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# Fabrication of bio-fiber based *Eichhornia crassipes*/$Al_2O_3$ particles hybrid biocomposites and investigation of important properties

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## Abstract

The need for environmentally friendly composite materials that meet the necessary criteria is growing. Making novel environmentally acceptable composites with hybrid *Eichhornia crassipes* (EGs)/$Al_2O_3$ particles is an option. This paper aims to investigate the thermal, tensile strength, and flexural strength properties of a polyester composite filled with hybrid EG/$Al_2O_3$ particles. The tensile strength, flexural strength, and morphology of EGs/$Al_2O_3$ hybrid composite will be investigated in this work. The hot pressed for 60 minutes at 170°C procedure was used to shape the hybrid composite. EGs/$Al_2O_3$ particles content was altered from 0:25 to 5:20, 10:15 to 15:10, 20:5, and 25:0 (vol.%). The results reveal that when the EGs content of the composite is in the range of 10–15% (vol.%), the tensile and bending strength of the composite increases. The EGI (15% EGs:10% $Al_2O_3$) and EGH (10% EGs:10% $Al_2O_3$) composites had the highest tensile and bending strengths, with 38.697 and 77.786 MPa, respectively. The boost in strength is thought to be due to $Al_2O_3$ acting as a cursor in the composite, preventing fracture progression. The scanning electron microscope (SEM) fracture morphology reveals a strong and tight interfacial connection between the EGs, $Al_2O_3$, and polyester layers. In addition, when the EGs grew, the composites' thermal characteristics improved. According to the findings, the EGs/ $Al_2O_3$ particle hybrid composite can be used in automotive applications.

**Keywords**
Hybrid composite, water hyacinth particles, $Al_2O_3$, tensile and bending properties, morphological properties

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## Introduction

Today, almost every country in the world strictly adheres to the guidelines and standards established by environmental regulatory agencies. These environmental rules and regulations direct researchers to develop environmentally friendly materials to replace non-biodegradable materials.[1,2] Because of their simple fabrication procedures, low cost, light weight, comparable strength, and durability, synthetic fiber-reinforced composites are one of the non-biodegradable materials used in a variety of fields such as automotive, construction, and packaging.[3] According to recent environmental policies, alternative materials for synthetic fiber-reinforced composites are required. Plant fiber-reinforced composites are an environmentally friendly alternative to synthetic fiber-reinforced polymers, with comparable mechanical, thermal, and morphological properties. The ability of plant fibers to bond with polymer resins is an important factor in determining the mechanical performance of fiber-reinforced plastics.[4] Untreated plant fibers have a smooth hydrophilic surface, which reduces their ability to bond with polymers. Plant fibers are typically chemically treated to improve their bonding ability. This type of chemical treatment also alters the fiber's chemical composition, thermal stability,

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surface roughness, and tensile performance. For surface modification, researchers use aqueous sodium hydroxide (NaOH) solution, potassium permanganate in acetone, and silanes in ethyl alcohol. NaOH treatment is the most cost-effective and efficient of these.[5]

*Eichhornia crassipes* (EG) is a plant that grows in water and is often considered a weed. The EG plants grow very fast, spread rapidly throughout rivers, and float on the surface of the water, causing damage to waterways and water pollution.[6] Like other fibers, water hyacinth has a high percentage of holocellulose so it becomes an advantage in its application as a reinforcing material for polymer materials.[7] They also contain important compounds such as cellulose of 64.51%, pentose of 15.61%, lignin of 7.69%, silica of 5.56%, and ash of 12%.[7] The potential of environmentally friendly EG fiber as a composite reinforcement is an opportunity to reduce the use of synthetic fibers such as glass fibers because they are not environmentally friendly, and harmful to health.[8] Several researchers have investigated the physical and mechanical properties of EG fiber composites. Ramirez et al.[9] have investigated the mechanical and thermal characteristics of an EG particle-filled polyester composite. They reported that polyester composites with EG concentrations in the range of 5–10 (weight%) gave the best results in terms of dynamic modulus of elasticity of 0.33–0.45 kg/cm$^2$. Static modulus elasticity and density of the composites were found in the range of 40,000–10,000 kg/cm$^2$ and 1.6–1.53 g/cm$^3$ obtained from composites with a volume fraction of EG particles of 0–20 (wt.%). They also revealed that there was no evidence of a negative effect on the mechanical and thermal properties of the composites with the addition of EG to the polyester resin.[10] Furthermore, water hyacinth fiber can provide competitive reinforcing qualities when compared to other natural fibers, such as hemp, abaca, and rice straw. Optimal mechanical properties of high-density polyethylene composites were obtained when the ratio of water hyacinth and HDP fiber content was 30%:70%. The density of the composite is known to tend to decrease when EG particles increase.[11] The maximum tensile strength of the composite containing 10% EG fiber (% volume) is known to be 27.27 MPa, and the maximum impact strength of 0.0161 J/mm$^3$ was obtained from the composite with a fiber volume fraction of 40%.[12] From several perspectives, EG particle filler can reduce production costs and improve the mechanical properties of composites for application in various industries. Unfortunately, the mechanical properties of this water hyacinth fiber-reinforced composite are known to be low compared to synthetic fiber-reinforced composites. This weakness can be solved by hybridizing EG with $Al_2O_3$ in the composite. This hybrid composite offers characteristics that cannot be obtained with a single filler. $Al_2O_3$ particles can increase the hardness and impact energy of epoxy composites compared to modifications using $SiO_2$ and $TiO_2$ particles.[13] Heyi et al.[14] have investigated the addition of $Al_2O_3$/SiC filler in polyester–bagasse fiber composites. They reported that the tensile and bending strength of the composite after the volume fraction of $Al_2O_3$ (wt.%) was increased. Then there was a decrease after adding more than 8% of SiC by weight and more than 10% of bagasse fiber by weight fraction. Tominaga et al.[15] have combined $Al_2O_3$ and hexagonal boron nitride (h-BN) particles. They reported that the relative density of the composite film increased with increasing wt.% $Al_2O_3$, which was greater than wt.% cellulose nanofiber (CNF) and nano-diamond particles (ND). The thermal conductivity of the composite film may vary depending on the shape of the ceramic filler. Previous studies have shown that hybrid $Al_2O_3$ with EG fiber needs to be developed and investigated to obtain the best properties and fulfill the desired application requirements such as in automotive field.

Therefore, this study aims to provide an understanding, and detailed information related to the thermal properties, tensile strength, and flexural properties of EG fibers (EGs)/$Al_2O_3$ particle composites. The ratio of EGs and $Al_2O_3$ particles has been varied to quantify the tensile strength and flexural strength properties of the composite.

## Materials and methods

### Materials

$Al_2O_3$ particles were obtained from PT. Estrachemical Indonesia with a purity of 98% and a particle size of 325 mesh. EG plants were collected from the Batu Jai area, Central Lombok, Indonesia. Furthermore, the unsaturated polyester resin was used as a matrix, and methyl ethyl ketone peroxide (MEKPOSE) as a curing catalyst with a ratio of 1% of the resin volume fraction. Specifications of polyester resins are presented in Table 1.

### Extraction of water hyacinth particles (EGs)

The process of extracting EGs is shown in Figure 1. The stems from the EG plant (Figure 1(a)) were cleaned of adhering impurities (Figure 1(b)) and cut to a length of 10 mm (Figure 1(c)). Next, they were dried in an oven at 105 °C for 1 h, then mashed using a ball mill to produce particles. The particles were then sieved using a 200-mesh sieve (Figure 1(d)), then oven-dried at 105 °C for 1 h, and finally, the EG particles (EGs) were ready to be used for the manufacture of composite samples. The density of EGs has known as 0.5 g/cm$^3$. The chemical composition of the EGs is shown in Table 2.

**Table 1.** Specification of polyester resin.[16,17]

| Specification | Value |
|---|---|
| Tensile strength | 40 MPa |
| Flexural strength | 45 MPa |
| Maximum elongation | 1% |
| Modulus of elasticity, (E) | 3.3 GPa |
| Density | 1.09 (g cm$^{-3}$) |
| Viscosity | 6–8 P (at 25 °C) |

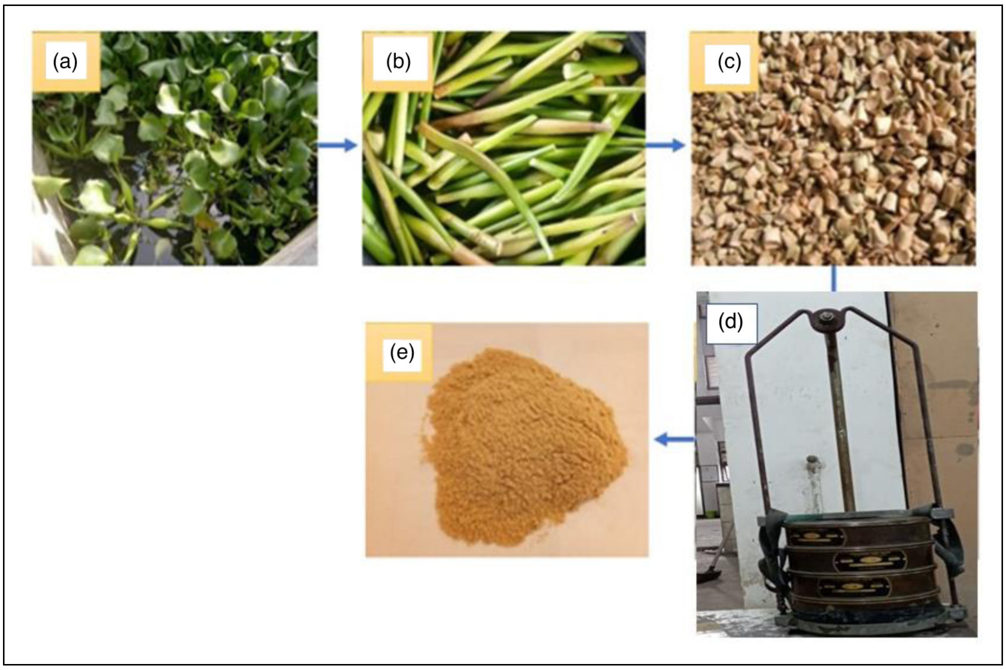


**Figure 1.** EGs extraction process: (a) EG plant, (b) EG rod, (c) EG pieces with a length of 10 mm, (d) EG rod refining process, and (e) particles of EG (EGs) were ready to be used as composite filler.

**Table 2.** The chemical composition of the *Eichhornia crassipes* particles.[18–22]

| Chemical composition | Content (%) |
|---|---|
| Cellulose | 18–23.86 |
| Hemicellulose | 50 |
| Lignin | 3.8–5.8 |
| Ash | 19–20.1 |
| Moisture | 4.9 |

## Hybrid composite fabrication

Hybrid composites were fabricated with a predetermined ratio of EGs versus $Al_2O_3$ particle composition (Table 3). The polyester resin and catalyst were mixed and stirred at 600 rpm for 10 minutes, then poured into a steel plate mold filled with EGs and $Al_2O_3$, then the mold was closed with an emphasis of 5 MPa at a temperature of 105 °C. The composite is removed from the mold for further characterization. Figure 2 shows the samples of tensile and flexural tests of composites, respectively. There are six different types of samples have been made with three repetitions for each different composite.

## Characterization

*Density.* The density of composites can be obtained experimentally by the use of equation 1.[23]

$$\rho_c = \frac{m}{v' - v} \quad (1)$$

Where, $\rho$ is density (g/cm$^3$); $m$, $v'$, and $v$ are the mass of the composite sample (g), and the volume of water after and before the sample is immersed (cm$^3$), respectively.

**Table 3.** The composition ratio of EGs, $Al_2O_3$, polyester in composites.

| | | Volume fraction (vol.%) | | |
|---|---|---|---|---|
| No. | Codes | Polyester | EGs | $Al_2O_3$ |
| 1 | EGA | 75 | 0 | 25 |
| 2 | EGB | 75 | 5 | 20 |
| 3 | EGH | 75 | 10 | 15 |
| 4 | EGI | 75 | 15 | 10 |
| 5 | EGX | 75 | 20 | 5 |
| 6 | EGY | 75 | 25 | 0 |

*Tensile strength test.* Tensile strength testing on composites is intended to measure the force required to stretch the composites, and the amount of elongation until fracture of the composite. Tensile testing was carried out using a universal tensile machine (UTM) RTG-1310 at a room temperature of 28 °C with a relative humidity of 40%. The UTM machine is operated with a loading speed of 5 mm/min and a maximum load of 5 kN. The composite was formed according to the ASTM D3039 standard with dimensions of 250 mm × 25.4 mm × 6 mm.

*Bending strength test.* Flexural testing of the composite has been carried out concerning the ASTM D790 standard. The three-point bending method was adopted to investigate the bending characteristics of the hybrid composite and carried out with the same test equipment for the tensile test with a crosshead speed of 5 mm/min. The composite sample measures 127 mm × 13 mm × 6 mm. In each group, five specimens were tested, and mean values were computed.

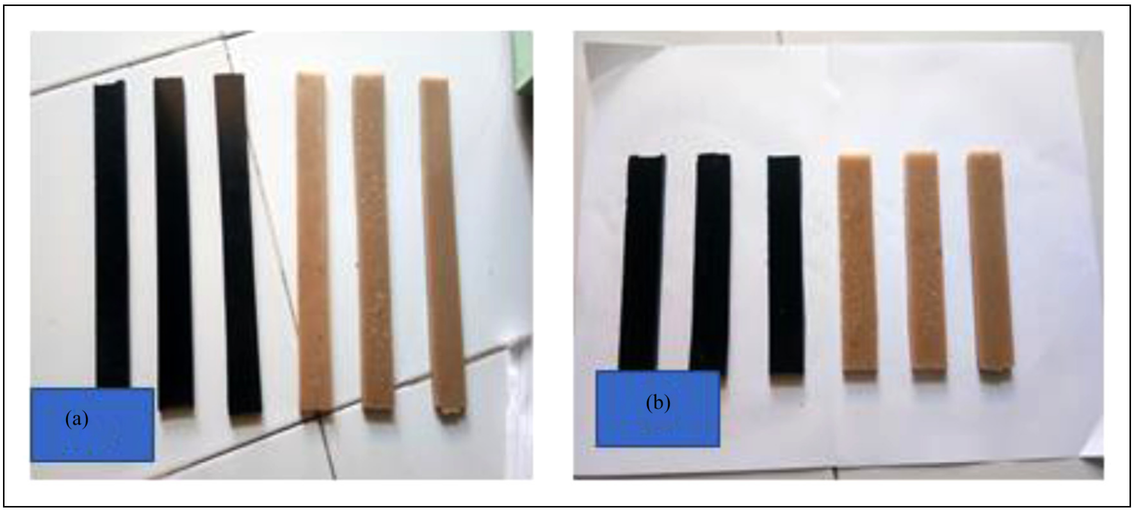


**Figure 2.** Samples of composites: (a) tensile test and (b) flexural test.

*Scanning electron microscopy.* Morphological analysis of the fracture surface in the composite was carried out on the sample fracture after a tensile test was carried out using an Inspect S50 scanning electron microscope (SEM). The SEM is run with an acceleration voltage of 20 kV and an emission current of 18 mA. The sample was coated with a 10 nm thin gold layer for taking morphology photos. Enlargement of the image is done to get a clear image.

*Thermogravimetric analysis.* Composites were tested using a TA Instrument thermogravimetric analysis (TGA) Q500 V20.13 Build 39. All the samples were heated from 25 to 600 °C with a heating rate of 10 °C/min.

## Results and discussions

### Density analysis

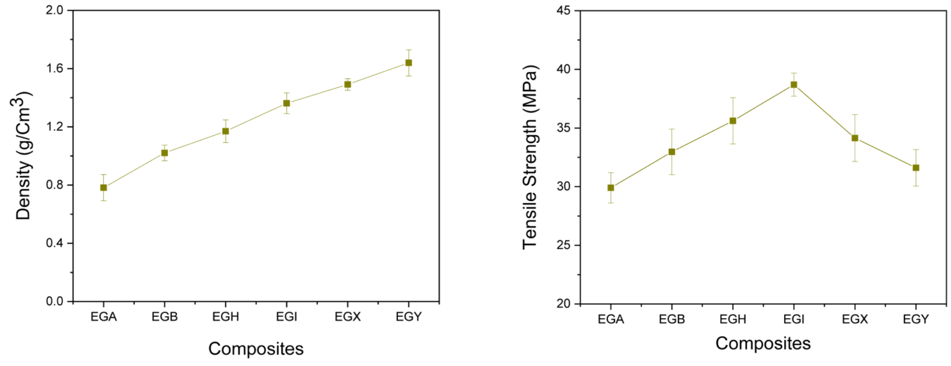
Figure 3(a) shows the densities of the different EGs/$Al_2O_3$ hybrid composites. It was found that more voids were found in the composites with the addition of EGs in composites. The density of a composite material depends on the relative proportion of reinforcing and matrix material, and it is one of the key factors in determining the properties of the composites. The voids significantly affect some of the mechanical properties and even the performance of composites in the workplace. Understandably, a good composite should have fewer voids.

### Tensile strength analysis

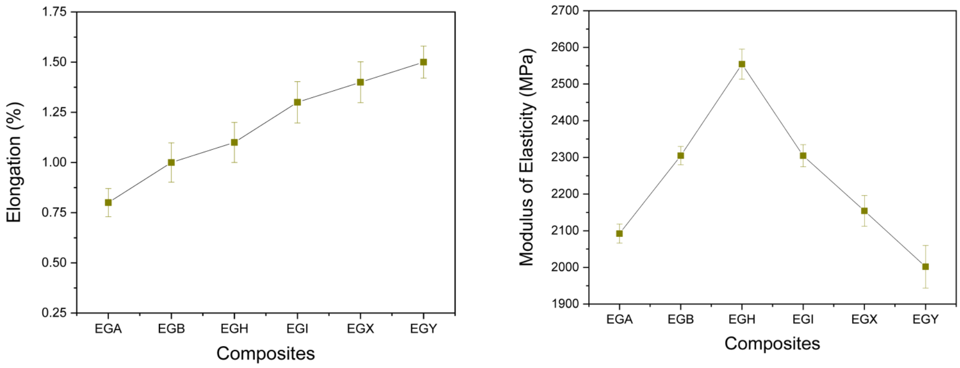
Figure 3(b) shows the tensile strength of the different EGs/$Al_2O_3$ hybrid composites. From Figure 3(b) it is known that the tensile strength of the composite increased significantly in the range of 10.25–32.75% of the EGA composite. The composite (EGI sample) with the highest tensile strength had a denser interface between EGs–$Al_2O_3$–polyester and the particle distribution was more even than the other composites evaluated. The addition of EGs in the range of 5–10% in the composite is supposed to help the polyester resin effectively transfer the produced stress to the particles, hence enhancing the tensile strength. On the other hand, a decrease in the tensile strength of the composite indicates that improper adhesion inhibits the increase in tensile strength. When the $Al_2O_3$ content increases (15–20%), there is an accumulation of agglomeration of particles so that the polyester cannot wet the particles because the resin does not enter between the two adjacent filters,[24] and the cavities become trapped in the composite, which in turn reduces the tensile strength. However, the tensile strength value of the $Al_2O_3$/EG hybrid composite (sample EGB. EGH, EGI, EGX, EGY) was higher than that of the flax fiber-reinforced composite with $Al_2O_3$ filler with a tensile strength value of 25.01–32,8 MPa.[25] This shows that the EGs/$Al_2O_3$ hybrid composite considered in terms of its tensile properties can replace the flax fiber/$Al_2O_3$ composite in the automotive industry.

Figure 3(c) shows the elongation values of different EGs/$Al_2O_3$ hybrid composites. The elongation of the hybrid composite increased significantly as the volume fraction of EGs increased, or in other words, the elongation value of the composite decreased with the increase in the volume fraction of $Al_2O_3$ in the composite. The highest elongation is owned by the EGY sample (1.5%) and the lowest elongation is owned by the EGA sample (0.8%). This shows that the $Al_2O_3$ particles are harder and brittle, causing the hybrid composite to be stiffer, which in turn reduces the % elongation of the composite. Maitra et al.[26] revealed the fact that $Al_2O_3$ filler in composites makes it difficult for the chain of movement of the polyester resin molecules which in turn reduces the composite strain. Meanwhile, the hydrophilic nature of natural materials (EG) causes the composite to be softer and unable to sustain the force deformation so that when a tensile load is applied, the composite will shift before fracture.

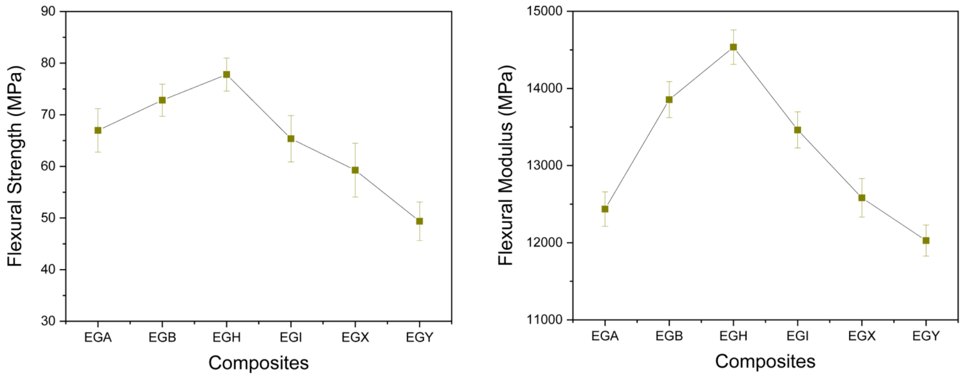
Figure 3(d) shows the modulus of elasticity of the hybrid composite EGs/$Al_2O_3$. It was found that the



(a) Density (b) Tensile strength



(c) Elongation (d) Modulus of elasticity



(e) Flexural strength (f) Flexural modulus

**Figure 3.** Mechanical properties of the EGs/$Al_2O_3$ hybrid composite.

modulus of elasticity of the hybrid composite increased significantly when the content of EGs 5 and 10 (vol.%) was 10.166% and 22.776%, respectively, of the EGA sample, then decreased with increasing volume fraction of $Al_2O_3$ particles (≥15 vol.%). The EGH composite has the highest modulus of elasticity with a modulus of elasticity of 2554.302 MPa. The modulus of elasticity of the EGA composite is 2092.145 MPa. The value of this modulus of elasticity also shows the stiffness of the composite. The increase in modulus of elasticity is due to the even distribution of $Al_2O_3$ particles which increases the interface with EG and polyester particles. These $Al_2O_3$ particles have a higher surface area which allows complete wetting by the resin and can adapt during failure leading to more effective stress transfer between $Al_2O_3$, EG, and resin. Manaila et al.[27] stated that complete wetting of the resin in the filler can develop a cross-linked structure that limits the free mobility of the polymer chains, thereby causing the modulus of elasticity of the composite to increase. Meanwhile, for EGI, EGX, and EGY composites, the modulus of elasticity values tends to decrease with increasing volume fraction of EG or decreasing volume fraction of $Al_2O_3$. In EGI composites, EGX and EGY modulus of elasticity decreased by 9.78%, 15.666%, and 21.631%, respectively, from EGI composites. This decrease was due to the reduced volume

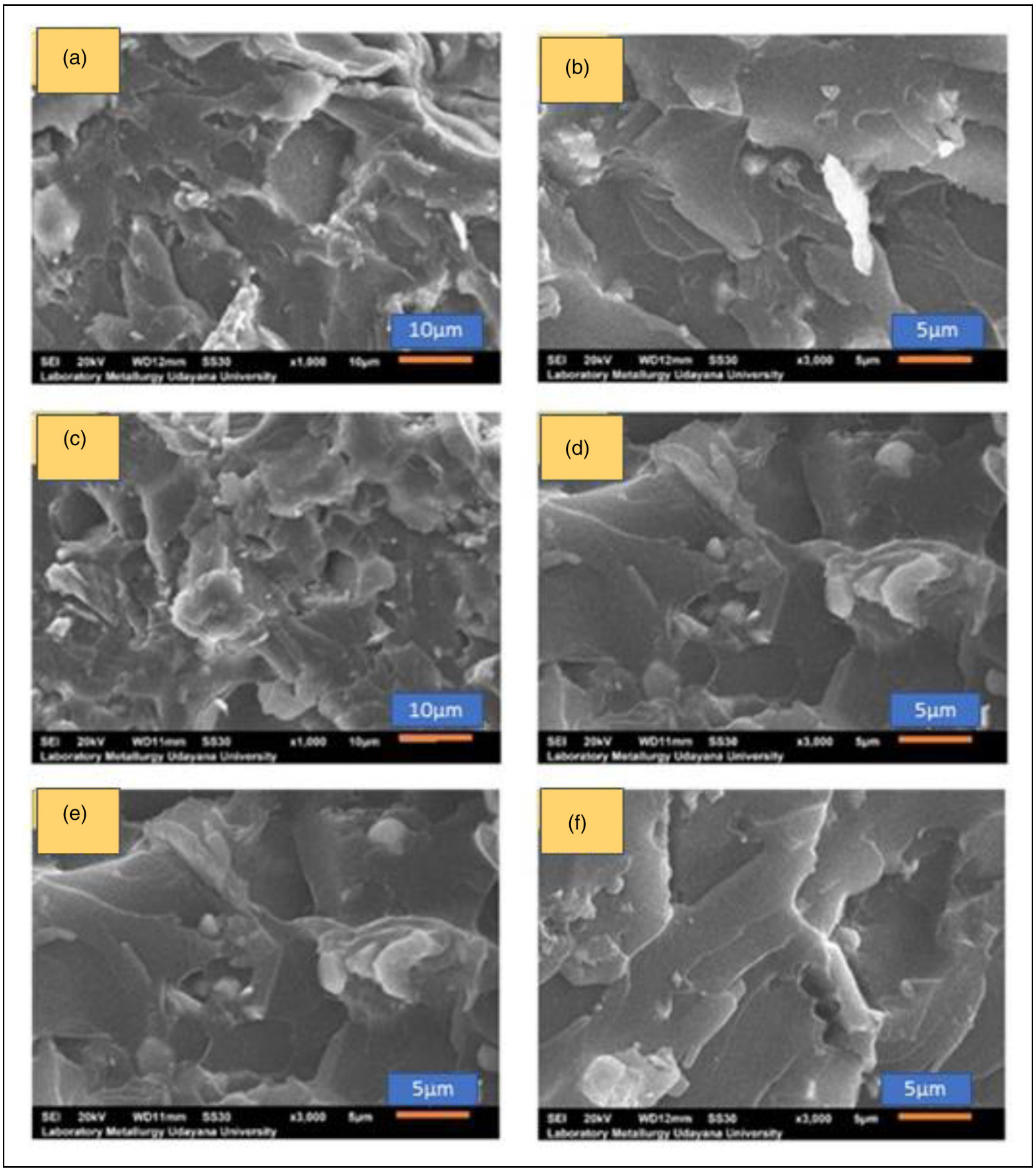


**Figure 4.** Composite fracture morphology: (a) EGY, (b) EGX, (c) EGI, (d) EGH, (e) EGB, and (f) EGA.

fraction of $Al_2O_3$ which is the fact that a large amount of $Al_2O_3$ can increase the interfacial bond between EG particles and the resin which in turn causes an increase in the modulus of elasticity in the composite.

## *Flexural strength analysis*

Figure 3(e) shows the flexural strength of the different $Al_2O_3$/EGs hybrid composites. Figure 3(d) it is found that the bending strength of the composite tends to increase significantly when the volume fraction of EGs is in the range of 5–10% and decreases when the $Al_2O_3$ content is above 10%. The highest bending strength was obtained from the EGH composite of 77.78 MPa. The increase in flexural strength of the composites (EGB and EGH samples) from the EGA samples suggested the intrinsic toughness of the EGs as indicated by the number of $Al_2O_3$ along the crack path. In addition, the strong interfacial bond of the EGs–polyester particles with $Al_2O_3$ (which acts as a cursor) makes it an efficient inhibitor for immobilization and the development of crack propagation during bending testing, thereby increasing its strength.

Figure 3(e) also shows that the bending strength of the EGA sample (66.96 MPa) is lower than that of the EGB sample (72.822 MPa) presumably because a large number of $Al_2O_3$ particles are the beginning of the formation of micro-cracks for composite failure. On the other hand, the EGA composite was still more effective in resisting bending strength than the EGY composite sample (49.36 MPa). This phenomenon indicates that the EGs have a lower interaction with the polyester matrix compared to $Al_2O_3$ particles. Other factors that cause high flexural strength of composites, such as organic powder–polyester–inorganic powder interactions, voids, compatibility of particles with the matrix, and uniformity of particle size. In addition, finer particles can provide mechanical properties. which is higher than the composite due to the strong interaction between the particles and the matrix.[28]

Figure 3(f) shows the flexural modulus of the EGs/$Al_2O_3$ hybrid particle composite. The bending modulus of the EGA composite was 12436.35 MPa, then increased by 11.41% and 16.88% (EGB and EGH composites), respectively. EGH composite has the highest bending modulus of 14535.62 MPa. This increase is a result of the increased interaction of EG–polyester–$Al_2O_3$ particles so that the particle–matrix interface bond also increases. However, for the volume fraction of EGs greater than 10%, the composite stiffness modulus decreased. For EGI, EGX, and EGY composites, the bending stiffness decreased by 7.38%, 13.44%, and 17.25%, respectively, from the EGH composite. This decrease may be due to the incompatibility of EGs with polyester so that the resulting bonding interface is low, and ultimately accelerates crack propagation and decreases the bending stiffness of the EG/$Al_2O_3$ hybrid composite.

### Morphology analysis

Figure 4 shows the fracture surface of the tensile test of the EGs/$Al_2O_3$ particle hybrid composite. Figure 4a–d shows almost the same fracture surface where the interface bonds between the particles and the resin appear to be getting tighter and stronger. But compared to the other composites studied; strong and tight interfacial bonds are found in EGI composites, this supports the reason why the strength of EGH composites is the highest. After the addition of $Al_2O_3$ particles of about 5–15 (vol.%), crack deflection started to occur, and an increase in the hackle area could be attributed to the increase in the stiffness value of the composite. The fracture morphology of the EGX and EGY samples (Figure 4(e) and (f)) showed an increasing number of EGs pull-outs with increasing EGs; and the fracture surface was found to be smoother indicating the type of brittle fracture, this is thought to be the cause of the tensile strength of the composite tends to decrease. Greenhalgh[29] stated that brittle fracture in hybrid composites is characterized by the presence of mirror, mist, and hackle regions on the fracture surface.

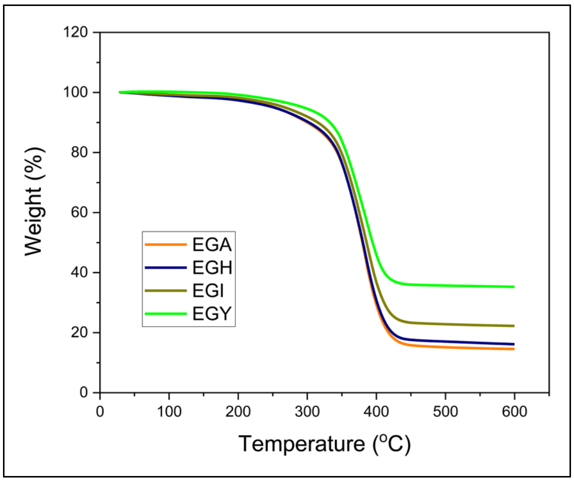


**Figure 5.** TGA curves of EGs/$Al_2O_3$ hybrid composite.

### Thermogravimetric analysis

Figure 5 illustrates the TGA curve of the various EGs/$Al_2O_3$ composite hybrid. The composites EGA exhibits a slight weight loss starting at approximately 240 °C, and the sudden drop at approximately 300 °C corresponds to the thermal decomposition of EGA, whereas the corresponding temperature of the single filler composites is significantly enhanced. A decomposition temperature of approximately 375 °C was acquired in the EGs–$Al_2O_3$ composite. Moreover, the residual weight of the EGY composite reached 81%, which is an evident enhancement compared to 78% for EGI, 59% for EGH, and 39% for EGA. The enhancement in thermal performance may be attributed to the combined effects of the hybrid fillers. The good dispersion of fillers in the hybrid composite boosts the interaction between the matrix and fillers, which can successfully restrict the kinetic motion of molecular chains from the matrix. Hence, this indirectly enhances the thermal stability of the composite materials. The outstanding thermal resistance of EGs composites can effectively guard the bump heat decomposition, which indicates considerable potential as an underfill encapsulation material for electronic packaging.

## Conclusion

Bio-fiber based EG/$Al_2O_3$ particles hybrid biocomposites have been developed in this work and their properties have been investigated. The following conclusions can be drawn:

- The EGI sample and the EGH sample had the highest tensile strength and flexural strength of 38.697 and 77.786 MPa, respectively.
- The increasing EG concentration in the composite from 5% to 10% has increased the bond strength between EGs–$Al_2O_3$–polyester, enabling the mechanical strength of the hybrid composite to increase. Because it forms several voids in the composite, the presence of a considerable amount of $Al_2O_3$ in the composite diminishes the mechanical and thermal properties of the composite. As a result, the mechanical strength of the composite reduces.
- The total composite demonstrated strong thermal properties with the addition of EGs, with the best heat resistance properties obtained when the composite comprised solely EGs.
- According to the experimental results, the mechanical properties of the EGs/$Al_2O_3$ hybrid composite are suitable for replacing flax fiber composites with $Al_2O_3$ filler in the automotive industry.

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## Declaration of conflicting interests

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## References

1. Sari NH, Suteja S, Rangappa SM, et al. A review on cellulose fibers from *Eichornia crassipes*: synthesis, modification, properties and their composites. *J Nat Fibers* 2023; 20: 2162179.
2. Liu Y, Xueman L, Bao J, et al. Characterization of silane treated and untreated natural cellulosic fibre from corn stalk waste as potential reinforcement in polymer composites. *Carbohydr Polym* 2019; 218: 179–187.
3. Ilyas RA, Zuhri MYM, Aisyah HA, et al. Natural fiber-reinforced polylactic acid, polylactic acid blends and their composites for advanced applications. *Polymers* 2022; 14: 2.
4. Syafri E, Wahono S, Irwan A, et al. Characterization and properties of cellulose microfibers from water hyacinth filled sago starch biocomposites. *Int J Biol Macromol* 2019; 137: 119–125.
5. Palai BK and Sarangi SK. Characterization of untreated and alkalized *Eichhornia crassipes* fibers and its composites. *J Nat Fibres* 2020; 19: 1–16.
6. Niyasom S and Tangboriboon N. Development of biomaterial fillers using eggshells, water hyacinth fibers, and banana fibers for green concrete construction. *Constr Build Mater* 2021; 283: 122627.
7. Huda N, Nath N, Amin P, et al. Charpy impact behavior of water hyacinth fiber based polymer composite. *J Mater Sci Manuf Technol* 2017; 2: 1–13.
8. Devnani GL and Sinha S. Effect of nanofillers on the properties of natural fiber reinforced polymer composites. *Mater Today: Proceedings* 2019; 18: 647–654.
9. Ramirez NF, Hernandez YS, de Leon JC, et al. Composites from water hyacinth (*Eichhornia crassipes*) and polyester resin. *Fibers Polym 2015* 2015; 16: 196–200.
10. Wirawan R, Pasaribu R and Kholil A. Thermogravimetric analysis of untreated water hyacinth (*Eichhornia crassipes*)/HDPE composites. Composite Science and Technology: 2020-Scientific and Technical Challenges, Proc. 9th Int. Conf. Compos. Sci. Technol. (ICCST-9) 2013; 418.
11. Potluri R and Rao S. Water absorption and density tests on the water hyacinth-based partial green composite. (Chapter 10), 77–88. https://dx.doi/10.1007/978-981-13-6374-0_10. 2019.
12. Putri LD and Mahyudin A. Analisis pengaruh persentase volume serat eceng gondok dan serat pinang terhadap sifat mekanik dan biodegradasi komposit hibrid matrik epoksi. *Jurnal Fisika Unand* 2019; 8: 288–294.
13. Dilip KK and Shantharaja M Ravindra. Effect of $Al_2O_3$ nano filler on mechanical behaviour of hybrid polymer composite—a Taguchi approach. In *TEST engineering & management*, 2020, pp. 2854–2862. The Mattingley Publishing Co., Inc., 2020, ISSN: 0193-4120.
14. Heyi YA, Woyessa GK, Jiru MG, et al. Investigation of hybrid composite properties fabricated from bagasse fibers reinforced with $Al_2O_3$ and SiC for light weight applications. *J Modern Mech Eng Technol* 2021; 8: 48–56.
15. Tominaga Y, Sato K, Hotta Y, et al. Effect of the addition of $Al_2O_3$ and h-BN fillers on the thermal conductivity of a cellulose nanofiber/nanodiamond composite film. *Cellulose* 2019; 26: 5281–5289.
16. Islam F, Islam MN, Shahida S, et al. Mechanical and interfacial characterization of jute fabrics reinforced unsaturated polyester resin composites. *Nano Hybrids Compos* 2019; 25: 22–31.
17. Sari NH, Pruncu CI, Sapuan SM, et al. The effect of water immersion and fibre content on properties of corn husk fibres reinforced thermoset polyester composite. *Polym Test* 2020; 91: 106751.
18. Fileto-Pérez HA, Rutiaga-Quiñones JG, Aguilar-González CN, et al. Evaluation of *Eichhornia crassipes* as an alternative raw material for reducing sugars production. *BioRes* 2013; 8: 5340–5348.
19. Pintor-Ibarra LF, Rivera-Prado JJ, Ngangyo-Heya M, et al. Evaluation of the chemical components of *Eichhornia crassipes* as an alternative raw material for pulp and paper. *BioRes* 2018; 13: 2800–2813.
20. Shoyakubov RS and Aitmetova KI. Chemical composition of *Eichhornia crassipes* and *Pistia stratiotes*. *Chem Nat Compd* 1999; 35: 227–228.
21. Singh A and Bishnoi NR. Comparative study of various pretreatment techniques for ethanol production from water hyacinth. *Ind Crops Prod* 2013; 44: 283–289.
22. Sukarni S, Zakaria Y, Sumarli S, et al. Physical and chemical properties of water hyacinth (*Eichhornia crassipes*) as a sustainable biofuel feedstock. *IOP Conf Ser: Mater Sci Eng* 2019; 515: 012070.
23. Sari NH, Setyawan PD, Thiagamani SMK, et al. Evaluation of mechanical, thermal and morphological properties of corn husk modified pumice powder reinforced polyester composites. *Polym Compos* 2022a; 43: 1763–1771.
24. Vinod A, Vijay R and Singaravelu DL. Thermomechanical characterization of Calotropis gigantea stem powder-filled jute fiber-reinforced epoxy composites. *J Nat Fibers* 2018; 15: 648–657.
25. Aynalem GF and Sirahbizu B. Effect of $Al_2O_3$ on the tensile and impact strength of flax/unsaturated polyester composite with emphasis on automobile body applications. *Adv Mater Sci Eng* 2021; 2021: 1–9.

26. Maitra U, Prasad KE, Ramamurty U, et al. Mechanical properties of nanodiamond-reinforced polymermatrix composites. *Solid State Commun* 2009; 149: 1693–1697.
27. Manaila E, Stelescu MD, Craciun G, et al. Wood sawdust/natural rubber ecocomposites cross-linked by electron beam irradiation. *Materials (Basel)* 2016; 9: 03.
28. Vigneshwarram K, Srimala S, Mutharasu D, et al. Effect of hybrid filler ratio and filler particle size on thermal conductivity and oil bleed of polydimethylsiloxane/$Al_2O_3$/ZnO liquid thermal filler for microelectronics packaging applications. *J Mater Sci: Mater Electron* 2020; 32: 861–874.
29. Greenhalgh ES. *Failure analysis and fractography of polymer composites*. Oxford: Woodhead Publishing Limited, 2009.