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Effects of Ramie Fiber/Boron Nitride Exposure on the Mechanical Characteristics of Injection-Moulded Polypropylene Composites for Automated Structural Applications

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Research Article

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Abstract

Hybrid fiber/ceramic to polymer matrix combination provides better tensile strength, improved flexural strength, good fracture toughness, durability, improved corrosion resistance, better chemical stability and good thermal behaviour reason; the composites are applied for high strength-to-weight ratio automotive structural applications. The present hybrid polypropylene composite is made with constant weight percentages of ramie fiber (chemically treated) and boron nitride (BN) particles (50nm) via an injection moulding machine configured with a hot press. Influences of ramie fiber (biodegradable) and BN on yield-tensile, elongation, and microhardness behaviour of hybrid polypropylene composite was experimentally studied with a statistical significance of 5 % followed by three trials. The composite of polypropylene is fabricated with 12 wt% of ramie (biodegradable) fiber along with BN of 6 wt% of BN and is exposed to superior yield & tensile strength, elongation percentage, and microhardness performance; it is superior to the value of unreinforced polypropylene. The yield & tensile strength & microhardness of polypropylene/12 wt% ramie fiber/ 6 wt% BN are 59.4±0.5MPa, 72.4±0.6MPa, 41.5%, and 53±0.2HV respectively. This polypropylene hybrid nanocomposite with 12 wt% and 6 wt% ramie (chemically treated) fiber and BN is recommended for automated structural application due to its enhanced tensile strength, microhardness, and improved elongation behaviour.

Keywords: Boron nitride; Injection mould; Polypropylene; Ramie fiber; Properties.

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1. Introduction

The utilization of biodegradable polymer composite is hiked in various technical applications and has better functional behaviour, which is better than the monolithic polymer matrix [1]. The biodegradable natural fiber is extracted from the natural source and involves chemical processing to obtain better quality. It is a better choice for replacing synthetic fiber [2]. The biodegradable natural fiber integrated polymer composites are synthesized for high-strength and lightweight applications [3]. Among the various polymer matrix, polypropylene facilitates better strength, lower specific strength, better chemical and thermal resistance, moisture resistance, and economics [4]. Recently, polypropylene has been merged with Kevlar fiber and cotton stalk via injection moulding as different weight percentages (wt%). As per ASTM standards, the developed polypropylene hybrid composites are evaluated, and the contribution of 12 wt% cotton stalk/7 wt% granite particle featured polypropylene/Kevlar fiber offered optimum behaviour of tensile/impact/flexural and better thermal stability [5].

Biodegradable jute-ramie (natural) fiber-made epoxy hybrid composite is observed to have better flexural strength, high impact toughness and lower density behaviour. The presence of ramie fiber is exploited for better stiffness behaviour [6]. Characterization of multi-natural fiber incorporated epoxy composite is studied with distinct sodium hydroxide (5 %NaOH) treatment. The NaOH-treated hybrid composite facilitates superior tensile strength, and the fibers are effectively interfaced with an epoxy matrix, resulting in superior impact & flexural strength behaviour [7]. The bamboo/cotton fiber is utilized as a reinforcement phase for developing the epoxy composite laminate in different ratios. The influences of bamboo/cotton fiber laminates on epoxy hybrid composite mechanical performance are studied. The 45 wt% of bamboo/cotton fabric laminate is exposed to superior mechanical and fracture toughness values [8]. Hybrid polypropylene composites are made with glass, jute, and sisal fiber combinations via compression moulding. Hybrid fiber influences mechanical properties like the composite evaluated's composite's flexural strength, hardness, and impact strength. The composite records its results contained 10 wt% of glass, jute and sisal fiber own superior flexural and impact strength performance [9]. Polypropylene-based composites have the potential for structural application and offer better fracture toughness and hardness value than monolithic polymer matrix [10]. The boron nitride with hexagonal structure is the source for composite fabrication and embedded with polypropylene matrix via injection moulding process found to better interfacial strength resulting in good strength, improved hardness, and enhanced thermal behaviour [11].

Moreover, the natural fiber treated with a chemical (sodium hydroxide) solution is the source of reinforcement fiber material for composite fabrication, and these fiber materials are future opportunities for hybrid composite fabrication [12]. The sisal fiber of 5mm length is utilized as reinforcement for making polypropylene composite via injection mould process. The fibers are treated with NaOH solution to enhance composite behaviour [13]. Recently, the polypropylene hybrid composite was developed with glass and hemp fiber combinations via injection moulding. Higher glass-hemp fibre loading in polypropylene matrix has better tensile strength and improved flexural & impact strength behaviour [14]. The polypropylene composite is made with short carbon fiber via injection mould associated with extraction technique. The investigation results are exposed with the loading amount of short carbon fiber and its processing influences the improved tensile and compression strength behaviour [15]. Graphene-incorporated polypropylene composites are developed via advanced in situ processing methods and studied their thermal behaviour. The three-dimensional framework of polypropylene composite with graphene is exploited superior thermal stability [16]. The processing of polymer composite and the selection of reinforcement may influence the material properties [17]. Graphene oxide-based filler material incorporated polymer composite made through advanced processing is recorded better enhancement in mechanical properties and utilized for biomedical applications [18]. Advanced 3D technology segregated structure is framed with polypropylene/boron nitride via hot pressing method. It recorded better mechanical and thermal behaviour [19]. The Jute-sisal-glass fiber hybrid composite laminate exhibited superior tensile and thermal behaviour compared to monolithic polymer, which is utilized for automotive front bumper application due to its high strength-to-weight ratio, improved impact toughness value and good hardness value [20]. Lightweight with specific strength property materials are influenced to reduce the weight of automotive components [21]. The polypropylene-based composite is prepared with carbon [22] and graphene [23] via advanced processing, exposed to superior mechanical and thermal performance. It is utilized for automotive applications. Hybrid polypropylene composite made with natural fiber has been found to be economical and suitable for automotive top roof applications [24-26]. The natural fiber incorporated polypropylene composites are made via injection mould technique found to have superior composite behaviour and utilized for acoustic automotive applications [27]. The epoxy hybrid composite with jute and bamboo fiber via casting technique found superior fiber distribution, resulting in improved mechanical and thermal behaviour. It is applied for automotive components applications [28]. Besides, the carbon nanotube was found to be a better choice for polymer composite and suitable for automotive applications as it reduces the weight of components and increases fuel economy [29]. Recently, natural coir fiber developed composite has better specific strength and economic for automotive applications [30].

The proposed research related to past literature is studied and found that the composite is synthesized by combining fiber/ceramic, found to have better mechanical properties. Moreover, the without surface-treated natural fiber developed composite found inadequate adhesive and high moisture absorption quality results decreased mechanical properties was identified as the main research gap. The key objectives of the investigation are to enhance the tensile (yield & ultimate) and microhardness of polypropylene composite by adding ramie (NaOH processed) fiber merged with BN nanoparticle via injection moulding route. The impact of ramie fiber/BN nanoparticles on functional behaviour like tensile performance and microhardness of composite is evaluated.

2. Materials and Method

2.1. Materials details for composite fabrication

With distinct characteristics like lower specific weight, improved tensile strength, better resistance to moisture, and chemical and thermal reasons [20], polypropylene is selected as the primary material for composite fabrication. The natural ramie fiber is chosen as the secondary phase fiber material, which is involved in the NaOH treatment process to increase the fibre quality and limit the moisture absorption behaviour. Ramie fiber offers better strength, biodegradable, and economical [21]. The BN nanoparticles of 50nm are selected as secondary phase filler material for composite fabrication and have superior thermal stability, better stability, and suitability for composite fabrication [22]. The basic behaviour of polypropylene, ramie and boron nitride nanoparticles is highlighted in Table 1.

Table 1. Basic properties of primary and secondary materials

Behaviour	Density	Nature	Tensile strength
	g/cc	-	MPa
Polypropylene	0.90	Polymer	28
Ramie fiber	1.6	Natural fiber	450
BN	2.2	Ceramic	-

With the following water, the ramie fiber is cleaned and dried at ambient temperature for 10 h and immersed into 5 % sodium hydroxide (NaOH) solution for 3 h and stirred every 30 min to remove the dust and unwanted waste particle. After the NaOH process, it involves to drying process. During the drying process, the fiber is kept in an electrical oven with a processing temperature of 100 ºC for 30 min. Finally, it is sheared into the small piece varied from (3-5 mm), which is used as a fiber material for composite fabrication.

2.2. Synthesis of polypropylene composite

Table 2 shows the synthesis of hybrid composite details with its polypropylene, ramie fiber, and BN nanoparticle compositions. Totally five composite specimens are fabricated with different compositions.

Table 2. Composite fabrication details with its compositions

Composite samples	Polypropylene	Ramie fiber	Boron nitrides
	wt%		
AT1	100	0	0
AT2	85	15	0
AT3	83	15	2
AT4	81	15	4
AT5	79	15	6

Figure 1 (a) and (b) flow process chart for composite fabrication and injection moulding setup. It shows that the injection moulding machine is configured with a digitalized control panel and consists of a hopper unit with a 5kg capacity, plunger, and tool steel die. The primary material of polypropylene is considered a billet form (dia-5 mm & length 10 mm). It is merged by the required wt% of chemically processed ramie fiber (chopped) & 50nm BN particles through a mechanical blender with an applied blending speed of 100 rpm for 10 min. The blended slurry in the hopper unit is connected to the injection barrel setup. The injection mould temperature is increased by 250 ºC for 10 min. It improves the bonding between the matrix and fiber/ceramic filler material [23]. Afterwards, the heated polypropylene slurry is injected into a tool steel die configured with 200 mm X 200 mm X 10 mm size. Finally, injected composite samples are cured by ambient temperature with a relative humidity of 60 %.

The prepared polypropylene composite tensile performance is evaluated by an Instron-UT40 model tensile testing machine followed by the ASTM D3039 (200 mm X 15 mm X 5 mm) standard. The microhardness behaviour of composite specimens is evaluated by 0.1 kg load for 10-sec duration via I-MECH made VM50 micro hardness tester followed by ASTM D4762 (50 mm X 10 mm X 10 mm) standard. Moreover, each composite sample is divided into three trials to find the test significance.

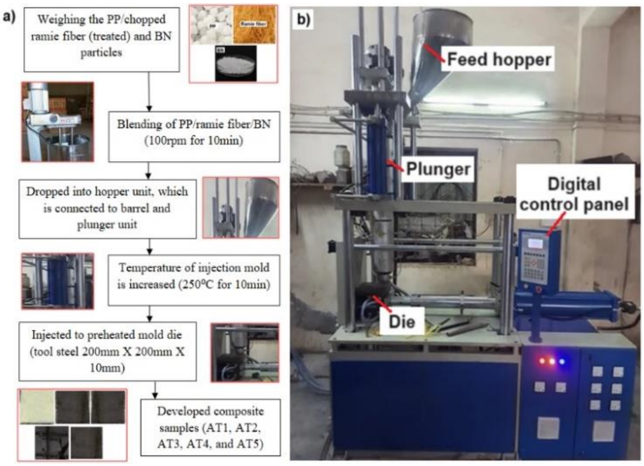

Fig. 1. a) Flow process chart for composite fabrication and b) Injection moulding setup

3. Results and Discussions

3.1. Stress-strain behaviour of composites

Figure 2 displays the stress-strain performance of the composite sample developed with varied wt % of BN and constant wt% of ramie fiber (AT1, AT2, AT3, AT4, and AT5). The yield strength is highlighted in yellow points in Figure 2. Hence, without fiber and filler particles, polypropylene matrix (AT1) contribution is indicated at 45.5±0.6 MPa in yield strength. While adding 15 wt% of ramie fiber (NaOH treated) and without filler, BN nanoparticles indicate the yield strength of composite (AT2) is 48.2±0.3 MPa. The NaOH-treated natural fiber caused increased yield strength of the composite [24]. The yield strength of polypropylene composite was merged with 15 wt% of ramie fiber & 2 wt% of BN nanoparticle is recorded by 53.5±0.4 MPa, and 54.6±0.3 MPa is noted by the incorporation of 4 wt% BN nanoparticle into polypropylene/15 wt% ramie fiber composite. The effective bonding of BN particles is interfaced with ramie fiber limits the crack initiation during high tensile load. However, the AT5 composite sample of its own 15 wt% ramie fiber and 6 wt% of BN exploited high yield strength behaviour, and its value is 59.4±0.5MPa. It is 30.5 % better than the AT1 composite sample without fiber/ceramic materials.

The tensile strength behaviour of polypropylene hybrid composite composed of 12 wt% of ramie fiber / differed wt% of BN is highlighted in Figure 2. The tensile strength behaviour of the unreinforced composite sample (AT1) is lower than the reinforced (fiber/ceramic) composite samples (AT2, AT3, AT4, and AT5). The composite of AT1 composed of polypropylene matrix is recorded by 58.5±0.9 MPa and exposed by 60.4±0.5 MPa on the incorporations of 15 wt% of ramie fiber. The composite of AT3 composed with 15 wt% ramie fiber and 2 wt% of BN is exploited by 65.4±0.7 MPa of its tensile strength behaviour and hiked by BN as 68.5±0.5 MPa records 4 wt%. The appearance of hard ceramic particles in the polypropylene matrix is enduring the maximum tensile load, and effective interfacial strength may lead to resisting the BN dislocation. Effective interfacial action between fiber and matrix results in enriched tensile strength of composite [25]. However, the composite sample of AT5 owns 15 wt% of ramie fiber, and 6 wt% of BN is reached maximum tensile strength behaviour. It is enhanced by 23.7 % higher than the tensile strength value of the AT1 composite sample. Figure 3 (a) and (b) present before and after tensile performance polypropylene composite samples.

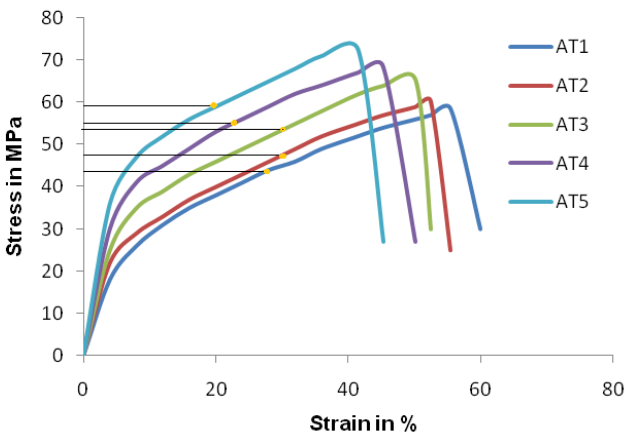

Fig. 2. Stress-strain curve for polypropylene composites

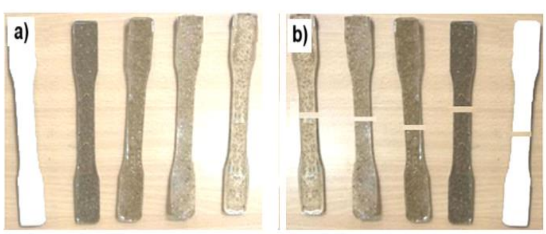

Fig. 3. Tensile performance polypropylene composite samples a) before test and b) after test

Polypropylene composite encompasses 15wt% of ramie fiber with 0, 2, 4, and 6 wt% of BN elongation percentage exposed in Figure 2. The elongation percentage behaviour of polypropylene composite is progressively decreased with increasing the content of BN. The AT1 composite sample without reinforcement is exposed by 55.5±1 % and decreased marginally. The composite sample AT2 developed with 15 wt% ramie fiber is 52.5±1 % of its elongation percentage. At the same time, the incorporation of BN particles as 2, 4, and 6 wt% is recorded by progressive decrement in elongation percentage. The elongation percentage of AT3 composite specimen own 15 wt% ramie fiber and 2 wt% of BN nanoparticle is recorded by 50.2±1 %, and 45.3 % is noted by 4 wt% of BN particle developed composite (AT4). However, the higher content of BN is found lower elongation percentage due to the presence of BN particles effectively adhered with the polymer matrix limits the crack propagation [26].

3.2. Microhardness behaviour of composites

Figure 4 illustrates the microhardness value of composite samples composed of 15 wt% of ramie fiber and differed wt% of BN nanoparticles via injection moulding.

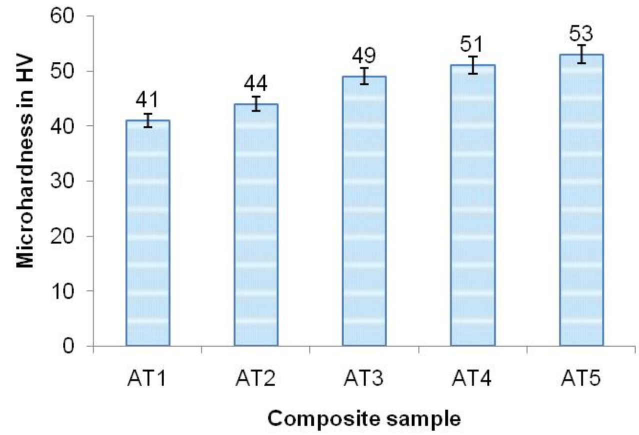

Fig. 4. Microhardness behaviour of polypropylene composites

The microhardness of polypropylene hybrid composite sample AT1 is noted by 41±0.2 HV, which is lower than the ramie fiber and ramie fiber/BN reinforced composite samples. The incorporations of 15 wt% of ramie fiber in polypropylene matrix are recorded by (AT2) 44±0.2 HV, and the AT3 sample is significantly hiked by 49±0.1 HV on loading of 15 wt% ramie fiber with 2wt% of boron nitrate composite. The coarse grain structure of BN leads to enhancing the microhardness value. A polymer matrix's uniform dispersion of ceramic particles results in a better hardness value [11].

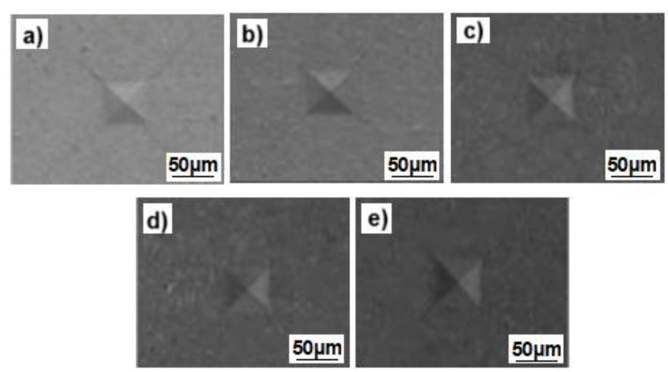

Fig. 5. Optical microscope image of microhardness tested samples a) AT1, b) AT2, c) AT3, d) AT4, and e) AT5

Polypropylene composite sample AT4 contained 15 wt% of ramie fiber along with 4 wt% of BN is noted by 51±0.3HV and the optimum microhardness value of 53±0.2 HV is noted by maximum BN of 6 wt% merged with polypropylene/15 wt% of ramie fiber. It is enhanced by 29 % better than the microhardness value of the AT1 composite sample. Figure 5 illustrates the optical microscope images of the microhardness-tested sample.

3.3. Scanning electron microscope analysis

Figure 6 (a-e) illustrates the scanning electron microscope image of a polypropylene composite sample made with ramie fiber (chopped 15wt%) with varied wt% of BN particles. Figure 6 (a) shows the defect-free structure due to an effective injection mould process. The composite sample AT2 is composed of 15wt%

ramie fiber and is found to be coarse fiber with an effective interface with the PP matrix, and the results improved mechanical behaviour [3].

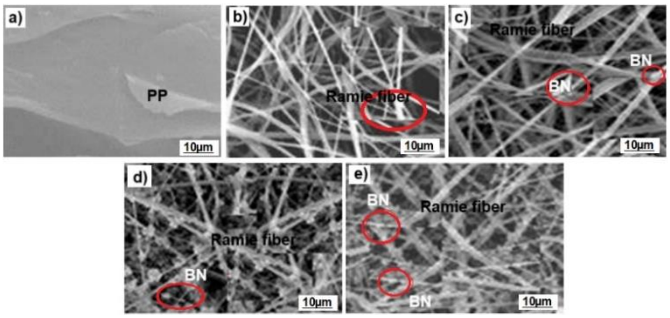

Fig. 6. SEM analysis of polypropylene composites a) AT1, b) AT2, c) AT3, d) AT4, and e) AT5

Fig. 6 (c-e) presents the SEM images of a polypropylene composite made with 15wt% ramie fiber and 2-6wt% of BN particle. The BN particles are widespread over the fiber and adhesive with PP matrix, as evidenced in Figure 6 (c), and few BN particles are observed due to the lower content of BN. The increased content of BN (4wt%) in PP matrix with 15wt% ramie fiber has been seen by coarse fiber with fine BN grain leads to improved load carrying capacity and limits the failure of composite [22]. The composite sample AT5 made with 15wt% ramie fiber and 6wt% BN particle is shown in Figure 6(e). It indicates the coarse fiber along with increased BN particle with better pinning effect and resulting in better tensile and hardness behaviour.

4. Conclusions

The proposed research investigation related to the enrichment of polypropylene composite mechanical performance by the inclusions of 15 wt% of ramie fiber (NaOH treated) along with differed wt% of BN via injection moulding technique is effectively done and follows the ASTM standard for texting of composite sample. The evaluated results of polypropylene hybrid composite are related to mono polypropylene and its composite made with ramie fiber. The following conclusions are detailed in below key points below.

- According to the investigational results, the AT5 composite sample of polypropylene hybrid composite is synthesized by 15 and 6 wt% of ramie fiber/ BN nanoparticle is exposed maximum yield strength and 30.5 % better than AT1 composite specimen (Polypropylene matrix without reinforcement).
- The tensile strength of the AT5 composite sample is raised by 23.7 % higher than the tensile strength value of the AT1 composite sample. However, the contribution of the BN particle limits the elongation percentage of the composite and is spotted by 41.5 %, which is lower than the AT1 composite sample.
- The microhardness of AT5 composite is optimum value and hiked by 29 % related to the microhardness of composite sample AT1 without reinforcements.
- The optimum properties of the AT5 composite sample are involved for high strength to lightweight applications, and future, this optimum hybrid composite will be involved in the drilling process.

Conflict of Interest Statement

The author declare that there is no conflict of interest in the study.

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