Mechanical And Thermal Characteristics Of Polypropylene Reinforced With Spheri-glass-3000 Produced By Twin Screw Extruder

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ABSTRACT

The use of polymer reinforced with fillers has increased in recent years as their properties have improved. The thermoplastic matrix chosen for this study was Polypropylene (PP) and reinforcement as Spheri-glass-3000 (SGS). The melt mixing method was used to produce PP/SGS nanocomposites with the aid of twin-screw-extruder. Test samples was manufactured by injection-molding-machine. The mechanical and thermal properties of the PP/SGS nanocomposites produced have been investigated. Field-emission-scanning- electron-microscope was employed to examine SGS dispersion in the PP matrix. When SGS was added at 2.5 wt. % there was an increase in mechanical characteristics and tvhermal characteristics improved at 7.5 wt. % addition of SGS in PP matrix.

Keywords: Extrusion; Impact strength; Spheri Glass 3000; Differential scanning calorimetry.

1. INTRODUCTION

Adding fillers to thermoplastic polymers and designing thermoplastic polymer composite products with customised properties has increased the engineering applications of thermoplastics and thermoplastic composites in recent decades. Thermoplastic materials reinforced with fillers are used in the medical, aerospace and automotive sectors. Pure polymers are typically reinforced with different fillers to form polymer nanocomposites, which is a significant way to increase the effectiveness of virgin polymers. Compared to virgin polymers, the mechanical properties, thermal properties, barrier properties and wear rate of polymer nanocomposites are superior (Daniel and Panneerselvam 2019). The factors influencing the strength of polymer nanocomposites are (i) the size of the reinforcement selected, (ii) bonding characteristics of the filler and matrix, and (iii) the polymer nanocomposite manufacturing process.

According to (Dekkers and Heikens 1983) adding glass to the polystyrene matrix enhanced the tensile properties, owing to the filler's adhesion to the matrix. (Vyazovkin, Sbirrazzuoli, and Dranca 2004) examined the thermal degradation of polystyrene nanocomposites and virgin polystyrene under the nitrogen conditions. They also noted that virgin polystyrene samples degraded without any residue formation. The first study on the thermal stability of biodegradable nanocomposites containing polylactide and organically modified fluorohectorite or MMT was reported by (Krikorian and Pochan 2005). Thermal degradation was resistant to the polylactide intercalated between the galleries of fluorohectorite or MMT. (Altan and Yildirim 2010) reinforced PP by 5wt. % nano Al2O3 and found that there was an increase in loss modulus values. (Yoo, Spencer, and Paul 2011) used two reinforcements to nylon6, organoclay and glass fiber, and studied their impact strength characteristics. They came to the conclusion that adding glass fibres increased impact strength while adding organoclay decreased it.

Proper mixing of fillers with polymers can only be achieved if there is a strong chemical bond between the matrix and the fillers with better dispersive forces between them. The weak dispersion, on the other hand, is due to the incomplete mixing of fillers in the polymer, forming a void surface. Among the manufacturingmethods for melt intercalation is the most commonly used one (Watt et al. 2020). Melt intercalation was initially performed by Toyota Research Center,

and later by many others in which partial or complete exfoliation was achieved. A twin or single screw extruder or a brabender plasticorder is used in the melt intercalation process. (Ray and Okamoto 2003) concluded that the melt intercalation methods have added an advantage over other methods due to their environmental-friendly functionality. The lack of organic solvents during the above mentioned process is a key consideration when choosing this method. During the process of twin screw extrusion process the crucial factors considered are feeder screw rpm, polymer residence time inside the extruder, twin-screw speed, temperature profile, and cooling time (Daniel and Panneerselvam 2016). The majority of polymers like PP, Polyamide (PA6), Ethylene Vinyl Acetate (EVA), polyolefins and Polycaprolactone (PCL), etc., are selected for major of research process.

(Cho and Paul 2001) investigated the effects of PA6 nanocomposites using single and twin screw extruders. When nanocomposites were made with a single screw extruder, the fillers were not blended properly. The increase in tensile strength was noted when it was manufactured using a twin-screw-extruder. The end properties depends upon the parameters selected for processing.

Polyolefins are responsible for the production of approximately 90-100 billion kg of thermoplastic materials in each year. PP is an essential thermoplastic material used because of its less cost, easy to process and availability. Polypropylene (PP) accounts for approximately 20 percent of polyolefin production. PP is the most frequently used thermoplastic, according to Jafrey and Panneerselvam [12], because of its combination of mechanical, physical, and recyclability properties. PP also has some disadvantages such as inferior strength characteristics, poor stiffness and poor in-service temperature which make PP unfit for most applications. To resolve these disadvantages, certain filler like talc and mica were reinforced with PP initially. While some properties changed with the inclusion of fillers, there was improvement in several properties. Nanotubes, glass fibers and several types of fillers have been reinforced to the PP matrix to solve the drawbacks. Although the properties of PP reinforced with different fillers have been documented in previous literature, work on SGS reinforced in the PP matrix has not been published elsewhere. The work began with the use of a twin-screw-extruder to melt intercalate PP/SGS nanocomposites, which was followed by injection moulding to prepare the test specimen.

2. EXPERIMENTAL

The selected materials, the manufacturing processes and the characterization methods are discussed in the following sections.

2.1   Materials

The material chosen for this project is PP with the grade name Repol H110MA. In this study, the reinforcement selected was SGS which was acquired from Potters industries.

2.2   Manufacturing of PP/SGS nanocomposites

Twin screw extruder was used for manufacturing of PP / SGS nanocomposites with a 40:1 L/D ratio. The designation of the material and its composition are given in Table 1. The process parameters of the extrusion process was selected from our previous studies (Daniel and Panneerselvam 2016). The screw-speed was maintained at 65 rpm, with a 7 rpm inlet feed rate. The strands coming out of die was water cooled. Finally, pelletizer was used for cutting the strands of size 3 X 3 mm (Daniel and Panneerselvam 2019).

Table 1. Material Designation and their compositions

Materials Description	PP (wt. %)	SGS (wt. %)
PP-1	98.75	1.25
PP-2	97.5	2.5
PP-3	95	5
PP-4	92.5	7.5

2.3 Injection Molding of Extruded PP/SGS samples

A horizontal injection moulding system is used to make characterization samples. The temperature was set at 180°C-220°C, die locking pressure at 130 bars, injection pressure at 90 bars. Once the moulding is completed it was water cooled for 30 seconds.

2.4 Characterization methods

The manufactured PP / SG3 nanocomposites were characterized as follows on the basis of their mechanical and thermal characteristics.

2.4.1 Mechanical characteristics of manufactured PP/SGS composites

PP/SG3 composites were determined in accordance with ASTM D638-14 and ASTM D790-10 for their tensile and flexural properties. The manufactured PP/SG3 nanocomposites were examined for impact strength by computerized impact testing machine. Impact test was used for evaluating the toughness characteristics with accordance to ASTM D256-10. Hammer was released at an angle of 150°, and the hammer force used was 6.5 J.

2.4.2 DSC

The melting temperature (Tm) of manufactured PP/SG3 nanocomposiites was found out by DSC using DSC 6000 – PerkinElmer apparatus. The PP/SGS samples were placed in a closed ceramic pan. DSC experiments on PP/SGS nanocomposites were carried out in a nitrogen environment at temperatures ranging from 30°C to 220°C which was heated at 10°C/min.

2.4.3 TGA

Thermogravimetric Analysis (TGA) was done on manufactured PP/SGS nanocomposites to find the thermal characteristics of the manufactured PP/SG3 composites at 600°C. TGA of PP/SGS nanocomposites was carried out using TGA 4000 Thermogravimetric analyzer (Make: Perkin Elmer machine). TGA samples of PP/SGS nanocomposite ranged in size from 5 to 10 mg, with heating temperatures ranging from 30°C to 600°C in a nitrogen atmosphere.

2.5 Field Emission Scanning Electron Microscope

The dispersion characteristics of the manufactured samples were done using (FESEM).

3. RESULTS AND DISCUSSION

3.1 Tensile strength

Tensile strength and modulus of the fabricated PP/SGS nanocomposites are shown in Figures 1(a) and (b). The tensile strength and tensile modulus of the PP-2 samples was higher among the manufactured composites. The strong interfacial adhesion and fine dispersion of SG3 in the PP matrix improved tensile strength and tensile modulus characteristics, as shown in Figure 2(a). The main reason for the increase in tensile strength and tensile modulus is the transfer of stress between the matrix and the filler, as well as the strong bonding between them. When the addition of SGS was beyond 2.5 wt. % in PP / SGS composite, the lack of homogeneous structure transformation results in decrease in the tensile modulus and tensile strength. When SG3 was added at 7.5wt. % (i.e. PP-4) in the PP matrix, the dispersion of SGS was very difficult during the manufacturing, and it led to agglomerated structure as depicted in Figure 2 (b). The agglomerated structure produced a localised stress concentration on the surface, resulting in a decrease in tensile strength and modulus. Tensile strength was reduced as a result of the poor bonding strength between the PP and the SG3. The observed tensile strength and tensile modulus results were also consistent with (Yan, Lin, and Bhattacharyya 2006) findings.
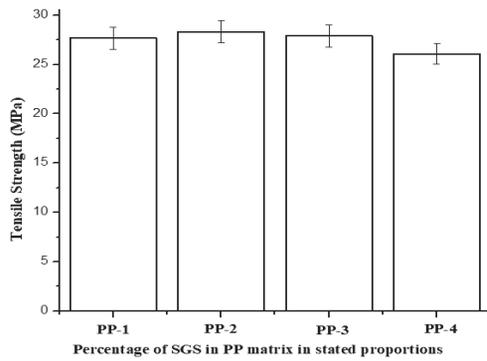
Figure 1(a). Tensile strength of PP/SGS nanocomposites in stated proportions
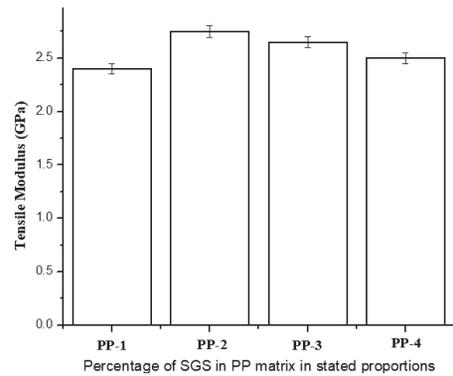
Figure 1(b). Tensile modulus of PP/SGS nanocomposites in stated proportions
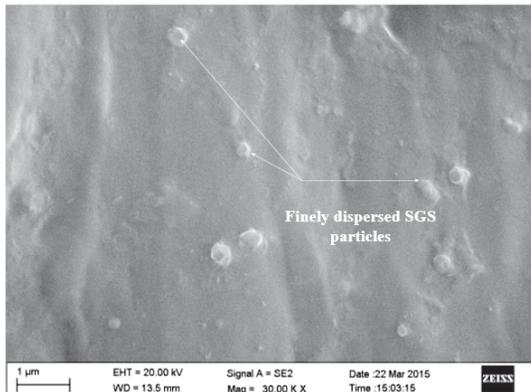
Figure 2 (a). FESEM image of PP-2 (2.5 wt. %) composite
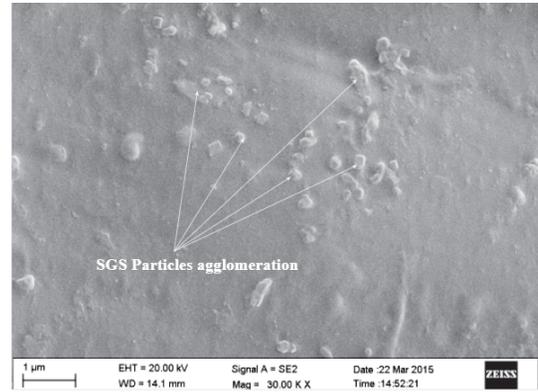
Figure 2 (b). FESEM image of PP-4 (7.5 wt. %) composite

3.2 Flexural strength

The upper half of the flexural samples were in the state of compression while the lower half   was in the state of tension when flexural strength was carried out. This phenomenon has made it difficult to spread the crack on the tension side, which was a vital reason for increase in flexural strength. The flexural strength of PP/SGS nanocomposites at various weight percentages is shown in Figure 3. When 2.5 wt. % (i.e.PP-2) of SGS was added to the PP matrix, the flexural strength was higher. The increased flexural strength was due to the fine dispersion of SGS in the PP matrix. The fine dispersion of SGS in the PP matrix at 2.5wt. % increased the interfacial area. Stress transfer was improved as the interfacial area was increased, resulting in increased flexural strength in the case of PP-2 samples. In the case of PP- 2 samples flexural strength was more. As the addition of SG3 to the PP matrix exceeds 2.5 wt. %, the flexural strength characteristics decrease, in comparison to the tensile strength characteristics. This was due to SG3 particles agglomeration, resulting in poor interfacial adhesion of SG3 and PP. Because of this, SGS-SGS interactions occurred rather than PP-SGS interactions.

3.3 Impact strength

The impact strength of various manufactured PP/SGS composites is depicted in Figure 4. The impact strength was maximum when 1.25 wt. % (i.e. PP-1) SGS addition to PP matrix. There was a decrease in impact strength when the addition of SGS was greater than 1.25 wt. %. When SGS was added to the PP, its toughness decreased, resulting in a decrease in impact strength. When SGS was added at higher concentrations, agglomerated structure was formed which resulted in great inhomogeneity and also reduced the impact strength. (Phang et al. 2005) reported a similar reduction in the impact test values for nylon 6 composites, in which they concluded that the addition of fillers above a certain level had reduced the impact strength.
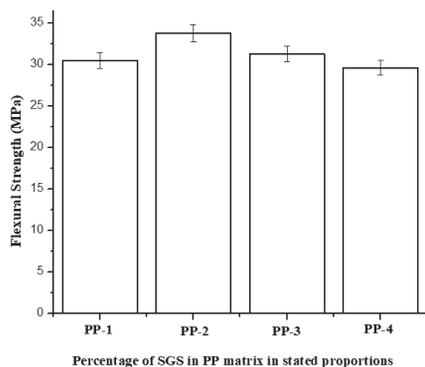
Figure 3. Flexural Strength of PP/SGS in stated proportions
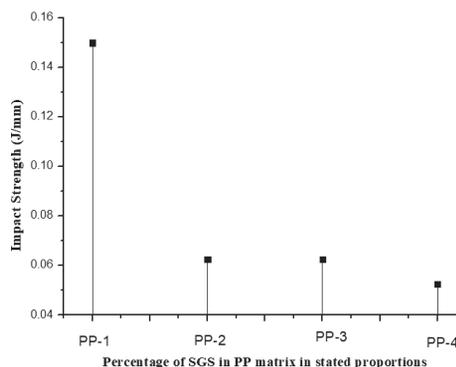
Figure 4. Impact Strength of PP/SGS composites in stated proportions

3.3 DSC

The melting temperature (Tm) of the manufactured PP/SGS nanocomposites was investigated using DSC, and the heating curves of the PP/SGS composites are depicted in Figure 5. Tm values showed only a slight deviation, which confirmed that the addition of SG3 particles acts as a nucleating agent. As a result, adding 7.5 wt. % of SGS (i.e. PP-4) to the PP matrix resulted in a higher Tm value. The increase in Tm value was due to the increase in thickness of lamellar which results in reduction of mobility of PP. Adding SGS to PP matrix might act as a thermal insulator, which in turn increased Tm values at higher levels (i.e. 7.5 wt. %). (Di et al. 2004) have published similar findings.

3.4 TGA

TGA of the manufactured PP/SGS nanocomposites is depicted in Figure 6. It was analyzed for characteristics such as decomposition-temperature, onset- temperature, and char-residue values are reported in Table-2. When the reinforcement was reinforced from 1.25 wt. % to 7.5 wt. %, the onset temperature increased from 329.67 °C to 340.73 °C, which was attributed to efficient heat transfer between PP and SGS. As a result, incorporating SGS into the PP matrix improved the PP / SGS nanocomposites' initial thermal stability. As the percentage of SG3 in the PP matrix was increased, the decomposition temperature of PP / SGS nanocomposites increased from 458.67 ° C to 466.73 ° C. The plausible reason for increase in decomposition temperature is due to the better transfer of stress between the SGS and the PP matrix. When SGS was added at 7.5 wt. % (i.e. PP-4) to the PP matrix, the amount of char residue at 600 °C was higher, indicating that it is has more thermal resistance.
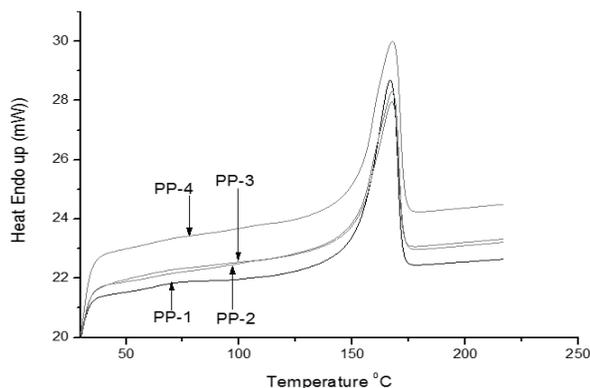
Figure 5. DSC thermograms of PP/SGS in stated proportions
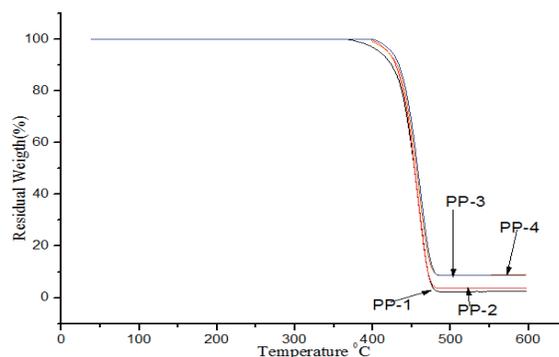
Figure 6. TGA thermograms of PP/SGS composites in stated proportions

CONCLUSION

A twin screw extruder was used to produce the PP/SGS nanocomposites. The PP / SGS nanocomposites manufactured were characterized on the basis of their mechanical characteristics and thermal characteristics. The observation from the present study are

- The tensile strength, tensile modulus and flexural strength was better in the case of PP-2 samples. Improved SG3 adhesion in the PP matrix and good interaction between them result in improvement in properties. There was a development of agglomerated structure when the addition was greater than 2.5 wt. %, resulting in reduction of tensile strength, tensile modulus and flexural strength properties.

- The impact strength was maximum in the case of PP-1 samples. The decrease in impact strength is due to the ductile to brittle transition in the case of other samples.

- In the case of PP – 4 composites there was an increase in thermal stability of PP/SGS composites due to formation of agglomerated structure

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