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Investigation of Mechanical Properties of Chopped Strand E-glass Fiber and Basalt Fiber Reinforcement with Epoxy Resin with and without Addition of Crab Shell Powder

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ABSTRACT: Lightweight eco-friendly composites with enhanced mechanical properties combined with cost-effectiveness are widely used in recent industrial applications. Basalt and E-glass composites are such combinations used extensively but they are not eco-friendly and cost-effective. In this work, to improve the degradability and cost-effectiveness, a new hybrid composite is prepared by using basalt fiber, chopped strand E-glass and crab shell powder as filler material. The crab shell is a natural material made up of highly mineralized chitin–protein fibers structured in a twisted pattern of plywood. However, there is no significant research on the use of crab shell powder as a filler material. The present work is an assessment of the mechanical behavior of composites made up of E-glass chopped strand fiber and basalt fiber as reinforcement with epoxy as a matrix with and without crab shell powder as filler. Flexural, compression, impact, and tensile strengths along with the hardness of composites are tested by varying the weight percentage of filler material. Specimens are prepared using 2.6%, 5.2%, and 7.6% by weight of crab shell powder through the hand lay-up technique with a curing time of 24 hours. A trend of increment of mechanical properties can be observed with an increase in the percentage composition of crab - shell powder. The hybrid composite with 7.6% by weight of crab shell powder as filler material has obtained high properties such as tensile strength of 164.63 MPa, the compression strength of 17.66 MPa, a flexural strength of 281.511 MPa, the hardness of 58.039 Kg/sq. mmand toughness of 13.85J/sq. mm. The experimental study shows that the mechanical properties are enhanced and the material cost is also reduced with an increase in the weight percentage of crab shell powder as a filler material.

Keywords: Crab shell powder, Epoxy, Chopped Strand E-glass Fiber (CSEF), Basalt fiber, Hand lay-up method, Filler material.

Abbreviations: Chopped Strand E-glass Fiber (CSEF), Basalt fiber (B).

I. INTRODUCTION

Modern technological advances require materials with high strength to weight ratio, high fatigue strength, dimensional stability, high stiffness, corrosion resistance, and affordability, which can't be met through conventional materials. Therefore, intensive studies are being executed regarding the improvement of composites fabricated out of unconventional and naturally occurring material.

To improve the flexural strength and cost-effectiveness, some carbon layers are replaced by basalt and glass fibers by sandwiching them between extreme layers of carbon in carbon fiber reinforced polymer (CFRP) composites [1]. The mechanical properties of hybrid bio-composite, prepared by mixing the walnut shell powder and coconut fiber in epoxy resin are studied and the results are compared with that of pure epoxy resin [2]. Basalt composites also exhibit better hoop tensile strength and superior properties of interlaminar shear stress when compared to other extensively used glass fibers [3].

Flexural and tensile properties are intermediate and the impact properties are higher in basalt-glass polyester than those of plain basalt and plain glass [4]. Polyester composites reinforced with chopped strand mat glass fiber have higher mechanical properties than woven glass reinforced fibers [5].

Basalt has better mechanical properties along with high corrosion resistance and low thermal conductivity when compared to asbestos and conventional glass fibers put together [6].Three-layered vacuum-bagged epoxy composite with chopped strands and plain woven e-glass mat have better flexural, tensile and interlaminar shear strength but lower impact strength than the laminates with one layer of plain-woven mat and two layers of chopped strand mat [7]. A detailed review has been conducted on the behavior of basalt fiber to understand its fiber structure and other significant material properties. The interaction of basalt as reinforcement with different matrix materials is also studied [8].

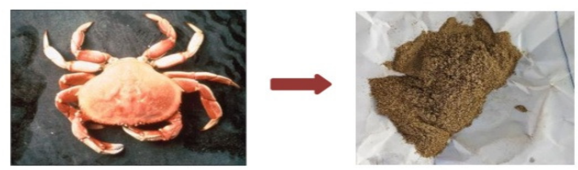
The effect of basalt fiber hybridization on the effective low impact velocity behavior of glass/basalt woven material/epoxy resin composites is studied and the maximum favorable flexural properties are significant in laminates of symmetric sandwich-like configuration [9]. Under abrasive wear conditions, chopped glass fiber

reinforced composites have higher mechanical and abrasive characteristics than the bi-directional glass fiber reinforced composites [10]. The effects of filler on epoxy in basalt fiber epoxy added with aluminum laminates are studied to compare the results with conventional basalt fiber epoxy resin [11].
The mechanical properties of E-glass chopped strand fiber reinforced with wood/PVC composites are studied and suggested that the flexural and tensile modulus and strengths of the wood/PVC composites increase with increasing glass fiber content [12].
Detailed investigation revealed that the crab shell cuticle is an anisotropic material with highly mineralized chitin–protein fibers arranged in a twisted plywood pattern with a shell hardness twice to that of the inner layers. The properties of the crab cuticle are found to be closely relatable to those of pre-stressed concrete [13]. The mechanical behavior of crab shell and prawn solid cuticle is identical, especially when low-stress discontinuity occurs in their bulk tensile stress stress-strain curves [14]. When individual lamellae gradually fail, the isolated crab chitin splits in tension and exhibits post-fracture de-lamination. The entire cuticle of crabs fails in a fragile way [15].
From the literature review, it is observed that the mechanical properties of fiber-reinforced composites depend upon the type of fiber, fiber quantity, the orientation of fiber, a type of matrix and filler material used. Basalt fiber has good mechanical properties and favorable costs. There is an increase in the use of basalt fibers in research due to their improved mechanical properties. Chopped Strand Matrix of E-glass has an excellent weight uniformity and superior corrosion resistance. The only limitations of the chopped strand E-glass matrix and Basalt fiber-reinforced composite are the high cost of material and non-degradability. Here, the crab shell cuticle comes to our advantage because of its cost-free availability and its natural origin. It is also observed from the literature review that there is no actual work initiated to involve crab-shell powder in composites.

II. MATERIAL PREPARATION

Chopped strand E-glass fiber and Basalt are used as reinforcement materials in this work, where chopped strand E-glass fiber is a synthetic material and basalt is a natural fiber. In the hybrid composite, the matrix used is Epoxy Araldite (LY556) with a 10:1 Epoxy to Harderner ratio where the hardener is Aradur (HY951). Crab shell powder is used as a filler material with a composition of 5 grams, 10 grams, and 15 grams or 2.6%, 5.2%, 7.6% by weight.

— Preparation of Crab Shell Powder: Crab shells are initially cleaned in water and dipped in Sodium Hydroxide (NaOH) solution for 12 hours to remove impurities on the crab shell. Later the crab shells have been exposed to sunlight for 24 hours. These crab shells are ground to prepare a fine powder.



(a) Crab shell (b) Crab shell powder.

Fig. 1.

— The relative weights of the fibers and resins. Fiber and resin weight ratio for Basalt fiber is 1:1 and for chopped strand E-glass fiber is 1:1.5.

Table 1: Number of layers and weight of the individual fiber.

Fibers	No. of Fiber layers	Fibers weight in grams	The Resin weight is in gram	Desired Thickness in mm
Hybrid(CSEG+B)	2+3	80	102	3
Hybrid (CSEG + B + Crab shell Powder 5g)	2+3	80	107	3
Hybrid(CSEG+B+Crab shell Powder 10g)	2+3	80	112	3
Hybrid (CSEG+B+Crab shell Powder 15g)	2+3	80	117	3

— Composite Hybrid Composition:

Table 2: The composite fiber and matrix weight ratio.

S.No.	Name of specimen	Composite Hybrid Composition by (wt. %)
1.	Hybrid (CSEG +Basalt)	Basalt (19.78%) + Chopped strand E-glass fiber (24.17%) + Epoxy (56.04%)
2.	Hybrid with 5g filler material	Basalt (19.25%) + Chopped strand E-glass fiber (23.52%) + Epoxy (54.54%) + Crab shell powder (2.67%)
3.	Hybrid with 10 g filler material	Basalt (18.75%) + Chopped strand E-glass fiber (22.91%) + Epoxy (53.12%) + Crab shell powder (5.2%)
4.	Hybrid with 15 g filler material	Basalt (18.36%) + Chopped strand E-glass fiber (22.33%) + Epoxy (51.77%) + Crab shell powder (7.6%)

III. MECHANICALTESTING

On thefabricated hybrid composite material, the following tests are performed.
(a) Tensile test
(b) Compression test
(c) Flexural test
(d) Charpy impact test
(e) Brinell's hardnesstest
Tensile, compression and flexural tests are performed on the INSTRON 8801 testing machine, Hardness test was conducted on the Brinell Hardness test machine and a toughness test was conducted on the Charpy impact test machine.

Fig. 2. INSTRON 8801 testing machine.

Fig. 3. Brinell's hardness testing machine.

Fig. 4. Impact testing machine.

Fig. 5. Specimens after testing.

— **Tensile test:** The dog-bone-shape tensile test specimens (250 × 25 × 3 mm^3) with ASTMD3039 standards are tested at a strain rate of 3mm/min using the INSTRON 8801 testing machine. The results of the tensile test are presented in Table 3.

— **Compression test:** The rectangular shape compression test specimens (140 × 25 × 3 mm^3) with ASTM D3410 standards are tested using an INSTRON 8801 testing machine. The results of the tensile test are shown in Table 4.

— **Flexural test:** The Flexural test is conducted to get the modulus ofrupture. Specimens of size 125 × 20 × 3mm^3 with ASTM D709 standards are tested with a 3-point bending test machine (INSTRON 8801 testing machine).

— **Brinell hardness test:** The hardness of the composite specimens was calculated by using 500 Kgf load and using a 5 mm diameter indenter on Brinell's hardness test machine.

The formula used to determine the Brinell's hardness number is

$$\text{BHN} = \frac{2P}{\pi D\,[D - \sqrt{D^2 - d^2}\,]}$$

P – load in kgf
D – steel ball diameter in mm
D – depression diameter in mm

— **Impact test:** The Impact strength was calculated using a Charpy impact testing machine as per the ASTM D256 standard for specimens measuring 63.5×12.7×3 mm^3.

IV. RESULTS AND DISCUSSION

Table 3: Tensile test results.

S.No.	Name ofspecimen	Maximum load (KN)	Load at break (KN)	Modulus of Elasticity (E)(MPa)	Ultimate tensile strength(MPa)
1.	Hybrid	10139.10	10.06	9361.70	225.31
2.	Hybrid with 5 g filler Material	7234.24	7.19	6722.69	160.76
3.	Hybrid with 10 g filler material	7372.61	7.37	6956.52	163.84
4.	Hybrid with 15 g filler material	7408.45	7.41	7083.33	164.63

Table 4: Compression test results.

S.No.	Nameofspecimen	Maximum load (N)	Compressive strain at Maximum Comp. load (mm/mm)	Modulus of Elasticity(E) (MPa)	Compressive strength (MPa)
1.	Hybrid	1208.61	0.00237	11729.18	16.11
2.	Hybrid with 5 g filler material	884.99	0.00373	8112.45	11.80
3.	Hybrid with 10 g filler material	1023.27	0.00408	10866.21	13.64
4.	Hybrid with 15 g filler material	1324.78	0.00477	10027.58	17.66

Table 5: Flexural test results.

S.No.	Name of specimen	Maximum load (N)	Flexural stress at maximum flexural load (MPa)	Flexure strain at Maximum Flexure stress (mm/ mm)	Modulus (MPa)
1.	Hybrid	407.08	271.389	0.021	15769.54
2.	Hybrid with 5 g filler material	346.04	230.697	0.025	11564.80
3.	Hybrid with 10 g filler material	382.03	254.692	0.025	12055.55
4.	Hybrid with 15 g filler material	422.26	281.511	0.022	13741.68

Table 6: Hardness test results.

S. No.	Name of specimen	Applied load (N)	Indenter diameter D=5mm	Avg. indentation diameter (d in mm)	Brinell Hardness Number (BHN) Kg/mm^2
1.	Hybrid	4905	5	2.9	68.681
2.	Hybrid with 5 g filler material	4905	5	3.375	48.562
3.	Hybrid with 10 g filler material	4905	5	3.275	52.10
4.	Hybrid with 15 g filler material	4905	5	3.125	58.039

Table 7: Impact test results.

S.No.	Name of specimen	Cross-sectional area below the notch (mm^2)	Initial energy (J)	Reading after impact (J)	Error in reading (J)	Actualenergy (J)	ToughnessJ/mm^2
1.	Hybrid	24	300	14	2	284	11.833
2.	Hybrid with 5 g filler Material	32	300	10	2	288	9.0
3.	Hybrid with 10 g filler Material	28	300	8	2	290	10.357
4.	Hybrid with 15 g filler Material	21	300	7	2	291	13.85

Fig. 6 presents the graph ultimate tensile strength of different specimen used in the study.

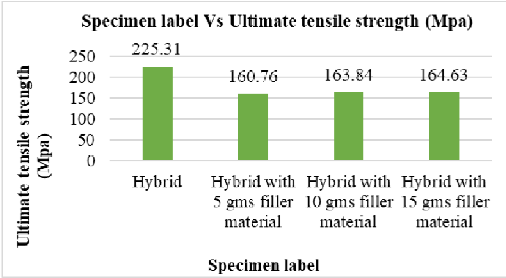


Fig. 6. Graph between the name of the specimen and the tensile strength of the specimen.

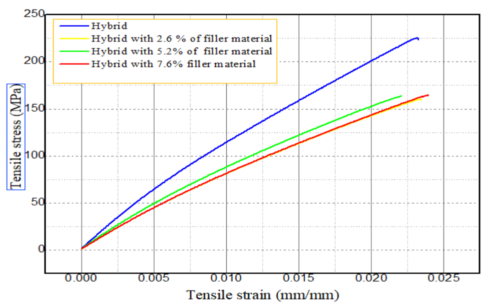


Fig. 7. Stress-strain curve for all composite specimens.

Fig. 7 shows the stress-strain curve for the composites with different percentages of filler material.

Fig. 8 presents the compression strengths graph of the specimen with different filler material composition.

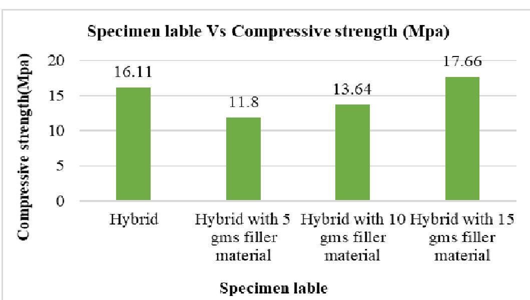


Fig. 8. Graph between the name of specimen and compression strength of the specimen.

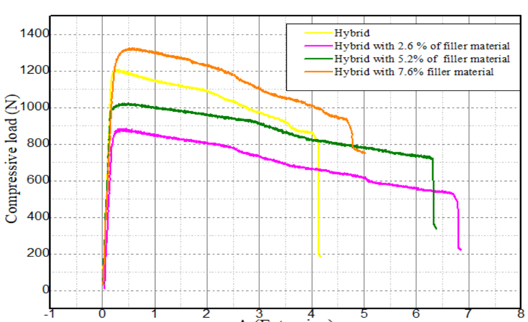


Fig. 9. Graph for compressive extension against compressive load for all composite specimens.

Fig. 9 is a graph of compressive extension against compressive load for different specimen tested.

Fig. 10 is a comparative graph to show the relative values of compressive and tensile strengths for different specimen.

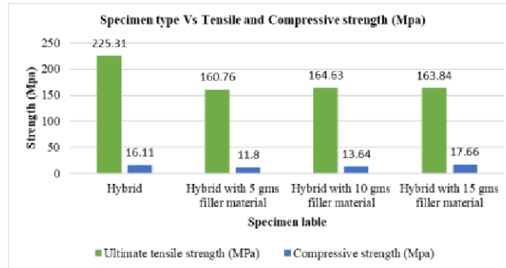


Fig. 10. Graph between the name of the specimen and the relative tensile strengths and compression.

Fig. 11 presents the graph to show the flexural strength of a different specimen.

Fig. 12 is the graph of flexural strain against flexural strength for different specimens tested.

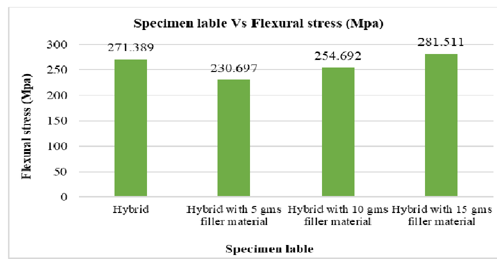


Fig.11. Graph between the name of the specimen and the flexural stress of the specimen.

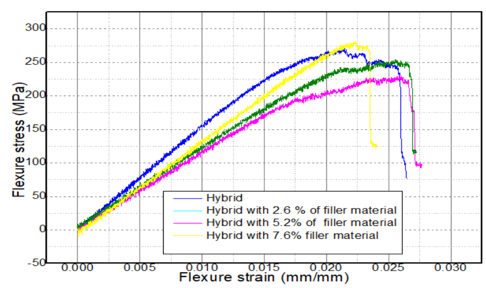


Fig. 12. Graph for flexural strain against flexural stress for all composite specimens.

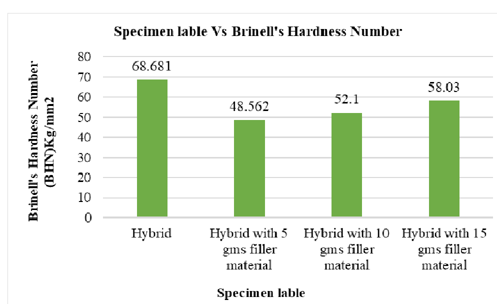


Fig. 13. Graph between the name of the specimen and hardness number of the specimen.

Fig. 13 presents the graph to show the Brinell Hardness number of different specimens.

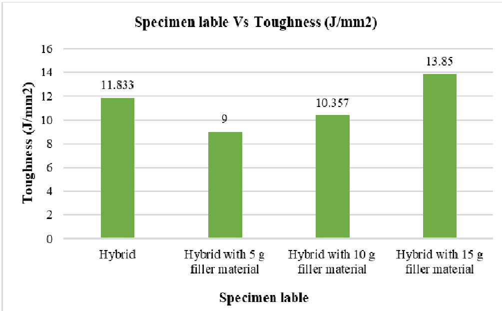


Fig. 14. Graph between the name of the specimen and the toughness of the specimen.

Fig. 14 presents the graph to show the toughness of different specimens.

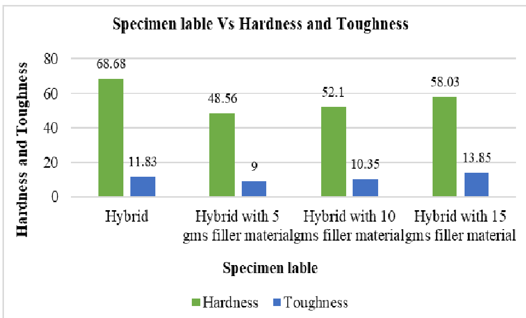


Fig. 15. Graph between the name of the specimen and their relative hardness and toughness.

V. DISCUSSION

(a) Fig. 6 reveals that the hybrid composite without filler material is obtained highest tensile strength (225.31 MPa) rather than other specimens. And it is also observed that the tensile strength of hybrid composites is influenced by the addition of filler material.
(b) From Fig. 8 and 9, It has been observed that the hybrid composite with 7.6% filler material got high compression strength up to 17.66 MPa. This is because of the addition of filler in a hybrid composite.
(c) Fig. 11 and 12 shows that the Flexural stress of hybrid composite with 7.6% of filler material is higher than the other composites because of its high strength and high resistance property which can withstand more stresses.
(d) Fig. 13 reveals that the hybrid composite without filler material obtain the highest Brinell's hardness number (68.681 kg/mm^2) and Hybrid composite with 7.6 % of filler material obtained 58.039 BHN and it shows that with the addition of filler material, the hardness increased. The Hardness of hybrid composites is influenced by the addition of filler. So the hardness of hybrid composites is increased.
(e) Fig. 14 shows that the hybrid composite containing 7.6% (15 grams) of crab shell powder filler material has shown high toughness From the result, it is evident that the addition of filler material improves the toughness of hybrid composites.

VI. CONCLUSION

By studying the results obtained from different tests conducted on specimens with different percentage composition of crab shell powder as filler material, the following conclusions are presented.
— It is observed that the hybrid composite with 15 grams (7.6% by weight) crab shell powder filler material has obtained superior properties over the other specimen with a lower percentage of crab shell powder.
— The tensile strength is increased up to 164.63 MPa, compression strength up to 17.66 MPa and flexural stress up to 281.51 MPa for the composite with 7.6% by weight of crab shell powder.
— Hardness is also increased up to 58.039 kg/mm^2 and toughness up to 13.85 J/mm^2 with an increase of the percentage of filler material.
— Results show that the mechanical properties of the composite material are improved due to the addition of crab shell powder. The properties of hybrid composite material are increased by increasing the percentage of crab shell powder.
— Though the properties of the composite with the 7.6 % of filler material are lower than the composite without filler material, the tests show a trendline of a gradual and significant increase in the mechanical properties with the increase in the percentage composition of the crab-shell powder.
— This may imply that the composite with filler material displays superior properties over the composite without filler material with further increase in the weight percentage of crab shell powder, with a significant advantage of cost reduction and eco-friendliness.

VI. FUTURE SCOPE

(a) In this paper the mechanical behaviour of the fabricated hybrid composites are studied. This work can further be continued to perform surface analysis of the composite materials by using SEM (scanning electron microscope) images.
(b) This filler material percentage may also be further increased to find the optimum amount of weight percentage for achieving maximum property values.

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Conflict of Interest. The authors declare that we have no conflict of interest.

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