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Research Article

Thermal Adsorption and Mechanical Behaviour of Polypropylene Hybrid Composite Synthesized by Glass/Hemp Fibre via an Injection Moulding Process

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Thermoplastic-based polymers are gathering importance in several engineering fields like electrical, electronic, automotive, aerospace, and structural. The additions of secondary phase reinforcements such as natural and synthetic fibre improve thermoplastic-based polymer's properties. The thermoplastic and natural fibre combinations are found to have low mechanical strength and incompatibility and need special treatment for synthesizing the natural fibre. The present experimental investigation deals with the enhancement of polypropylene hybrid composite by using the combinations of glass (synthetic)/ hemp (natural) fibre for the ratio of 0 : 35, 5 : 30, 10 : 25, and 15 : 20 reinforced with 5 wt% compatibilizer through injection moulding. The revealed test results of polypropylene hybrid composite showed improved mechanical impact and flexural and tensile strength of 37.5%, 14.2%, and 21.1%, respectively. The thermal adsorption characteristics were evaluated by thermogravimetric analysis apparatus. It showed the decomposition of composite limited by hemp fibre at 27°C to 700°C.

1. Introduction

Recently, automotive industries are expanding their demand for new lightweight materials with good corrosion resistance, higher strength, and good thermal behaviour at low cost. To meet the above demands, industries are interested in natural fibre-based polymer matrix composite as the best alternative material, which is reinforced to the filament, nanofiller, and fabric, which leads to increased composite performance [1, 2]. In the past decades, natural fibre-reinforced thermo-/thermoset plastic composites improved tremendously in the automobile industries. It could make an environmentally user-friendly, economic, reduced weight, and renewable composite, resulting in increased strength and fuel economy [3–5]. Most common natural fibres like kenaf, flax, hemp, and jute have less density, are easy to process, and are low cost compared to synthetic fibre [6–9]. So, polymer matrix composites bonded with natural fibre gained awareness in various engineering fields, researchers, and industries. However, the main drawback of natural fibre-reinforced polymer composite was reduced compatibility, poor elongation, and lower impact strength [10, 11]. It was essential to adjoin a minor amount of synthetic fibre added into natural fibre-reinforced polymer composite via physical or chemical, which resulted in increased compatibility [12].

Similarly, the combined weight could be reduced with increased performance of composite that leads an economic operation at applications of the automobile, structural, and aerospace [13, 14]. The current choice of polypropylene (PP), polyvinyl chloride, and polythene has been considered as matrix material due to their extreme performance of robust, reliable, easy to process, economic, and good thermal stability compared to conventional thermoplastics. So it was used for lining materials for automotive applications [15–17]. The polypropylene-based polymer was enhanced via natural hemp fibre for automotive components via various techniques like compression moulding, resin transfer moulding, vacuum impregnation, and hand layup [18, 19]. The polypropylene composite was developed using 40 wt% of hemp fibre through a compression mould assisted with the film stacking route.

The result found high stiffness and strength compared with all other natural fibres [20, 21]. The carbonized bone ash particulate-reinforced compression mould route results in synthesized polypropylene composite showed good wear resistance [22, 23]. The biopolymer composites were synthesized with chopped hemp by extrusion setup injection mould technique. The experimental results found that the presence of chopped hemp fibre enhanced the stiffness and flexural strength of the composite [24]. Similarly, bioplastic composites were developed from hemp fibre [25]. The author investigated the effect of fibre loading on the mechanical and thermal performance of hemp-reinforced polypropylene composite [26]. They found that the presence of natural hemp fibre has good thermal stability and enhanced mechanical strength compared to unreinforced polymer composites. Recently, polymer coating techniques on conventional steel materials were increased on low-cost fabrication with increased corrosion resistance [27]. One of the researchers found good tribological performance on the polypropylene composite reinforced with basalt fibre [28]. However, the hybridization of natural fibre composite is an excellent choice to overcome the composite's poor compatibility and strength. It facilitates reducing the process cost, increasing the thermal performance, limiting the wear, and enhancing the composite's mechanical properties. Therefore, the current research focuses on fabricating the polypropylene hybrid composite, and their thermomechanical characteristics are enhanced with the secondary reinforcement fibres like glass/hemp. The additions of 5 wt% compatibilizer increase the polypropylene/glass/hemp fibre combination adhesive properties. The developed polypropylene hybrid composite thermomechanical properties are evaluated through ASTM test standards.

2. Materials and Processing Details

2.1. Materials. The PP6331 grade polypropylene is chosen as matrix material, which has a density of 0.90 g/cc and 1.71 g/10 min melt flow index during hybrid composite processing at 230°C. The selected PP6331 grade polypropylene has enhanced properties like high stiffness, good heat deflection, and good compatibility and is suitable for food and medical product storage with microwavable reheating [2].

The natural hemp fibres are chopped to -12 mm size, and the polypropylene composite with hemp fibre is enriched with a minor amount of E-glass fibre (10 mm) to hybridize polypropylene resulting in increased mechanical and thermal performance. Among the various natural fibres, hemp fibre is very cheap, strong, and durable.

2.2. Synthesis of PP6331 Hybrid Composite. Polypropylene hybrid composite is prepared with the constitutions of glass/hemp fibre hybridization by using compatibilizer as mentioned in Table 1. Initial stage, the required quantity of polypropylene (PP6331) and glass/hemp fibres are weighted by digital balancing machining configured with ±0.01 g accuracy. The weighted polypropylene and glass/hemp fibres were blended with the help of an electronic-assisted mechanical stirrer operated at 80-100 rpm speed for 10 min durations at 180°C temperature. After delicate blending of both polypropylenes, glass and hemp fibres were mixed with 5 wt% of compatibilizer to enhance the adhesive properties between the polypropylene matrix and fibre [22].

The thoroughly blended matrix and fibre constitutions are fed into the injection mould via a hopper, continued with screw-type drive motor pass granules into the injection nozzle. Finally, the molten mixture is injected into preheated mould die to form the desired shape like $200 \times 20 \times 20$ mm. The developed composites are cooled by natural convection at elevated temperatures. The prepared polypropylene hybrid composite samples are shown in Figure 1.

2.3. Evaluation Procedure for Testing of Developed Polypropylene (PP6331) Hybrid Composites

2.3.1. Thermal Adsorption Behaviour of PP6331 Hybrid Composites. The thermal adsorption performance on the degradation of PP6331 hybrid composite is evaluated by thermogravimetric analysis (TGA) configured with the maximum temperature range of 1000°C. The Q500 series TGA is used to find the effect of thermal radiation on the degradation of composite weight loss during 27°C to 700°C at 25°C/min heat flow rate.

2.3.2. Heat Deflection Temperature Studies on Developed PP6331 Hybrid Composites. The heat deflection effects on developed polypropylene hybrid composite samples are estimated by the ASTM D648 standard. A three-jaw point fixes the test sample, and the heat is supplied by 23°C/min.

2.3.3. Mechanical Properties of Developed PP6331 Hybrid Composites. The mechanical properties of developed PP6331 hybrid composite samples are experimentally tested by the ASTM test standard. The Izod impact toughness of polypropylene hybrid composite was tested by an impact tester configured with 0-300 J capacity pursued via ASTM D256 (63.5 mm × 12.7 mm × 12.7 mm). The universal tensile test equipment was utilized to evaluate the tensile and flexural strength composite under the cross-slide speed of 10 mm/min. It was estimated by the standard of D638 (165 mm×19 mm×13 mm) and D790 followed ASTM.

Table 1: Constitution of polypropylene (PP6331) hybrid composite.

Sample	Weight percentages in wt%			
	PP6331	Compatibilizer	E-glass fibre	Hemp fibre
1	60	5	0	35
2			5	30
3			10	25
4			15	20

Figure 1: Developed polypropylene (PP6331) hybrid composite samples.

3. Results and Discussions

3.1. Thermal Adsorption Studies. The thermal adsorption properties of developed (PP6331) polypropylene hybrid composite samples are estimated by the thermogravimetric apparatus. The effect of glass/hemp fibre on the polypropylene composite decomposition range is evaluated by the constant heat flow rate of 25°C/min with a temperature span of 27°C to 700°C. Figure 2 illustrates the thermal adsorption properties of E-glass/hemp fibre-reinforced polypropylene hybrid composite with their decomposition weight.

During the starting stage, the composite temperature was 27°C at 25°C/min heat flow rate, showing 100% weight, while the increase in the temperature of more than 27°C represents progressive weight loss. It was due to the degradation of polypropylene structure with redistricted fibre movement at a higher temperature. The decomposition initiated by more than 220°C showed a two-step degradation curve up to 310°C. It was because incorporating compatibilizer in the polypropylene hybrid composite increases the adhesive properties, resulting in the decomposition rate on two stages mentioned in the two-step curve. It was found in minor physical changes. This physical change may be varied due to interfacial bonding between fibre and matrix. However, the interfacial bonding strength was increased by adding a 5 wt% compatibilizer which gives better adhesive properties. The management of thermal adsorption and its steady state flow may change the phase during steam generation applications [29]. The primary decomposition rate was observed from 296° to 302°C, but the composite containing 15 wt% glass showed better thermal ability than all others. The glass fibre has good thermal and mechanical properties, while the fibres combined with natural hemp fibre found good thermal stability. Similarly, the weight loss of 75%, 50%, and 25% percentage of the composite was valued in Table 2. Moreover, the presence of glass fibre has enhanced thermal stability with reduced degradation of composite values referred from Table 2, and the 75% weight loss occurred by the temperature range from 272°C to 324°C. Similarly, 50% and 25% of weight loss were found at 325°C-412°C and 427°C-471°C. More than 550°C found 10-14% weight loss due to the decomposed layers on polypropylene composite. It may lead to a significant physical change in the structure of the composite.

3.2. Heat Deflection Temperature Studies. The influences of heat deflection temperature on glass/hemp fibre-reinforced polypropylene composites are evaluated by the ASTM D648 standard. It is the fundamental data that has been considered during designing a product that needs dimensional stability and can withstand the specific temperature span. Similarly, the materials can maintain the elastic limit and retain their stiffness at room temperature. Figure 3 indicates the heat deflection temperature of polypropylene and its hybrid composite contained glass/hemp fibre.

The heat deflection temperature of PP6331 is 58°C, while adding glass fibre content in PP6331 matrix/hemp fibre increases the deflection temperature from 58°C to 121°C in sample 1 as identified in Figure 3. Similarly, samples 2, 3, and 4 illustrate improved composite heat deflection temperature. The maximum heat deflection temperature of 141°C is found on 60 wt% PP6331/15 wt% glass fibre/20 hemp/5 wt% compatibilizer. It was because their E-glass fibre can withstand the maximum temperature of 324°C with 75% weight loss, which is proved above the thermal adsorption performance curve from Figure 2. Normally, the heat deflection temperature of the composite was enhanced by the inclusion of filler materials [15, 26]. However, the hemp/polypropylene composite is hybridized with E-glass fibre to attain maximum thermal characteristics and retain the stiffness with a reduction of the material's volume. The developed composites are dimensionally stable and are used for automotive door frame, rooftop, and frame applications.

3.3. Impact Strength of PP6331 Hybrid Composites. Figure 4 represents the Izod impact strength histogram illustration of the PP6331 hybrid composite containing glass/hemp fibre. The composite material measurement can resist the high impact force that may damage the structure, like fracture or bending. It is directly connected with material toughness. Here, the minor amount of E-Glass fibre plays a vital role in PP6331 hybrid composite that is able to withstand the high impact load, resulting in the integration of crack propagation without a break of composite. The PP6331 matrix has a low impact strength of 21 J/m. At the same time, the addition of 35% hemp fibre in PP6331 shows 90% improved impact strength.

Further increase in hemp fibre in PP6331 matrix hybridization with 0 wt%, 5 wt%, 10 wt%, and 15 wt% E-glass fibre enhanced the impact strength of PP6331 hybrid composite. The maximum impact strength is 55 J/m, found in sample 4. It is improved 1.6 times of PP6331 and 37.5% of sample 1. However, a small amount of E-glass fibre enhances the resistance against the impact load, and 5 wt% compatibilizer augments suitable adhesive between matrix and fibre. The glass fibres have good fracture toughness properties [22].

3.4. Flexural Strength of PP6331 Hybrid Composites. The effect of E-glass fibre content on the flexural strength of hemp/PP6331 composites is shown in Figure 5. It is observed from Figure 5 that the flexural strength of the PP6331 hybrid

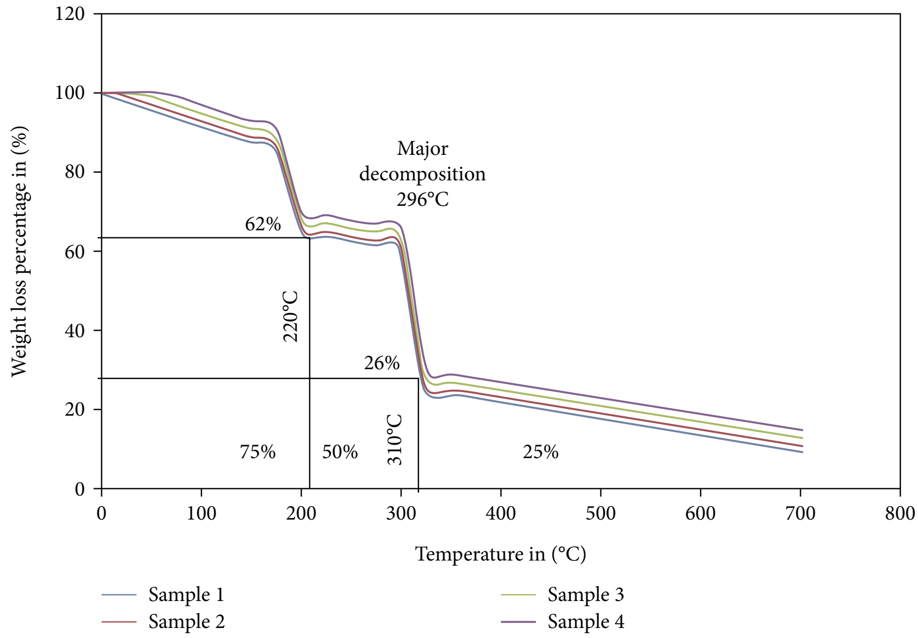

Figure 2: Thermal adsorption curves of PP6331 hybrid composites.

Table 2: Thermal adsorption behaviour of polypropylene hybrid composites.

Sample no.	The temperature range in °C			Weight loss %
	75%	50%	25%	More than 550°C
1	272	325	427	10
2	291	354	440	11
3	315	371	451	13
4	324	412	471	15

composite is increased significantly with the additions of E-glass/hemp fibre. The flexural strength of the PP6331 matrix is 44.1 MPa, and its property is significantly improved by the incorporation of hemp at 35 wt% maximum which shows 91 MPa. Its strength is improved by 1.06 times of PP6331 matrix strength. At the same time, adding E-glass fibre into the hemp/PP6331 matrix has higher flexural strength than the unhybridized PP6331 matrix. The composite containing 5 wt%, 10 wt%, and 15 wt% of E-glass fibre shows a superior flexural strength of 95 MPa, 98 MPa, and 104 MPa. Sample 4 is found to have maximum flexural strength and improved by 1.4 times of PP6331 material and 14.2% compared to sample 1. The increased flexural strength is due to their adequate bonding of shot fibre, which can make good strength and resist fibre movement. One of the authors reported a similar statement during the evaluation of natural fibre-reinforced polypropylene biocomposite [10]. The presence of both synthetic and natural fibre can withstand the maximum tensile load and resist internal movement.

3.5. Tensile Strength of PP6331 Hybrid Composites. The tensile strength variations of the E-glass/hemp fibre-reinforced PP6331 hybrid composite are represented in Figure 6. The overall contribution of fibre is 35 wt%, and the content of E-glass fibre varies from 0 wt% to 15 wt% with an interval of 5 wt%. Similarly, 5 wt% of compatibilizer is added with the PP6331/glass/hemp fibre hybrid composite, increasing the adhesive behaviour of the composite. The tensile strength of developed composites is tested by universal tensile testing apparatus built up manual controller assisted by an electronic plotter. The cross-slide movement is limited to 10 mm/min. Correspondingly, every reaction to physical changes of composite is noted.

The tensile strength of PP6331 is found to be 30.3 MPa, and the incorporation of a glass/hemp fibre ratio of 0 : 35 showed that 52 MPa and 58 MPa are noted on a 5 : 30 fibre ratio (sample 2), which improved by 11.53% compared to sample 1. So, from this, PP6331's hybridization with E-glass fibre is proven. Further increases in E-glass fibre in PP6331 composite found increased tensile strength of composites. It was due to the reaction-free polypropylene matrix that has been perfectly bonded with chopped fibre filler [2, 10]. The higher tensile strength identified from Figure 6 shows that the composite containing 15 wt% of glass fibre/20 wt% of hemp fibre added

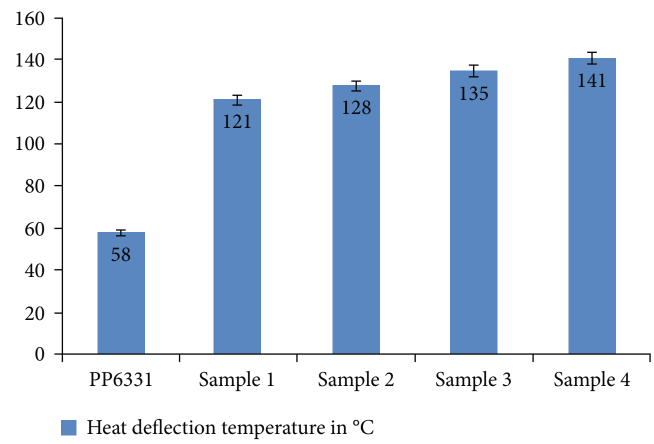

Figure 3: Heat deflection temperature histogram of PP6331 and its hybrid composites.

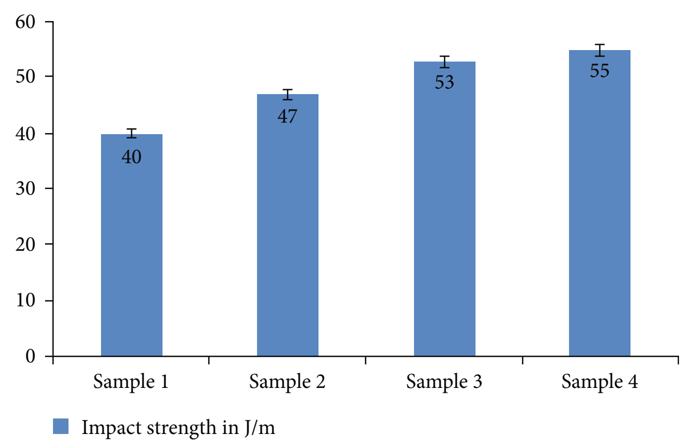

Figure 4: Impact strength of PP6331 hybrid composites.

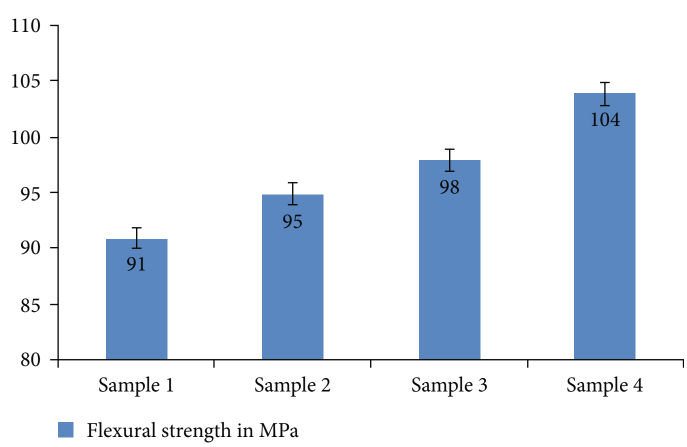

Figure 5: Flexural strength of PP6331 hybrid composites.

with constant weight percentages of compatibilizer (5 wt%) is 63 MPa and improved by 1.07 times of PP6331 matrix and 21.1% of sample 1. The maximum enhancement of the composite was due to the incorporation of hemp, limiting the tensile fracture against the high tensile load.

3.6. SEM Micrograph of Sample 4 Polypropylene Hybrid Composite. Figure 7 illustrates the SEM micrograph of sample 4 polypropylene hybrid composite containing 15 wt% of E-glass fibre and 20 wt% of hemp blended by 5 wt% of compatibilizer. This composite attained maximum tensile, impact,

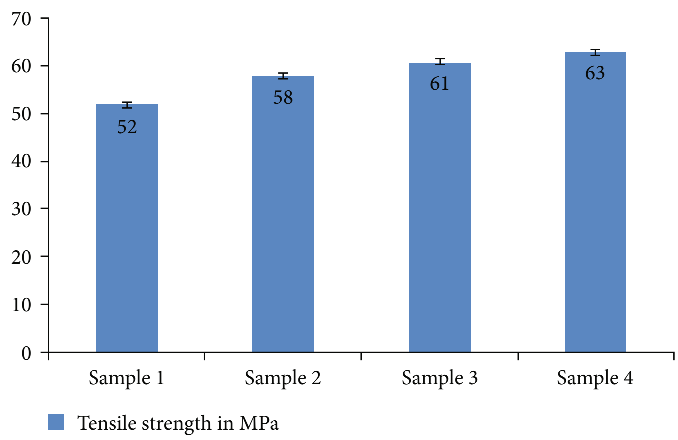

FIGURE 6: Tensile strength of PP6331 hybrid composites.

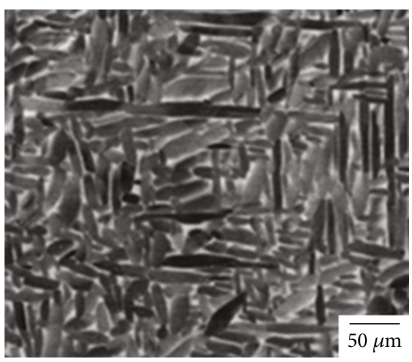

FIGURE 7: SEM micrograph of (sample 4) polypropylene hybrid composite.

and flexural strength compared to other compositions. The micrograph's dark and light field image represents the hemp and E-glass fibre. It was revealed from Figure 7 that both E-glass and hemp fibres interacted with the base matrix. Both fibres were uniformly bonded with a polypropylene matrix phase with increased adhesive properties. It is proof of good interfacial bonding and enhances mechanical and thermal properties.

4. Conclusions

The current investigation of polypropylene hybrid composite thermal and mechanical properties was successfully enriched by using the different weight percentage ratios of 0 : 35, 5 : 30, 10 : 25, and 15 : 20 glass/hemp fibre hybridization with the utilization of 5 wt% compatibilizer via injection moulding technique. The evaluated experimental ASTM test results showed that the thermogravimetric analysis of thermal adsorption properties of PP6331 hybrid composite found that 75% of weight loss occurred at 272°C to 324°C, and 50% and 25% of weight loss were found at 325°C-412°C and 427°C-471°C, respectively. The heat deflection temperature on 60 wt% PP6331/15 wt% glass fibre/20 hemp/5 wt% compatibilizer is 141°C. Therefore, the developed composite with 15 wt% E-glass fibre can be dimensionally stable at higher temperatures for automotive door frames, rooftop, and frame applications. The mechanical properties like the impact, tensile, and flexural strength of sample 4 were found to have a maximum strength of 55 J/m, 63 MPa, and 104 MPa and improved 1.6 times, 1.4 times, and 1.07 times of PP6331 of sample 1.

Data Availability

All the data required are available within the manuscript.

Conflicts of Interest

Authors declare no conflicts of interest.

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