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Mechanical Characterization of Waste Polyester Fiber Reinforced Polypropylene Composites

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Abstract

In this study waste polyester fiber reinforced polypropylene composites are developed with a view to recycling the wastes from textile industries. These composites were reinforced with waste fiber at different weight ratios and distributions in hot press machine. Their physical, mechanical and thermal behaviors are discussed in terms of tensile strength, tensile modulus, flexural strength, flexural modulus, Charpy impact strength, hardness and thermal stability. It was found that in general their mechanical properties decreased and on the other hand their impact strength increased with fiber volume fraction. The 10% waste fiber composites distributed in three layers showed better mechanical properties than that of the other distribution. Thermal transitions of the composites were determined using the Thermal Gravimetric Analysis (TGA), Differential Thermal Analysis (DTA) and fracture surface analysis was carried out with Scanning Electron Microscope (SEM).

Keywords: Polyester fiber, polypropylene composites, hot pressing, recycling.

1. Introduction

A significant amount of fibrous waste is disposed worldwide from various sources (e.g. from the textile industry and post-consumer product) [1]. The waste products can be considered as an environmental nuisance because of its non-biodegradability [2]. By considering the increasing cost of waste disposal and its harmful effects on environment [3, 4], in recent years increased emphasis has been placed on reusing techniques for various fibrous waste products [5]. One of the most viable applications of these waste materials is in the combination of polymeric matrices, producing composite materials [6, 7]. Waste fiber reinforced composites are gaining progressive importance as biodegradable starting material for various applications. They also possess good mechanical and thermal properties, [8-11].

Properties of the waste fiber reinforced composites can be influenced by fiber content. Ingeneral, high fiber content up to a limit is required to achieve high performance of the composites. Another important factor that significantly influences the properties and interfacial characteristics of the composites is the processing parameters used. Several studies have been carried out on utilizing different types of fibers as efficiently as possible to produce superior quality fiber-reinforced polymer composites for a wide range of applications [12-14].

The aim of this research is to process waste fiber reinforced polymer matrix composites and to determine their mechanical and thermal properties. Fabrication of randomly oriented textile waste fiber reinforced polypropylene matrix composites with varying fiber distribution at different weight percentage were carried out.

2. Experimental

Sample Preparation

Pure polypropylene (pp) sheets were collected from local market. It has a melting point that ranges from 160 to 180°C. Waste polyester fibers were collected from a local textile industry. PP sheets were cut into 150 mm*150 mm size and weighed. Fibers in different amounts (10%, 20% and 30%) and distributions (2, 3 and 4 layers) were placed into PP sheets. Then hot pressing was carried out. A pressure of 30kN was applied. Initially the temperature was allowed to rise 160ºC and kept at this temperature for 10 minutes. Then again the temperature was increased up to 180ºC–190ºC and kept at this temperature for 10 minutes. Then the water supply line was turned on and after cooling the sample was then removed from the die.

Tensile Test

For 10mm span length, polyester fiber's tensile properties were measured by using Instron Machine. The crosshead speed was maintained at 2mm/min. and a 10 N load cell was used. The tensile strength of the composites was determined by using the Universal testing machine of model INSTRON 3369. ASTM D638 was followed for making the tensile specimens

Flexural Test

The three-point bend test of the composites was performed. The flexural test specimens were prepared by following ASTM D 790-98.

Hardness Test

Hardness test of the composites was carried out in Shore A scale by Bareiss HPE II Hardness Tester by following ASTM D2240.

Impact Test

The dynamic Charpy impact test of the composites was conducted by using an impact tester MT 3016.Specimen was prepared according to ASTM D 6110-97.

Field Emission Scanning Electron Microscopy (FESEM) Analysis

The FESEM images of the fracture surfaces of the tensile specimens were performed in order to understand and investigate the tensile test results.

Thermo-Gravimetric Analyzer (TGA)

TGA analysis was performed for the composites in order to study the effect of the presence of fiber on the thermal stability of PP matrix. TGA test started at room temperature and ended at 650ºC temperature. Heating rate was 10ºC/min.

Differential Thermal Analysis (DTA)

The melting temperatures of the composites were measured with SII EXSTAR TG/DTA 6300. For DTA a piece of about 25 mg sample was placed into a Pt pan. For melting temperatures, the samples were scanned up to 650^{O}C at a rate of 10^{o}C/min under nitrogen gas atmosphere.

3. Result and Discussion

Tensile Test

The average tensile strength of 0.25 mm dia and 0.4 mm dia polyester fibers were 36.16 MPa and 12.61 MPa respectively and the modulus were 25.19 MPa and 11.36 MPa respectively. Fibers with larger diameter have a greater chance to have a large flaw and will therefore be weaker than smaller fibers [16].

Tensile test of 2, 3, 4 layers of 10% waste fiber reinforced polypropylene composites was performed and their results are illustrated in Fig. 1 and Fig. 2. It was observed that 3 layers 10% waste fiber reinforced polypropylene composite showed better tensile properties. The main reason for higher tensile strength in three layers fibers were the uniform distributionof the fibers throughout the polypropylene matrix and also the absence of the formation of clusters of fibers within PP matrix.

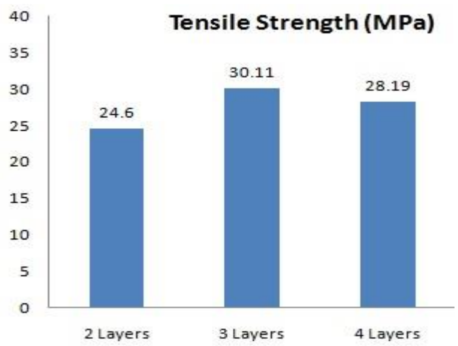


Fig. 1 : Variation of tensile strength with fiber layer

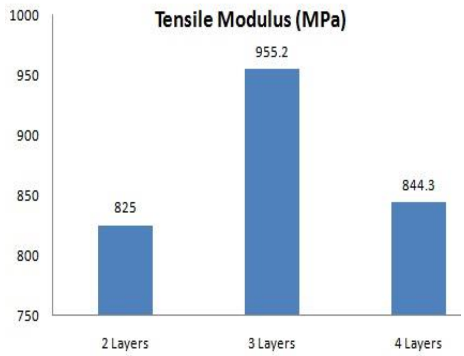


Fig. 2 : Variation of Young's modulus with fiber layer

Tensile test results of unreinforced PP and composites (10%, 20% and 30%) are illustrated in Fig. 3 and Fig. 4. It was observed that tensile strength of the composites decreased with increasing volume fraction of fiber. The tensile modulus of the composites increased up to a certain amount and then decreased. This behavior can be explained by the presence of voids in the composites. These voids caused poor bonding between PP and waste fiber [17].

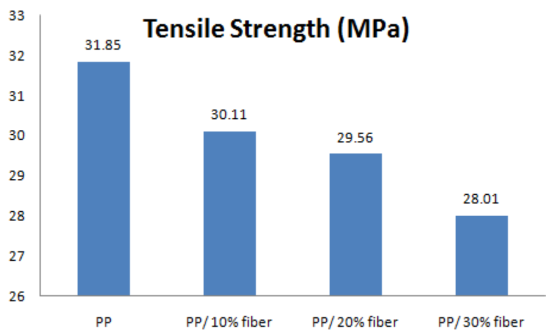


Fig. 3: Variation of tensile strength with fiber wt%

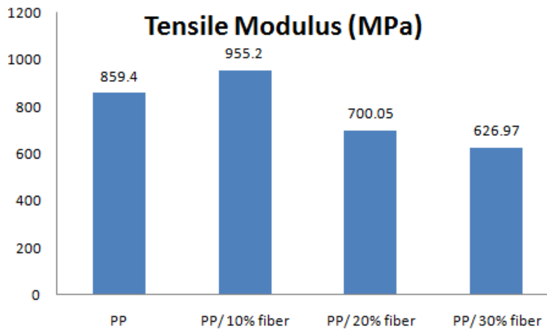


Fig. 4: Variation of Young's modulus with fiber wt%

Flexure Test result

Flexural test of 2, 3, 4 layers 10% waste fiber reinforced polypropylene composites was performed and their results are illustrated in Fig. 5 and Fig. 6. It was observed that 3 layers 10% waste fiber reinforced polypropylene composite had much better flexural properties than others. In three layers, fibers are more uniformly distributed throughout the polypropylene matrix.

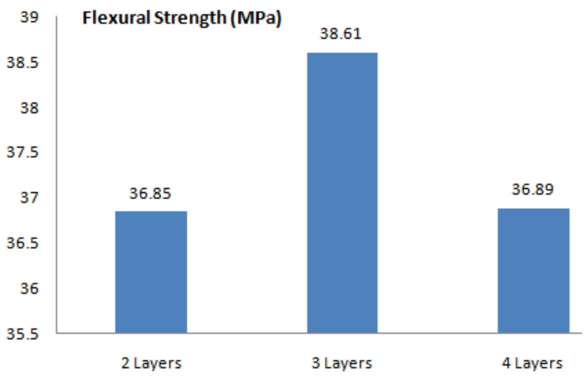


Fig. 5: Variation of flexural strength with fiber layers

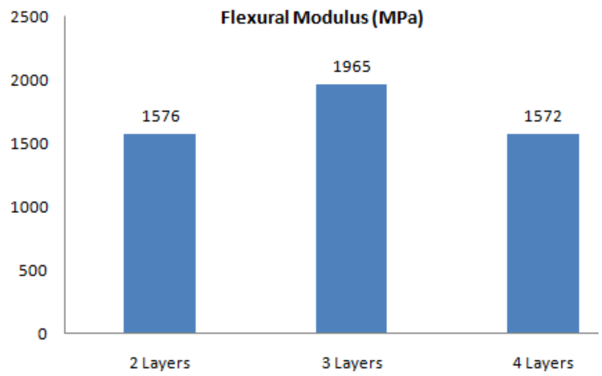


Fig. 6: Variation of Flexural modulus with fiber layers

Flexure test results of unreinforced PP and composites (10%, 20% and 30%) are illustrated in Fig. 7 and Fig. 8. It was observed that flexural strength of the composites decreased with increasing volume fraction of fiber. The flexural modulus of the composites increased up to a certain amount and then decreased.

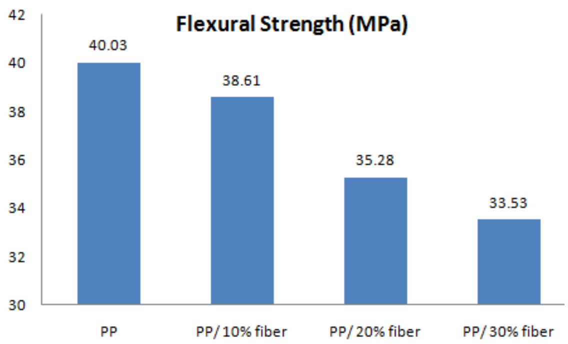


Fig. 7: Variation of flexural strength with fiber wt%

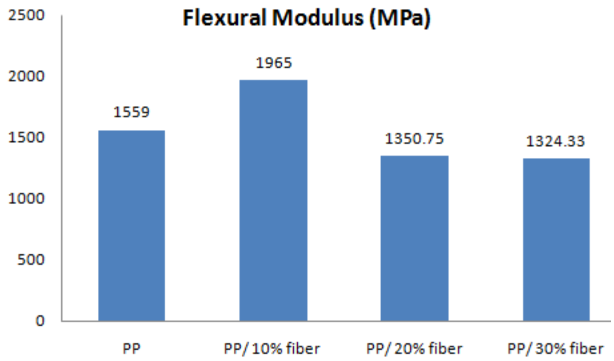


Fig. 8: Variation of flexural modulus with fiber wt%

Impact test result

Impact test of 2, 3, 4 layers 10% waste fiber reinforced polypropylene composites was performed and their results are illustrated in Fig. 9. It was observed that 3 layers 10% waste fiber reinforced polypropylene composite had much better impact strength than others. In three layers, fibers were more uniformly distributed throughout the polypropylene matrix. Impact strength of composites increased with fiber volume fraction that is illustrated in Fig. 10. This result suggests that the fiber was capable of absorbing energy because of favorable entanglement of fiber and matrix.

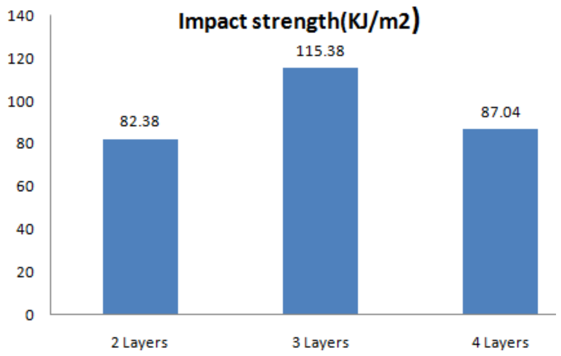


Fig. 9: Variation of Impact strength with fiber layers

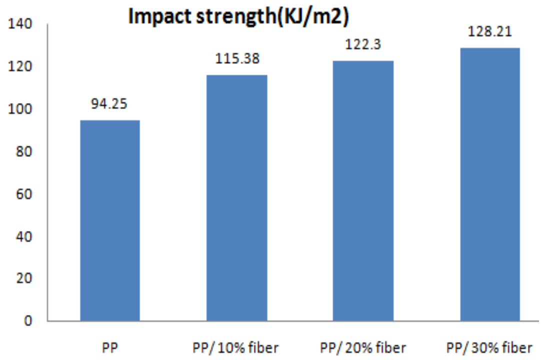


Fig. 10: Variation of Impact strength with fiber wt%

Hardness test result

From the Hardness test results that are illustrated in Fig. 11, it was observed that 2, 3, 4 layers 10% waste fiber reinforced polypropylene composites had much similar hardness values. The lower values of hardness at higher fiber volume fraction that is illustrated in Fig. 12 are due to the presence of voids and porosity. Voids caused de-bonding of the fiber and matrix which results poor matrix-fiber adhesion.

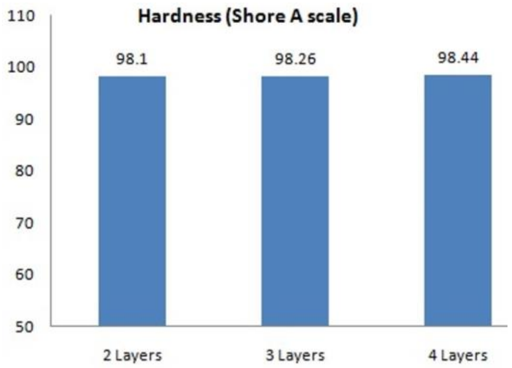


Fig. 11: Variation of Hardness with fiber layers

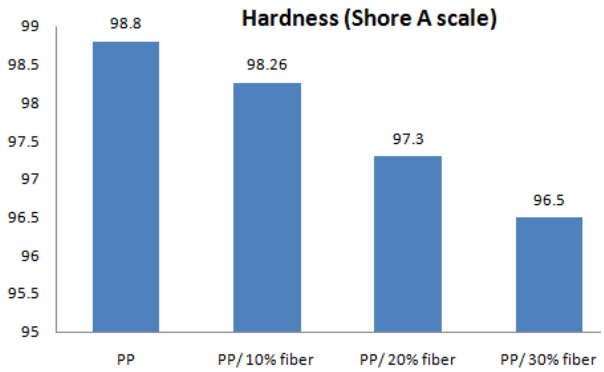


Fig. 12: Variation of Hardness with fiber wt%

SEM Analysis of Fracture Surface

Tensile fracture surface of 10% waste polyester fiber reinforced polypropylene composite is shown in Fig. 13. The main reason for poor mechanical properties in polyester fiber reinforced composites was the weak bonding between the fiber and matrix and this is evidential in the micrograph. The important feature of this micrograph is that fractured fiber surface and fiber pull-out are shown.

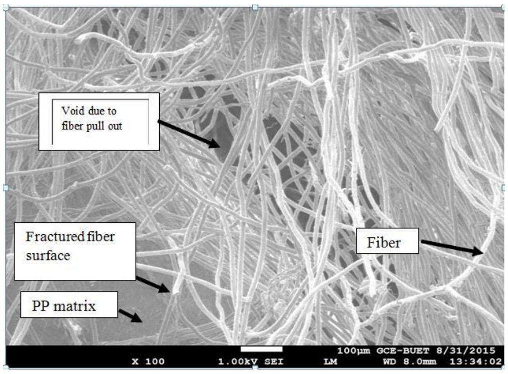
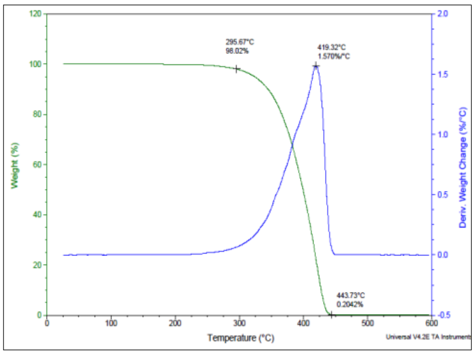


Fig. 13: Tensile fracture surface of 10% polyester fiber reinforced polypropylene composite100x

Thermal Gravimetric Analysis (TGA)



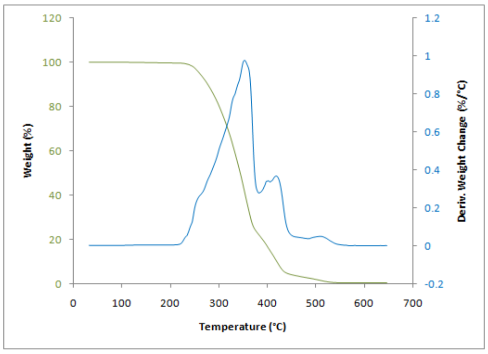
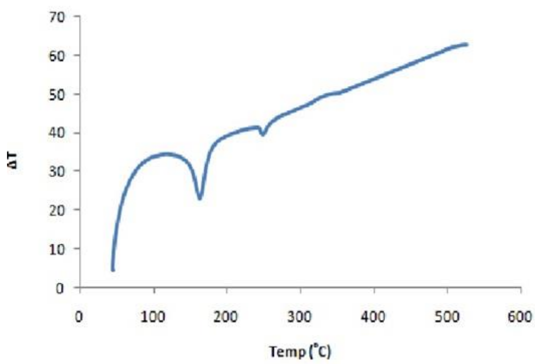


Fig. 14: TGA curve for PP

Fig. 15: TGA curve for PP/ fiber (80/20) composite

Fig. 14 and Fig. 15 show that PP and PP/Polyester (80/20) composite start to decompose respectively at 296ºC and 235ºC. So addition of polyester fiber decreases the thermal stability of PP. After heating and decomposition of PP is completed, negligible residual substance remains due to the extremely volatile nature of PP. In the case of PP/Polyester (80/20) composite almost 5% residual products are obtained after decomposition. This is due to some non-decomposable organic oxides and impurities present in the composite.

Differential Thermal Analysis (DTA)



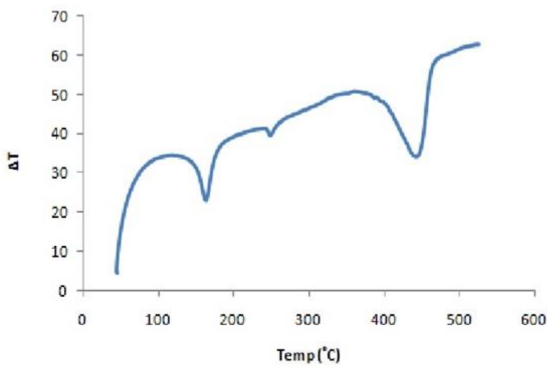


Fig. 16: DTA curve for PP

Fig. 17: DTA curve for composite (80/20)

First DT/ [illegible] ndothermic [illegible] two endothermic peaks for composite because of the presence of waste fiber. First thermal event represents melting temperature of polypropylene and second thermal event represents the decomposition of waste fiber.

4. Conclusions

In hot pressing it is very difficult to obtain uniform distribution of fibers within PP matrix. By distributing fibers within PP sheets at 2, 3 and 4 layers of 10% waste fiber reinforced PP composites were made to obtain uniform fiber distribution and to get the desired results. In 3 layers 10% waste polyester fiber reinforced PP composite, fibers were more uniformly distributed than other systems and no clusters of fibers formed within PP matrix. From the experimental results it was evident that 3 layers composite showed better tensile properties, flexural properties, impact properties & hardness. With increasing fiber volume fraction, tensile and flexural strength of the composites decreased. Elastic and flexural modulus increased with increasing the volume fraction of fiber up to a certain amount and then decreased again. Impact strength increased with fiber volume fraction however hardness value decreased. SEM showed poor adhesion between matrix and fiber. TGA suggested slightly lower thermal stability of composites than that of pure PP. DTA has been carried out to study the thermal event during thermal analysis of PP and composite (80/20).

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