

Experimental Investigation on the Effect of Thermal Parameters on Glass-Fiber Reinforced Composite

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Abstract The study investigated the effect of thermal parameters on the glass fiber reinforced bio-composite produced. The materials used were locally sourced within Adeleke University campus, Ede, Nigeria. The reinforced bio-composite was produced by mixture of prepared bamboo, PET and glass fiber powders, with epoxy resin serving as the bonding agent. Each of the powdered bamboo, PET and glass fiber was sieved using three different screen sizes of 250, 425, and 600 μm , respectively. The samples produced were subjected to sintering process and the heat distribution within the composite was measured using type-k thermocouple and digital thermometer. The results show reveal that the quantity of heat decreases with addition of glass fiber and increase in the particle size of the reinforced bio-composite. Also, the specific heat capacity of the composites decreases with increase in particle size and addition of glass fiber. Likewise, the thermal conductivity increases with increase in particle size of the reinforced composite but reduces with addition of glass fiber. Similarly, the thermal diffusivity of the reinforced bio-composite decreases with increase in particle size however it increases with the addition of glass fiber. Therefore, the presence of glass fiber and the particle size have significant effect on the thermal parameters of the reinforced bio-composite.

Keywords: Bio-composite, particle size, glass fiber, quantity of heat, specific heat capacity, thermal diffusivity, thermal conductivity

I. Introduction

The quest for sustainable, high-performance materials has spurred a significant shift in material science and engineering, especially in the development of composites. Composite materials, which consist of two or more constituent materials with distinct physical or chemical characteristics, have garnered immense attention due to their superior mechanical, thermal, and chemical properties compared to conventional materials [1, 2]. These properties, particularly the high strength-to-weight ratio, durability, corrosion resistance, and design

flexibility, make composites indispensable in critical sectors such as aerospace, automotive, civil infrastructure, and renewable energy systems [3, 4, 5]. Among the various classes of composites, glass fiber-reinforced composites (GFRCs) have emerged as particularly important due to their unique combination of lightweight, high tensile strength, and thermal stability. Glass fiber acts as a reinforcing phase, offering remarkable resistance to environmental degradation and significantly improving the structural integrity of composites [1, 6]. The reinforcement provided by glass fibers enhances tensile and flexural strength, modulus of rupture, toughness, and energy absorption capabilities [6]. Additionally, the fibrous architecture of glass allows it to bridge micro-cracks and distribute stresses uniformly, thereby mitigating crack propagation and transforming brittle matrix

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behaviour into ductile responses [7]. These characteristics contribute to their expanding application in sectors requiring long-term durability under thermal and mechanical loads [8]. However, while synthetic polymers and epoxy resins have traditionally served as matrices in composite systems, recent global environmental concerns have necessitated a shift toward renewable, biodegradable, and eco-efficient alternatives. One such promising natural resource is bamboo. Bamboo is a fast-growing, renewable grass with high mechanical strength, low density, biodegradability, and thermal stability, making it a suitable candidate as a matrix in sustainable composites [3, 9]. Its high compressive and tensile strength, which are comparable to or surpass those of traditional materials like concrete and steel, further enhance its appeal in structural applications [10]. In many parts of the world, especially Asia, Africa, and Latin America, bamboo has long served as a primary material for construction and utilities, owing to its resilience and cost-effectiveness [11, 12]. In hybrid composite systems, bamboo can serve as a matrix material when complemented with polymers that can enhance its mechanical and thermal stability. Polyethylene terephthalate (PET), a widely used thermoplastic polymer, presents itself as an optimal choice in this regard. It possesses excellent tensile and impact strength, high thermal resistance, and chemical stability [13, 14]. PET's impermeability to gases and liquids and its recyclability make it attractive not only from a performance standpoint but also from an environmental one, as it addresses the global challenge of plastic waste management [13, 15]. When PET is repurposed in composite fabrication, it contributes to a circular economy model, transforming waste into high-value, sustainable materials [14]. To ensure cohesive bonding and stress transfer between the matrix

and the reinforcement, epoxy resin is employed as a binder agent. Epoxy resin offers excellent thermal stability, mechanical strength, and chemical resistance due to its highly cross-linked molecular structure [7]. It helps resist deformation under load and protects the structural and chemical integrity of the reinforcing fibers [7]. This synergistic interaction among the bamboo matrix, PET polymer, epoxy binder, and glass fiber reinforcement potentially results in a composite material with enhanced thermal and mechanical performance suitable for demanding applications. Thermal parameters—such as thermal conductivity, thermal degradation temperature, and resistance to thermal cycling—are critical indicators of composite performance under fluctuating temperature conditions. These properties directly influence the composite's reliability, structural lifespan, and safety in real-world applications. Industries such as automotive, construction, and electronics demand materials that can sustain mechanical performance under thermal stress without experiencing deformation or loss of integrity [5, 8]. While there is substantial literature on the mechanical performance of GFRCs and bamboo-reinforced composites, there remains a significant knowledge gap concerning the thermal behaviour of hybrid composites composed of bamboo, PET, epoxy resin, and glass fiber. Previous studies have focused largely on mechanical characterization, leaving a limited understanding of how such composite systems behave under varying thermal conditions. Given the increasing demand for lightweight, durable, and thermally stable materials in structural and thermal-sensitive environments, it becomes crucial to investigate the thermal dynamics of these novel composites. Therefore, this study aims to investigate the effect of thermal

parameters on glass fiber reinforced bio-composite.

II. Materials and Method

The materials and method used in carrying out this experiment are itemized as follow:

A. Materials

The materials adopted for this work include used plastic bottles, bamboo, epoxy resin, and glass fiber.

i. Polyethylene terephthalate (PET)

The PET came from post-consumer plastic bottle waste that was obtained locally from the Adeleke University campus in Ede, Nigeria.

ii. Bamboo

Bambusa vulgaris is the species of bamboo used in this study, and it was obtained locally from the Adeleke University Research Center, Ede, Nigeria. The bamboo stems were matured as at the time of harvested.

iii. Reinforcing materials

Bamboo and glass fiber were adopted for the study as the reinforcing materials due to their effectiveness and sustainability in order to enhance the load-bearing capacity of the composite produced. Glass fiber was added in the same proportion for some set of samples produced.

iv. Matrix materials

Epoxy resin served as the matrix material in this work and it was selected because of its binding-ability which holds the reinforcing fibers together and transferring of loads between fibers. Similarly, polyethylene terephthalate contributed as a matrix material in the composite material produced due to its recyclability.

v. Equipment

The equipment used to carry the study are hacksaw, digital thermometer, digital scale,

hydraulic press, hammer mill, universal testing machine (UTM).

B. Methods

i. Recycling of polyethylene

terephthalate (PET) and glass bottles

Post-consumer plastic bottles were gathered from the waste dump and carefully rinsed to get rid of anything that could have affected the outcome. To increase the surface area for subsequent processing, the bottles were granulated into flakes after being air-dried to remove moisture. The dried flakes were subsequently recycled by melting at temperature of 250°C. The melted PET was allowed to cool and solidify into lumps that are subsequently ground to powder using hammer milling machine. Similarly, the glass fiber used in this study was sourced locally from wine bottle waste that was gathered from Adeleke University staff quarters. The collected glass wastes were cleansed to get rid of unwanted particles, sun-dried and ground into powder form.

ii. Making of bamboo powder

The harvested bamboo culms were sun-dried for two weeks before processing to lower their moisture content. Since the components of the composite materials had to be in powder form for the study, the bamboo underwent a number of operations such as trimming and cutting, crushing and milling before being ground into powder form.

iii. Production of the reinforced bio-composite samples

The reinforced bio-composite material was developed by mixture of prepared bamboo, PET and glass fiber powders, with epoxy resin serving as the bonding agent. Each of the powdered bamboo, PET and glass fiber was sieved using three different screen grades of 250, 425, and 600 μm , respectively. The samples of reinforced

bio-composite were made using varied proportions of the components for the three different sieve sizes (Table 1). This formulation was thoroughly mixed to produce a uniform mixture for each of the sieve size. The mixture with and without addition of glass fiber in three different grain sizes was put into a 70 x 70 x 70 mm steel molds and compressed with a 20 KN hydraulic press. Two samples were produced for each grain size; one was reinforced with glass fiber and the other without glass fiber. The samples produced were subjected to sintering

process and the heat distribution within the composite was measured using type-k thermocouple and digital thermometer. The type-k thermocouples were inserted into each sample at random points (Figure 1). Each sample with the thermocouples was placed inside an electric furnace where it was heated to temperature of 280 °C. The temperature readings were taken and recorded with the digital thermometer for each sample at particle sizes considered.

Table 1: Mixture Ratio of Constituents for Each Sample

Sample	Particle size (µm)	Bamboo (wt%)	Polyethylene terephthalate	Glass fiber
A	250	60	40	-
	250	60	40	Yes
B	425	60	40	-
	425	60	40	Yes
C	600	60	40	-
	600	60	40	Yes



Figure 1: Reinforced Composite Sample with Type-K Thermocouples Inserted.

C. Thermal Parameters of Reinforced Bio-composite

The temperature readings that were measured and recorded were effectively used to evaluate the following thermal properties of the reinforced composite produced.

- i. Quantity of heat flow (Q)

$$Q = Q_1 + Q_2 \quad (1)$$

Q_1 is the quantity of heat flowing in the reinforcement material,

Q_2 is the quantity of heat flowing in the matrix material.

- ii. Specific heat capacity (C)

$$C = \frac{Q}{M \cdot \Delta T} \quad (2)$$

Q is the total quantity of heat flowing in the composite,

M is the mass of the composite,

ΔT is the change in temperature.

- iii. Thermal conductivity (K)

$$K = \frac{Q/A}{\Delta T/\Delta L} \quad (3)$$

Q is the total quantity of heat flowing in the composite,

A is the cross-sectional area of the composite,

ΔT is the change in temperature,

ΔL is the overall thickness of the composite.

- iv. Thermal diffusivity (α)

$$\alpha = \frac{K}{\rho \cdot C} \quad (4)$$

K is the thermal conductivity of the composite,

ρ is the density,

C is the heat capacity of the composite.

III. Results and Discussion

The results of effect of thermal parameters on glass fiber reinforced bio-composite produced are discussed in this section.

A. Quantity of Heat

Table 2 shows the values of quantity of heat of reinforced bio-composites with and without addition of glass fiber. At particle size of 250 μm , sample A without glass fiber has amount of 11162.20 J/s heat. Also, at particle sizes of 425 and 600 μm , samples B and C without addition of glass fiber have heat amount of 9219.23 and 7446.26 J/s, respectively. Similarly, at particle sizes of 250, 425 and 600 μm , samples A, B and C with addition of glass fiber have heat amount of 9512.26, 6758.06 and 4442.64 J/s, respectively. The result shows that the quantity of heat decreases with increase in the particle size of the reinforced bio-composite with and without addition of glass fiber. The reason behind this is that the smaller particle size has larger surface area to volume ratio which increases the interfacial area between the reinforcing and matrix material thereby improving their bonding ability [16, 17]. The stronger the bonding ability, the better the heat distribution and uniformity of absorption. However, the addition of glass fiber reduces the quantity of heat of the reinforced bio-composite with respect to their particle size. This is because the presence of glass fiber acts as a thermal barrier, resulting in a more uniform structure and less heat movement through the composite.

B. Specific Heat Capacity

Sample A with particle size of 250 μm reinforced with glass fiber has specific heat capacity of 390.59 J/kgK, while the sample with the same

Table 2: Quantity of Heat of the Reinforced Bio-omposite

Samples	Particle size (μm)	Quantity of heat (J/s)	
		without glass fiber	with glass fiber
A	250	11162.20	9512.26
B	425	9219.23	6758.06
C	600	7446.26	4442.64

particle size but without the reinforcement of glass fiber has specific heat capacity of 399.25 J/kgK (Table 3). Also, sample B with particle size of 425 μm , reinforced with glass fiber has specific heat capacity of 380.12 J/kgK whereas the same sample without the reinforcement of glass fiber has specific heat capacity of 396.81 J/kgK. Similarly, sample C with particle size of 600 μm reinforced with glass fiber has specific heat capacity of 375.00 J/kgK but same sample without the reinforcement of glass fiber has specific heat capacity of 385.05 J/kgK. According to the result, it can be observed that the specific heat capacity of the reinforced composites with and without glass fiber decreased with increase in the particle size of the composites. This is because the smallest particle size has a higher surface area to volume ratio,

which might improve heat transfer with the matrix material and perhaps affect the specific heat capacity. Also, the interfacial interaction between the reinforcement and the matrix particles varies with particle size; with fine particles resulting in greater bonding and more efficient load transmission, which can impact thermal characteristics. Similarly, the composite samples reinforced without the addition of glass fiber have higher specific heat capacity compared to samples reinforced with glass fiber (Table 3). When glass fiber was added to bamboo reinforced composite, the total proportion of bamboo lessened, while the influence of glass fibre rose. This result in a reduced specific heat capacity for the composite, which means it will heat up and cool down faster than pure bamboo reinforced composite.

Table 3: Specific Heat Capacity of the Reinforced Bio-Composite

Samples	Particle size (μm)	Specific heat capacity (J/kgK)	
		without glass fiber	with glass fiber
A	250	399.25	390.59
B	425	396.81	380.12
C	600	385.05	375.00

C. Thermal Conductivity

Table 4 presents the values of thermal conductivity of reinforced bio-composites with and without addition of glass fiber. The thermal conductivity for samples with glass reinforced composite ranges from 1886.07 - 1918.53 W/mK, and without glass fiber ranges from

1905.00 - 1926.22 W/mK. These ranges of thermal conductivity varied with particle size of the composites. For instance, at particle size of 250 μm , the thermal conductivity obtained for reinforced composite with glass fiber is 1886.07 W/mK. At particle sizes of 425 and 600 μm , the

values of thermal conductivity obtained are 1903.09 and 1918.53 W/mK, respectively. Also, similar trend was observed for samples of reinforced composite without glass fiber as shown Table 4. The result shows that the thermal conductivity of the samples of reinforced composite with and without glass fiber increases with increase in the particle size of the samples. This is due to the fact that the smaller particle size increases the number of interfaces between the reinforcing and matrix materials. These interfaces serve as thermal

barriers by reducing heat transfer. However, the larger particle size causes less interfacial barriers which allow heat to transfer more easily. Furthermore, the result demonstrates that the values of thermal conductivity of the samples without addition of glass fiber are higher than those with glass fibre. This is as a result of the addition of glass fiber with the constituents of the reinforced composite reduced the thermal conductivity because glass fiber impedes the flow of heat by slowing down or preventing heat transfer within the composite material.

Table 4: Thermal Conductivity of the Reinforced Bio-Composite

Samples	Particle size (μm)	Thermal conductivity (W/mK)	
		without glass fiber	with glass fiber
A	250	1905.00	1886.07
B	425	1916.80	1903.09
C	600	1926.22	1918.53

D. Thermal Diffusivity

The values of thermal diffusivity of the reinforced bio-composite with and without addition of glass fiber as obtained from the result are as stated in Table 5. These values reduced with particle sizes of the composite from 0.004928 - 0.004680 m^2/s with addition of glass fiber and 0.004885 - 0.004564 m^2/s without glass fiber, respectively. The result shows that the thermal diffusivity of sample of the reinforced bio-composite with glass fiber for smaller particle size is higher compared to bigger particle size. For instance, at particle size of 250 μm , the thermal diffusivity is 0.004928 m^2/s and at particle size of 600 μm , the thermal diffusivity is 0.004680 m^2/s . Also, the same trend was observed for samples of reinforced composite without glass fiber (Table 5). Hence, the thermal diffusivity of the reinforced bio-composite decreases with increase in the particle size of the

samples with or without adding of glass fiber. This is attributable to the fact that the smaller particle size affected the packing density of the composite which could have brought about reduction in voids and improved thermal diffusivity while the bigger particles might have created more voids in the composite which could reduce thermal diffusivity since air is a poor conductor of heat [16, 17]. Additionally, the result shows that the thermal diffusivity of the samples with addition of glass fiber is higher than those without glass fibre. This is owing to the fact that glass fiber could fill the voids and reduce spaces within the composite which could have resulted to improved thermal diffusivity since lesser pores allows better heat transfer

Table 5: Thermal Diffusivity of the Reinforced Bio-Composite

Samples	Particle size (μm)	Thermal diffusivity (m^2/s)	
		without glass fiber	with glass fiber
A	250	0.004885	0.004928
B	425	0.004701	0.004806
C	600	0.004564	0.004680

IV. Conclusion

The study investigated the effect of thermal parameters on glass fiber reinforced bio-composite. The results show reveal that the quantity of heat decreases with addition of glass fiber and increase in the particle size of the reinforced bio-composite. Also, the specific heat capacity of the composites decreases with increase in particle size and addition of glass fiber. Likewise, the thermal conductivity increases with increase in particle size of the reinforced composite but reduces with addition of glass fiber. Similarly, the thermal diffusivity of the reinforced bio-composite decreases with increase in particle size however it increases with the addition of glass fiber. Therefore, the presence of glass fiber and the particle size have significant effect on the thermal parameters of the reinforced bio-composite.

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