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Influence of Graphitic Carbon Nitride (g-C_3N_4) on Mechanical and Thermal Properties of Pineapple Leaf Fibre Reinforced Polyester Resin Composites

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ABSTRACT
Natural fibres, which are recyclable and environment friendly, are becoming more popular than synthetic fibres which are commonly utilized in manufacturing composite materials. Scientists have drawn attention to natural fibres because of their availability, cost-effectiveness, and biodegradability. Recently, it has been popular practice to include natural fibres in composite materials for industrial uses. The research deals with the fabrication of pineapple leaf fibre (PALF) reinforced polyester composites prepared from PALF used as reinforcement with 6 wt% (weight fraction). Synthesized graphitic carbon nitride (g-C_3N_4) was used as filler in different weight fractions such as 0.25, 0.50, 0.75, and 1.00 % to improve the mechanical and thermal properties of the fabricated composites. Graphitic carbon nitride (g-C_3N_4) was synthesized by one-step heating methods from scrap melamine. Fourier-transform infrared spectroscopy was utilized to characterize g-C_3N_4 and ensured successful synthesis. According to the results, the composite with 0.75 wt% of g-C_3N_4 has a higher modulus and tensile strength. Tensile strength increases as g-C_3N_4 weight percentages rise, demonstrating the filler's beneficial effects. The appearance of cracks in PALF/polyester composites with g-C_3N_4 was captured by scanning electron microscopy, which points to the morphological changes arising after tensile testing. With the addition of g-C_3N_4 in several weight percentages, the thermal resistance and water repellency of composites were significantly improved. Overall, this research reveals the effect of filler weight percentage on the mechanical, thermal, and morphological properties of PALF/polyester composite. The investigation concludes that a defined weight proportion of g-C_3N_4 with PALF and polyester resin produces composite materials with acceptable mechanical properties suitable for engineering applications where composites are best.

KEYWORDS
graphitic carbon nitride, pineapple leaf fibre, composites, polyester resin

INTRODUCTION

Polymer composites are becoming a more popular option because of not only their superior mechanical qualities and adaptability to a wide range of industries, aerospace, automobile, household, and building applications but also the low cost of manufacturing which increased interest in its advancement [1-3]. A composite material, consisting of two or more materials, demonstrated superior mechanical and thermal properties when compared to its constituent materials [2]. Natural fibres are gaining the interest of industry and researchers due to their distinct advantages over traditional synthetic fibres because of several significant characteristics, such as low specific density, low cost, strong strength, and high sustainability of natural fibre [3]. The fibre-reinforced polymer composites can be made by using natural fibre. The growing interest in natural fibre-reinforced polymer composites has led to investigations into a variety of natural fibre sources [2]. Fibre orientation, volume fraction, type, and length affect the mechanical behaviours of fibre-reinforced composite materials. Other factors that affect this behaviour include matrix type, matrix/reinforcement interface, fibre hybridization, and the introduction of nanoparticles into the composite material [3]. Agricultural waste that makes fibre has greater strength to make yarn, and apparel is also suitable for composite. Pineapple Leaf Fibre (PALF) having the scientific name *Ananas comosus* is derived from pineapple leaves, which is one such source. As a reinforcement material for composites, PALF has demonstrated its potential. Pineapple leaves are the third most popular fruit in the world, but their presence in reinforced composites has only lately been investigated. Arib et.al reviewed the mechanical properties of PALF-reinforced polymer composites and stated that PALF is a natural fibre, suitable for composite fabrication, and has environmental advantages [4]. Resin is an adhesive material that creates a bond between fibres through its adhesion properties. Epoxy, Polyester, and Vinyl ester resin are common examples of resin [5]. Like other resins, polyester resins cure exothermically and are thermosetting. Unsaturated polyesters (UPR) have been used as the matrix material for various composites across various industrially significant markets [6]. The main benefit of polyester resin is its high degree of hydrophobicity and mechanical, chemical, and electrical stability [3] and ease of manufacturing [5]. Also, polyester resin is over three times less expensive than epoxy [4]. Polyester resin does, however, have certain disadvantages, including brittleness, a high rate of thermal expansion, low resistance to weathering, the possibility of stress cracking, and trouble bonding at low temperatures. The aforementioned constraints can be alleviated by adding natural fibre to the product during the manufacturing process. Incorporating natural fibre in the composite materials enhanced water adsorption, flexural strength, lifted tensile strength, and adequate impact strength [7]. Efficient load transfer between the components and an improved fibre-matrix interaction is ensured by the additional fillers [8]. Filler materials sometimes defined as inert materials can be employed to lower material prices, improve material performance, as well as enhance temperature resistance, dimensional stability, surface smoothness, water resistance, and stiffness properties of composites [9]. Filler materials can be organic or inorganic. The size, shape, aspect proportion, surface area, and dispersion of the fillers within the composite determine how these fillers affect the composite's properties [10,11]. Graphitic carbon nitride (GCN), also referred to as g-C_3N_4, and also a member of the carbon nitride compound family and has a general formula that is quite similar to C_3N_4 is a novel filler that is used in the manufacturing of polyester and pineapple leaf fibre (PALF) composites. Melamine must be polymerized to create graphitic carbon nitride [12]. Because it is an inexpensive, metal-free, visible light-responsive photocatalyst that can be applied to environmental cleanup projects, g-C_3N_4 is a two-dimensional conjugated polymer that has garnered a lot of interest from a variety of fields. The graphitic carbon nitride (g-C_3N_4) based materials have demonstrated remarkable electron-rich properties, strong physicochemical stability, and exceptional electronic band [13]. Numerous researchers have been working on PALF-reinforced polyester resin and its hybrid [14-21]. However, only a few researchers worked on PALF/polyester composites with g-C_3N_4 as filler. Several studies and research have shown that adding filler or micro/nanoparticles at varying weight fractions to composites has improved their mechanical, thermal, and physical properties for a variety of engineering and structural load applications [22]. Devi et al. stated that tensile and impact strength were increased with fibre content, while flexural strength increased with longer fibre length. Untreated fibres show higher water absorbency [15]. However, increased fibre weight fraction in a matrix increased ultimate tensile strength and modulus of elasticity, while decreased elongation at break and Shetty et al. also found that water absorption behaviour increased with fibre volume in treated pineapple leaf fibre reinforced polyester resin composites [17]. The tensile and flexural strength of PLAF-polyester composites increased linearly with fibre weight fraction up to 30%, with surface treatment enhancing strength. 10% engrafted PALF composite showed the best improvement, while cyanoethylated treated PALF composites showed better flexural and impact strength but no specified application area was reported by Mishra et al. [23].The kenaf/pineapple hybrid composites improved interfacial rigidity and strength under accelerated weathering circumstances, while also lowering the moisture sensitivity [24]. Mishra and his colleagues utilized polyester and glass fibre as the matrix materials, along with PALF sisal fibre as the reinforcing materials, to investigate the flexural and tensile properties of hybrid composites. Through their research, they were successful in enhancing the mechanical characteristics and modifying the chemical structure of the resulting composites [25]. Based on research conducted by IS Aji and colleagues, it has been found that the optimal ratio of PALF/Kenaf fibre for tensile qualities is 1:1. Additionally, the tensile and flexural properties decrease when the PALF fibre ratio decreases. The hybrid fibre composite with a 1:1 ratio of PALF/Kenaf had the lowest impact strength, while the Kenaf fibre composite demonstrated the highest impact strength [26]. A study conducted by Saha et al. revealed that the mechanical properties of PALF-reinforced composites were enhanced when pineapple leaf fibre was introduced [27]. The mechanical characteristics of the polymer composite reinforced with pineapple leaf fibre (PALF) are examined in a two-step study conducted by Rakesh Potluri to investigate the impact of incorporating silicon carbide (SiC) particles [28]. Finite element analysis was conducted to characterize the properties of the epoxy/SiC matrix. Subsequently, the hybrid composite incorporating PALF fibre was examined in terms of its matrix properties. The introduction of particles was found to significantly enhance the shear characteristics of the fibre-reinforced composite material. Also, several studies and research findings consistently show improved mechanical, thermal, and physical properties when micro/macro fillers are added to composites with different weight fractions. These advances make these composite materials more suited for a variety of engineering and structural load applications [19,22,29-33]. One notable example of producing lightweight, affordable materials for structural and engineering applications is the incorporation of fillers in composites made of pineapple leaf fibres [15]. Using natural fillers such as rice husk, wood apple shell, banana filler, eggshells, oil palm filler, sawdust from wood, coconut coir, and wheat husk can enhance the overall performance of the hybrid composites [34].

The aim of this research was, to develop polyester resin composites utilizing PALF as agro wastage filled with varying weight percentages of g-C3N4 synthesized from industrial wastage (melamine scraps). The Composites were fabricated with short pineapple leaf fibre in random orientation. After the composites were successfully fabricated, the mechanical, thermal, and morphological characterizations were investigated.

EXPERIMENTAL

Materials and Methods

Raw Materials

Pineapple Leaf Fibre (PALF) was kindly donated by Buro Craft, Bangladesh. Scrap melamine for the synthesis of g-C_3N_4 (GCN) was collected from Sharif Melamine Industries Ltd, Narayangonj, Dhaka, Bangladesh. Other supporting raw materials and chemicals such as Unsaturated Polyester Resin P9509, laboratory-grade HP- MEKP Hardener (Methyl Ethyl Ketone Peroxide), and Ethanol (70%) were supplied by *Modern Scientific Co*. Hatkhola, Dhaka.

Table 1. Physical and mechanical properties of pineapple leaf fibre

Fibre Properties	Value
Average Fibre length (mm)	530
Fibre colour	Ivory white
Fibre linear density (den)	148
Moisture regain (%)	13.2
Tensile strength (gm/tex)	34

Preparation of PALF

The fibres of pineapple leaves were soaked in a solution of 2% NaOH [26]. After two hours, the PALF was neutralized using a solution of 1% HCl for 30 minutes. It was then rinsed with distilled water. The dried PALF was cut into 3 mm lengths for the composite samples [35].

Synthesis of graphitic carbon nitride (g-C_3N_4)

Scrap melamine was collected from the industry. After that, 10 gm. of melamine scrap was placed on a crucible that was sealed with foil paper and heated in a Muffle Furnace (DMF-05, Korea) at 6500 °C for 5 hours. 1 gm of powder from the Muffle Furnace was then sonicated with an Ultrasonicator (621.06.010, Germany) with 200 ml of ethanol for 14-16 hours. After sonication, the particle was dried by Incubator (T5028, West Germany) at 1200 °C until the ethanol evaporated and made yellow colour g-C3N4 powder through grinding. The successful synthesis of *g-C_3N_4* was determined by FTIR analysis (Figure 5 (a)) and the particle size of *g-C_3N_4* was found to average 690.11 nm from SEM (Figure 4(c)).

Fabrication of Composites

Polyester resin and g-C_3N_4 were taken in a breaker with MEKP hardener. Then, they were blended for two to three minutes. After that, the treated PALF was added manually to the resin solution and stirred thoroughly and ensure that the PALF and resin were properly mixed. The mixture of PALF and resin mixture was taken from the beaker into a 10 × 10-inch stainless steel mould. The mould was uniformly wax-coated with a brush previous. A roller was used to eliminate air pockets and ensure uniform resin impregnation into the fibre during fabrication. The composites were then allowed to cure until it was completely dry, and samples were taken after 2 to 3 hours. A schematic diagram for the fabrication of PALF-reinforced polyester composites is shown in Figure 1.

Figure 1. The schematic diagram for PALF reinforced polyester composite using g-C_3N_4filler

In this study, composite materials were fabricated by hand layup technique based on weight percentage (wt%). Hand layup composite fabrication is a simple and conventional method used by numerous researchers and weight percentage (wt%) is preferred for fabrication procedures where accuracy and consistency are essential because it offers a more dependable and constant measurement of the composites.

Table 2. Composite sample ID varying filler content (wt%)

Sample ID	Filler content (wt%)	PALF content (wt%)	Polyester content (wt%)	PALF length (mm)
S1	0.00	6	94	3
S2	0.25	6	93.75	3
S3	0.50	6	93.50	3
S4	0.75	6	93.25	3
S5	1.00	6	93	3

Tensile Strength

In the tensile strength test, a critical parameter also influences material selection, design, product performance, safety, and overall efficiency in engineering and material science, where a sample is controlled under stress until it shows deformation. Understanding this property is critical for designing components that will not fail or deform under the applied forces, ensuring the longevity of products. In compliance with ASTM D638 [26-28], four samples for the tensile test specimens were prepared in dimensions 175 mm by 15 mm by 4 mm. A floor-type, computer-controlled universal testing machine called the Victor universal testing machine, UTM (VEW 2302A, Malaysia) was utilized to conduct the test on a cross head speed of 100 mm/min.

Flexural Test

The three-point bending flexural strength, also known as the modulus of rupture or bend strength, is a crucial mechanical property such as the flexural stress, flexural strain, and the flexural stress-strain response of the composite that measures a material's ability to withstand deformation under bending forces [41,42]. For this test, the Victor UTM (VEW 2302A) from Malaysia was utilized at 2.5 mm/min cross-head speed. Four specimens were prepared for the flexural strength test. The dimensions of each specimen were 120 mm x 15 mm x 4 mm for conducting flexural tests following ASTM D790.

Impact Strength Test

The impact strength test is a critical evaluation method used to assess the ability of a material to withstand sudden, dynamic loads or shock. This test provides valuable insights into a material's toughness and its resistance to fracture under impact or sudden force. The material's total toughness, which is its capacity to withstand applied energy, is closely linked to its impact qualities. Impact strength, however, is a gauge of toughness [38]. According to ASTM D256, an Izod impact strength tester (HT-8041B, Taiwan, China) was used for the test. Each sample's length was 120 mm, and its cross-sectional area was 60 mm^2, here four specimens were tested and the mean value was taken. It offers information in J/m, ft-lb/inch, or kg/cm. Here choose J/m for easy understanding.

Water Absorption Test

A water absorption test of the PALF-reinforced polyester composite using g-C_3N_4 filler has been conducted at room temperature followed by ASTM D 570-81 [34,35]. Thus, the dimension of the test specimens was 75 mm x 15 x mm x 4 mm. This procedure was repeated every ten days till the weight increased. The test was completed in 50 days. Water absorbency can be determined by applying the formula below:

$$\text{Water up} - \text{take}(\%) = \frac{\text{Wf} - \text{Wi}}{\text{Wi}} \times 100 \quad (1)$$

Wi represents the weight at the beginning (dry weight from the oven), and Wf denotes the weight at the culmination in the distilled water for 24 hours maintained at 23±1 °C.

Thermal Conductivity & Thermal Resistance Test

Using a Lees Disc apparatus (HOAE-LD18, Kerala, India), the thermal conductivity of various specimens was measured by a guarded heated plate method according to ASTM C177 with a broad measurement range of 0.001 to 3 W/K [29]. The sample dimensions were 100 × 100 mm^2. Thermal conductivity (K) was calculated (According to the assumption, the heat will not lose in its phases) as

$$\text{K} = \frac{\text{Q/A}}{\Delta\text{T}/\Delta\text{L}} (\text{W / K}) \quad (2)$$

Here, Q represents heat flux (W), A is the specimen's cross-sectional area (m^2), ΔT is the temperature change (K), and ΔL is the total distance (m). Afterwards, the thermal resistance (R) was determined using the following equation 3

$$\text{R} = \frac{\text{D}}{\lambda} \left(\frac{\text{K}}{\text{W}}\right) \quad (3)$$

Where D is the composite thickness(m) and λ represents thermal conductivity (W /K)

Scanning Electron Microscope (SEM)

In this study, the SEM (SU 1510, Hitachi, Japan) was used to examine the surface structure, such as the presence of holes and air pockets, and micro-cracks of PALF-reinforced polyester resin with g-C_3N_4.

Fourier Transform Infrared Spectroscopy (FTIR) Analysis of Composites Material

To ensure the successfully synthesized g-C_3N_4 prepared from melamine scraps and to identify the presence of a relevant group of PALF/polyester composites with g-C_3N_4 as filler, FTIR was carried out using an IRAffinity-1S FT-IR on Attenuated Total Reflection (ATR) mode.

RESULTS AND DISCUSSION

Effect of Filler Weight Percentage on Mechanical Properties of Composite

The impact of filler content on the mechanical properties of PALF/polyester composites was investigated. Four specimens were tested, and each test's average results were recorded to assess tensile strength, flexural strength, and impact strength. In this work, the fibre weight fraction was kept at 6% while graphitic carbon nitride (g-C_3N_4) was amalgamated to the PALF/polyester composite at varied weight percentages, such as S1=0.00%, S2=0.25%, S3=0.50%, S4=0.75%, and S5=1.00%. Table 3 shows the various mechanical parameters of the PALF/polyester composite at varied filler contents (wt%) in the below-

Table 3. Different mechanical properties of PALF/polyester composite varying filler content (wt%)

Sample ID	Mean Tensile Strength (MPa)	Mean Flexural Strength (MPa)	Mean Impact Strength (J/m)	Mean Young Modulus (MPa)	Mean Flexural Modulus (MPa)
S1	23.13	84.00	45.17	1058	2527
S2	24.86	71.00	21.68	1518	2318
S3	25.23	68.00	21.92	1639	2210
S4	33.88	65.00	27.34	2470	2117
S5	29.20	63.00	26.37	2129	2115

The tensile and flexural strength of the PALF/polyester composite of g-C_3N_4 as filler are shown in Figure 2(a). It was found that the tensile strength is affected and increased to a point after which more amount g-C_3N_4 mixing could reduce the overall tensile strength. Here, the optimum tensile strength of g-C_3N_4 filled PALF/polyester composite was found 33.88 MPa. at 0.75 wt% of g-C_3N_4. It was increased by 46.51% from the PALF/polyester composite having 0.00 wt% of g-C_3N_4. The tensile strength of PALF/polyester composites was significantly increased might be due to the strong physical interlocking and chemical bonding between g-C_3N_4 and polyester resin. On the other hand, tensile strength was shown to progressively rise with g-C_3N_4 loading (wt%) until declining to 29.2 MPa at 1.00 wt%. This decline with a higher weight percentage of g-C_3N_4 happened due to the aggregation of large g-C_3N_4 [39].

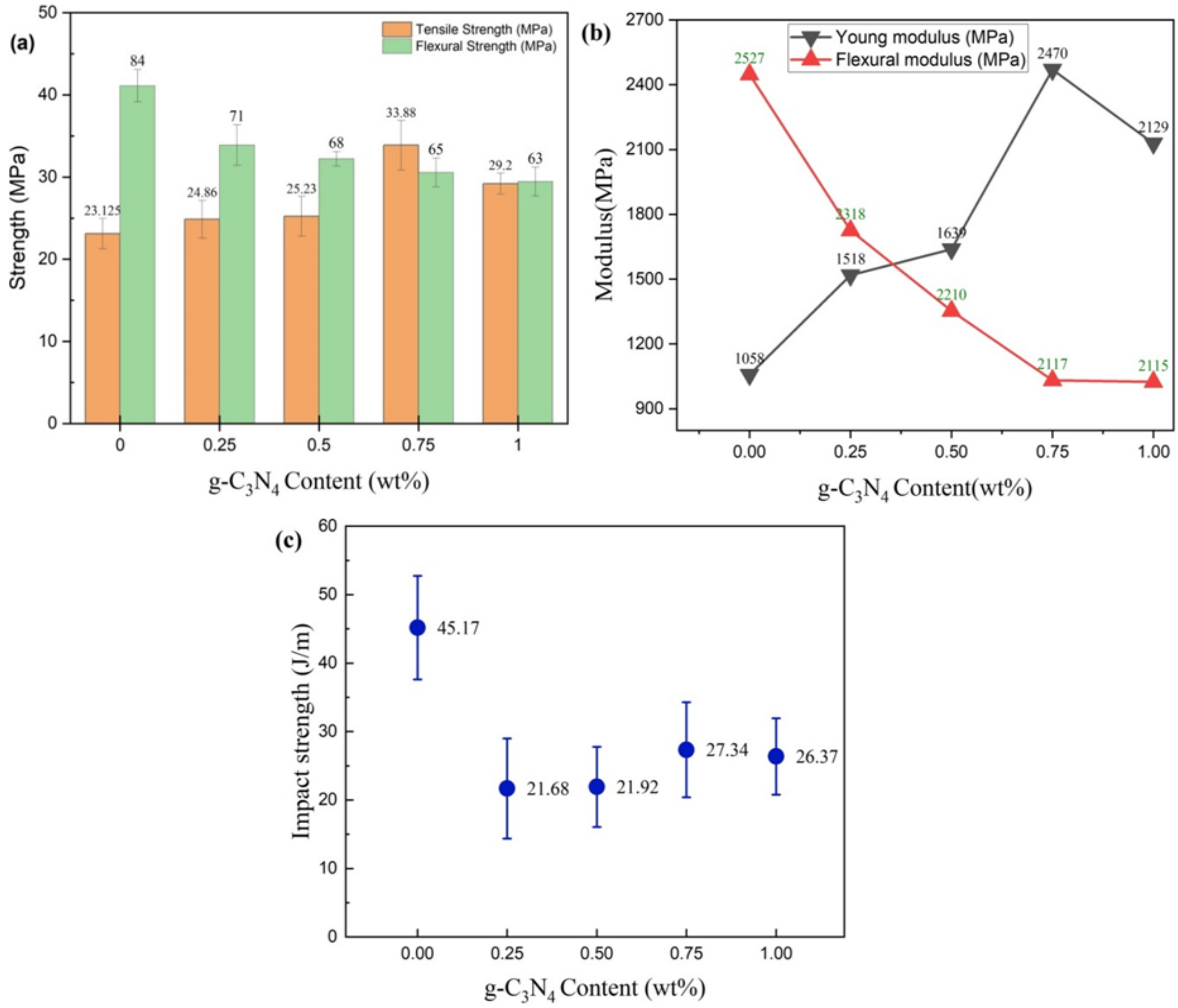


Figure 2. Variation of mechanical strength with g-C_3N_4 filler content (wt%) in the PALF-polyester composite; (a) tensile and flexural strength (b) Young modulus & flexural modulus (c) impact strength

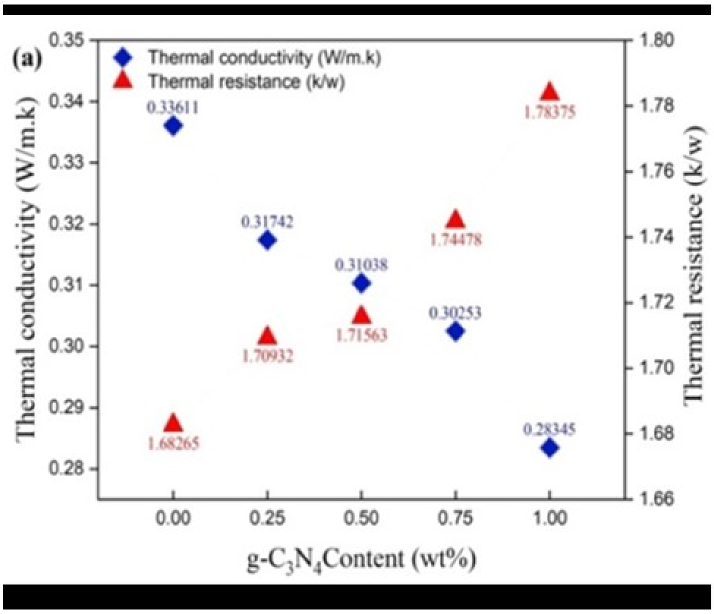
The Young modulus of g-C_3N_4 -filled PALF/polyester composites was increased with filler loading as tensile strength is shown in Figure 2(b). The maximum growth of the young modulus from 1058 MPa to 2470 MPa, was obtained in 0.75 wt% of g-C_3N_4. The markedly enhanced tensile strength and Young modulus of composites can be attributed to the good interfacial bonding between g-C_3N_4 and polyester [40,41]. The flexural behaviour of g-C_3N_4-filled PALF/polyester composites including, flexural strength and flexural modulus are presented in Figure 2(a) and Figure 2(b) respectively. Observing in Figure 2(a) through increasing g-C_3N_4 content (wt%) on PALF/polyester composites, flexural strength drastically decreased as well as the same behaviour in flexural modulus (Figure 2(b)). Subsequently, the flexural strength dropped to 63 MPa from 71 MPa and the flexural modulus declined to 2115 MPa from 2318 MPa. The optimum flexural strength of 84 MPa and flexural modulus of 2527 MPa are found in the composite which has 0 wt% g-C_3N_4. The addition of g-C_3N_4 to PALF/polyester composites can lead to decreased flexural and impact strengths due to its rigidity induceness. The stress concentration, micro cracking, and the presence of irregularities like voids as well as pores of the composites are responsible for composite failure [42,43]. The presence of voids and cracks is seen from (Figure 4) SEM analysis. Moreover, the consequences of loading g-C_3N_4 on the impact properties of the composites are illustrated in Figure 2(c). The impact strength of g-C_3N_4-filled PALF/polyester composite was decreased with increasing g-C_3N_4 content (wt%) and it was observed at 26.37 J/m whereas 45.17 J/m at 0 wt% g-C_3N_4. Although 0.75 wt% showed slightly higher impact strength compared to 0.25, 0.50, and 0.75 wt% of g-C_3N_4, PALF/polyester composite without g-C_3N_4 had optimum impact strength. Graphitic carbon nitride (g-C_3N_4) forms agglomerate in the composites, which induces localized brittleness and cracking [44]. Weak interfacial between the filler and polyester resin decreased impact strength [40].

Thermal Properties and Water Absorption Behavior of Composites

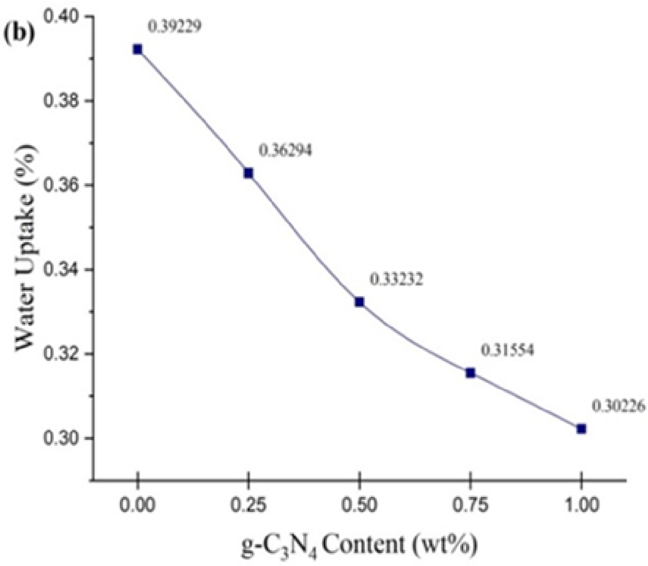
Thermal behaviour of fibre-reinforced polymer composites, like thermal resistance and thermal conductivity, identify the materials' thermal reactions in different end uses. Reliable temperature measurements of fibre-reinforced polymer composites are crucial for certain composite material applications. Table 4 displays the thermal conductivity and resistance values of polyester composites reinforced with PALF at various weight percentages of g-C_3N_4.

Table 4. Thermal properties of PALF/polyester composite varying filler content (wt%)

Sample ID	Thermal Conductivity (W/m.k)	Thermal Resistance (k/w)
S1	0.3361	1.68
S2	0.3174	1.71
S3	0.3104	1.71
S4	0.3025	1.74
S5	0.2835	1.78



a)



b)

Figure 3. a) Thermal conductivity and thermal resistance behaviour of PALF/polyester composite with varying filler content b) Water absorption behaviour of PALF/polyester composite with varying filler content

As can be seen in Figure 3(a), shows that the optimum thermal resistance of g-C_3N_4 -filled PALF/polyester composite materials was found at 1.00 wt%, and it was 1.78 k/w. The thermal resistance increased by 5.95 % from the composites of PALF/polyester with 0.00 wt% g-C_3N_4. In contrast, the thermal conductivity dropped 15.67 % (0.28 W/m.k from 0.33 W/m.k). Thermal conductivity was decreased with the loading of g-C_3N_4 wt%. The results of this study indicated that the PALF/polyester composite of 6 wt% PALF volume with 1.00 wt% g-C_3N_4 possesses good thermal insulating properties. These behaviours of composites were shown due to the lower thermal conductivity of pineapple leaf fibre and g-C_3N_4 also [45]. The literature states that the thermal conductivity of composites depends on the conductivity of each component [46]. Composite performance is determined by several critical factors, including thermal expansion mismatch, relative modulus of the fibre and matrix, fibre length, and fibre aspect ratio [47].

Water uptake percentages of varying g-C_3N_4 wt% filled PALF/polyester composites are illustrated in Table 5.

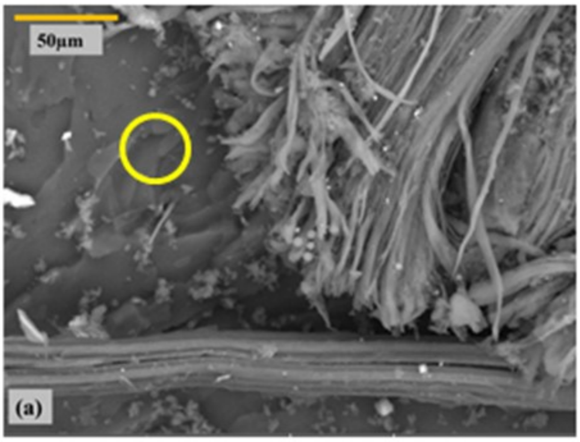
Table 5. Water uptake percentages of varying filler content (wt%)

Sample Designation	Dry Weight W*i* (gm)	Wet Weight W*f* (gm)	Water Uptake (%)
S1	12	12.047	0.392
S2	12	12.043	0.363
S3	12	12.040	0.332
S4	12	12.038	0.316
S5	12	12.036	0.302

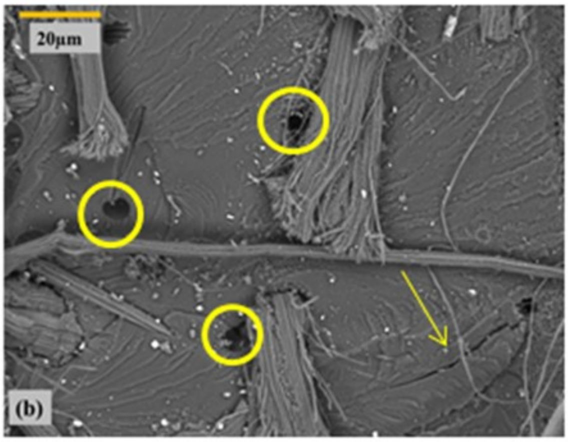
The water absorption behaviour of natural fibre-reinforced polymer composites hinges on several factors, including the quantity of the fibre, the orientation of the fibre, the temperature during immersion, and the surface area exposed to water. Additionally, the permeability of fibres, void content, and the hydrophobicity of the individual components of composites, specifically PALF and polyester resin, play significant roles [33]. Figure 3(b) illustrates that PALF in the polyester resin composites becomes swell and hydrophilic when exposed to water. However, after adding g-C_3N_4 to PALF/polyester composite with different weight percentages water uptake slightly decreased (it was 0.302 % from 0.392 %) with increasing g-C_3N_4. This was because both g-C_3N_4 and polyester resin are hydrophobic and crystalline although the characteristics of PALF are hydrophilic after being treated with NaOH but only 6 wt% PALF absorbs water slightly. After incorporating g-C_3N_4 some water was absorbed by the composite in the presence of voids [48,49]. Nonetheless, when the weight percentage of g-C_3N_4 progressed, correspondingly grew the water repellency.

SEM (Scanning Electron Microscope) of composite under mechanical failure

SEM had been performed on the fracture surface of the composite to better understand the results of mechanical testing. Figures 4(a) and 4(b) demonstrate that the PALF-polyester composite with g-C_3N_4 filler exhibits normal brittle behaviour. The fracture in this instance followed a clear path, suggesting low g-C_3N_4 interaction and brittle behaviour [50].



a)



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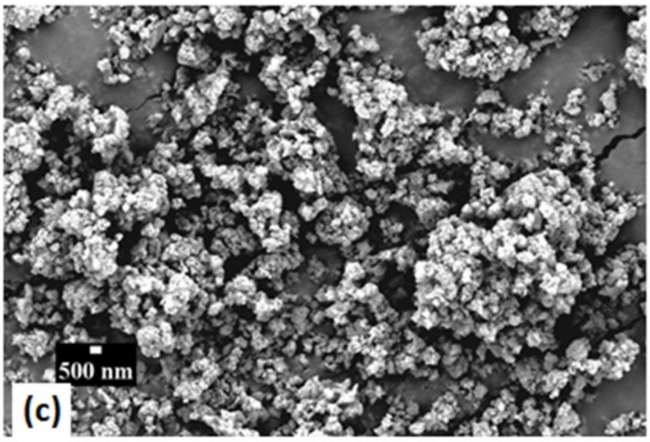

c)

Figure 4. a) Typical iceland-like structures formation of PALF-polyester composite and fibre breakage; b) SEM of the fracture surface of PALF-polyester composite material under tensile failure and presence of void and crack on composite; c) Surface view of synthesized g-C_3N_4

The capacity of g-C_3N_4 to deflect the cracks resulted in the observation of numerous cracks and holes (yellow marks in the figures) in different positions. It was observed that the mechanical properties with 0.75 wt% g-C_3N_4 increased the material's strain energy consumption and also created interfacial bonding strength between the filler and resin [47, 51]. A homogenous dispersion of the filler was achieved in the composites that increased the mechanical properties at 0.75 weight per cent. The filler loading below and beyond 0.75 weight per cent did not provide a substantial improvement in the PALF/polyester composites. The increase in g-C_3N_4 weight per cent caused the formation of filler-rich iceland-like structures within the resin (yellow mark in Figure 4(a)). Their presence creates areas of higher stress concentration where fractures initiate and increase the specimen's failure [51,52]. The average particle size of g-C_3N_4 was 690.11 nm also observed from Figure 4 (c) SEM images.

FTIR analysis of composite

The FTIR spectrum g-C_3N_4 from Figure 5(a) showed several distinctive peaks. The triazine rings' breathing mode is responsible for the peak at 750 cm^{-1}, whereas the stretching vibration of the carbon-nitrogen bond is responsible for the peak at 1392 cm^{-1}. The stretching vibration of N-H bonds is responsible for the peak, which is located between 3182 and 3400 cm^{-1}. GCN's FTIR spectra also show peaks associated with surface functional groups. The bending vibration of N-H bonds is linked to the peak at around 1500 cm^{-1}, while the stretching vibration of C=C bonds is linked to the peak at approximately 1627 cm^{-1}. These peaks were proposed as evidence that the surface of g-C_3N_4 contains a significant quantity of amino and imine groups [19].

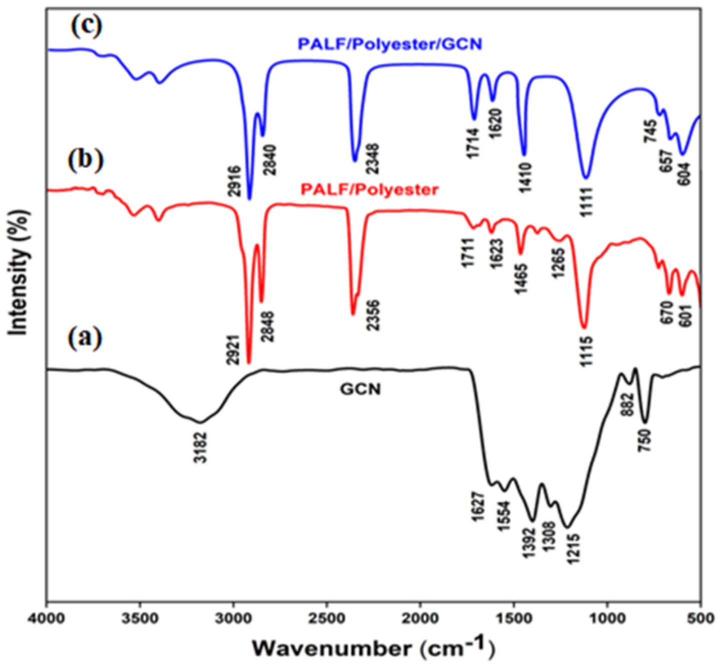

Figure 5. FTIR spectrum of (a) g-C_3N_4 from melamine (b) PALF/polyester composites (c) PALF/polyester/ g-C_3N_4 composite

FTIR spectroscopy of the PALF-polyester composite with g-C_3N_4 and without g-C_3N_4 is presented in Figure 5(b) and Figure 5(c). The peak values at 745 cm^{-1} that were observed in the FTIR spectra of PALF-polyester resin with g-C_3N_4 in Figure 5(c) indicate the presence of triazine rings. But in Figure 5(b) the absence of such kind of pick indicates the absence of g-C_3N_4. Another pick at 1410 cm^{-1} indicates the presence of a carbon-nitrogen bond in the g-C_3N_4 incorporated PALF-polyester resin. Some picks were not shown clearly in Figure 5(c) because a small amount of g-C_3N_4 % 0.75% was added to the composite. In contrast, the major group of g-C_3N_4 as triazine and carbon-nitrogen bond is absent in the PALF-polyester composite without adding filler g-C_3N_4 in Figure 5(b).

CONCLUSION

The research demonstrated a simple and rapid fabrication of PALF/polyester composite using g-C_3N_4 as filler, which was successfully synthesized from melamine. The successful manufacturing of g-C_3N_4 was confirmed by analyzing the FTIR spectrum. Tensile strength increased by 46.47% and this was shown when 0.75 wt% of filler was incorporated into the composite. The flexural and impact strength decreased after incorporating filler from 0.25% to 1%. The reason for this could be seen in the SEM image experiencing the presence of g-C_3N_4 granules in the composite. This also creates holes and cracks in the composite, creating areas of higher stress concentration. Less water absorption was achieved by 1.00% wt% of g-C_3N_4. Melamine is hydrophobic and therefore the addition of a 1.00 wt% g-C_3N_4 makes the composite more hydrophobic. In the g-C_3N_4 filled PALF/polyester composite, the improvement of thermal resistance (increasing by 5.33%) makes it suitable for interior design, flooring, kitchen furniture, wall fixtures, automotive and furniture industries, etc. The study shows that melamine from industrial waste offers good heat resistance when incorporated into thermoset resins and for fibre reinforcement from agricultural waste containing pineapple leaves. This work has proven that an optimum loading of 0.75 wt% of g-C_3N_4 into PALF/polyester composites can improve the tensile properties. However, the filler, g-C_3N_4 did not affect the flexural and impact strength of the composites.

Author Contributions

Conceptualization – Nabi N and Belal SA; methodology – Nabi N; formal analysis - Nabi N; investigation – Nabi N; resources – Nabi N; writing- Nabi N; writing-review and editing – Nabi N and Belal SA, Khan RA and UDDIN B; supervision – Belal SA. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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