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MANUFACTURING AND MECHANICAL TESTING OF DUCK EGGSHELL POWDER REINFORCED EPOXY COMPOSITE - A STUDY ON EFFECT OF REINFORCEMENT

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Abstract

The world produces roughly 7.2 million tons of eggshell waste each year, which is about 11% of the weight of an egg. The leading egg-producing countries are China, India, and the United States. However, eggshell waste can also contribute to environmental pollution if it is disposed of in landfills. In landfills, eggshell waste can produce odors and encourage microbial growth. However, eggshells can be used in many ways, including producing composite materials. Duck eggshells are popularly stronger than chicken eggshells, with a more compact palisade layer and higher calcium content. Since eggshells are a calcium carbonate ($CaCO_3$) source, they could be used as fillers in composite materials to improve mechanical properties. Using eggshell waste as fillers can help reduce waste and increase the strength and wear resistance of the final product. For the first time, this work aimed to investigate the mechanical properties of duck eggshell epoxy composites. Duck eggshell powder is used with epoxy resin to prepare the composite material. Different composites are prepared using different wt% duck eggshell powder with epoxy matrix material. The composites are manufactured by a simple casting pouring process. Specimens were cut and tested for mechanical properties according to ASTM standards. The experimental results substantiate the potential use of duck eggshell powder as a reinforcement filler in polymeric composites, with 12 wt% being the optimal weight fraction for further applications.

Keywords: *Duck Eggshell, Epoxy, Mechanical properties.*

1. Introduction

A composite material is prepared using reinforcement and matrix, which have different properties. Reinforcement material plays a key role in making composite material. A polymer composite is a material consisting of more than one phase in which the reinforcing phase is integrated with a polymer. Composite material, a superior material, is becoming a vital part of today's material industry due to its benefits, such as lightweight, corrosion resistance, strength, stiffness, and toughness. They are extensively used as materials in manufacturing automotive and aircraft structures and space vehicles. The commonly designed composites utilize a polymer-based material, often called a resin solution. The generally used resin solutions are epoxy, polypropylene, polyethylene, polyester, vinyl ester, phenolic, polyimide, polyether ether ketone (PEEK), and others [1&2]. Polymer-based composites are in demand due to their inexpensive and simple fabrication techniques. A powder-reinforced polymer composite is a new material that combines rigid reinforcement particles with a polymer matrix. The reinforcement particles can enhance the properties of the composite, such as its strength and toughness. Eggshells are a biodegradable material, and they could be utilized as reinforcement filler in bio-epoxy composites, which could then be selected for various applications that involve greater strength and lower cost [3&4]. It also helps to address challenges faced by every waste disposal infrastructure. Egg shells are commonly considered waste byproducts in many food industries, restaurants, houses, etc.; eggshell powder can be considered a substitute for standard plant-based materials. The attempt to use waste eggshells in polymer composites is an effort to decrease the adverse effects of waste on the environment. The powder obtained from eggshells as a source of calcium carbonate can be successfully used to alter the properties of polymer composites [5-12]. The present work aimed at investigating the mechanical properties of duck eggshell epoxy composites.

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2. Composite Manufacturing

The composite is prepared by using a plywood mold. Later, the required dimensional area is marked to manufacture the composite. The steps followed during the manufacture of the composite plate are described below:

2.1 Eggshell Powder Preparation

Duck eggshell was obtained from the Central Poultry Development Organization in Hessaraghatta, Bangalore, Karnataka, India. Then, the duck eggshells were dried in a solar dryer for 48 hours. The required amount of powder was taken and ground into powder (size: 100 µm). A sieve obtained an average duck eggshell powder particle size of 100 µm. The powder was treated with Sodium Hypochlorite (NaOCl) to remove the dust particles.

2.2 Preparation of Test Samples

Fig. 1 (a) Waste eggshells, (b) Fine duck eggshell powder, (c) Mixture of resin and eggshell powder, (d) Tensile specimens.

Epoxy resins are regularly used for most advanced composites because of their excellent adhesion, superior mechanical and electrical properties, and good stability at high temperatures. Epoxy LY-556 resin was used as the matrix and hardener HY-951 for room temperature curing. A releasing agent, such as wax, is applied to the working surface of the mold for simple composite removal before the fabrication activity begins. Three molds of various sizes were utilized to fabricate the composite plates. The weighed resin and hardener in a 10:1 identical ratio, in addition to the weighed eggshell powder (Based on the theoretically calculated weight of the composite), were stirred manually until a homogeneous mixture was produced. Later, the homogeneous liquid mixture was poured and flooded into the mold cavity and allowed to cure for 1 day. After 1 day, the cured composite plate was withdrawn from the mold and subjected to post-curing for 30 minutes at 100°C. Further, the composite plate, after post-curing, was kept at room temperature for three to four days. Post-curing aims to promote the ductility of epoxy composite plates by exposing them to high temperatures after the curing process. After the post-curing process, specimens were prepared according to ASTM standards for various mechanical characterizations. Figure 1 shows the systematic process of manufacturing the composite slabs using a casting process and preparation of samples as per ASTM standards. Table 1 shows the notations used for different wt% of duck eggshell while conducting experiments:

Table 1 Specimen notation

Sample	Eggshell Powder (ESP) (%wt)	Epoxy Resin (ER)(%wt)
1	0	100
2	4	96
3	8	92
4	12	88
5	16	84

3. Mechanical Testing and Discussions

The characterization of the prepared composites showed that the duck eggshell powder reinforcement has a considerable impact on the improved strength of the composite. The results of mechanical tests of duck eggshell powder reinforced epoxy composites fabricated by various weight percentages of reinforcement are presented. It was noticed that the elastic properties of the fabricated composite are increasing with the increment of duck eggshell powder content as reinforcement. The tensile, flexural, and impact strengths of duck eggshell powder reinforced epoxy composites are higher than those of neat epoxy. The mean values of mechanical properties of three identical samples are tabulated, and the reasons for the increase in strengths and ductility are outlined in detail using various graphs for each mechanical/elastic property.

3.1 Tensile Test

Uniform thickness flat specimens are regularly used for tensile tests. Commonly, two kinds of flat specimens are available: rectangular and dumbbell-shaped. In the current research investigation, specimens with the standard ASTM D638-III dumbbell-shaped specimens are used and loaded in the UTM to perform the tensile test at 10mm/min cross-head speed. The tensile test determines the tensile strength (TS), % elongation, and Young's modulus of different composite specimens. A tensile load of 'F' Newton is applied at the end points of the composite sample during the test. The specimen loading procedure and computerized UTM utilized for the tensile test are depicted in Figure 2(a). Three specimens were tested for every composition to determine the "TS; the mean result was utilized.

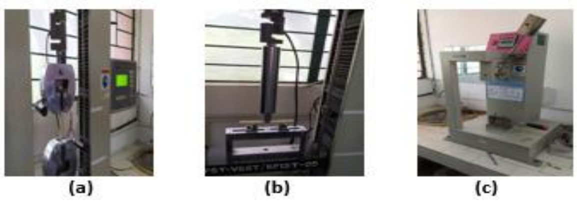

Fig 2. (a) Tensile test sample loading, (b) Flexural test sample loading, (c) Impact test sample loading.

Table 2 Tensile test results

Sample	Tensile strength (TS) (MPa)	% Elongation	Young's modulus 'E' (MPa)
1	28.11	6.81	654.84
2	34.72	8.51	709.47
3	40.13	9.04	698.24
4	50.13	10.02	803.79
5	33.57	8.09	698.99

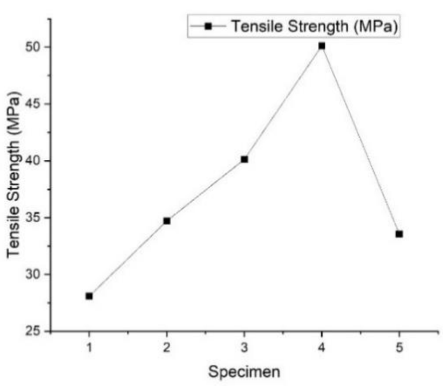

Fig. 3 Specimen vs.Tensile strength

The tensile strength values of all the composite variants are represented in Figure 3. In the figure, the tensile strength of the composite material gradually increases with the increase in eggshell powder percentage. The specimen 4 (12% eggshell powder-filled composite) variant exhibited a 59.88% improvement in strength compared to specimen 1 (unfilled variant). The lowest value of tensile strength was observed with the unfilled variant. Incorporating duck eggshell particles improves the epoxy resin's molecular interaction, increasing tensile strength. The higher tensile strength could be due to a transfer of tensile stress from the epoxy to the duck eggshell particles. Additionally, the higher surface area of the duck eggshell particles reinforced composite compared to the surface area of the unfilled variant may contribute to better performance.

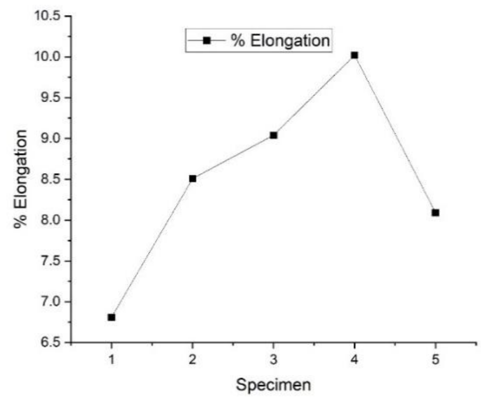

Fig. 4 Specimen vs. % Elongation

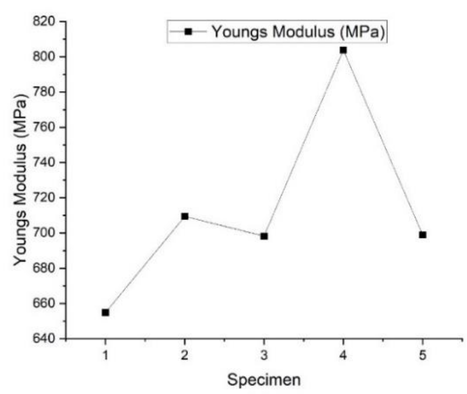

Fig. 5 Specimen vs. Young's modulus

The variation in Young's modulus and percentage elongation between all the composite variants is represented in Figures 4 and 5. The specimen 4 (12% eggshell powder filled composite) variant exhibited 18.53% and 32.03% higher tensile modulus (Young's modulus) and percentage elongation than the unfilled variant. The increase in tensile modulus and percentage

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elongation with the increase of duck eggshell powder content in the epoxy resin shows the improvement in ductility. Young's modulus increases due to eggshell powder-filled composites' improved stiffness and ductility.

3.2 Flexural Test

Flexural or bending strength is a basic mechanical/elastic property that defines a material's capacity to resist deformation under transverse load and the upper limit of tensile strength that it can sustain when bent before breaking. In a conventional 3-point bending test, the load is supplied midway, and the sample is supported at two locations. A load is incrementally applied to the sample during the 10mm/min cross-head speed test by a computerized universal testing machine on a prepared specimen fabricated as per ASTM D-790 with dimensions of 127×12.7×3.2mm. Figure 2(b) illustrates the loading of the flexural test specimen. The test was continued 3 times for each variant, and the mean or average value of the FS was found.

Table 3 Flexural test results

Sample	Flexural strength (FS) (MPa)	Lateral deflection 'δ' (mm)
1	56.18	2.12
2	66.13	2.72
3	73.72	3.91
4	156.49	8.79
5	74.83	3.78

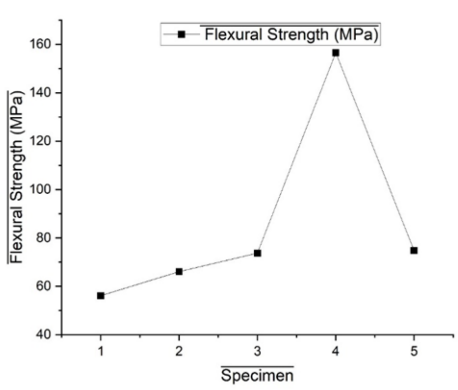

Fig. 6 Specimen vs. Flexural strength

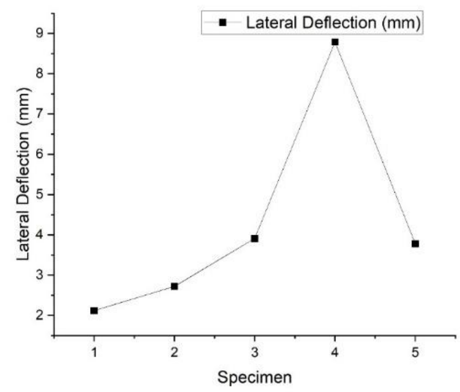

Fig. 7 Specimen vs. Lateral deflection

The strength under transverse load (flexural strength) of duck eggshell powder reinforced epoxy composite material gradually increases with the increase of Eggshell powder percentage. Graph 6 shows the variation of flexural strength with the increase in percentage of Eggshell powder. In the present study, the specimen 4 (12% eggshell powder-filled composite) gives the maximum flexural strength. This is further compared with specimen 1. The flexural strength of specimen 4 is 64.1% higher than that of specimen 1. From the results, it was noticed that the reinforcement of the duck eggshell powder increases the flexural strength.

The variation of lateral deflection among all the composite variants is depicted in Figure 7. The effect of duck eggshell powder in specimen 4 (12% eggshell powder-filled composite) exhibited a 75.8% higher lateral deflection than the unfilled variant. The enhancement in the flexural modulus could be because of the improved stiffness and ductility of duck eggshell-filled composites. Integrating duck eggshell particles increases the molecular interaction with the resin, leading to increased flexural strength.

3.3 Izod Impact Test

The Izod impact test was executed according to ASTM-D256 for specimen sizes of 63.5 mm×12.7mm×3.2mm. The test is intended to measure the energy absorbed by the prepared composites in J/m. The V-notch was cut at the midpoint of the specimen to a depth of 10 mm. When the pendulum strikes the notched specimen clamped in the impact testing machine clamp, the energy absorbed by the specimen can be immediately noticed from the dial indication of the

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impact testing machine. Figure 2(c) illustrates the loading of the impact test specimen. The impact strength is represented in Table 4, which shows the average impact strength of three experimental values.

Table 4 Izod impact test results

Sample	Izod impact strength (IS) (J/m)
1	4
2	5.6
3	7.2
4	9
5	6.8

The purpose of the impact test is to measure the energy absorbed by all the composite variants in Joules per meter (J/m). The results obtained in the Izod impact test for the epoxy composites reinforced with Eggshell powder and pure epoxy resin are presented graphically in Figure 8. It was noticed that the energy absorbed under impact by all the composite variants gradually increases with the increase of eggshell powder percentage compared to pure epoxy. Regarding the other composite variant, specimen 4 (12% eggshell powder-filled composite) appears to have greater energy absorption before fracture. The impact strength of specimen 4 is 55.55% higher than that of specimen 1. This could be because the rigid particles of duck eggshell powder chemically combine with the epoxy resin and help to absorb more energy. Further, there was a significant difference in impact strength values for 12 wt% and 16 wt%. An increase in the amount of duck eggshell powder in a composite can increase energy absorption and impact strength. However, too much duck eggshell powder can reduce the elastic properties due to the reduction in porosity.

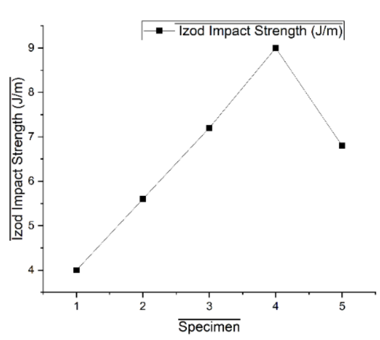

Fig. 8 Specimen vs. Izod impact strength

4. Conclusion

Epoxy resin is popularly used to manufacture composite materials due to its excellent adhesive and mechanical/elastic properties. In the present study, for the first time, epoxy composite reinforced with duck eggshell powder was subjected to various tests for mechanical properties. The following conclusions may be drawn from the results:

i. The composite with 12% eggshell powder, as presented in the tensile test results, showed the maximum tensile strength and percentage elongation.
ii. The composite Specimen with 12% eggshell powder demonstrated the maximum flexural strength compared to other composite variants.
iii. The Izod impact test revealed that adding 12 wt% of duck eggshell powder resulted in an appreciable increase in impact strength related to the pure epoxy, indicating that the impact strength is directly proportional to the duck eggshell powder content.

Since the bending strength is greater than the tensile strength, the manufactured composite could be used in automotive and aerospace applications.

5. Nomenclature

Symbol	Meaning	Unit
TS	Tensile strength	MPa
E	Young's modulus	MPa
FS	Flexural strength	MPa
δ	Lateral deflection	mm
IS	Impact strength	J/m

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