maximum level of 6500 min^{-1}. In addition, external cooling was performed with vortex tube in order to prevent heating of the device during the process.

Dimension measurement: The length of the glass fiber was measured using optical microscope and accordingly 135 data were collected from the remaining burnt composite waste. In this study, several composite samples were produced with and without waste material. There was no difference in fiber diameter in PP/FG/LFG-0 samples, is 200 data were taken. For the other sample sets, 100 data were obtained with the fiber diameter being thin and thick. The surface area information of the milled grains obtained from the waste sample was measured as 0.4 mm^2 by optical microscope.

2.3. Preparation of PP/FG/LFG Composites

In the preparation of PP/FG/LFG composites, the waste PP/LFG (LFG-X, wt.%) content was determined as 1, 5, 7, 10, 15 and 20% by weight. The total weight of each blend containing polypropylene, glass fiber, waste PP/LFG, and Polybond® 3200 is 1500 grams. The combination of all samples were determined according to the combustion test which is based on TS 1177 EN ISO 1172 standard. Firstly, the waste material was directly incinerated at 610 °C. As a result of the combustion, the polymer fraction was burned and leaving only glass fibers. Glass fiber ratios of waste composite were calculated by taking the weight difference before and after combustion. According to this calculation, the glass fiber content of composite composition by weight was 30%. By knowing the content of the waste product, combinations were formed with final glass ratio of 30%. The combination of PP/FG/LFG composites are given in Table 2.

2.4. Extrusion and Injection of PP/FG/LFG Composites

The temperature ranges of extrusion process were set to 240-230-230-230 °C for PP. The processing temperature for PP and glass fiber reinforced PP composites was determined as 230-240 °C, according to the literature (35, 36). The prepared batch sets were fed to COMAC Plast single screw extruder machine (screw speed: 6-6.6 rpm). The molten blend was cooled with cold water and dried with cold air. The dried long yarn-shaped material was passed through the cutting machine for the granular form.

The obtained granules were kept in the oven at 80 °C for 24 hours to remove moisture. The temperature ranges of injection molding were set to 230-230-230-230 °C for four zones, respectively. The granules were fed to the ENGEL injection molding machine. After the heat and pressure treatment molten PP pressed into the mold suitable for mechanical tests.

Table 2: The combination of PP/FG/LFG composites prepared with waste PP/LFG.

Blend Samples	Pure PP (g)	Pure Glass Fiber (FG) (g)	Binder (Polybond®) (g)	Waste PP/LFG (g)	Waste Glass Fiber (g)
PP/FG/LFG-0	1029.0	450.0	21.0	-	-
PP/FG/LFG-1	1018.5	445.5	21.0	10.5	4.5
PP/FG/LFG-5	976.5	427.5	21.0	52.5	22.5
PP/FG/LFG-7	955.5	418.5	21.0	73.5	31.5
PP/FG/LFG-10	924.0	405.0	21.0	105.0	45.0
PP/FG/LFG-15	871.5	382.5	21.0	157.5	67.5
PP/FG/LFG-20	819.0	360.0	21.0	210.0	90.0

2.5. Characterization

2.5.1. Mechanical tests

Mechanical tests are applied to four different types molded products. The main tests are basically divided into three subjects; impact, bending, and tensile. Impact tests are classified according to their vertical-horizontal and notched-unnotched form.

Izod: Samples (80*4*10 mm in size) are used for vertically applied impact test. One of the two test specimens in the mold sample was mechanically tested on the Zwick universal test machine, one notched and the other unnotched. MF 10 Basic-IKA WERKE notching device was used for notching. Five samples were tested for each composite and the average values were reported. Izod impact tests were done according to TS EN ISO 180 standard test method.

Charpy: This horizontal impact is applied to five of the samples of the same length and the same procedures as for the Izod impact test. Izod impact tests were done according to the EN ISO 179-2 standard test method for the Charpy impact test.

Bending: Three-point bending tests were done according to TS EN ISO 178 standard test method. The dimensions of the bending samples are 60*4*10 mm. As a result of this test, F-max flexural strength and F-max deformation data are examined.

Tensile: Tensile tests were done according to TS EN ISO 527-1 standard test method. In accordance with the standard, a dog bone sample of 4*10 mm was used. As a result of this test, F-max tensile strength and F-max elongation at break are examined.

2.5.2. DSC Analyses

Differential Scanning Calorimetry (DSC) test was performed on the sample taken from four different parts of the waste battery cover. Analysis was performed on the samples taken, polypropylene, and Polybond® 3200 raw materials.

2.5.3. SEM Analyses

To perform the SEM analyses of PP/FG composites, the surface of each samples was coated with Au/Pd. SEM Images were taken from the fracture surfaces of Izod impact samples in each set. The fracture surfaces of PP/FG composite samples and the bonding between the glass fiber and polypropylene matrix were investigated from the SEM images.

3. RESULTS AND DISCUSSION

3.1. Mechanical Properties

In this study, the PP/FG composites with short glass fiber using with the waste PP/LFG composites containing with long glass fibers are prepared with the different ratios of recycled waste PP/LFG composite. The diameters of the long fibers from the waste composite are larger than that of the short fibers using in the prepared PP/FG composite, and are 18.61 and 14.05 µm, respectively. As a result of the mechanical tests, it is seen that increasing the fiber diameter with the adding of waste PP/LFG in composite structure decreases the strength of PP/FG/LFG composites. The effect of the addition of waste composite with long fiber on the mechanical strength values of PP/FG/LFG composites can be evaluated with the data given in Table 3.

As the flexural strength of prepared composites is examined, a significant decrease is observed above the 10% of waste PP/LFG ratio added to the PP/FG composite. The flexural strength and modulus are similar to the reference PP/FG composite value prepared without any waste material, up to the PP/FG/LFG-10 composite with the 10% of waste material and then starts dropping, due to the addition of long fiber in higher weight fraction. On the other hand, the tensile strength values of composites decreases linearly with increasing waste amounts in prepared PP/FG/LFG composite. For the amount of waste composite above the 1%, more than 3% decrease is observed in the breaking strengths of composites prepared with all other waste additives, but the addition of waste material in the ratios of 5, 7 and 10% gives similar values, are of 88.1, 87.8, and 87.1, respectively. In this case, as in the results of flexural strength, it is appropriate to add the waste composite up to 10%. It was observed that in all the specimen under with the 20% of waste additive, the flexural and tensile properties were close to those of reference PP/FG composite without waste additive. Mechanical properties of a composite mainly depend on the fiber ratio, individual properties of fiber and polymer matrix and interfacial bonding of them (17, 18). Besides that, it can be said that the aspect ratio of fibers is the major factor in deciding and affecting the mechanical properties of the composites.

Histogram of fracture energy (kJ/m^2) at F_{max} against PP/LFG content (wt.%) for the same specimen sizes of composites at 25 °C are depicted in Figure 5. From the histogram, it can be observed that, generally, the tensile strength and fracture energy values decrease with respect to increasing the waste PP/LFG content with long fiber for tensile and impact specimens, respectively.

For tensile specimens, this trend is expected as the presence of fibers tends to reduce resistance to crack initiation, therefore increasing the material brittleness, while at the same time reducing crack propagation through the matrix by forcing crack lines around the fiber ends. However, for unnotched Charpy impact specimen, there is no sharp decrease in fracture energy (8%) with the incorporation of up to 15% of waste PP/LFG loading compared with neat PP/FG composite (54.8 mJ).

For unnotched Izod impact specimens, this trend is similarly observed that the fracture energy (7.5%) decrease with up to 15% of waste PP/LFG content in composite accordance with neat PP/FG composite (55.2 mJ). For the results of notched Izod and Charpy impact tests, no significant variation for fracture energy is observed with increase in waste PP/LFG content of composites. It is observing to note that further addition of up to 20% of waste PP/LFG does not produce any significant effect on fracture energy values of prepared composites. Meanwhile, in order of increasing the waste loading to 15%, identical trends in notched Izod and Charpy impact values are observed as resulted in 10.5 kJ/m^2.

Table 3: Mechanical test results of PP/FG/LFG composites.

Samples	**PP/FG /LFG-0**	**PP/FG /LFG-1**	**PP/FG /LFG-5**	**PP/FG /LFG-7**	**PP/FG /LFG-10**	**PP/FG /LFG-15**	**PP/FG /LFG-20**
Flexural Strength (MPa)	141.1±1.4	142.4±1.8	139.0±2.3	138.6±1.6	139.3±1.2	128.9±0.6	127.8±0.1
Flexural Modulus (GPa)	6.7	7.0	6.9	6.9	7.0	6.1	6.1
Tensile Strength (MPa)	92.4±1.0	91.3±0.8	88.1±0.1	87.8±0.3	87.1±1.3	85.9±0.6	84.3±0.5
Tensile Modulus (GPa)	5.8	4.7	5.3	5.1	5.5	5.9	5.9
Unnotched Izod Impact (kJ/m^2)	59.7±3.3	60.2±5.4	56.5±4.5	55.7±3.2	55.4±2.5	55.2±2.1	54.0±3.0
Unnotched Charpy Impact (kJ/m^2)	54.8±4.4	56.2±1.6	51.2±2.8	51.9±2.2	50.9±2.7	50.4±2.7	47.6±2.5
Notched Izod Impact (kJ/m^2)	11.7±0.7	11.8±0.3	10.5±0.3	10.7±0.5	10.4±0.3	10.5±0.4	9.9±0.3
Notched Charpy Impact (kJ/m^2)	10.8±0.2	11.2±0.3	10.6±0.5	10.4±0.5	10.7±0.4	10.5±0.6	9.6±0.2

Figure 3 shows the relationship by the way the flexural strength and strain data for the bending test. In Figure 3 (a) (red line), and (b) (green line) refer to the neat PP/FG/LFG-0 composite and the PP/FG/LFG-7 with 7% of waste material, respectively. As can be seen from this graph, the flexural force values are close to each other and the resistance value decreases slightly with the addition of recycled waste. In Figure 4, the tensile strength of PP/FG/LFG-10 composite is given by the graphs obtained from repeat tests of 5 samples. For the tensile strength of the composite loaded with 10% of recycled waste, the repeatable values appear to be obtained in close agreement.

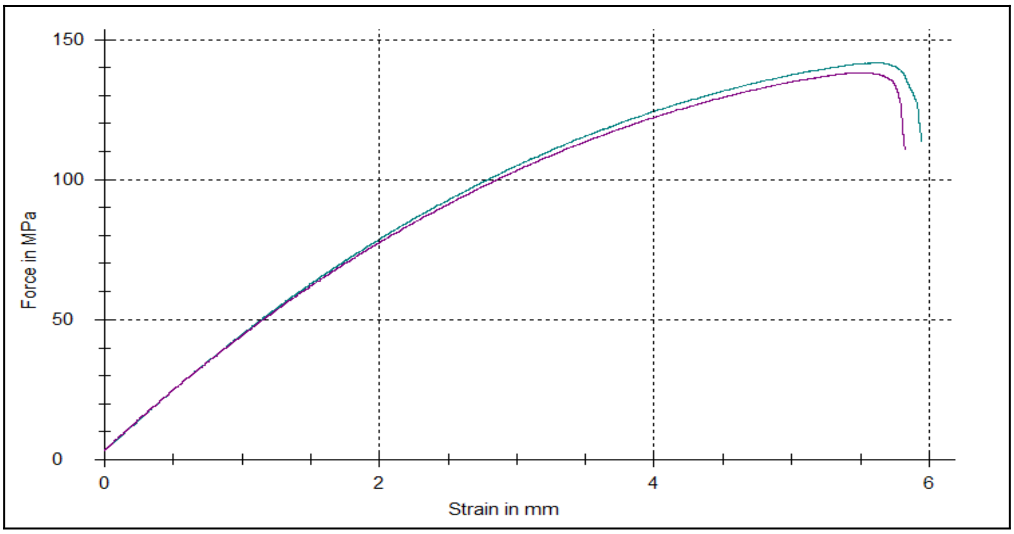


Figure 3: Graphs for the flexural strength: (a) PP/FG/LFG-0 (green line; top) and (b) PP/FG/LFG-7 (red line; bottom).

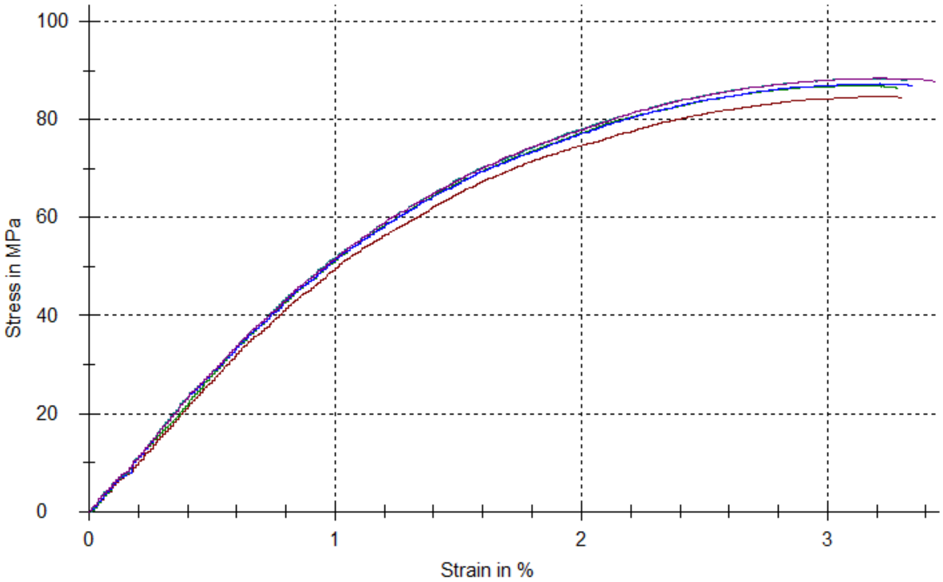


Figure 4: Graphs for tensile strength of PP/FG/LFG-10.

As a result of the strength values of PP/FG/LFG composites, it is found that the optimum ratio of recycled waste is 10% and above this ratio, it affects the mechanical strength of composites negatively. While the flexural strength is not significantly altered with an increase in recycled waste loading, the tensile strength values decreases to a certain extent. It is observed that the impact strength is reduced with incorporation of recycled waste in the composites. The data on mechanical strength properties are given in Figure 5.

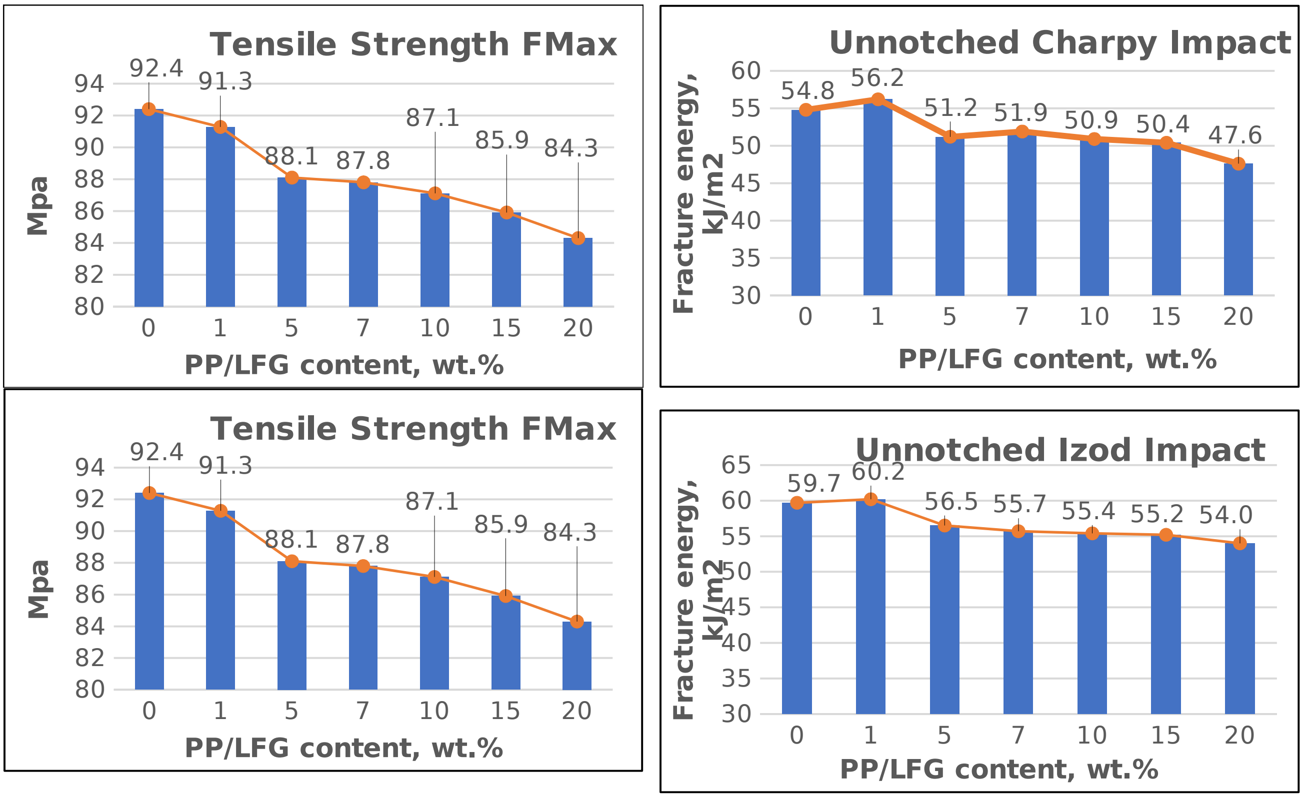


Figure 5: Mechanical strength properties for PP/FG/LFG composites.

In a previous study, it was reported that the recycled glass fiber reinforced composites showed lower tensile strength (-30%) compared to the untreated glass fiber composite (32). The loss in mechanical performance can be explained by the fact that the recycled glass fiber filled composite is subject to fiber breakage and is unable to regenerate the fibers during the injection molding process.

3.2. Thermal Properties

As seen in Figure 6, DSC thermograms show that the neat PP/FG/LFG-0 composite, which is the reference sample, and recycled waste containing samples exhibit similar behavior. Temperature range from -40 ℃ to 200 ℃, suitable for PP. All measurements were taken under nitrogen atmosphere at the same heating and cooling rates of 10 ℃ /min. The process, which starts and ends at room temperature, is carried out with cooling and then heating.

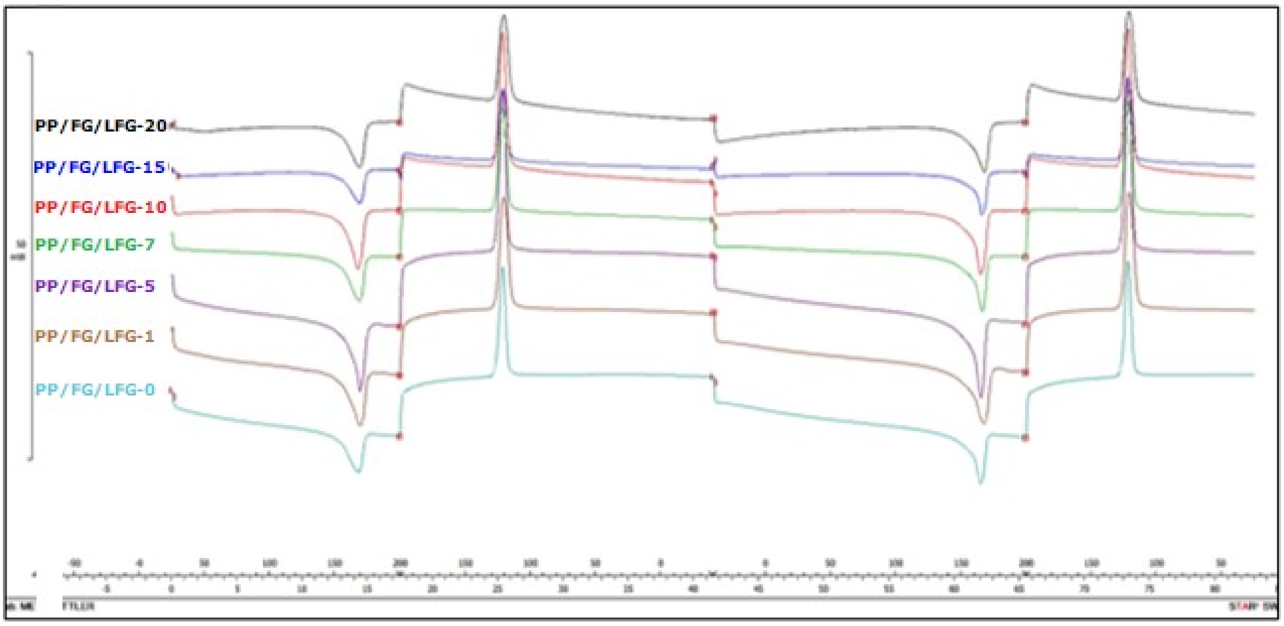


Figure 6: DSC thermograms of PP/FG/LFG composites.

During this process, the first peak gives melting temperatures, and the second peak refers to the crystallization temperature. Applying DSC analysis to all samples gives close melting and crystallization temperatures. Therefore, it is understood that the contributions of thermally converted wastes are at a standard level. These results are consistent with the literature. Lee et al. showed that crystallinity of the PP decreases with wood flour whereas it increases with clay and MAPP (33).

The percentage of crystallinity (X_C;%) of a sample was calculated as follows Equation 1:

$$X_c(\%)=\left[\frac{\dfrac{\Delta H_f}{W\%}}{\Delta H_0}\right]\times 100 \qquad \text{(Eq. 1)}$$

where ΔH_f is the heat of fusion of PP/FG/LFG in a composite determined from the DSC thermogram, ΔH^O is the heat of fusion of 100% crystalline PP/FG/LFG-X which equals 183.1 J/g, and W% is the weight percentage of PP/FG/LFG-X in the composite (34).

The melting temperature (T_M), crystallization temperature (T_C) and percentage of crystallinity (X_C; %) of these recycled materials are listed in Table 4.

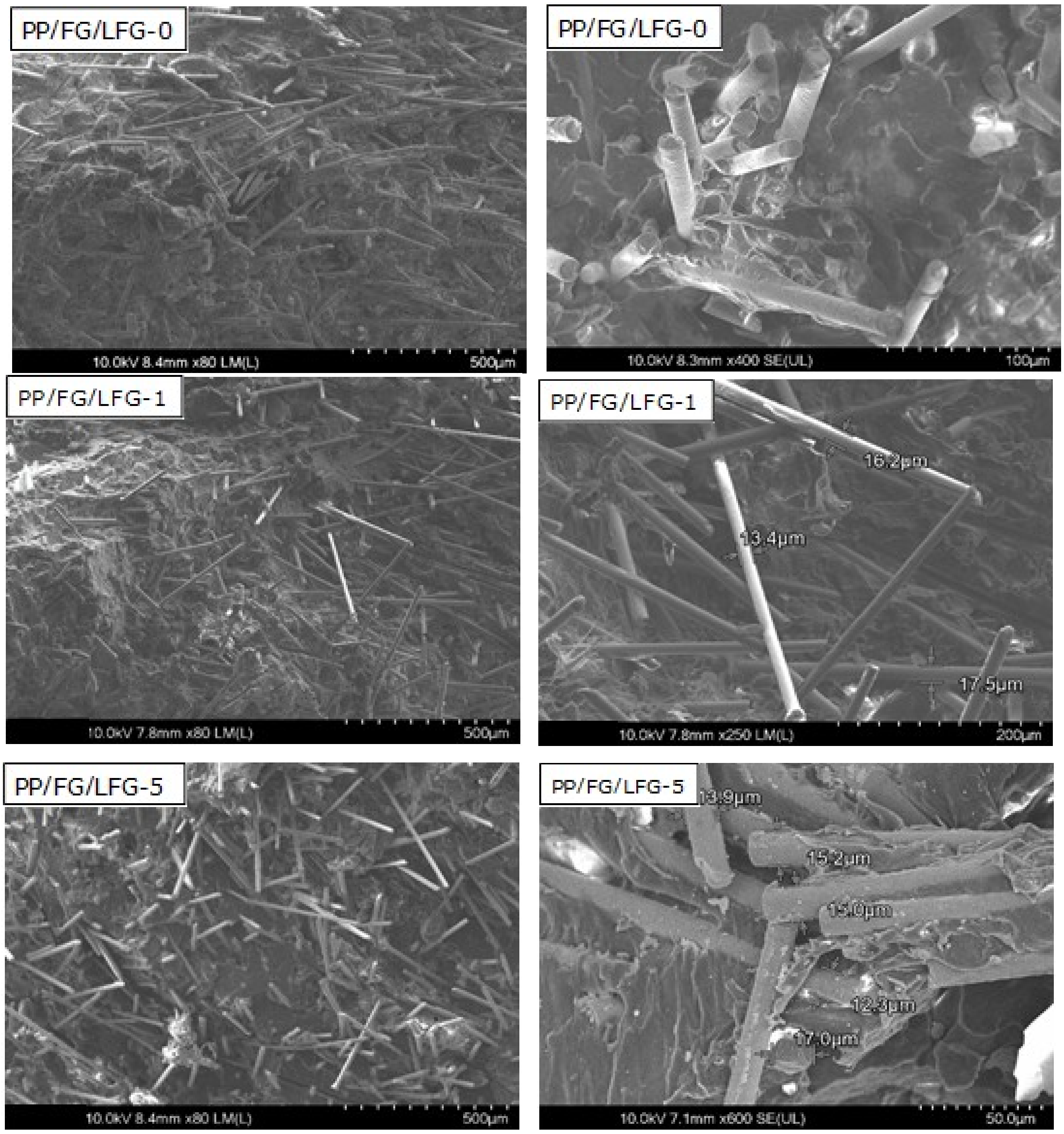
Table 4: Melting temperature, crystallization temperature and crystallinity of PP/FG/LFG composites.

Samples	T_M (°C)	T_C (°C)	X_C (%)
PP/FG/LFG-0	155.26	129.00	28.265
PP/FG/LFG-1	158.36	129.03	28.829
PP/FG/LFG-5	156.48	128.17	28.487
PP/FG/LFG-7	157.79	128.71	28.725
PP/FG/LFG-10	157.89	128.63	28.743
PP/FG/LFG-15	159.01	128.25	28.947
PP/FG/LFG-20	156.05	128.18	28.408

3.3. The Morphology of PP/FG/LFG Composites

Figure 7 shows the SEM micrographs of all sets and these images were taken from the samples subjected to Izod impact test. The SEM images show the properties of adhesion, orientation, and separation after impact. Good fiber dispersion is observed for all compounds. The images in the left column show the remote views of the samples. In the right column, the images were taken closer and the fiber diameters were measured in order to reveal the diameter difference.

For the PP/FG/LFG-0 sample, no diameter difference was observed because there was no long fiber coming from the waste composite additive. The presence of long fibers in the PP/FG/LFG-1 sample is seen by the measuring fiber diameter. As can be seen from SEM images, both short fibers with a diameter of 13.5 µm and long fibers with a diameter of 18.2 µm are found in PP/FG/LFG composite structures. In the PP/FG/LFG-5 sample, it is understood that the matrix and the supplements adhere well. In the PP/FG/LFG-7 sample, it is observed that the orientation of the glass fibers varies. It was determined that PP/FG/LFG-10 had good adhesion with the matrix on long fibers as seen in the close image. The PP/FG/LFG-20 sample has proven to be capable of separating the fiber from the matrix by impact. With the SEM analysis, the increase in the amount of waste and the increase in the amount of long fibers are proved by observing the fiber diameter data. With this analysis, it is seen that the part which is mechanically recycled in adhesion also adheres like pure products. It is observed that after the rupture process the fibers can break or come out at the break points.



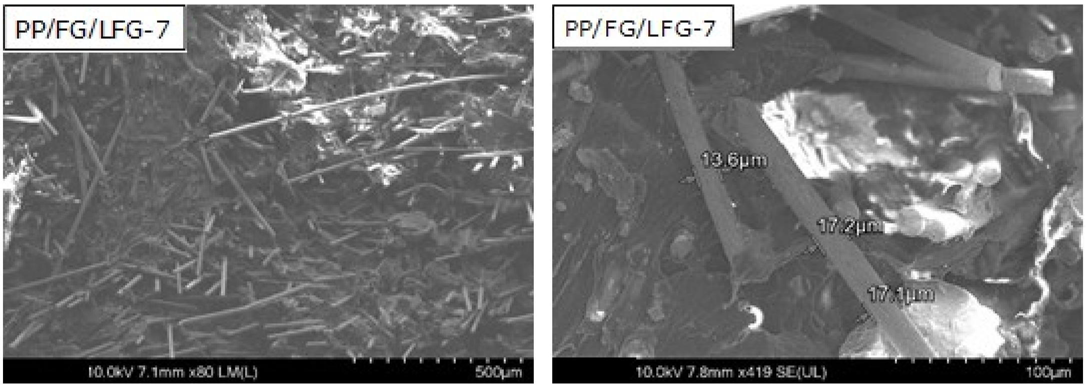


Figure 7: SEM micrographs of fractural surface of PP/FG/LFG composites.

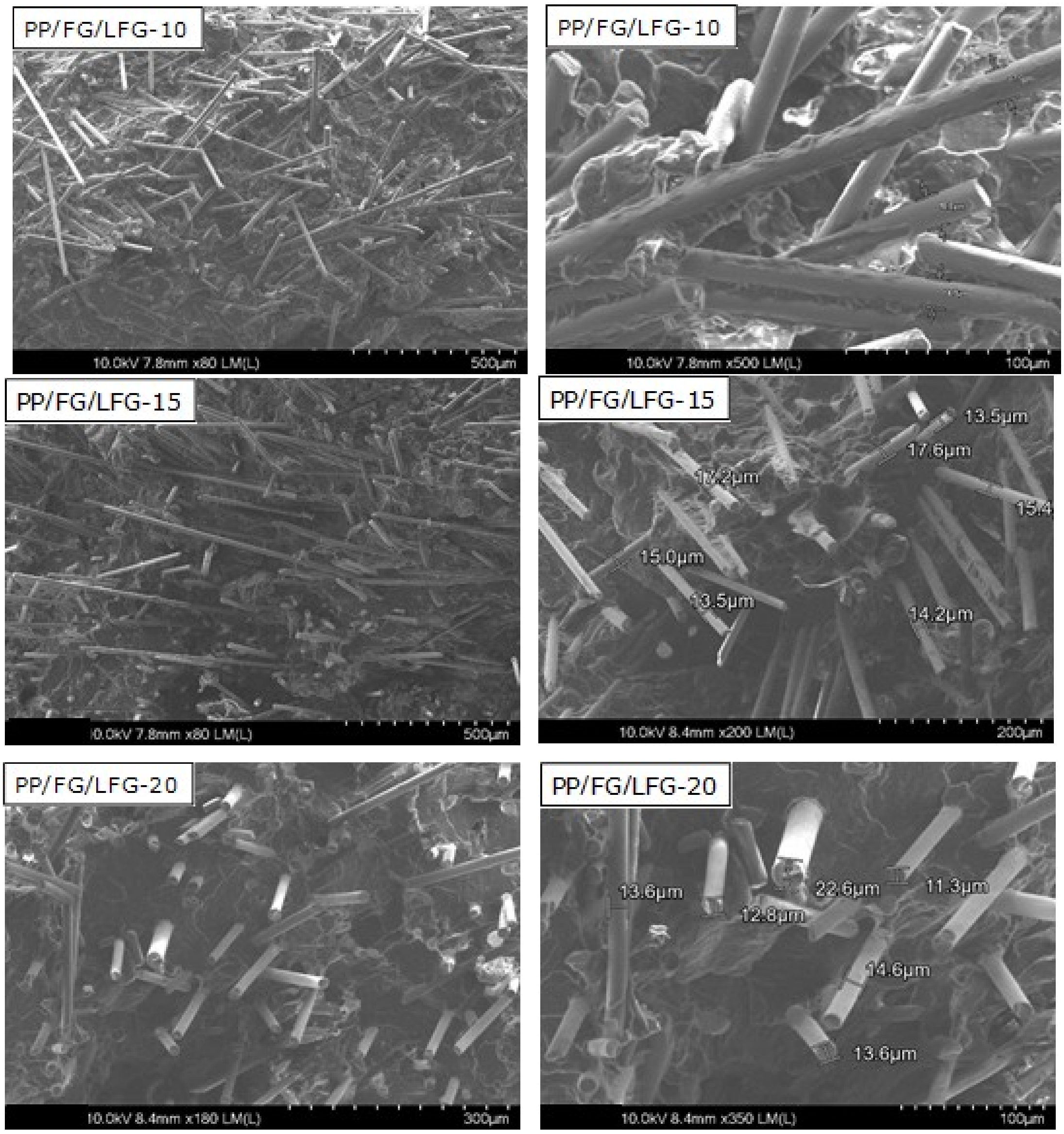


Figure 7 (contd): SEM micrographs of fracture surface of PP/FG/LFG composites.

As a result of the mechanical test results and SEM images, it can be said that the tensile behavior of PP composites prepared with discontinuous glass fiber depends on the fiber length and the fiber orientation according to the loaded direction by looking at the distribution of the fibers in the composite material.

4. CONCLUSION

In this study, it is aimed that recycling of waste polypropylene composites with long fibers obtained from battery covers of trucks. Since long fiber products are new and superior technology, long fiber reinforced waste PP/LFG composite recycled with mechanically is added to short fiber reinforced PP/FG composite in this work. The thermal, mechanical and morphological properties of composites were presented and discussed. As a result of the characterization tests performed on the PP/FG/LFG composites prepared with recycled waste PP/LFG, it was reasoned that the waste PP composite contribution to PP/FG composite structure could be optimum amount of 10%. Also, the SEM micrographs revealed that the adhesion and bonding limits between the fibers and the matrix were exceeded as fiber pull out and interfacial delamination were observed. As a result of mechanical tests, it can be said that the increasing in the fiber diameter decreases the strength values of prepared PP/FG/LFG composite with more than 10% of waste PP with long fibers. As for the thermal properties, for the all contents of the recycled waste PP/LFG composite, the short and long glass fibers in PP composite structures had no effect on the crystallinity of PP matrix. Based on the experimental results, it can be concluded that recycled long fiber reinforced PP composites have great potential to replace traditional PP composite used in various applications.

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