



Effect of Different Layers on the Performance of Laminate Epoxy Composite Reinforced with Textile Waste

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Abstract. Post-consumer textile waste poses significant environmental problems, but its potential for commercial recycling remains under-researched. Therefore, this study utilizes calico textile (CT) waste as reinforcement in polymer composites. The effect of layering number of CT in epoxy composite will be investigated. CT was varied with three layers, namely 1, 3, and 5 embedded in epoxy resin with the hand lay-up method in open molding. The mechanical testing of pure epoxy as a control point for tensile, flexural, and impact strengths of 13.68 MPa, 16.44 MPa, and 0.013 J/mm². In tensile strength, the increase occurred in CT1 and CT3 by 21% and 39.7%, A significant rise of 43.5% occurred in the CT5 flexural test, and impact strength saw a significant jump from CT1 to CT3 by 58%. Overall, observations of the composite laminar tensile fracture morphology indicate that the longitudinal loading effectively increases the tensile strength. However, void bubbles were found between the textile layers, but this condition does

not contribute a significant reduces the mechanical performance. Further research is recommended using the synthetic fabric waste as a reinforcement composite.

Keywords: calico textile, waste, laminar, molding, morphology, mechanical testing.

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1. Introduction

The textile industry continues to grow from 70.6 million tons in 2007 to 90.8 million tons in 2014. It could become 100 million tons in 2025 [1]. Textiles can be obtained from natural fibers such as cotton, wool, linen, and silk, and synthetic fibers such as polyester, nylon, and acrylic [2], [3]. The increase in textile production and consumption, coupled with low levels of reuse and recycling, has resulted in a continuous increase in the amount of textile waste [4].

Textile waste can be controlled through reuse, recycling, and reselling into economically valuable products [5]. Several studies using textile reinforcements, 100% polyester fabric waste mixed with a polyethylene HDPE matrix [6], waste carpet fiber (WCF), and palm oil fuel ash (POFA) mixes with ordinary Portland cement (OPC)[7], Embedding reclaimed polyester–spandex textile waste into cementitious composites [8], Utilization of textile fibers to enhance the reinforcement of polymeric composites [9] textile fiber waste replace wood particles [10]. The utilization of calico textile waste into composite products because it has environmentally friendly properties, low production costs, easy fabrication, good mechanical properties, is environmentally friendly and lightweight, supports green products, and creates a sustainable industry [11], [12]. In composite manufacturing, calico acts as reinforcement in the polymer matrix. Calico is made in sheet form using a hot press machine with various layers, temperatures, pressures, and times [13].

Calico has compatible properties to be combined with epoxy, polyester, and high-density polyethylene, as well as fillers such as bamboo and chorisia fiber [14], [15], [16]. However, the concentration, fabrication method, and material selection are crucial aspects in achieving maximum composite strength, Polyester-based composites can be fabricated incorporating approximately 1.5 wt.% of textile manufacturing waste [17], influence of waste fabric size during shredding, together with measurements of recycled fibre proportion and resultant fibre length [18], 40% flake cotton waste and 60% matrix material [19], cotton, polyester, and cotton/polyester blend fabrics are utilized as reinforcements and incorporated into an epoxy resin matrix [20]. As a natural textile fiber, calico combines desirable mechanical and physical properties, making it well-suited to performance and sustainability considerations [21]. Using textile waste in the composite industry has become an important study area. This research explores a new understanding of laminated composites using calico. Therefore, this study aims to analyze the effect of different numbers of layers on the performance of the epoxy composite reinforced with textile waste.

2. Methods

2.1. Materials

The calico textile utilized in this study was white calico fabric waste obtained from a textile industry in Jakarta, Indonesia. The CT was prepared in plain cross-woven form, as shown in Figure 1. The polymer matrix of epoxy MX 500 was purchased from PT Justus Kimiaraya, Semarang, Indonesia.

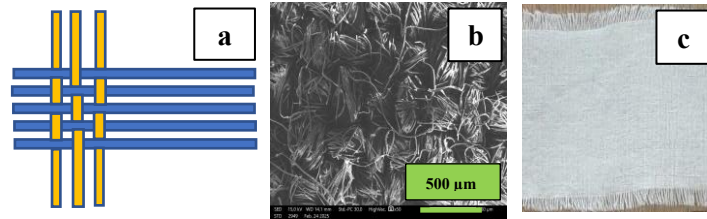


Figure 1. The schematic of woven CT (a), SEM woven morphology (b), and woven CT (c)

2.2. Fabrication of Composite

A silicone open molding with dimensions of $400 \times 400 \times 3$ mm was prepared for composite manufacturing. The concentrations of epoxy and CT were set with the compositions presented in Table 1. Epoxy and hardener with a ratio of 2:1 were mixed in a plastic container and stirred with a stainless-steel stick at room temperature until they reached a homogeneous condition. After that, it was poured into an open mold containing CT with layer variations of 1, 3, and 5, then leveled with a soft roll (Hand Lay-up) and covered using mechanical clamping tools to get accurate dimensions. The composite was allowed to harden at room temperature for 24 hours.

Table 1. Composition epoxy matrix composite reinforced with textile waste

| Sample | Layers | Epoxy (wt.%) | Calico Textile (wt.%) |
|--------|--------|--------------|-----------------------|
| Epoxy | 0 | 100 | 0 |
| CT1 | 1 | 96.56 | 3.44 |
| CT3 | 3 | 90.04 | 9.96 |
| CT5 | 5 | 85.30 | 14.70 |

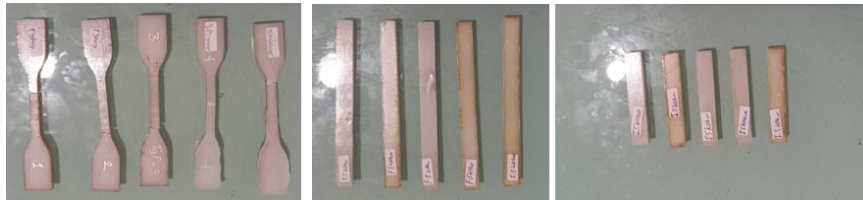


Figure 2. Specimen of Tensile, Flexural, and Impact Test

2.3. Testing

The CT composites that have been made go through a laser cutting process to obtain five mechanical test samples for each composition, as shown in Figure 2. The dog-bone and flat size applied in this study were tensile, flexural, and impact tests based on American Standard Testing and Materials (ASTM) D638, D790, and D256 [22], [23], [24]. Tensile and flexural tests were conducted using a 30 kN universal testing machine (INSTRON, USA) with a crosshead speed of 2 mm/min, and impact testing was conducted using a Schenk Trebel P2W300 (GERMANY). The fracture surface of the tensile test specimen was utilized as a sample for scanning electron microscopy using JEOL JSM-IT 200, JAPAN.

3. Results and Discussion

3.1. Mechanical Properties

The mechanical properties test results show that increasing the CT layer in the epoxy matrix significantly increases tensile strength and flexural strength compared to pure epoxy (control sample), as presented

in Figure 3. Table 2 shows the pure epoxy sample, the tensile strength was 13.68 MPa, and the flexural strength was 16.44 MPa. After adding 1 layer of CT, the tensile strength increased to 16.57 MPa, and the flexural strength rose to 22.81 MPa. The presence of 3 and 5 layers of CT on the epoxy matrix caused the tensile strength to rise to 19.11 and 19.75 MPa, while the flexural strength rose to 22.84 and 23.60 MPa.

Table 2. Mechanical properties of epoxy matrix composite reinforced with textile waste

| Sample | Tensile Strength (MPa) | Tensile Modulus (GPa) | Tensile Displacement at Break (mm) | Flexural Strength (MPa) | Flexural Modulus (GPa) | Flexural Displacement at Break (mm) |
|--------|------------------------|-----------------------|------------------------------------|-------------------------|------------------------|-------------------------------------|
| Epoxy | 13.68 | 1.16 | 1.18 | 16.44 | 0.33 | 4.31 |
| CT1 | 16.57 | 1.50 | 1.06 | 22.81 | 0.37 | 7.65 |
| CT3 | 19.11 | 1.88 | 1.13 | 22.84 | 0.41 | 6.35 |
| CT5 | 19.75 | 1.64 | 2.36 | 23.60 | 0.34 | 6.75 |

Important mechanical properties under applied stress were demonstrated in composite samples reinforced with calico fabric from 1 to 5 layers. This suggests that the woven fibers act as reinforcement transmitted by the matrix while the composite receives external loads. As more layers are added, the fibers inhibit failure before fracture [25]. In addition, the strong interface between the matrix and CT contributes to creating a more rigid laminate composite structure that reduces stress concentration and increases its tensile and compressive strength [26]. These findings demonstrate the structural integrity and quality of the material, as well as enhanced mechanical response to bending stress. Additional examination of these results could yield significant insights for applications in materials science and engineering.

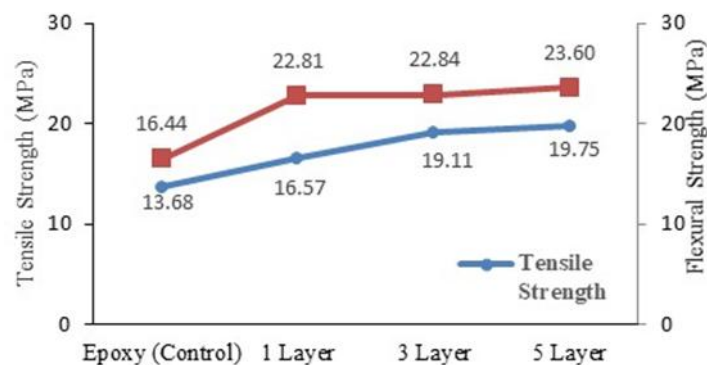


Figure 3. Tensile and Flexural strength of the epoxy composite reinforced with different layers

Figure 4 shows the effect of increasing the number of CT layers on the impact strength of textile waste-reinforced epoxy composite laminate. This study's results show that increasing the number of CT layers causes an increase in impact strength. In pure epoxy (control sample), the impact value was recorded as 0.013 J/mm² and increased after adding 1, 3, and 5 layers by 0.017, 0.027, and 0.037 J/mm². There was a significant increase in impact from pure epoxy to adding CT5 of 0.25 J/mm².

These test results show a consistent increasing trend from CT1 to CT5, which indicates that the more layers there are, the better the composite resistance to impact force. However, there is a notable difference in the increasing phenomenon, where the addition of the control sample to one layer shows a relatively small increase of 30%. In addition, the increase from one layer to three layers shows a significant jump of about 58%. However, adding layers from three to five shows a slightly smaller

percentage of about 37%. The phenomenon may occur due to the presence of CT in the epoxy; the fiber enhances the composite's structure, making it more resistant to cracking and breaking due to impact. The greater the number of CT layers, the more fiber functions in reducing the effects of the amount of energy received by the composite and increasing its impact strength [27].

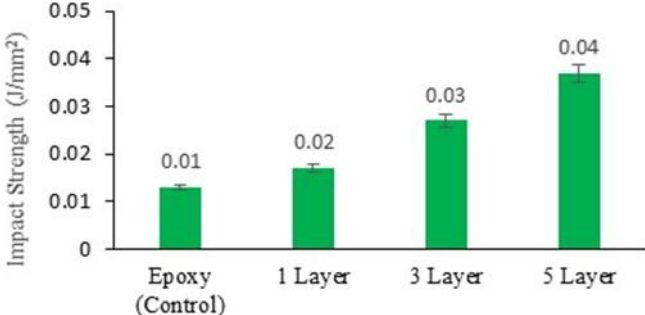
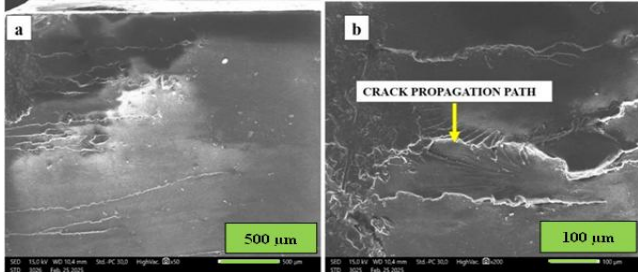


Figure 4. The impact strength of the epoxy composite with different layers

3.2. *Scanning Electron Microscopy*

The surface morphology and fracture pattern of the laminate epoxy composite reinforced with CT were observed using scanning electron microscopy. Figure 5 shows the fracture surface of the tensile test specimens for pure epoxy, CT1, CT3, and CT5. The white line pattern in the pure epoxy (Figure 5b) indicates brittle behavior, where cracks form and accelerate rapidly, leading to material failure without any visible signs of deformation. Pure epoxy cannot resist tensions without fibers because it only relies on its relatively low intermolecular bonds. After adding 1, 3, and 5 layers of CT (Figure 5c-5g) into the epoxy matrix, the fracture surface shows fiber pullout, where the fibers are partially pulled out of the matrix, indicating interfacial damage [28]. These results suggest the role of fibers in supporting the strength of the composite structure, so that there is an increasing trend in tensile, bending, and impact strength.

In addition, fiber breakage is visible at the addition of 3 and 5 layers of CT (Figure 5e-5h). This phenomenon interprets the bonding strength between the matrix and the fiber as strong sufficient that the matrix passes the load directly to the fiber and increases its strength [29]. Moreover, the higher the CT layers, the more fiber occupies the epoxy area. This makes a positive contribution to supporting a stronger composite structure. However, the number of 5 CT layers in the epoxy creates slight voids that may occur due to the matrix's hindered movement and air trapping during the fabrication process [30] [31]. This leads to a lower increase in tensile strength between the addition of CT from 0 layers to 5 layers (about 37%) compared to the rise in CT from 0 layers to 3 layers (about 58%).



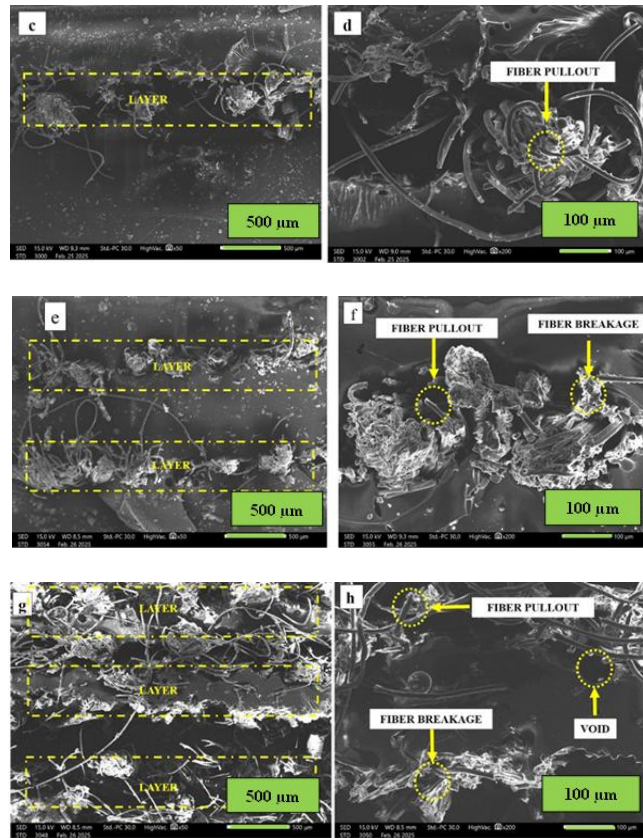


Figure 5. Fracture morphology of pure epoxy (a-b), the laminate epoxy composite reinforced with 1 layer (c-d), 3 layers (e-f), and 5 layers (g-h)

4. Conclusion

Our goal in this study is to examine the mechanical and morphological characteristics of the effect of different layers of textile-reinforced composite material, demonstrating its suitability for use in a variety of industrial applications. Furthermore, we aimed to establish that a large amount of unused waste fabric can be fabricated into a composite reinforcement material. Characterization of the mechanical properties and morphology of recycled textiles is the core of this research, considering their potential as reinforcement in epoxy resin composites. Mechanical testing demonstrated the effectiveness of calico fabric in improving structural integrity, demonstrating that composites containing calico fabric reinforcement exhibited superior tensile strength and modulus compared to those with plain epoxy resin. Understanding the behavior of composites under mechanical stress requires an understanding of the interfacial bonding and the distribution of calico fabric within the resin matrix, which can be obtained through morphological examination using SEM. A few voids in the 5-layer CT composites may be due to hindered matrix movement and trapped air during fabrication. However, this condition does not contribute a significant negative influence to the strength of the composite. Calico fiber is a type of natural fiber with great potential in making green composites because it creates high-performance, environmentally friendly, and sustainable products. Further investigation will focus on the use of synthetic fabrics as composite reinforcement to enhance the physical and mechanical properties of laminated composites. This research is expected to advance composite materials science and meet the growing demand for environmentally friendly materials from various sectors.

Declaration of AI and AI assisted technologies in the writing process

During the preparation of this work the author(s) used ChatGPT in order to paraphrase sentences, improve academic language, and organize the structure of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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