Research Article

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Dynamic Analysis of Laminated Composite with Inclusion

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ABSTRACT

With growing environmental awareness, ecological concerns and new legislations, bio-fibre reinforced polymer composites have received increasing attention during the recent decades. This study focuses on the processing of seashell powder into micron size and utilizing the same as filler with glass fibres and epoxy resin in the preparation of the composite, thereby increasing mechanical strength. The constituents used in this composite showcase properties like higher strength, higher stiffness, chemical resistance, good insulation to electricity and lightweight. The components found in seashell such as Na, Ca, Al and C along with the S-glass fibre and the binding provided by the resin are responsible for enhancing hardness and tensile strength of the composite. Numerical analysis for the tensile test was done using ANSYS simulation for both composites with 5% filler (50% fibre + 45% resin+ 5% seashell) and without filler (50% fibre + 50% resin). Two laminate composites, with 5% filler (50% fibre + 45% resin+ 5% seashell) and without filler (50% fibre + 50% resin) were fabricated and their mechanical properties were compared using various tests like tensile and low velocity impact test with an impact velocity of 1 m/s, 2 m/s, 3 m/s and 4 m/s. The results from these tests were interpreted. The findings show that the specimen with 5% filler has more ultimate strength and impact strength when compared to the one without filler.

Keywords: Seashell filler; ANSYS; Tensile strength; Impact strength; Laminated composite.

1. INTRODUCTION

Composite materials are formed by combining two or more materials that have quite different properties. The different materials work together to give the composite unique properties. The reinforcement and matrix are the two constituents of composites. The reinforcing phase is said to be made either of fibres, particles, or flakes and the matrix phase in composite is said to be continuous (Dickson *et al.* 2017).

In an advanced society, the composite materials play a crucial role in many industries and such a material is “fibreglass”. Fibreglass was produced in the late 1940s becoming the first modern composite material made during that period. It has now become a common material used everywhere, taking up about 65% in the composite production. It is used for boat hulls, surfboards, sporting goods, swimming pool linings, building panels, car bodies and plays a significant role in the aerospace field (Shettigar *et al.* 2018; Gopal *et al.* 2021). Due to its effective strength, high stiffness-to-density ratios, superior physical properties and cost effectiveness, scientists tend to conclude that composite materials are the future of aerospace components. Being the high-performance material available in the market nowadays, it attracts the aircraft manufacturers with unrelenting passion to enhance the performance of commercial and military aircraft (Sanjay *et al.* 2015).

Structural components in aircraft are subjected to dynamic loading in their operational life leading to many damages and failures regularly (Ferreira *et al.* 1999; Nanda *et al.* 2009). As much as composites have enhanced properties and high performance, it’s difficult to conclude that they will not undergo any failure (Satyanarayana *et al.* 1986). Composites are fragile and susceptible to transversal impact loading with the appearance of various interlaminar and intralaminar damages such as delamination, fibre breakage and matrix cracking(Yarlagaddaa and Ramakrishna, 2019). Hence, it is necessary to have a thorough understanding of the structural characteristics of them such as deflection, stress distribution across thickness, natural frequencies, buckling loads and external loadings (Hosseini and Raji, 2023).

Due to growing environmental awareness, ecological concerns and new legislations, bio-fibre reinforced polymer composites have received more attention in this new generation. The late 1980s researchers have concentrated more on producing different products from the naturally occurring biodegradable fibre materials. But the cost of production using these fibre materials is relatively high compared to other materials. So, natural fillers are considered an environmentally friendly alternative to conventional reinforcing fibres(Lee and Jang, 1999).

Generally, filler materials are considered to be inert materials, which are normally added to FRPs to enhance the material performance by improving the physical and mechanical properties of the composites (Seshavenkat and Krovvidi, 2021). They not only reduce the cost of composites but also frequently impart performance improvements that might not otherwise be achieved by the reinforcement and resin ingredients alone. Fillers can improve mechanical properties of composite materials including temperature resistance, dimensional stability, and stiffness(Žmak *et al.* 2017; Dhanaraj and Suresh, 2018). It was also stated in many research studies that the addition of filler increases the fibre–matrix interaction and when the load is applied, it promotes increased stress transfer between the fibre and matrix (Varga *et al*. 2010).

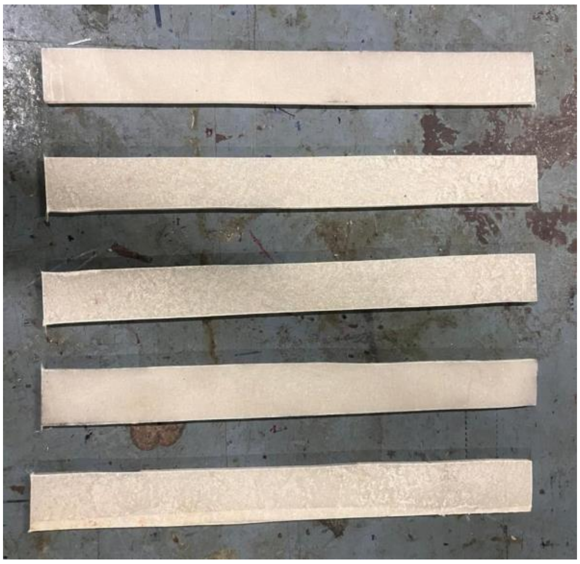

Fig. 1: Fabricated specimen for tensile testing

Filler materials are either organic or inorganic. The influence of these fillers on the properties of the composites depends upon the size, shape, aspect ratio, surface area, and dispersion of fillers within the composite. Among the various fillers available, seashell could be a very interesting material as filler due to its good thermal stability compared to others (Ravi *et al.* 2013). They are mainly considered as marine waste and abundant in nature. The seashell can be easily crushed into chips or particles and is mainly composed of calcium carbonate ($CaCO_3$) in two forms, calcite and aragonite, or a mixture of them with some organic compounds (Moustafa *et al*. 2017; Santulli *et al.* 2023). The synthesised seashell-based composite can be used as floor and wall tiles, decorative arrangements, interior designs and furniture, etc (Norazlina *et al*. 2015). Addition of this filler increases the surface hardness, compressive and tensile strength and also the presence of elements like Ca and C provide binding of resin and fibre effectively (Koçhan, 2019; Stanciu *et al*. 2021). Resins with filler shrink less than unfilled resins, thereby improving the dimensional control of moulded parts (Owuamanam and Cree, 2020).

Our work focuses on the processing of seashell powder into a particular micron size and utilisation of the same as reinforcement with glass fibres and epoxy resin in the preparation of the composite and to study its mechanical behaviour under various loading conditions under different composition of the material (Andersons *et al.* 2002; Azarian and Sutapun, 2022; Salawu *et al.* 2023).

2. FABRICATION OF COMPOSITE

2.1 Selection of Materials

(a) Reinforcement Phase: In our work, we chose S-glass fibre as reinforcement phase since it is technically an important fibre among the classification of glass fibres. It has the highest strength, stiffness, higher density compared to carbon fibres and organic fibres and softening point of any commercial reinforcement glass fibre.

(b) Matrix Phase: The resin used in our work is Epoxy resin LY556 with hardener HY951. This resin offers a number of beneficial properties to composites. It has a low tendency to crystallise and mainly used for aircraft and aerospace adhesives.

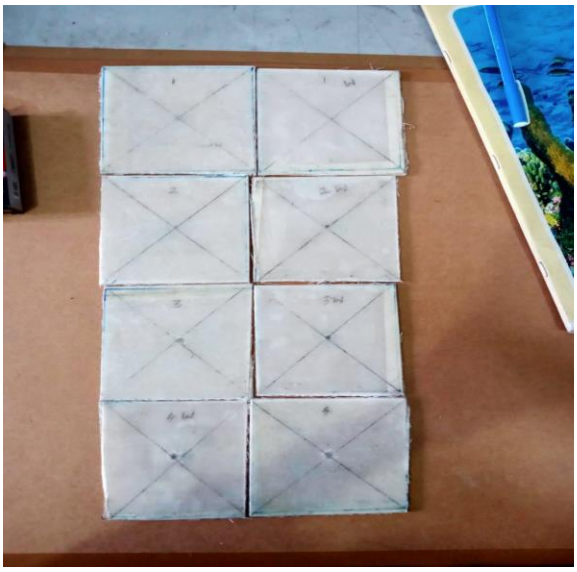

Fig. 2: Fabricated specimen for impact testing

(c) Filler/Inclusion Material: In our study, we considered seashell as the dispersed phase in the composite material. It is also observed that seashells have been used as a replacement for both cement and aggregate. Furthermore, seashell waste can be utilised as a partial aggregate at a replacement level of up to 20% for adequate workability and strength. In composite materials, we can observe that adding the seashell waste as filler can improve tensile strength if the optimum filler loading is not exceeded.

Fig. 3: Tensile testing machine

2.2 Fabrication

The specimens used in this work are made up of GFRP with weight of 297 g and are cut into 16 pieces of dimension 300×300 mm, respectively. In accordance with the weight of glass fibre, the weight of the resin needed for fabrication was found. Epoxy resins were extremely compressive materials with great corrosion resistance, fatigue strength, high tensile strength features and more. The hardener was mixed with the resin in the mass ratio of 10:1. The seashell filler used as filler had a grain size of 450 microns. This seashell powder was prepared by ball-milling method using an aluminium oxide cup and balls for 100 min and at a rotation speed of 500 rpm room temperature.

2.2.1 For Fabrication without Filler

The laminate involved in this work is made of 16 layers of S-glass fibre resulting in thickness of 4.6 mm approximately. Composite specimens were moulded using a compression moulding press with 50-ton weight. All the specimens were cured at room temperature for 24 hrs.

2.2.2 For Fabrication with Filler

The S-glass fibre was cut into 16 pieces with dimensions: 300×300mm for fabrication. Composition of epoxy resin with respect to fibre: 25% S-glass fibre +35% seashell powder + 40% epoxy resin with hardener. Then, the fabrication of the fibre and resin was done by hand layup process followed by compression moulding process under 50-ton weight where curing was done for a period of 24 hrs.

3. EXPERIMENT

3.1 Tensile Test

A specimen with equal thickness and dimensions 240×25 mm was selected for tensile testing as in Fig. 1. Tensile testing was carried out for the following specimen. Fig. 2 shows the fabricated specimen for impact testing. Tensile testing was done according to ASTM D3039 standards on a 100kN Universal Testing Machine as in Fig. 3, which is available at MIT Composite laboratory.

(a) Tensile test on composition 50% fibre + 45% resin + 5% seashell: Wt % of the laminate (without aluminium grip) = 62 g, thickness of the laminate = 4.67 mm, Wt % of S-glass fibre = 298 g, Wt % of epoxy resin = 268 g, hardener wt% as per 10:1 ratio with resin = 26.8 g, Wt % of seashell powder for filler = 30 g, dimension of the laminate = 240×25 mm.

(b) Tensile test on specimen without seashell filler 50% S-glass fibre + 50% epoxy resin: Wt% of the laminate = 27.5 g, thickness of the laminate=4.3 mm, Wt% of S-glass fibre = 268 g, Wt% of epoxy resin = 268 g, hardener wt% as per 10:1 ratio with resin = 26.8 g, dimension of the laminate = 240×25 mm.

Fig. 4: Impact testing machine

3.2 Impact Test

The fabricated laminated composite to be used for impact testing was cut according to the specifications of the INSTRON CEAST impact testing machine (MIT laboratory) (Fig. 4). The velocity range of the machine for low velocity impact test is 0.75 m/s to 24 m/s. Dimensions of the specimen used for impact testing according to the CEAST standard are: 89×89 mm. Thickness of the specimen with seashell is 4.67 mm.

The testing was conducted on composite materials as shown in Fig. 2 by following the specifications of the INSTRON CEAST machine with ASTM D5628 FD standard (MIT laboratory) with velocity range 0.75 to 24 m/s as in Fig. 4. Intender diameter = 12.7 Φ, Mass of the intender = 1.926 kg, Impact velocities considered for our project ranged from 1 m/s to 4 m/s for the following specimen.

(a) Impact test on specimen without seashell filler: Wt % of the laminate = 27.5 g, thickness of the laminate = 4.67 g, dimensions of the laminate = 89×89 mm.

(b) Impact test on specimen with seashell filler: Wt% of the laminate = 62 g, thickness of the laminate = 4.67 g.

4. RESULTS & DISCUSSIONS

4.1 Numerical Analysis for Tensile Testing

For this study, numerical simulation was carried out in ANSYS for static structural.

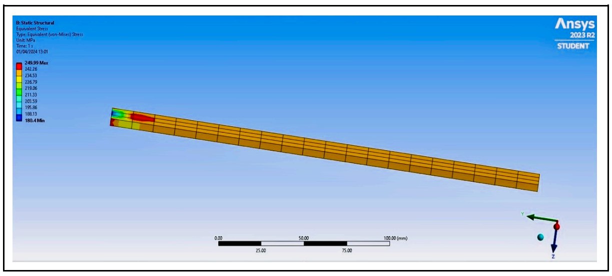

Fig. 5: Numerical analysis of equivalent stress w/o filler

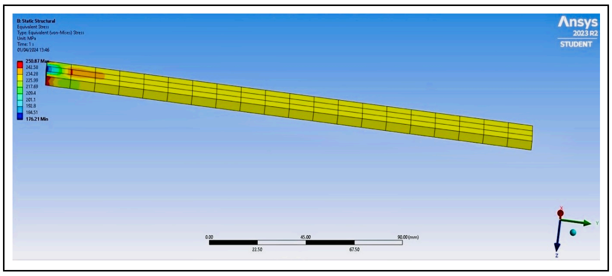

Fig. 6: Numerical analysis of equivalent stress with filler

From the simulation results (Fig. 5 & 7), it is found that the maximum stress for 50% fibre + 50% resin is 24.9.99 Mpa and maximum stress for 50% fibre + 45% resin + 5% seashell (Fig. 6 & 8) is 250.87 Mpa. We can infer that the maximum stress value has been increased by 0.35% when 5% seashell filler is added to the S-glass fibre reinforced polymer.

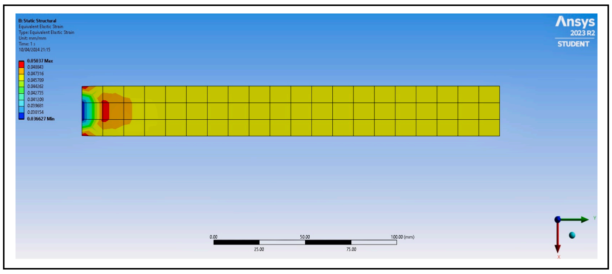

Fig. 7: Numerical analysis of equivalent strain w/o filler

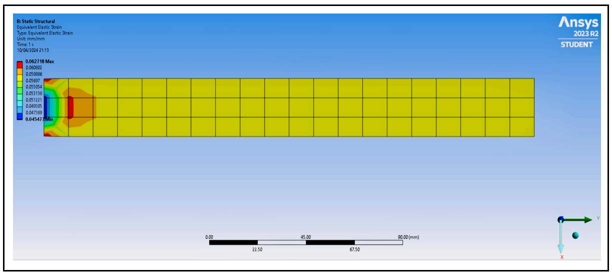

Fig. 8: Numerical analysis of equivalent strain with filler

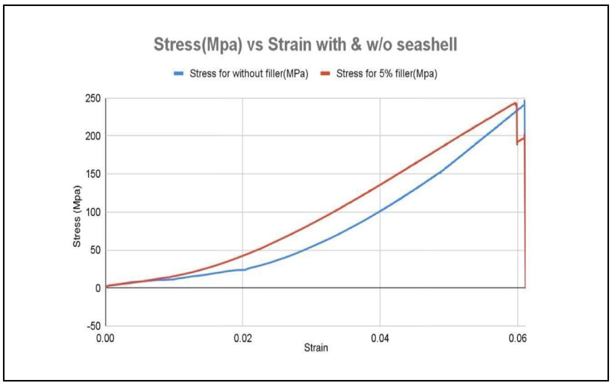

Fig. 9: Stress vs strain graph for with & without filler

Similarly, the maximum strain for 50% fibre + 50% resin is 0.05037 and maximum strain for 50% fibre + 45% resin + 5% seashell is 0.062718. We can infer that the maximum strain value has been increased by 24% when 5% seashell filler is added to the S-glass fibre reinforced polymer.

4.2 Tensile Test

Tensile testing was conducted for specimens with 5% filler (50% fibre + 45% resin+ 5% seashell) and without filler (50% fibre + 50% resin).

Table 1. Results obtained from tensile testing for with & without filler compositions

Specimen	Ultimate stress (Mpa)	Maximum strain	Ultimate force (N)
Without filler	241	0.061	18750
With 5% filler	243.5	0.07125	28300

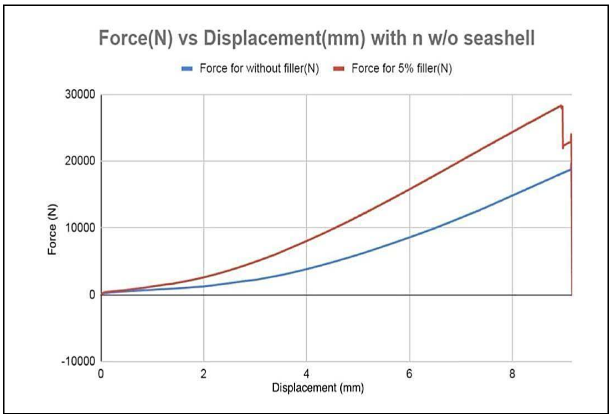

Fig. 10: Force vs displacement graph for with & without filler

From Figure 9 & 10, We can infer that the material with 5% filler has an ultimate force of 28300 N for a displacement of 10.7 mm, whereas, the S- glass fibre reinforced polymer without filler has an ultimate force value of 18750 N for a displacement of 9.15 mm. The ultimate force value has been increased by 51% when 5% seashell filler is added to the S-glass fibre reinforced polymer which can be observed from Table 1.

Similarly, the ultimate stress value has been increased by 1% from the S-glass fibre reinforced polymer stress value.

The ultimate tensile strength value for specimen without filler is,

$$\sigma_{max}\,(N/mm^2) = P_{max} / Ao$$
$$= 18750/ 107.5$$
$$= 174.41$$

Similarly for specimen with 5% filler,

$$\sigma_{max}\,(N/mm^2) = 28300/115$$
$$= 246.08$$

Ultimate strength value of the specimen is increased by 41.1% when compared to the one without filler.

The error percentage for maximum stress without filler between simulation results and experimental results is 3.7%. Similarly, the error percentage for maximum stress with 5% filler between simulation results and experimental results is 2.9%

The error percentage for maximum strain without filler between simulation results and experimental results is 21%. Similarly, the error percentage for maximum strain with 5% filler between simulation results and experimental results is 12%

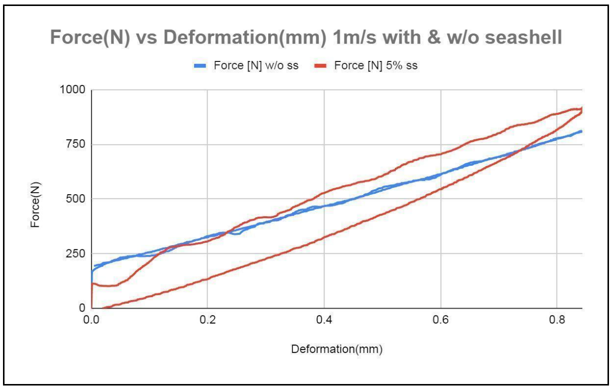

Fig. 11: Force vs deformation graph for with & without filler at 1 m/s

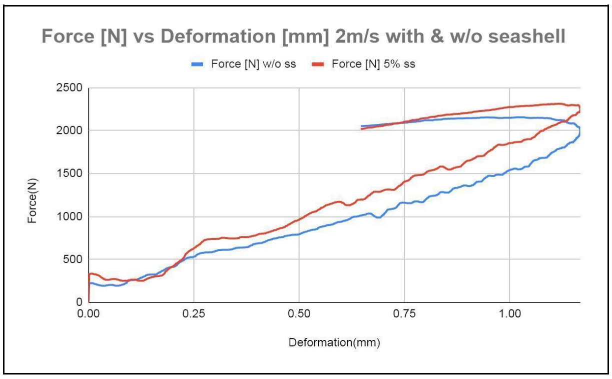

Fig. 12: Force vs deformation graph for with & without filler at 2 m/s

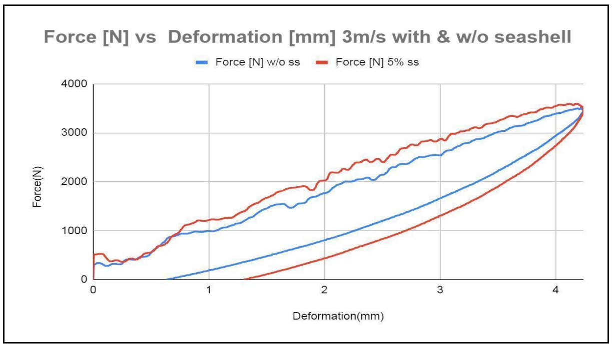

Fig. 13: Force vs deformation graph for with & without filler at 3 m/s

4.3 Impact Test

Impact testing was conducted for specimens with 5% filler (50% fibre + 45% resin+ 5% seashell) and without filler (50% fibre + 50% resin) for velocities 1 m/s, 2 m/s, 3 m/s and 4 m/s.

From Figs 11,12,13 & 14 the force vs deformation graph for with & without filler at velocities 1 m/s, 2 m/s, 3 m/s and 4 m/s are noted.

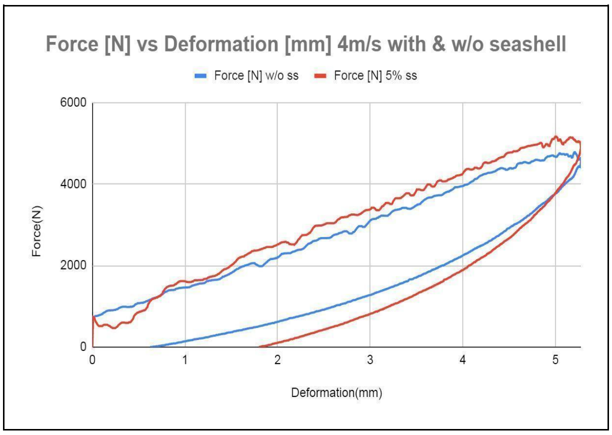

Fig. 14: Force vs deformation graph for with & without filler at 4 m/s

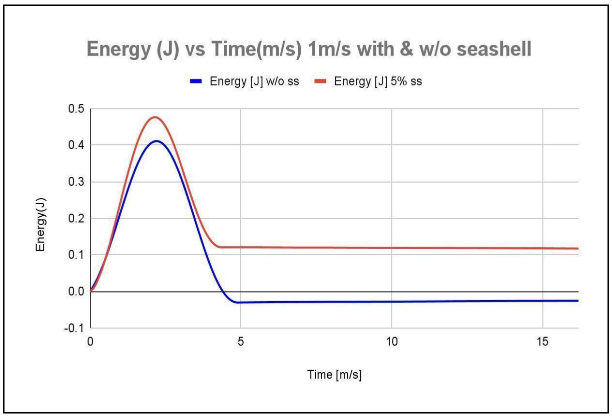

Fig. 15: Energy vs time graph for with & without filler at 1 m/s

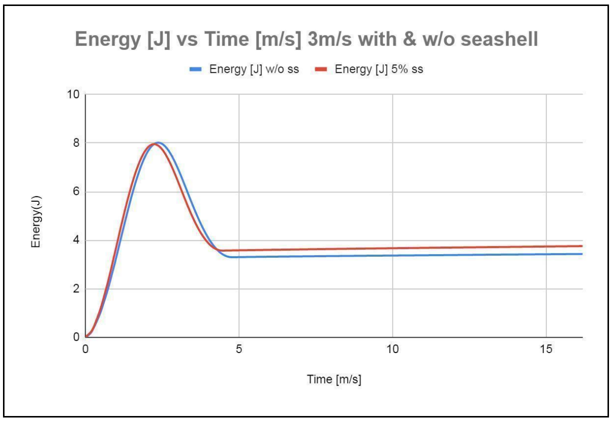

Fig. 16: Energy vs time graph for with & without filler at 2 m/s

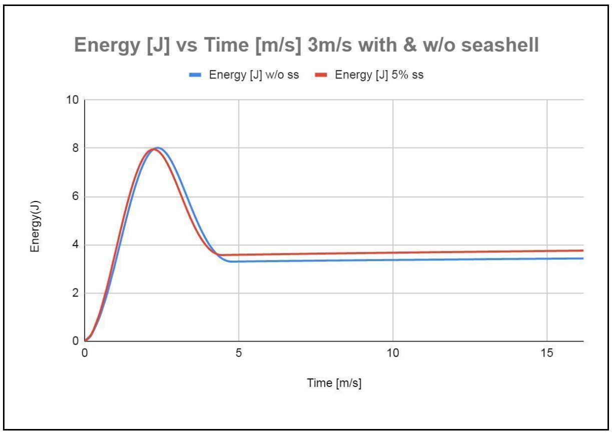

Fig. 17: Energy vs time graph for with & without filler at 3 m/s

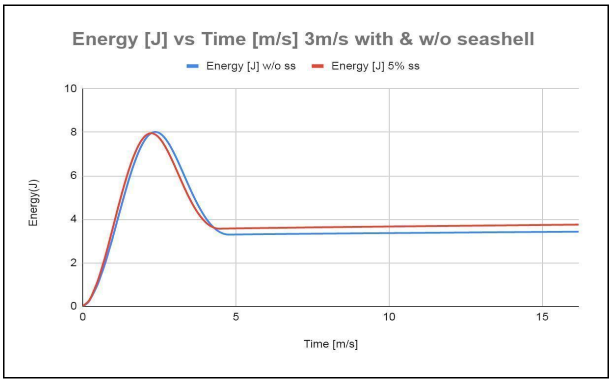

Fig. 18: Energy vs time graph for with & without filler at 4 m/s

From Figs 15, 16, 17 & 18 the energy vs time graph for with & without filler at velocities 1 m/s, 2 m/s, 3 m/s and 4 m/s are noted.

Table 2. Analysis of peak force and maximum energy for different compositions

Velocity (m/s)	Peak Force (N) (Without ss)	Peak Force (N) (5% ss)	Maximum Energy (J) (Without ss)	Maximum Energy (J) (5% ss)
1	809.455	913.332	0.41	0.475732
2	1611.2	2313.55	1.104359	3.059213
3	3496.66	3592.82	8.013553	8.855334
4	4782.26	5164.25	14.75067	14.97093

The specimen with 5% filler has an increased peak force of 7.7% compared to the one without filler which can be observed from Table 2. Thus, addition of filler has improved the ultimate tensile strength of the specimen by 41.1% compared to the one without seashell filler. Also, the maximum energy up to which the specimen can withstand deformation has increased (10-15%) in the laminate with 5% seashell filler.

5. CONCLUSION

From all the graphical representation and experimental values, we can conclude that the laminated composite of composition 50% fibre + 45% resin + 5% filler has shown better results when subjected to axial load and impact load (vertical load) under low velocity than the one with composition 50% fibre + 50% resin. The results obtained from the tensile test experiment are compared with simulation results for better analysis of mechanical behaviour of laminated composite. The obtained data can be utilised for designing helmets for military aircraft pilots to prevent any accident during sudden impact action while combat.

We can also reduce the cost of production of different structural components by addition of filler to the fibre reinforced composites. Seashell filler also acts as a better bonding agent when added with epoxy resin matrix phase for glass fibre reinforced polymers. Since glass fibres and resin materials are not abundant in nature, we can replace them with filler material like seashell, waste which is available to a greater extent in the environment.

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CONFLICT OF INTEREST

The authors declared no conflict of interest in this manuscript regarding publication.

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