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Mechanical Characterization of Cuttlefish Bone Particle-Glass Fiber Reinforced Epoxy Composites

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Abstract

This study explores the mechanical properties of cuttlefish bone particles (CFBP) -glass fiber reinforced epoxy composites. Variations in filler composition were investigated, and tensile strength, flexural strength, impact strength, and hardness were assessed. Results indicate significant changes in mechanical properties with varying filler content. Tensile strength decreases with increased filler content, while the initial rise in tensile modulus diminishes beyond a specific threshold. Flexural strength varies, with CFBP-6 demonstrating the highest resistance to bending forces. Impact strength differs among samples, with CFBP-3 exhibiting superior resistance to impact loading. Furthermore, hardness increases with higher filler contents, with CFBP-6 displaying the highest value. These findings contribute to our understanding of composite material behaviour.

Keywords: Epoxy, Glass fiber, Cuttlefish bone particle, Mechanical properties

1. Introduction

Cuttlefish bone, a natural filler rich in calcium carbonate, has diverse applications. Studies show that cuttlefish bone-derived hydroxyapatite (HA) enhances bone tissue repair and regeneration[1]. Additionally, cuttlebone fillers have been explored for their hemostatic potential in rectal suppositories, demonstrating supportive wound healing properties[2]. On the other hand, the presence of organic components in cuttlebone particles contributes to improved mechanical properties in rubber composites, highlighting their significance in enhancing material strength[3]. Furthermore, research on glass fiber-reinforced epoxy composites filled with natural fillers like cuttlebone particles indicates the importance of wear behaviour analysis for mechanical components, showcasing the growing interest in utilizing natural fillers for enhanced material performance[4]. Natural fillers like rice husk, wheat husk, and coconut coir have been used to reinforce epoxy composites, showing improved wear behaviour and specific wear rates of 10^-8 mm3/N mm under dry sliding conditions[5,6]. Glass fiber-reinforced epoxy composites have been extensively used in mechanical components due to their excellent mechanical properties and cost-effective manufacturing, with wear behaviour studies being crucial for practical engineering applications[7]. Additionally, the combination of cuttlebone with natural rubber has shown promising results in terms of mechanical properties and biodegradability, making them potential green composite materials[8]. Additionally, cuttlefish bone-derived hydroxyapatite has been incorporated into polymer scaffolds, showing improved cellular responses and bone tissue engineering potential[9]. Natural fillers, such as tree leaves, oak wood waste, peanut shells, and plant-derived fibers, are increasingly being explored for their potential as reinforcements in polymer composites. These fillers offer benefits like biodegradability, lightweight, and good mechanical properties, making them environmentally friendly alternatives to traditional synthetic fillers[10-12]. Studies have shown that composites incorporating natural fillers exhibit improved mechanical properties, including higher tensile strength, compressive strength, and flexural strength compared to pure polymer composites[13]. Additionally, the use of natural fillers in polymer composites can lead to enhanced adhesion between the filler and the polymer matrix, resulting in better overall performance of the composite material. The development of "green products" based on natural fillers and polymers is gaining momentum due to their sustainability, cost-effectiveness, and positive environmental impact. Natural fillers like eggshell, sawdust, date palm powder, hazelnut, chitin, starch, and coconut coir have been extensively studied for their potential in enhancing the properties of composite materials[14-18]. These fillers are being explored for their impact on mechanical properties such as tensile strength, bending strength, and durability of composites when combined with polymers like polyester, polypropylene, polyurethane, and natural rubber. Various treatment and functionalization methods have been employed to improve the interfacial bonding between these natural fillers and polymer matrices, leading to enhanced mechanical properties and reduced water uptake in bio-composites. The incorporation of natural fillers in polymer matrices shows promise for creating sustainable materials suitable for applications in industries like automotive, construction, textiles, and consumer goods. Glass fibers are versatile materials used in various industries like construction, transportation, aerospace, and defense[19]. They can be continuous or discontinuous and are commonly employed as reinforcements in plastic composites or as standalone materials for applications like thermal insulation[20]. The production of glass fibers involves essential steps such as raw material selection, batch-to-melt conversion, fiber drawing, and sizing functionality[21]. Glass fiber compositions typically consist of SiO2, Al2O3, MgO, CaO, and B2O3, contributing to high elastic modulus and fine-count fiber production[22]. Additionally, glass fiber impregnating compounds can enhance mechanical strength, corrosion resistance, and precursor adhesive force of the fibers, utilizing materials like epoxy resin, polyvinyl acetate, and coupling agents[23]. These fibers play a crucial role in modern optical telecommunication networks, especially when doped with rare-earth ions for fiber lasers and amplifiers. Epoxy resins are versatile materials used in various applications due to their desirable properties. Different types of epoxy resins have been developed to cater to specific needs. Some epoxy resins offer good heat resistance[24]. Modified epoxy resins with enhanced crystallinity and low viscosity are also available, providing excellent handling properties[25]. Additionally, there are epoxy resins containing mesogenic structures that contribute to unique properties like high thermal stability[26]. Furthermore, epoxy curing accelerators have been developed to improve the curing properties of epoxy resin compositions, ensuring reliability in semiconductor devices[27]. These advancements in epoxy resin technology cater to a wide range of industrial needs. This study investigates the use of natural fillers, specifically cuttlefish bone particle (CFBP), in Polymer Matrix Composite (PMC) to assess its influence on mechanical properties, namely, tensile, flexural, hardness and impact strength.

2. Materials and Methods

2.1 Materials

Cuttlefish bone, sourced from a local fish market, was employed in composite preparation. The composites were crafted using Araldite LY556 epoxy resin and a compatible hardener HY951. E-glass plain weave woven roving fabric served as the reinforcement material, aligning with the epoxy resin.

2.2 Preparation of Cuttlefish Bone Particles

The cuttlefish bone samples underwent washing with plain water and were brushed to eliminate residual flesh and other wastes. Subsequently, they were air-dried for one week. The dried cuttlebones were crushed, ground using a pulveriser, and sieved to achieve a particle size ranging from 5 to 30 μm. Prior to utilization as reinforcing filler, the cuttlebone particles were pre-dried in a furnace at 100 degrees Celsius for one hour, cooled to ambient temperature, and stored in a desiccator to prevent moisture absorption.

2.3 Preparation of Composites and Testing of Fabricated Specimens

The epoxy resin was precisely weighed and poured into a beaker according to the sample composition. Cuttlefish bone particles were then added to the epoxy resin in accordance with the specified composition, and the two components were thoroughly mixed. Subsequently, the hardener was measured, added to the epoxy-filler mixture, and stirred for ten minutes, maintaining a 10:1 ratio of epoxy to hardener. The resulting mixture was poured into a mild steel mould with dimensions of 210 x 170 x 3 mm, where two layers of woven roving glass fiber mat were placed for reinforcement. To facilitate specimen removal from the mould, a layer of wax was applied. A constant load of 1000 kg was applied to the mould for 24 hours using the compression moulding setup. Once the curing process was completed, test specimens were fabricated in accordance with the relevant ASTM standards for Tensile test (ASTM D638), Flexural test (ASTM D790), Impact test (ASTM D256) and Hardness (ASTM D2240). Table 1. illustrate the sample ID and composition of CFBP/glass fiber reinforced epoxy composite.

Table 1. Sample ID and Composition of CFBP-Glass fiber reinforced Epoxy composite

Sl. No.	**Sample ID**	**Composition**		
		Filler - Cuttlefish Bone Particle (v_f%)	**Reinforcement - Glass Fibre (v_f%)**	**Matrix - Epoxy Resin + Hardener (v_f%)**
1	CFBP-0	0	6	94
2	CFBP-3	3	6	91
3	CFBP-6	6	6	88
4	CFBP-9	9	6	85
5	CFBP-12	12	6	82

3. Results and Discussion

3.1 Tensile Strength

Utilizing CFBP-0 as the reference at 0% fillers as the baseline filler sample, the subsequent CFBP samples, from CFBP-3 to CFBP-12, exhibit observable differences in tensile strength as well as tensile modulus. This can be observed in Figure 1 for the tensile strength and tensile modulus of the CFBP-glass fiber reinforced epoxy composite. As filler content rises, there is a discernible decline in tensile strength across the samples. Specifically, when comparing CFBP-0 to CFBP-6, there is a notable decrease in tensile strength by approximately 28.5%, showcasing a significant impact of filler content on the composite's strength. This suggests that the incorporation of additional filler material may introduce structural weaknesses. Conversely, the tensile modulus experiences an initial augmentation, peaking at CFBP-6 with a 6% filler content (there is an impressive rise in tensile modulus by approximately 28.7% from CFBP-0 to CFBP-6). This indicates that up to this point, the stiffness of the composite improves with increased filler content, possibly due to enhanced reinforcement provided by the glass fibers. However, beyond this threshold, represented by CFBP-9 and CFBP-12, the tensile modulus begins to decline. This decline could be attributed to factors such as filler aggregation or insufficient matrix-filler interactions, which compromise the composite's overall stiffness. Additionally, figure 2 shows a typical stress-strain curve for sample IDs CFBP-0 to CFBP-12.

3.2 Flexural Strength

The results from Figure 3 demonstrate a discernible variation in flexural strength among the samples tested. Notably, sample CFBP-6 displayed the highest flexural strength, reaching 134 MPa, indicating its superior resistance to bending forces within the composite. Following closely behind, sample CFBP-0 exhibited a flexural strength of 133 MPa. The percentage difference in flexural strength between CFBP-6 and CFBP-0 is approximately

0.75%. This result suggests that the increase in filler-matrix interaction enables higher stress to be transferred from the matrix to the CFBP filler during external loading.

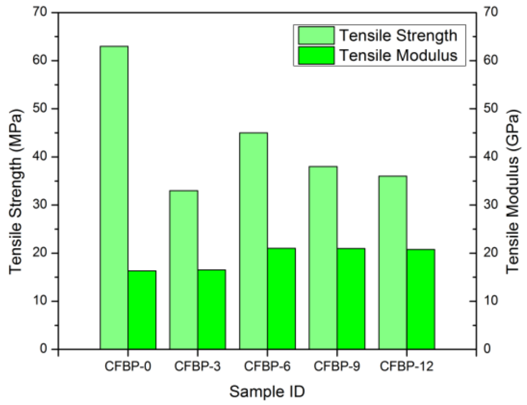

Figure 1. Tensile strength and tensile modulus of the CFBP-glass fiber reinforced epoxy composite.

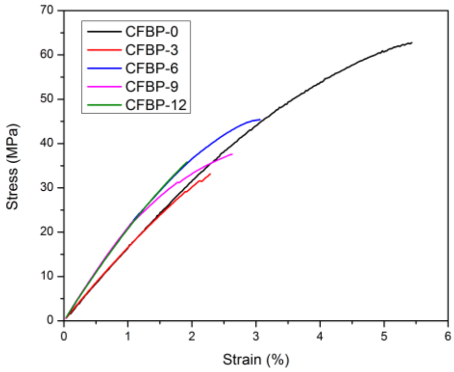

Figure 2. Typical stress-strain curve for sample IDs CFBP-0 to CFBP-12.

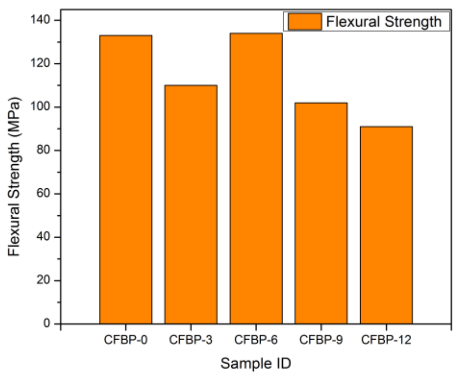

Figure 3. Flexural strength of the CFBP-glass fiber reinforced epoxy composite.

3.3 Impact Strength

The Charpy impact strength results for the CFBP-glass fiber reinforced epoxy composite samples are illustrated in Figure 4. Notably, sample CFBP-3 exhibited the highest impact strength at 60 kJ/m^2, indicating its superior resistance to impact loading compared to other samples. The percentage difference in impact strength between CFBP-3 and CFBP-0 is approximately 100%. Conversely, samples CFBP-0, CFBP-6, CFBP-9, and CFBP-12 displayed consistent impact strength values, suggesting minimal variations with changes in filler content.

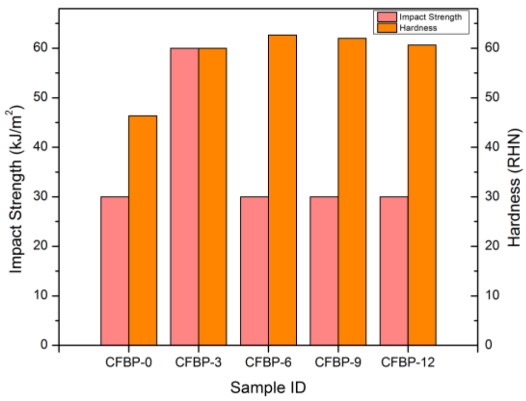

Figure 4. Impact strength and Hardness of the CFBP-glass fiber reinforced epoxy composite.

3.4 Hardness

The hardness values of CFBP- glass fiber reinforced epoxy composites are shown in Figure 4. Sample CFBP-6 exhibited the highest hardness value at 62.66 RHN (Rockwell Hardness Number), followed closely by samples CFBP-9 and CFBP-12, both at 62 RHN. Sample CFBP-0 displayed the lowest hardness value at 46.33 RHN, the percentage difference in hardness between sample CFBP-6 and CFBP-0 is approximately 35.24%. The increase in hardness observed in samples CFBP-6, CFBP-9, and CFBP-12 may be attributed to the enhanced reinforcement provided by the higher filler contents. Conversely, the lower hardness observed in sample CFBP-0 indicates the absence of additional reinforcement from filler material.

4. Conclusions

The composite materials, created by incorporating cuttlefish bone particle-glass fiber into epoxy resin, were successfully fabricated and investigated. From the observed results, the following points are drawn:

- Tensile strength decreases as filler content increases, indicating a notable impact of filler content on the composite's strength. While tensile modulus initially increases with filler content, it begins to decline beyond a specific threshold, suggesting a complex relationship between filler content and stiffness.
- Flexural strength exhibited variations among samples, with CFBP-6 notably demonstrating higher resistance to bending forces.
- The impact strength of the composites differed across samples, with CFBP-3 showing superior resistance to impact loading.
- Hardness increased with higher filler contents, with CFBP-6 displaying the highest values.
- Therefore, CFBP-6 can be considered the most promising composition among the tested samples. These findings offer valuable insights into the behaviour and performance of composite materials, presenting opportunities for further optimization.

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