Experimental Investigation on Mechanical properties and Morphological Analysis of aluminium foam sandwiched with glass fibre epoxy (GFEP) composites

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Abstract:

Aluminium foam has increased the performance of hybrid composites used in automotive applications. Many scientists are investigating how to develop substitute hybrid materials for ecological sustainability and environmental responsibility. In this study, laminates are made utilising a hand layup technique from a double aluminium foam (Al) core with thicknesses of (0.5, 1 & 1.5 mm) sandwiched between glass fibre (GF) and epoxy resin (EP). On the manufactured samples, mechanical characteristics like tensile, impact, and flexural strength are examined. In this work, it is found that an aluminium foam core with the 1.5 mm thickness sandwiched between glass fibre composites which has capable of attaining a maximum tensile strength of 140.7 MPa and the Impact strength of 12.5 J/m^2. It was also attained. Aluminium foam core measuring 1.5 mm thick had the 7.4KN flexural strength.

Key words: Glass, Fibre, Aluminium foam, Mechanical Properties, Tensile, Impact, Flexural, Hardness

1. Introduction

Sandwich structures are now primarily used in a variety of industries, including transportation, military, and automotive, because of their superior mechanical qualities. The majority of sandwich constructions used nowadays are made of polymeric foams like poly vinyl chloride and poly urethane. In recent years, more metal foams have been created to take the role of polymer foams. These metal foams are utilised in heat exchangers, automotive dampers, structural applications, and fire-retardant materials [1]. Aluminium foams are much lighter than dense metal since they are 95% porous. This aluminium foam is frequently used in the automotive industry for things like body panels and bumpers. In the aircraft industry, aluminium foam composites are also used for floor panels, protective devices, and engine mount brackets [2].

Depending on the intended use of the composites, fibres can be constructed of glass, carbon, aramid, kevlar, or other materials. Fibre reinforced polymer (FRP) composites are made of fibres with polymer matrix reinforcement. GFRP has less brittle characteristics and is less expensive [3,] despite having a mechanical strength that is substantially lower than that of carbon fibre reinforced plastic (CFRP) [2]. The stability of the structure depends on the foam core and glass fibre skins effectively bonding in order to provide suitable mechanical characteristics. The adhesion surfaces and curing conditions are what determine how well the composites can adhere [4]. Aluminium sandwich panels with a foam core and metal face sheets have frequently been made using epoxy as an adhesive [5].

Numerous researchers created composites with an aluminium foam core between two fibrous elements, like glass and carbon fibre. For the purpose of improving their properties, mechanical properties including tensile, impact, and compression are used. The current study's objective is to hand-layup an aluminium foam core sandwiched between glass fibre epoxy laminate with varying thicknesses (0.5, 1 and 1.5 mm). Investigating the constructed samples' tensile and impact strength. With the constituents contained in the sandwich composites, a research gap was found in accurately controlling the density of the sandwich composites.

Epoxy and aluminium foams used in hybrid sandwich composite materials are the subject of few research projects. There are fewer sandwich materials investigated, particularly when constructing foams with varying orientations (number of layers) and thicknesses of foam. The machining characteristics of these sandwich composite materials haven't been the subject of a lot of study.

The objectives of this current works is as follows

- To prepare aluminium foam and glass fibre mats.
- Fabrication by employing a novel class of sandwich composites by epoxy and reinforcing aluminium foam with 3 number of layers and three different thicknesses (0.5, 1 & 1.5 mm) through hand layup moulding technique.
- This is to evaluate the effects of the aluminium foam with number of 3 layers and three different thicknesses (0.5, 1 & 1.5 mm) on the mechanical properties of aluminium sandwich composites by tensile, flexural, impact, and hardness tests.
- This is to understand the characteristics of the microstructure of aluminium sandwich composites using SEM.

2.1. Materials and Methods

2.1. Materials

The aluminium foam core was purchased from M/S. Bhaseer Traders in Ambathur, Chennai, Tamil Nadu, India, in three different thicknesses (0.5, 1 and 1.5 mm). From Hayel Aerospace Ltd, Poonamalee, Chennai, Tamil Nadu, India, we obtained e-glass woven fibre, epoxy resin, and hardner. The glass fibre and aluminium foam core were constructed using a hand layup process. The dimensions of the samples were (300 X 300 X 6.3) mm [6]. Table 1 displays the various composite designations made up of a glass fibre epoxy laminate sandwiched between an aluminium foam core with varying thicknesses (0.5, 1 and 1.5 mm). The created composite is depicted in Figure 1.

The materials listed below were utilized to fabricate the sandwich hybrid composites:

1. Aluminium foam

2. Glass fibre

3. Epoxy resin

4. Hardener (HY951)

Fig.1. a) Aluminium foam, b) Glass fibre, c) Epoxy resin d) Hardener (HY951)

Table 1. Sandwich composite designations of aluminium foam core with different thicknesses (0.5, 1 & 1.5 mm)

S.No	Sample	Composite designation	Matrix Epoxy Resin - EP	Reinforcement GF- Glass Fibre Al- Aluminium Foam
1.	S1	EP GF without Al foam	EP	GF
2.	S2	EP GF 0.5 Al foam	EP	GF + 0.5 Al
3.	S3	EP GF 1 Al foam	EP	GF + 1 Al

4.	S4	EP GF 1.5 Al foam	EP	GF + 1.5 Al

2.2. FABRICATION OF HYBRID SANDWICH COMPOSITE

The hand layup process was used for fabricating the aluminium foam core sandwiched with glass fibre. Samples were fabricated with a size of (300 X 300 X 6.3) mm. The silicon rubber used to build the mould for this manual lay-up fabrication method. Aluminium rigid plates encircled the mold's base (Park H, 2019). The strong aluminium plate was positioned above the mould. Glass fibre is used as a reinforced fibre in the current experiment, along with an epoxy resin matrix and an aluminium (AA6061-T6) sandwich plate. Aluminium 6061 has a better quality than other grades of aluminium. Epoxy has better bonding property than any other polymers because of the presence of ether groups and hydroxyl which improves the adhesion and better load transfer between the different components of the matrix. The three different thicknesses of the aluminium foam panels used for this investigation are 0.5, 1 & 1.5 mm, with a glass fibre skin produced during the manufacturing process. Epoxy resin and hardener combinations are first added to the mould. After rolling out the thinner on the mould surface, glass fibres were added to the resin mixture. With the aid of rollers, foam cores were infused into the resin. Typically, resins are impregnated using steel rollers. Nip-rollers are used to improve impregnation. The mixture of hardener and resins is then smoothed over the surface of the glass fibre. Next, the foam was inserted into the mold. The next hardener and resin are polished above aluminium foam. Now, the glass fibre is placed above the resin. A known weight of 12 kg was placed over the mould to give the sandwich composite 24 hours to cure. Similar sandwich composites made of three layers of aluminium foam were also created. The prepared 4 samples were indexed as $S_1 – S_4$. Table 1 shows the various composite designations of aluminium foam core with different thicknesses (0.5, 1 & 1.5 mm) and three different layers sandwiched with glass fibre epoxy laminate. Figure 2 shows the fabricated aluminium sandwich composite samples. The test specimens are created in accordance with ASTM guidelines.

Fig. 2 The fabricated aluminium sandwich composite samples

2.3. Composites Testing

In order to determine its mechanical properties, samples of manufactured composites are subjected to a number of tests, such as the tensile test, impact test, and flexural test. Five composite specimens are used to get the results' average values for each category.

2.3.1 Tensile Test

Tensile testing are carried out using a Universal Testing Machine (FIE manufacture India). During the experiment, the sandwich composite was subjected to a single type of load. As indicated in Figure 3, composite samples are appropriately sized for the tension test in accordance with the ASTM: D 638 standard. The maximum tension that may be applied to a test sample without causing it to break is known as the tensile strength. Both ends of the object are subjected to a tensile load during the test. The measurement device is used to apply the tensile load to the test item until it breaks. Calculating the tensile force as the gauge length increases.

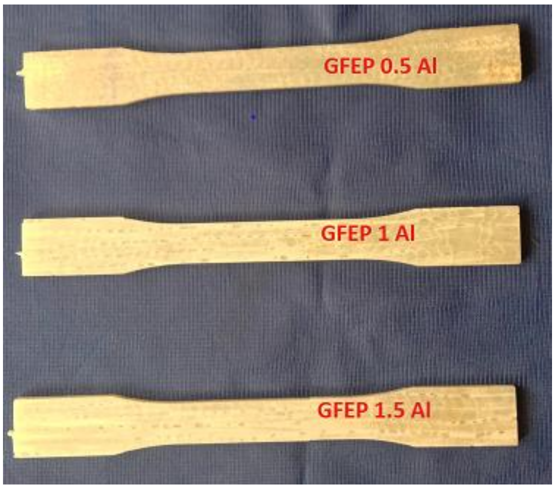

Fig.3 Tensile Test hybrid composite Samples

2.3.2 Flexural Test

Flexural strength is a material's capacity to withstand deformation when it is stressed. To determine how strong the shear strength between the layers is, the test sample is subjected to the short beam shear test. The ineffectiveness of the interlaminar shear notion is demonstrated using a three-point flexure test. Megapascals (MPa) is the unit of measurement for bending strength. The three-point static flexural test is the most often used technique. The UTM is used to conduct this test. Bending tests were required for materials that met the ASTM: D 790 grade. An ASTM object for the flexural test is shown in Figure 4.

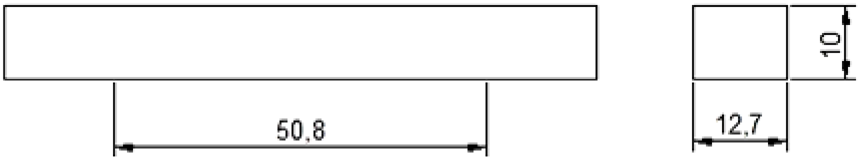

Fig. 4 Schematic diagram of the flexural test

2.3.3 Impact Test

The ASTM recommendation for the Charpy impact test is depicted in Figure 5. The impact test is fully explained in ASTM: D 256. Impact analyses are crucial for deciding the sandwich component's quality.

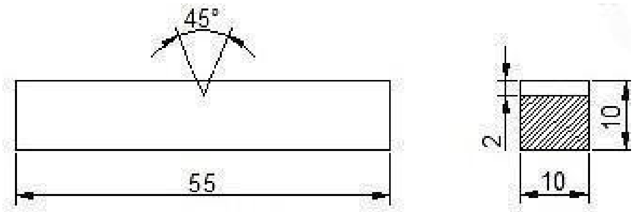

Fig.5 Schematic diagram of the impact test

2.3.4 Hardness Test

The degree to which a substance resists dents serves as a measure of its hardness. When a load is given to a substance, toughness and hardness are diametrically opposed to one another. The Rockwell 574 hardness machine RAB 250 SCNO: SN 7078 uses Shore A and Shore C durometers to measure each instance's hardness, as shown in Figure 6. Higher values on the scale imply a harder substance, which is less likely to dent. The industry standard for conducting hardness tests is ASTM D2240. A ball indenter with a 10 mm diameter was subjected to a force of 100 N/mm. Five copies of each measurement were made to acquire the average value across all measurements.

Fig. 6 Hardness testing equipment

2.3.5 Scanning Electron Microscopy (SEM)

SEM (JEOL JSM 5610 LV) is used by the Department of Manufacturing at Annamalai University in Annamalai Nagar, Tamil Nadu, India, to examine the surface morphologies of sandwich composites that have undergone tensile fracture. To boost conductivity, the composites are given a thorough cleaning, allowed to dry naturally, and then given a platinum coating. 15 kV is used for SEM observation.

3. Results and Discussion

3.1 Mechanical properties of hybrid composites

Figures 7, 9, 10 & 11 show the tensile, flexural, impact strengths and hardness of composites made of Aluminium foam / glass fiber reinforced polymer composite.

3.1.1 Tensile Properties

A sandwich made of glass fiber-reinforced aluminium foam composite is built, and the shape and dimensions are subsequently saw-cut to fit the requirements. The composite specimen is polished along its edge using an emery sheet. Figure 7 shows the results of the analysis of the tensile strength of the composite construction for the various specimens. The highest tensile strength is reached at 1.5 mm of double aluminium foam and was 140.7 MPa, up from 80.54 MPa for the layer without aluminium foam. By adding layers of aluminium foam to the sandwich composite structure, the tensile strength of the structure is improved, as indicated by these values. Although there may be some differences based on the precise composition and arrangement of the foam, the tensile strength generally increases with the thickness of the foam and the number of layers of aluminium foam added (Russell et al. 2013).

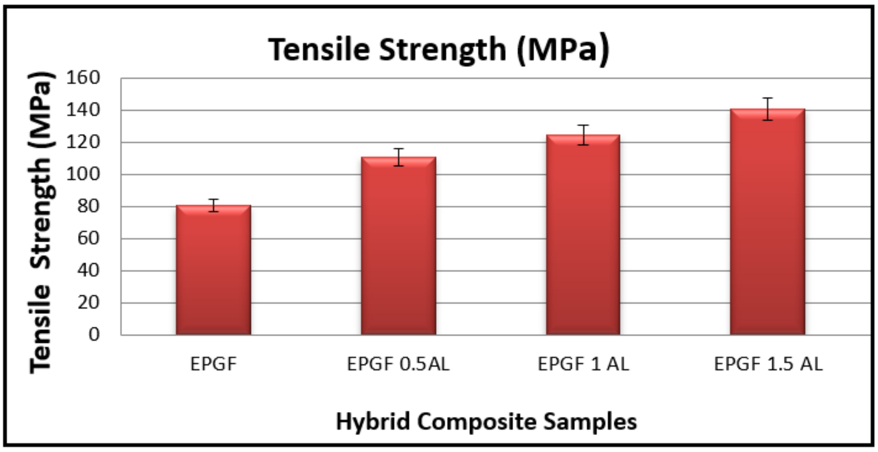

Fig. 7 Tensile strength obtained for Sandwich Composites

3.1.2 Tensile Fracture Surface Morphology Evaluation of Untreated aluminium sandwich Composites

The dispersion of glass fibres and aluminium foam in the matrix is validated by the tensile cracked zone of the sandwich composites made of aluminium foam illustrated in Figure 8. Aluminium foam took out glass fibres and aluminium foam when it fractured in the matrix, showing brittle fracture. Additionally, the frictional process' physics demonstrated energy loss. Figure 8(a), in which there is no aluminium foam, provides proof that a one-layer glass fibre mat exists. There are porous features visible in SEM micrographs. It demonstrates the great compatibility of the glass fibre and matrix due to the large porosity that permits the trapping of air that percolates inside the composite or on the surface (Asaithambi et al. 2014). An excellent correlation between the filled aluminium foam, glass fibre, and matrix was discovered in Figure 8(b). The aluminium foam is effectively contained and encased by the matrix, and there was good adhesion between the aluminium foam, glass fibre, and epoxy. Additionally, there were no obvious interfaces between the aluminium foam and epoxy. This results in an increase in the tensile characteristics of sandwich composites made of double layers of aluminium foam that are 1.5 mm thick.

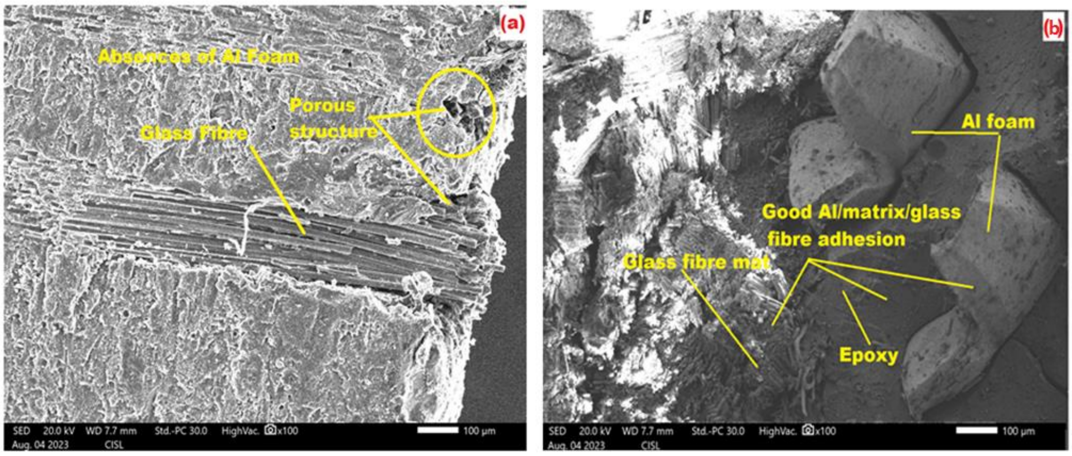

Fig. 8 Photomicrographs of Tensile Composite Fracture Surfaces (a) Pure 1 layers of Glass fibre and (b) Double Aluminum foam 1.5 mm

3.1.3 Flexural Properties

The ability of a material to resist deformation under force is known as flexural strength, a mechanical property of brittle materials also known as the modulus of rupture, bend strength, or fracture strength. According to Sawicki et al. (2017), the flexural test for sandwich structures can be performed in line with ASTM standards ASTM: D 790 to determine the static behaviour of the sandwich sample. As illustrated in Figure 9, the flexural strength increased from 2.4 KN for the layer of foam without aluminium to a maximum of 7.4 KN for 1.5 mm of double aluminium foam.

The aluminium foam was effectively contained and encased by the matrix, and there was good adhesion between the aluminium foam, glass fibre, and epoxy. Additionally, there were no obvious interfaces between the aluminium foam and epoxy (Carrillo and Cantwell, 2007). Due to this, double layer sandwich composites made of aluminium foam with a thickness of 1.5 mm experience an increase in their flexural properties that are equal to their tensile capabilities.

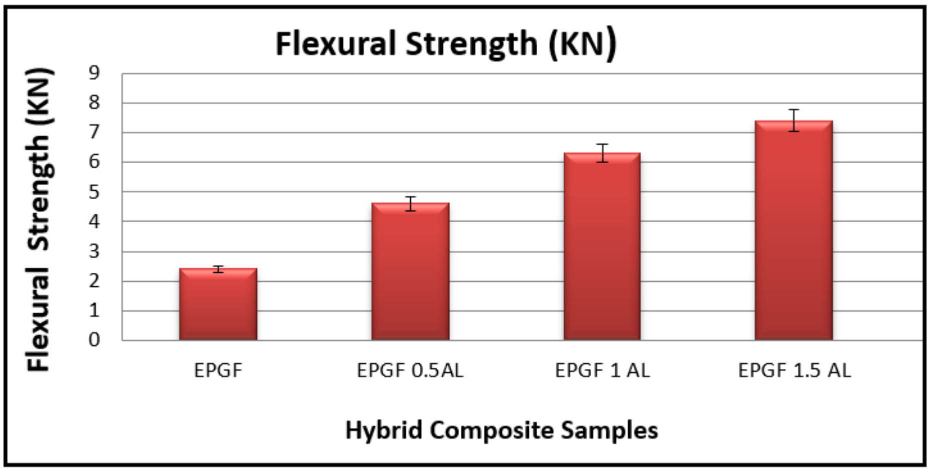

Fig. 9 Flexural strength obtained for Sandwich Composites

3.1.4 Impact Strength

Figure 10 shows how the impact strengths of sandwich composites are impacted by the loading of aluminium foam. The highest impact strengths at double-layer 1.5-mm-thick foam follow a pattern that is similar to that of tensile and flexural strength and are 12.62 J/m2. In comparison to the tensile strength of the sandwich composites, it displayed lower values. This increase in impact resistance demonstrates the possible benefit of the aluminium foam. Indicators of the sandwich composites' ability to absorb energy include impact strength. Strong interfacial adhesion between the foam and matrix is the cause of this (Kiratisaevee and Cantwell, 2004). Additionally, it depends on the type of foam, its thickness, and the type of polymer (Liu et al. 2017).

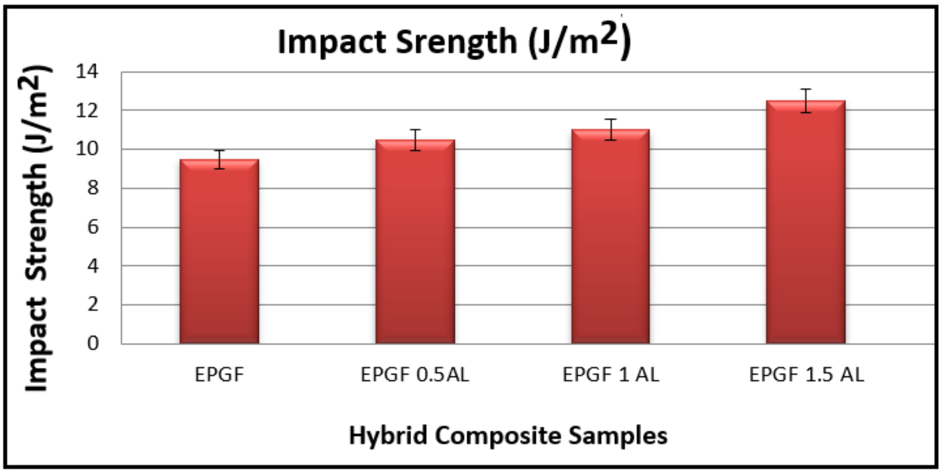

Fig. 10 Impact Strength obtained for Sandwich Composites

3.1.5 Hardness

Figure 11 shows that when the thickness of the aluminium foam within the sandwich composite's epoxy matrix increases, the hardness of the composite falls. Compared to tensile and flexural strength, this finding shows a different trend. According to two studies (Qi et al. 2017 and Kumar et al. 2021) the sample without aluminium foam has a maximum hardness value of 268 whereas a three layer, 0.5 mm thick foam has a maximum hardness value of 248. It's important to keep in mind that these relationships are not always linear and that sometimes an increase in tensile strength does not translate into an increase in hardness.

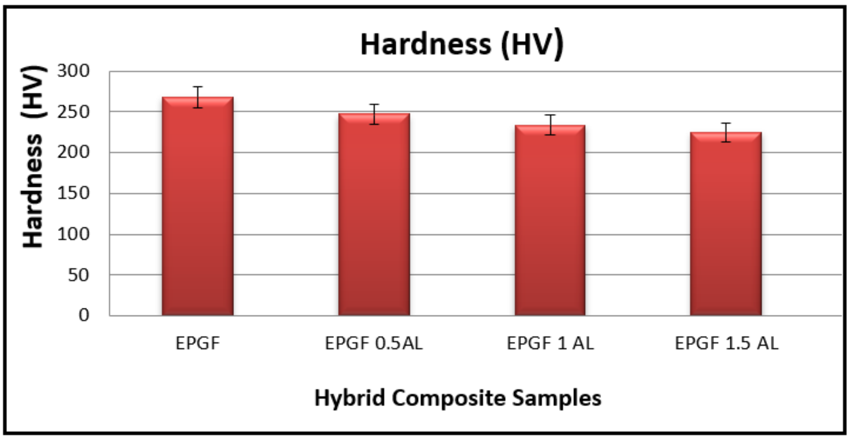

Fig. 11 Hardness strength obtained for Sandwich Composites

4 Conclusion

- The different combinations of aluminium sandwich composites have been successfully fabricated. The hand layup method has been used to blend epoxy resin with layers of foam (triple) and three different aluminium foam (AA6061-T6) thicknesses (0.5, 1 and 1.5 mm).
- The mechanical properties such as tensile, flexural, impact and hardness strength of aluminium sandwich composites have been studied, and the maximum values are found to be: 140.7 MPa, 7.4KN, 12.5 J/m^2 and 253 HV.
- The aluminum foam was well trapped and wrapped by the matrix, good adhesion between aluminum foam / glass fibre / epoxy and the interfaces between the aluminum foam and epoxy were not apparent. This causes an increment in the tensile properties of the double layer aluminum foam (1.5 mm thickness) sandwich composites.

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