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Tailoring epoxy resin impact performance by varying coconut coir fiber reinforcement

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INFO ARTIKEL

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A B S T R A K

Resin epoxy pada umumnya memiliki ketangguhan impak yang rendah dan cenderung getas saat menerima benturan pada beban yang tinggi. Indonesia merupakan negara kepulauan yang memiliki banyak tumbuhan kelapa. Tujuan penelitian ini adalah untuk memanfaatkan limbah dari serat serabut kelapa sebagai salah satu alternatif dalam peningkatan ketangguhan impak dari resin epoxy. Oleh karena itu, pada penelitian ini serat serabut kelapa akan dimanfaatkan sebagai penguat komposit bermatriks epoxy resin dengan perbedaan penggunaan variasi fraksi volume serabut kelapa dari 0% hingga 50%. Hasil penelitian ini menunjukan bahwa peningkatan rasio fraksi volume dari serat serabut kelapa dari 0 sampai 0% dapat menurunkan massa dari epoxy resin akan tetapi ketangguhan impak meningkatkan. Massa epoxy resin menurun dari 11.0±0 gram hingga- 9.3±0.6 gram dan ketangguhan impak meningkat dari 0.027±0.01 J/mm^2 hingga 0.075±0.02 J/mm^2.

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A B S T R A C T

Epoxy resin generally exhibits low impact toughness and tend to be brittle when subjected to high load impacts. Indonesia in an archipelagic country that has abundant coconut plants. The purpose of this study is to utilize coconut coir fiber waste as an alternative to improve the impact toughness of epoxy resin. Therefore, this research uses coconut coir fiber as a reinforcement in epoxy resin matrix composites, varying the volume fraction of coconut coir fibers from 0% to 50%. The results show that increasing the volume fraction of coconut coir fiber from 0% to 50% decreases the mass of the epoxy resin but increases its impact toughness. The epoxy resin mass decreases from 11.0±0 grams to 9.3±0.6 grams, while the impact toughness increases from 0.027±0.01 J/mm^2 to 0.075±0.02 J/mm^2.

1. Introduction

Epoxy resin is a thermosetting polymer that cures through a cross-linking polymerization process, forming a three-dimensional network structure. This type of resin is widely used as a structural material and applied in various fields such as automotive, aerospace, marine, and electronics. This widespread use is attributed to epoxy resin's rapid curing characteristics, active adhesion, thermal conductivity, electrical conductivity, corrosion resistance, and its favorable tensile and flexural strength properties [1,2]. However, the cross-linking polymerization of epoxy resin exhibits low impact toughness, which has drawn significant attention from many researchers aiming to develop composites that enhance the impact toughness of epoxy resin [3].

Composite materials generally consist of two types of constituents: a matrix that functions as a binder and fibers—either natural or synthetic—that serve as reinforcement. One of the most widely used polymers as a matrix in composite manufacturing is epoxy resin [4]. Natural fibers have long been used in the fabrication of polymer matrix composites due to their lower cost, easy availability, light weight, and good strength. Common natural fibers utilized as reinforcement materials in polymer matrix composites include flax, hemp, jute, roselle, abaca, pineapple leaf fibers, among many others typically employed in composite manufacturing [5].

Indonesia is an agrarian nation where the majority of its population relies on agricultural activities for their livelihoods, supported by abundant natural resources such as coconut coir [6]. Natural coconut coir fibers represent an environmentally friendly material proven effective as reinforcement in polymer matrices, while simultaneously reducing material density and production costs. These fibers exhibit several superior properties, including low production costs, high lignin content, low density, abundant availability, good elongation at break, and low elasticity. Given these characteristics, coconut coir fibers are widely utilized in the construction sector, as they enhance material sustainability and reduce construction waste [7].

Coconut coir fibers have attracted considerable interest from researchers for use as reinforcement in polymer matrix composites. The utilization of coconut coir fibers as

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composite reinforcement is attributed to their toughness and high strength properties [8]. In 2020, coconut coir fibers were used as reinforcement for epoxy resin with fiber contents ranging from 0% to 11%. The study results showed that tensile strength increased from 34.74 MPa to 44.1 MPa with the addition of coconut coir fibers from 0% to 5%, but the tensile strength decreased to 42.7 MPa when the fiber content was increased to 10% [9]. Subsequently, in 2024, coconut coir fibers were utilized as reinforcement in polyester matrix composites. The resulting composite exhibited an average impact toughness ranging from 1.11 kJ/m² to 2.44 kJ/m² with fiber contents between 5% and 15% [10].

Based on previous studies, the development of composites reinforced with coconut coir fibers continues to attract significant research interest. This study focuses on the effect of incorporating coconut coir fiber at concentrations of 0%, 30%, 40%, and 50% on the impact toughness of epoxy resin.

2. Experimental Procedure

2.1. Material

This study uses coconut coir fibers as reinforcement and epoxy resin as the matrix. A hardener is added to the epoxy resin mixture to function as the epoxy curing agent. Table 1 presents the volume fraction comparison between epoxy resin, hardener, and coconut coir fibers. Additionally, a 5% NaOH treatment was applied by mixing 50 grams of NaOH with 1 liter of water to remove the wax layer on the coconut coir fibers. In the final stage, wax was used as a coating to facilitate the easy removal of the epoxy resin from the mold.

Tabel 1. Perbandingan fraksi volume dari komposit

Epoxy (%)	Hardener (%)	Coconut Coir Fibers (%)
75	15	0
52.5	17.5	30
45	15	40
37.5	12.5	50

2.2. Specimen

In the initial sample preparation, coconut coir fibers were soaked in plain water to soften the cocopeat. The fibers were then combed to separate them from the cocopeat and subsequently soaked in a 5% NaOH solution for 2 hours. After soaking, the fibers were rinsed thoroughly with running clean water to remove residual NaOH. The fibers were then sun-dried for one day until completely dry. Next, coconut coir fibers, epoxy resin, and hardener were prepared according to the percentages listed in Table 1. The coconut coir fibers were cut into 1 cm lengths. Meanwhile, the epoxy resin and hardener liquids were mixed manually for 3 minutes before pouring the mixture into the mold. The mold was pre-coated with wax prior to pouring the epoxy resin and hardener mixture. After pouring, the resin was evenly spread within the mold. The 1 cm cut coconut coir fibers were then randomly placed into the mold, followed by additional pouring and leveling of the epoxy resin and hardener mixture. The composite was left to cure at room temperature for one day until completely dry.

2.3. Specimen testing

2.3.1. Mass testing

Mass testing utilized standard impact specimen dimensions. This test was conducted three times for each variable using the SF 400 series digital balance. The results are presented as the average mass for each composite variable.

2.3.2. Impact testing

Impact testing was conducted according to the ASTM D6110 standard. Each variable was tested three times using the HT-8041A Charpy Impact Tester. The results are presented as the average impact value for each specimen variable.

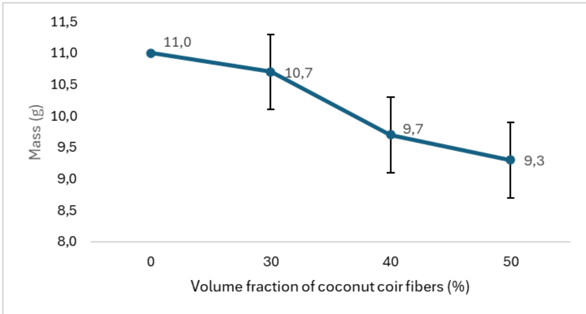
2.3.3. Macro photographs of impact fracture

Macro photographs of the impact fracture surfaces were captured using the Drive Forge G1000 digital microscope.

3. Results and discussion

3.1 Mass testing

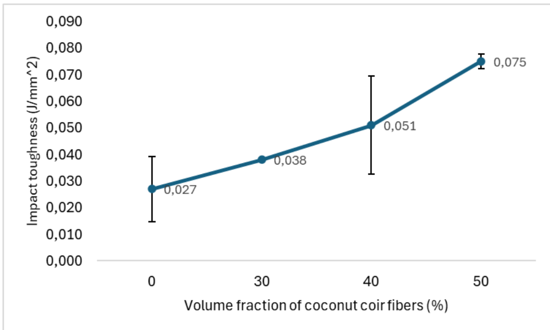
Based on the average mass testing data presented in Figure 1, the addition of coconut coir fibers from 0% to 50% reduced the composite mass from 11.0 ± 0.0 g to 9.3 ± 0.6 g.



Gambar 1. Mass of composites

3.2 Impact toughness

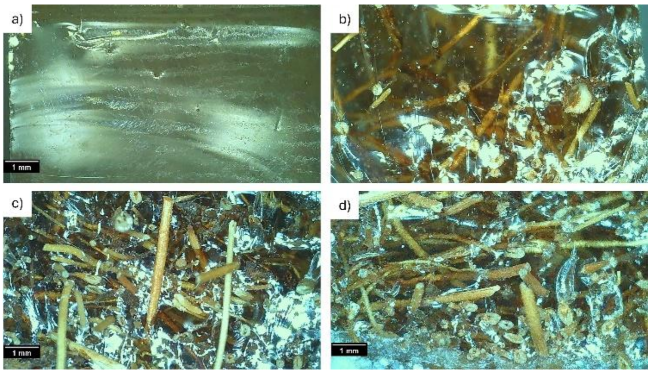
Figure 2 illustrates the effect of increasing coconut coir fiber volume fraction on the impact toughness of coconut coir fiber-reinforced epoxy composites. Impact toughness increased from 0.027 ± 0.01 J/mm² at 0% coconut coir fiber to 0.075 ± 0.02 J/mm² at 50% fiber addition.



Gambar 3. Impact results

3.3 Macro photographs of impact fracture

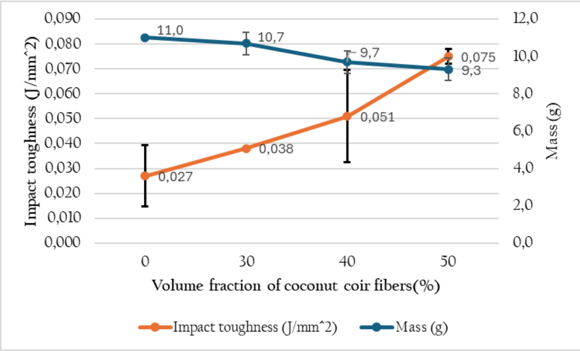
Figure 3 shows macro photographs of impact fracture surfaces from samples with varying coconut coir fiber volume fractions. Figure 3(a) depicts the macro fracture of pure epoxy resin (0% fiber), revealing crack propagation directions resulting from the impact testing process. Figure 3(b) illustrates the impact fracture at 30% fiber addition, where the epoxy matrix dominates the composite structure and visible air voids are evident, likely due to incomplete curing. Figures 3(c) and 3(d) demonstrate fiber pull-out from the epoxy matrix along with surface defects on the fracture plane of higher fiber content composites.



Gambar 3. Macro photograph of impact fracture from different volume fraction of coconut coir fibers (a) 0%, (b) 30%, (c) 40% dan (d) 50%

3.4 Discussion

Based on the results presented in sections 3.1 and 3.2, the composite mass decreases with increasing coconut coir fiber volume fraction. However, the impact toughness of the composite improves progressively with higher fiber content, as demonstrated in Figure 4. The mass reduction observed in this study may be attributed to the epoxy resin-hardener formulation composition, reinforcement size, curing process conditions, temperature effects, and the presence of voids or porosity [11–13]. As observed in Figure 3, air voids trapped during the curing process are visible in nearly all fracture surfaces. The impact toughness of composites with 30% coconut coir fiber addition was relatively lower than other compositions due to the dominant epoxy matrix presence in the fracture surface, whereas at 40-50% fiber content, coconut coir fibers exhibited more uniform distribution across the impact fracture. The addition of coconut coir fibers enhances the impact toughness of epoxy matrix composites. Higher proportions of natural fiber-polymer mixtures yield greater impact toughness under shock loading as fiber content increases [14]. Fiber-reinforced composites exhibit high impact resistance that depends on fiber orientation. Optimal fiber alignment enhances load distribution and energy absorption during impact loading, with random orientations often providing superior toughness compared to unidirectional configurations perpendicular to the impact direction [15].



Gambar 5. The effect of increasing volume fraction of coconut coir fibers on mass and impact toughness of composites

4. Conclusion

This study concludes that adding short coconut coir fibers at 1 cm and randomly oriented inside epoxy resin reduces composite mass, attributed to lower density evidenced by trapped air voids within the matrix. However, impact toughness increases with higher fiber volume fractions due to homogeneous fiber distribution throughout the epoxy resin.

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