Research Article

Effect of Al$_2$O$_3$ on the Tensile and Impact Strength of Flax/Unsaturated Polyester Composite with Emphasis on Automobile Body Applications

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This study has endeavored to develop an Al$_2$O$_3$-filled natural fiber reinforced polymer composite which is intended to substitute the most widely used synthetic E-glass fiber material. To attain the desired objective of the work, 0, 5, 10, and 15 wt% Al$_2$O$_3$-filled chopped flax/unsaturated polyester resin composite have been developed by the conventional hand-lay-up method followed by a compression molding process. Consequently, characterization and mechanical property tests are conducted based on the ASTM standard. The results revealed that both tensile and impact strength properties of the base chopped flax/unsaturated polyester resin composite are all affected due to the inclusion and variation of the content of Al$_2$O$_3$ in 15 and 25 wt% fiber loading cases. It has been noticed that a 39.06% increase in the ultimate tensile strength of the composite in 25/UPR-5 composition has been gained. The effect of Al$_2$O$_3$ on the impact strength of the base composite has also been analyzed and a 45% increase has been observed in 15/UPR-10 composition. The findings also witnessed that the newly developed composite can be applied to make automotive parts such as mud guard and engine undercover.

1. Introduction

In the current scenario, natural or synthetic fibers can be used to make composite materials by combining them with binders (matrix materials such as thermoplastic or thermosetting polymers). Natural fibers are reinforcing materials that can be prepared from plants, minerals, and animals. Hemp, jute, abaca, banana, bamboo, coconut coir, flax, kenaf, pineapple leaf, ramie, reed, sisal, sugarcane bagasse, henequen, soy protein, and sorghum are some examples of natural fibers which have been used for composite processing applications for structural and other industrial engineering fields [1]. On the other hand, composites from synthetic fiber-reinforced plastics now dominate with a high market acceptance in the aerospace, leisure, automotive, construction, and sporting industries. Glass fiber materials are the most widely used reinforcements with plastic binders since they are available with a reasonable cost and have good mechanical characteristics [2, 3].

Literature shows that about 87% of the 8.7 million tons of global fiber reinforced polymer composites are based on E-glass fiber [4]. However, these fibers have their own negative impacts that can be possibly solved by using natural fibers and some of which are of relatively high density (twice that of natural fibers), of high purchasing cost, nonrenewable, of high energy consumption, are not CO$_2$ neutral, have abrasion effect to machines and high risk when inhaled, and they are difficult to dispose of (not biodegradable) [5–10]. It is reported that lower energy is required to make the same amount of natural fiber compared to synthetic fiber reinforcement materials [11]. It will take 54 MJ of energy to produce 1 Kg of glass fiber and 15 MJ of energy is sufficient enough to produce 1 Kg of kenaf fiber (natural fiber material) [12].

Natural fiber-reinforced composites are good for environmental rewards that they are not dependent on nonrenewable sources, minimal pollutant releases, lower greenhouse gas emissions, improved energy retrieval, reduced tool wear (nonabrasive to processing equipment), and end of life biodegradability of the products. These eco-friendly performances are the main advantages for the futuristic use of natural fiber-reinforced composites applicable to fabricate automotive body parts and related materials in a simple way [1, 13, 14]. However, research works indicate that very little interest is given to utilize natural fiber materials in the automotive and transportation industries. This is said because 90% of the world's automotive and transportation industries' composite parts manufacturing is based on glass fiber [15]. The reasons for this to happen are the severe degradation/moisture susceptibility, inadequate mechanical performances, low compatibility with hydrophobic polymer matrices, loss in dimensional stability, and structural integrity with temperature which limits the application of natural fiber-reinforced composites for widespread practical applications in engineering fields [16–18].

The use of natural fibers, especially of plant species, has been increasing in recent times, which are able to provide a fiber reinforcement with matrix materials. Natural fibers are capable of using as a reinforcement material to replace glass fiber reinforced composite parts. As a result, using natural fiber materials as a reinforcement in composites, textile, and paper industries and biofuel applications is common in the current market situation, also, to use them in the area of green composites, materials used as a nonstructural part in automotive and railway industries that do not require enormous stress applications [19].

Among the various kinds of natural fibers, the industrial consumption of plant fibers is originated from bast (flax, hemp, kenaf, sugarcane, jute, etc.). Fibers from bast plants are used mostly as industrial sources because they are generally accepted to display top mechanical properties such as high specific strength and modulus compared to other plant fibers which are extracted from leaf or seed [19]. This is because the bast is the structural part of a plant that supports and holds its parts together, and it has a desirable mechanical property in addition to its lightweight characteristics. This fact ensures that bast fibers are used as an outstanding reinforcement material in automotive industries [20] with numerous advantages.

The mechanical property of bast fibers is relatively better than other natural fiber materials gained from leaf, seed, wood, stalk, fruit, and animals [4, 21]. This is because bast fibers are the top leaders in holding cellulose as a major constituent, making them have better mechanical properties such as high specific tensile strength and Young's modulus [21]. Among the different kinds of bast fibers, flax (*Linum usitatissimum* L.) is found ideal and preferable that it shows better mechanical properties (comparable specific tensile strength and higher specific Young's modulus with E-glass fiber). As compared to its alternatives, it is also preferable due to its local availability, recyclability, ecofriendly, low cost, small density, minimal energy consumption for the extracion processes, less skin and respiratory irritations, and abrasion effect to the processing equipment [5].

Studies on the mechanical properties (tensile strength, tensile modulus, and impact strength) of flax fiber-reinforced polymer composites have given credit aiming at identifying their smart and poor characteristics in a variety of composition, matrix property, manufacturing, and testing conditions. Perremans et al. [11] have used unidirectional (UD) flax fiber and epoxy resin to prove the effect of (3-aminopropyl) triethoxy silane (APS) and alkali (NaOH) treatments on the tensile modulus and strength properties. Test results exhibited that the tensile modulus has slightly improved from 20 to 23 GPa. Approximate longitudinal tensile strength results were observed for the untreated and alkali-treated composite samples, 200 MPa. However, the longitudinal tensile strength of water and APS treated composite samples have decreased from 200 to approximate values of 170 and 180 MPa, respectively. Similarly, the work of Xia et al. [14] has applied NaOH, Corona discharge, MA (maleic anhydride) grafting and Silane treatments intending to modify the tensile strength and tensile modulus of flax fiber/PLA (Polylactic acid) composites. Flax fiber having length and diameter, respectively, of 5 mm and 10–20 μm and extrusion grade PLA was used to fabricate composite samples by extrusion process. Results show that the tensile strength of treated and untreated flax fiber reinforced composites was approximately the same, 60 MPa. The tensile modulus of untreated flax fiber reinforced PLA composite was higher than the remaining treated flax fiber reinforced composite alternatives, 70 GPa.

However, Huo et al. [7] in their work on flax/VE (Vinyl ester) resin using acetic anhydride treatment after pre-treating with NaOH and Xue and Hu [16] on flax/UPR (unsaturated polyester resin) using NaOH treatment have conducted research regarding its tensile strength properties. Their test result reveals that a 40% improvement due to acetic anhydride treatment and a very positive effect in using NaOH on the tensile property of the composite was observed. Similarly, with the intent to improve the tensile strength property of acetic anhydride treated UD flax mat with conventional epoxy and the bio-epoxy resin was done and compared by Loong and Cree [22]. Composite samples were produced by hand-layup and vacuum bag successively by treating flax fiber with 1, 2, 3, and 4 wt% acetic anhydride. Final tensile test results show that all treated flax fiber composites show an increase in tensile strength. Related to this, a 2 wt% acetic anhydride treatment exhibited a significant increase in tensile strength (55%) for both epoxy composites, and the tensile modulus of bio-epoxy composite (3.4 GPa) was greater than the conventional epoxy composite (3.2 GPa). But, increasing the concentration of acetic anhydride to 3 and 4 wt% brings a decrease in tensile strength and modulus was observed, which might be due to fiber fibrillation. Accordingly, the investigation of Huo et al. [6] using NaOH, VE resin, THF (tetrahydrofuran), and VE toluene solution treatments independently evidenced that improving the tensile strength was possible using chemicals with different proportions.

Moreover, in recent days, using filler materials while processing natural fiber reinforced polymer composites improved mechanical properties. Related to this, Siengchin et al. [23] have used nano Al_2O_3 particle as a filler in flax/polylactide composites to analyze the impact weight behavior. 8 wt% with a size of 22 nm and woven flax fiber with 40 vol% were prepared by hot pressing using nanospraying technique with the polylactide resin matrix. However, a reduction in impact weight resistance was observed due to the incorporation of nano Al_2O_3 particles even if the creep and storage modulus properties were enhanced.

On the other side, nano ZnO particles with 0.02, 0.04, 0.08, and 0.12 wt% were used with 40 vol% woven flax fabric $(((0/90)_2)$ s)/UPR composite, and the mechanical and bioactivity properties were examined by Shaker et al. [24]. The composite was fabricated by vacuum molding technique that attaining a uniform distribution of nano ZnO particles in the composite was a problem that was solved by mixing UPR/ZnO with methanol. To this end, tensile test results show that the incorporation of nano ZnO particles has no significant effect due to the small amount of nano ZnO particles, and it was lower than glass fiber reinforced polyester resin composite. Nonetheless, improved bioactivity with 0.02 wt% of ZnO and tensile modulus gained with increasing the amount of ZnO particle.

The effect of nano TiO_2 particles on the mechanical properties of flax/epoxy composites was examined by Wang et al. [25] and Prasad et al. [26]. Nano TiO_2 particles with a range of 0.89 to 7.14 wt% were grafted to the flax fiber by mixing the particles into KH560 solution under sonification [25]. Final test results were compared with alkaline and silane coupling agent treated sample composites. Test results witness that enhanced tensile strength of the composite (23%) and interfacial shear strength by 40% with 2.34 wt% of nano TiO_2 was observed as compared to other treatment conditions and the control sample. Similar to this, the work of [26] shows that the fracture toughness of flax fiber/epoxy composite with nano TiO_2 filler was improved for both double cantilever beam and end notched flexure testing conditions.

Improving the mechanical properties of flax fiber-reinforced composites still needs additional work to use them in a variety of working conditions. It was noticed that some chemical treatment processes and filler incorporation techniques had been used to enhance their properties, but the variation was not significant to use them for high external load and high-temperature applications. This work aims to analyze the effect of Al_2O_3 filler on the tensile and impact strength of chopped flax/UPR composite after combined chemical treatment processes with the need for enhanced tensile and impact strength, which has not been proved before.

2. Materials and Methods

2.1. Materials.
Raw flax fiber has been purchased from the commercial market and chopped to a size between 30–40 mm after subsequent chemical treatments. Fiber treatment agents, NaOH and benzoyl chloride, Analytical Reagent Grade Al_2O_3 filler material (having a size of 63–100 μm), and ethanol has been purchased from *Sida* Chemicals Trading, Addis Ababa, Ethiopia. Moreover, UPR matrix, mold releasing agent, and methyl ethyl ketone peroxide catalyst have been purchased from *World Fiber Glass and Waterproofing Work*, Addis Ababa, Ethiopia, which has been utilized for subsequent composite manufacturing processes. Tables 1–4 [4, 27–30] show the various characteristics of the materials used to conduct the research.

2.2. Experimental Procedures

2.2.1. Primary (NaOH) Flax Fiber Treatment Process.
NaOH treatment helps to remove lignin and hemicellulose from the surface, which helps to increase the load transfer capability of the fiber to the microfibril. Besides, it has the advantage of activating the hydroxyl groups attached to cellulose and lignin.

$$\text{fiber} - \text{OH} + \text{NaOH} \longrightarrow \text{fiber} - \text{O} - \text{Na}^+ + \text{H}_2\text{O} \qquad (1)$$

Flax fiber strand has been purchased from the market (Merkato, Addis Ababa, Ethiopia) and immersed in a 5 wt% NaOH solution for 30 minutes [31] at room temperature (24°C). After this, the fiber is taken out, rinsed, washed with tap water several times, filtered, and dried in an oven for 24 hr at a temperature of 80°C.

2.2.2. Secondary ($C_6H_5C=O$) Treatment Process.
Benzoyl chloride ($C_6H_5C=O$) treatment has the advantage of decreasing the hydrophilic nature of the pretreated fiber and increasing its interaction with the hydrophobic matrix.

To do the benzoyl chloride treatment process, the first 5 wt% of NaOH solution was prepared using distilled water followed by the incorporation of 5 wt% of benzoyl chloride and agitating the mix for 30 seconds [31]. After this, the pretreated flax fiber has been added into the mix and soaked for 15 minutes at room temperature. In doing so, the flax-chemical mix was agitated between a range of minutes since benzoyl chloride has a tendency to sediment at the bottom which harms the fiber found at the bottom of the treating bowl. Subsequently, the fiber is taken out from the treating bowl, rinsed, washed with tap water, filtered, and dried in an oven for 24 hr at a temperature of 80°C. Later on, the dried flax fiber is soaked in ethanol for an hour to remove benzoyl chloride, followed by washing with tap water and drying in an oven for 24 hr at a temperature of 80°C again.

2.3. Composite Density and Mass Determination and Quantification of Fiber, Matrix, and Filler Proportions.
The calculation was based on the weight percentages of matrix, reinforcement, filler, and volume of the mold. The weight percentage variation and proportions are specified and tabulated in Table 5. The design and calculations are based on varying the weight percentage of filler with 0, 5, 10, and 15 wt% in 15 and 25 wt% of long chopped flax fiber loading.

TABLE 1: Characteristics of NaOH, benzoyl chloride, and ethanol (supplier information).

Material	Grade	Purity (%)	Impurities (%)	Form	Molecular weight g/mol	Density
NaOH	Analytical reagent (AR)	99.8	—	Pellet	39.99971	—
Benzoyl chloride	—	98	Nonvolatile matter (0.05) and phosphorus (0.01)	Liquid	140.57	1.21 g/cm^3
Ethanol	—	97	—	Liquid	46.07	789 kg/m^3

TABLE 2: Characteristics of flax fiber.

Property	Flax fiber
Density (g/cm^3)	1.45
Tensile strength (MPa)	510–910
Young's modulus (GPa)	50–70
Specific modulus (GPa)	34–48
Moisture content (%)	12

TABLE 3: Characteristics of Al_2O_3.

Description	Al_2O_3
Density (g/cm^3)	3.95
Tensile strength (MPa)	200–660
Young's modulus (GPa)	380
Bending strength (MPa)	200–600
Compressive strength (MPa)	1900–200
Poison's ratio	0.25–0.30
Coefficient of thermal expansion (/°C)	7.39×10^{-6}

TABLE 4: Characteristics of UPR.

Description	UPR
Density (g/cm^3)	1.09–1.35
Tensile strength (MPa)	40
Young's modulus (GPa)	3.3
Flexural strength (MPa)	45
Poison's ratio	0.44
Maximum elongation (%)	1

TABLE 5: Weight percentage proportions to fabricate the composite used for property testing.

Composition	UPR (wt%)	Flax fiber (wt%)	Al_2O_3 filler (wt%)
15/UPR-0	85	15	0
15/UPR-5	80	15	5
15/UPR-10	75	15	10
15/UPR-15	70	15	15
25/UPR-0	75	25	0
25/UPR-5	70	25	5
25/UPR-10	65	25	10
25/UPR-15	60	25	15

The density of the control samples (15/UPR-0 and 25/UPR-0) and filler incorporated composites have been calculated based on the rule of mixture provided in equations (2) and (3), respectively [10].

$$\rho_c = \frac{1}{(W_m/\rho_m) + (W_f/\rho_f)}, \tag{2}$$

where ρ_c is the density of Flax/UPR composite, W_m is the weight fraction of the matrix, W_f is the weight fraction of flax fiber, ρ_m is the density of the matrix, and, ρ_f is the density of flax fiber.

$$\rho_c = \frac{1}{(W_f/\rho_f) + (W_m/\rho_m) + (W_a/\rho_a)}, \tag{3}$$

where W_a and ρ_a are the weight fraction and density of Al_2O_3 filler, respectively.

2.4. Composite Manufacturing Process. The detailed schematic illustration of the overall layout of the composite manufacturing process and steps is depicted in Figure 1. The composite has been manufactured at room temperature in AASTU (Addis Ababa Science and Technology University). It is manufactured by a conventional hand lay-up technique followed by compression molding (by a subsequent adding of load during curing for 24 hr). 480N load has been used for 15 wt% of flax fiber and the load was increased to approximately 600 N for 25 wt% flax fiber composition while curing. The load was added progressively to avoid premature squeeze out of UPR, which will affect the final quality and property of the composite.

2.5. Characterizations

2.5.1. Tensile Strength Testing. Tensile strength test specimens of the composite were prepared as per ASTM D3039 standard [27]. Test specimens have been cut to a dimension of $250 \times 25 \times 3$ mm and tied on a Testometric 10 KN Model Universal Testing Machine found in Ethiopian Conformity Assessment Enterprise, Addis Ababa, Ethiopia. The tensile strength of the composite has been conducted at a constant crosshead speed of 10 mm/min and a gauge length of 150 mm by loading until failure of the test specimen. The ultimate tensile strength, tensile modulus, and (%EL) percent elongation of three specimens have been taken for analysis and characterization purposes. Tensile modulus (E) and percent elongation of the composite have been determined using equations (4) and (5), respectively:

$$\text{tensile modulus}(E) = \frac{\Delta\sigma}{\Delta\varepsilon}, \tag{4}$$
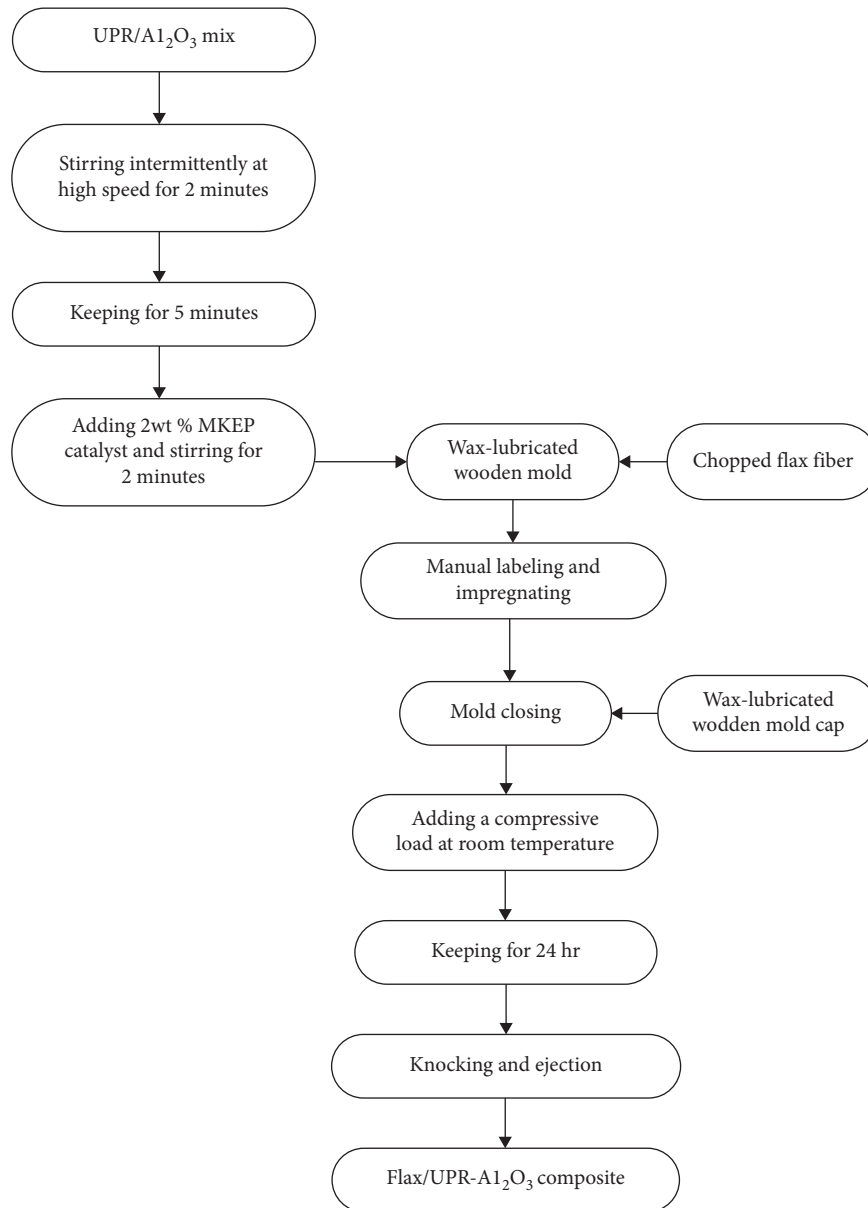
FIGURE 1: Composite processing flow chart.

where $\Delta\sigma$ is the change in tensile strength of the developed composite between two points laying on a straight line before yielding and $\Delta\varepsilon$ is the change in strain of the developed composite between two points laying on a straight line before yielding:

$$\% \, \text{EL} = \left(\frac{l_f - l_o}{l_o} \right) \times 100, \qquad (5)$$

where l_f is the fracture length of the specimen and l_o is the original gauge length (150 mm) of the test specimen.

2.6. Impact Strength Testing. Impact strength test of the composite was prepared as per ASTM D256 (prepared to a size of $64 \times 12.7 \times 3.2$ mm) [32]. A notch has been prepared with a depth of 2.5 mm at 45° inclination. The test has been conducted using Model JBS-500B impact testing machine found in Bahir Dar Institute of Technology at room temperature. The average test results of three specimens have been taken and (both energy absorbed and the impact strength) were then automatically displayed on the digital screen.

3. Results and Discussion

3.1. Ultimate Tensile Strength. Figure 2 depicts that the ultimate tensile strength of flax/UPR composite is affected by the inclusion of Al_2O_3 as a filler. The variation of the ultimate tensile strength of the composite has been analyzed utilizing 15 and 25wt% of chopped flax fiber and by altering the content of filler with 0, 5, 10, and 15 wt% in UPR matrix. Test result values indicate that the ultimate tensile strength has changed for both cases even if several results were gained among compositions. Related
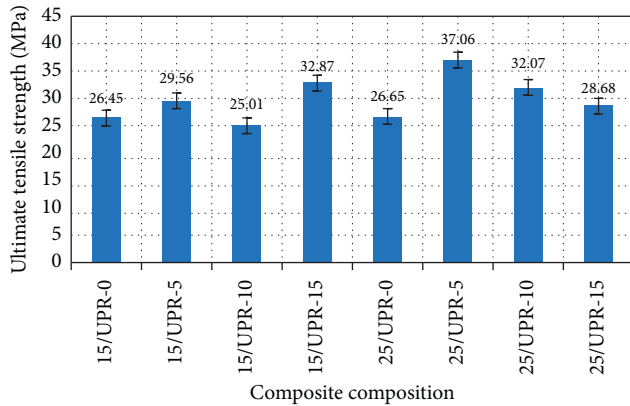
FIGURE 2: The variation of the ultimate tensile strength of the developed composite with changing the content of Al_2O_3 filler and flax fiber.

to this, for the case of 15wt% flax fiber, the ultimate tensile strength of the composite has been enhanced by 11.75% and 24.27% when 5 and 15 wt% Al_2O_3 was incorporated, respectively. Accordingly, for the case of 25 wt% reinforced UPR composite, the ultimate tensile strength of the chopped flax/UPR composite has been enhanced by 39.06%, 20.33%, and 7.61% when 5, 10, and 15 wt% Al_2O_3 filler has been incorporated. The reason for these improvements is attributed to the uniform distribution of Al_2O_3 filler and the higher UPR/filler interface adhesion. This helps the UPR matrix to effectively transfer the induced stress to the chopped flax fiber and Al_2O_3 filler, bringing improved tensile strength. Also, the increase in ultimate tensile strength of the composite may be due to the fact that Al_2O_3 makes the movement of molecular chains of chopped flax fiber and UPR matrix difficult which may assist in resisting tensile load better than the unfilled composite [33].

However, the ultimate tensile strength of the composite was decreased by 5.4% when 10 wt% Al_2O_3 is added to the 15 wt% flax/UPR composite and this was unexpected. The reason for this reduction in strength is deduced due to the nonuniform distribution of the chopped flax fiber in the UPR/filler mix or the nonuniform distribution and agglomeration of Al_2O_3 filler in the UPR matrix by itself. On the other hand, when the flax fiber is increased to 25 wt%, insignificant change in ultimate tensile strength (26.65 MPa) of the composite is observed as compared to the strength of 15 wt% flax fiber-reinforced UPR composite (26.45 MPa). This makes the merit of incorporating Al_2O_3 filler greater than other alternatives, such as increasing the composition of the reinforcing fiber to increase the ultimate tensile strength of the composite [34].

3.2. Tensile Modulus.
Figure 3 clearly shows the effect of Al_2O_3 filler on the tensile modulus behavior of the developed chopped flax/UPR composite. It is evidently observed that the tensile modulus of the Al_2O_3 filed composite has increased with increasing the weight percentage of filler for both fiber compositions. The reason for these improvements

in the tensile modulus of the composite is deduced due to the fact that the hard-ceramic filler increases the interfacial bonding among the reinforcement and the matrix which in turn leads to improved stiffness of the composite. It is also inferred due to the higher stiffness of the added ceramic filler which imparts its property to the weaker matrix and reinforcement. Similar test results were also observed with the incorporation of ceramic filler in natural fiber-reinforced polymer matrix composites [10]. Therefore, the tensile modulus of Al_2O_3 filled chopped flax/UPR composite has increased with an increase in both the fiber loading and filler even if the merit of the added filler is higher than increasing the content of fiber loading. However, the system appears brittle to a greater extent, even if a higher tensile modulus of the composite is achieved.

3.3. Breaking Elongation (%).
Figure 4 depicts the percent elongation of the Al_2O_3 filled composite for both fiber loading conditions. It is in a similar fashion with the ultimate tensile strength of the composite that Al_2O_3 filler has an impact on the elongation of the composite while it was under tension. It was unexpected to get increased breaking elongation of the composite due to the hard and brittle nature of the incorporated Al_2O_3 filler. For 15 wt% chopped flax fiber loading, a 24.43% increase and a 15.51% increase in elongations for 25 wt% chopped flax fiber loading were gained when 15 and 5 wt% Al_2O_3 filler is incorporated, respectively. The increase in percent elongation due to the inclusion of Al_2O_3 in the chopped flax/UPR composite is ascribed due to the higher interlocking capacity of the ceramic filler which hinders early rapture of the composite and brings more ductile while it was subjected to tension.

However, the percent elongation of 25/UPR-15 composite has decreased by 4.4% and this is deduced due to the higher content of the filler decrease the interfacial adhesion among the fiber and binding matrix at the higher composition of the reinforcement. Also, the percent elongation of 15/UPR-10 composite has decreased by 14.12% and this was unexpected.

3.4. Energy Absorbed and Impact Strength.
It is exhibited that the impact strength of the developed composite is also affected due to the involvement of Al_2O_3 filler in the chopped falx/UPR composite. Figure 5 portrays the variation of the energy absorbance capacity and impact strength of the composite with changing the content of filler with 0, 5, 10, and 15 wt% in the control samples. It is observed that an increase in impact strength with 38.60, 45.03, and 5.14% has exhibited when 5, 10, and 15 wt% Al_2O_3 filler are added, respectively, as compared to the control sample, 15/UPR-0. It is noticed that the impact strength has increased far superior when the content of the filler is increased to 5 and 10 wt% followed by a relative decrement when the filler loading is increased to 15wt% even if it is still higher than the impact strength of the control sample. These improvements are ascribed due to the strong interfacial adhesion, which renders an efficient barrier for immobilization and development of the advancing cracks [9, 35]. For the case of 25/
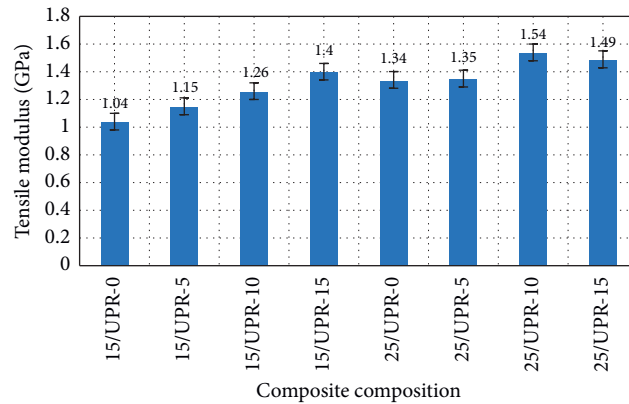
FIGURE 3: The variation of tensile modulus of the developed composite with changing the content of Al_2O_3 filler and chopped flax fiber.
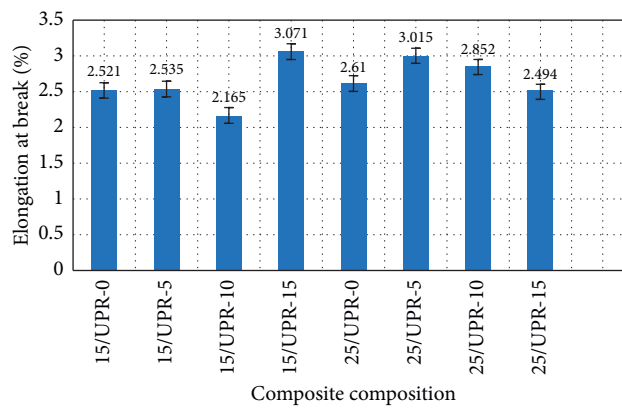

FIGURE 4: The variation of breaking elongation of the developed composite with changing the content of Al_2O_3 filler and chopped flax fiber.
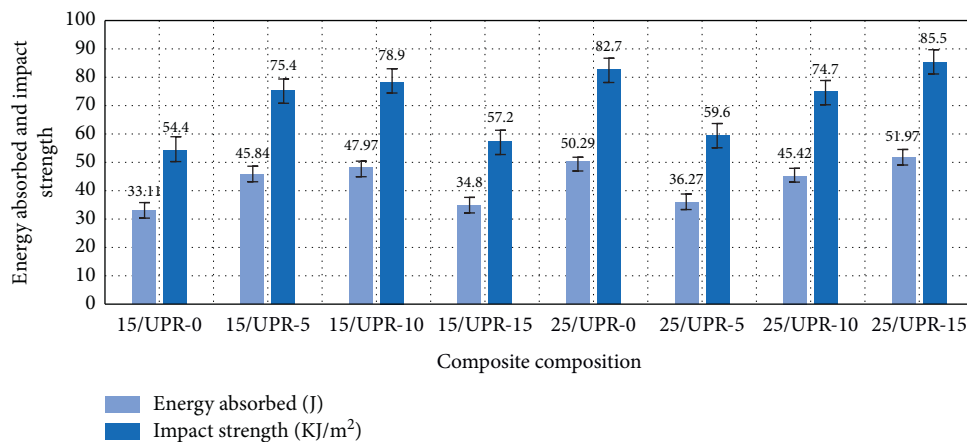

FIGURE 5: Influence of Al_2O_3 on energy absorbance capacity and the impact strength of the developed composite.

UPR loading, the impact strength decreased first and then has increased progressively with increasing the filler loading. Only an improved impact strength of the composite by 3.38% has been gained when 15 wt% Al_2O_3 filler is incorporated into the control sample. The first decrease in the impact strength is suggested due to the relatively small Al_2O_3 filler loading initiating the formation of microcracks at the interface that it is not capable of blocking the propagation of

cracks in the composite at higher fiber loading conditions (25 wt% chopped flax fiber).

4. Conclusion

(1) It is seen that developing natural fiber reinforced polymer composite utilizing Al_2O_3 as a filler is possible with the merits of both improved tensile and

impact strength properties than the ordinary flax/UPR composite.

(2) The ultimate tensile strength of the base flax/UPR composite has improved from 26.45 MPa to 32.87 MPa due to the addition of 15 wt% filler for the 15 wt% fiber loading case. Accordingly, the ultimate tensile strength of the base 25/UPR composite has increased from 26.65 MPa to 32.07 MPa due to the inclusion of 5 wt% Al_2O_3 filler. It was also able to gain a composite that is both stiff and relatively ductile as compared to the control sample compositions. Moreover, it has been observed that the merit of increasing the fiber loading from 15 to 25 wt% was insignificant as compared to the effect of Al_2O_3 filler on the tensile properties of the developed composite.

(3) The energy absorbance capacity and impact strength of flax/UPR composite are highly affected due to the incorporation of Al_2O_3 filler. Improved impact strength of the composite has been recorded for all filler proportions for the 15 wt% fiber loading case, increased from 54.4 KJ/m^2 to 78.9 KJ/m^2 when 10 wt% filler has been added. The impact strength of 5 and 10 wt% filler loaded composite has been found lower than the impact strength of the control sample (25/UPR-0). However, a slight improvement in impact strength of the base composite has been exhibited when the content of filler has varied to 15 wt% (increased from 82.7 to 85.7 KJ/m^2).

(4) The prospective application area of the newly developed flax/UPR-Al_2O_3 composite is believed to manufacture few automobile body parts such as mudguard and engine undercover in place of glass fiber with the simple manufacturing technique and lower material cost. Importantly, it could be applicable as an alternate material to manufacture the roof cover of a three-wheel taxi (Bajaj) in place of the currently used thermosetting polymer (Hypalon). Moreover, it could be used as an alternate asbestos brake pad material which has a carcinogenic effect on humans during manufacturing.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest described in this article.

Acknowledgments

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