Design and analysis of hybrid composite using the finite element method

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Abstract. Hybrid composites are those composites that have a combination of two or more reinforcement fibres and could be used for the superior properties that are unachievable by any monolithic material. The objective of the present study is to design the aluminium-epoxy hybrid composite of varying number of fiber strands. The fibres are kept in 0°/90° orientation and the width of the fibre strands is varied in the analysis keeping the length and the height of the matrix constant. A 100 N load is applied on the hybrid composite block and the corresponding mechanical behaviour along with the material properties is obtained using finite element analysis (FEA). The results observed in the 0°/90° orientation of the hybrid composite include the assembly stress distribution and assembly displacement. The parameters are varied to obtain the corresponding set of results and the optimized structure is suggested using FEA.

1. Introduction
Nowadays Aluminium hybrid composites have been subject of permanent interest of various industries such as automobile and aerospace industries. Composite materials provide various mechanical advantages to meet the demands of growing technological advances [1],[2]. It favours lower noise, lower fuel consumption, that are unachievable by any monolithic materials. Composite materials are being widely used by human civilization since ancient times but it became popular during the growth of industries in the mid-19th century. In a generalised manner, the composites are comprised of two or more phases named as (a) matrix and (b) reinforcement [1]. It is a material consisting of two or more chemically and physically distinct parts which when stacked up and arranged, shows unique properties. The use of composite material limits due to their high cost and difficult manufacturing.

Hybrid composite is one of the solutions for the limiting factors, its structural designs and ease of manufacturing has led its way to research studies [2]. There are several design varieties of composites, such as use of fibre reinforced composites, carbon fibre reinforced polymers (CFRP), Glass Reinforced Aluminium (GLARE) and Fibre Metal Laminates (FML) which hold the properties of high strength-to-weight and high stiffness-to-weight ratios that are comparable to aluminium metal alloys [3]. The composites are manufactured by preparing layup that consists of a fibre matrix with a layer of epoxy resin bonded to the surfaces [4]. The prepreg layer was then adhered with aluminium sheets on its either sides. It has been found that the density, hardness, tensile behaviour and fracture toughness of these aluminium composites are higher-up compared to other type of composites [5]. These composites demonstrate high specific modulus while it has cognitively low values of strength, strain to failure and impact resistance [6]. Due to its lightweight property aluminium composites has found its
way into the manufacturing of rockets and spacecraft [7]. It has been found that some of the metal matrix composites designed which are used in the aircraft industries suffer from issues due to lightning. The electrical discharge produced due to thunderstorm causes severe damage to airplane materials with one lightning strike every 1500-3000h [8]. The several authors have studied and analysed wing of an aircraft using Carbon fiber reinforced polymer (CRFP), Glass fiber reinforced polymer (GRFP) and compare with Al alloy to find suitable material for wing [9]. Epoxy/carbon fibre composites has been a suitable option to reduce the damages due to lightning. Most of the metal matrix composites are formed of aluminium, cobalt, iron, oxides, carbides, or metallic alloys [10]. When compared to all the metal matrix composites, it has been found that aluminium has been well suited for industries like aeronautics and automobiles due to its lightweight. Reduction of aluminium composites weight has been a part of highly concentrated research, by using epoxy/carbon fibre matrix with aluminium metal has been a part of research and development of hybrid composites which can meet the need of lightweight materials [11][12].

In this study, the hybrid composite of aluminium-epoxy with woven E glass fibre matrix is taken into account [12]. The development of long strands of continuous fibres and using them in a form of a woven matrix has been favourable for development of mechanical properties like higher stiffness and efficient crack bridging whilst to lower crack growth rate leading to fatigue resistance [12-16] The E glass fibre strands are arranged in a 0/90 orientation forming a woven structure, on which liquid epoxy is poured. The epoxy layer is bonded with the woven matrix of E-Glass fibre [17]. The epoxy and glass fibre sheet are sandwiched between two aluminium sheets. The thickness and the block size of the overall structure is kept constant while the number of strands is varied. The design is then analysed using finite element analysis (FEA) on ABAQUS. The simulation data obtained from the FEA demonstrated the characteristics of the hybrid composite under the influence of stress, bending, shear and compression [18]. In this work, only the role of the woven structure on the stress distribution in a multi-layered hybrid composite is studied using finite element method, and that is the novelty of the work. The novelty of the work is that the effect of strand width and the gap between the strands in the fibre epoxy structure between the aluminium plates on the stress distribution, keeping the volume fraction and directions same, are studied.

2. Methodology

2.1. Material selection and properties

Two different aluminium grades typically used in industries which are Aluminium-2024 and Aluminium-2020, out of which aluminium-2024 is best suited as a composite material [3]. Aluminium alloys are highly recommended for aerospace and automobile industries because of its light weight, environmental resistance and useful mechanical properties like specific modulus, strength, toughness and impact resistance [4-5]. For the study of hybrid aluminium composite, aluminium alloy-2024 is selected as a material for the composite. Additionally, the aluminium alloy sheet is glued to the sheet of woven E-Glass fibre bonded with epoxy resin. The thickness of the aluminium sheet is considered as 1mm with a constant block size (9mm x 9mm). The group of E-glass fibre strands have a thickness of 0.4mm with a length of 9mm whilst the width of the strands is varied based on the number of strands considered for a 9mm x 9mm composite block size. The E-glass fibre strands are woven in a criss-cross pattern with an orientation of 0/90 on which the liquid epoxy resin is poured and is cured. The total thickness of the woven E-glass fibre and epoxy resin sheet is considered as 0. 8mm. The arrangement of different materials in the hybrid composite is shown in figure 1. The material specifications are listed in table 1.
2.2. Design of hybrid composite

The best approach for the design of this hybrid composite was by using design software and simulation using finite element analysis (FEA) method. There are several other approaches for the composition of structural design. In order to design the composite material systematic step by step processes are done. Using design software CATIA-V5, the Aluminium sheet is designed with specification (9mm x 9mm x 1mm). The E-glass fibre strands are made with a dimensional specification (9mm x 2mm x 0.4mm) for a (3 x 3) strands group with a gap of 1.5mm between each strand. Epoxy resin is to be poured over the structure to fill up the voids between the woven E-glass fibre strands. The woven glass fibre and the epoxy resin structures are assembled to form the prepreg layer of specification (9mm x 9mm x 0.8mm). This structure is further compiled with the aluminium sheets to make a 3/2 layered arrangement i.e. 3 layers of aluminium and 2 layers of epoxy resin sheet arranged in an alternative manner. This hybrid composite is named as C3 in the present work. Similarly, for (4 x 4) strands group (9mm x 1.5mm x 0.4) with a gap of 1mm between each strand and poured with epoxy and placed between Al plates as before is named a C4. The design is finalized with respect to industrial standards and the design is used further for the simulation with FEA method using Abaqus package. A typical 4x4 strand is shown in figure 2. The required design data are listed in

| Structures          | Material Specifications       | Young’s Modulus (Mpa) | Poisson’s ratio | Ref           |
|---------------------|-------------------------------|-----------------------|----------------|---------------|
| Aluminium Blocks    | Aluminium alloy-2024          | 73090                 | 0.33           | [25]          |
| Strands Fibre       | E-glass fibre                 | 72300                 | 0.35           | Industrial standard considered |
| Resin Sheet         | Epoxy Resin                  | 3500                  | 0.33           | [26]          |

Figure 1. The layered structure of the hybrid composite.
Table 2 and Table 3. It may be noted here that for hybrid composites the volume fraction of fibre in the fibre/epoxy composite is same in both cases.

**Table 2.** Dimensions of the aluminium block and epoxy resin sheet in the hybrid composite structure.

| Structures      | Length (mm) | Breadth (mm) | Thickness (mm) |
|-----------------|-------------|--------------|----------------|
| Aluminium Block | 9.0         | 9.0          | 1.0            |
| Epoxy Resin     | 9.0         | 9.0          | 0.2            |

![Diagram of woven fibres in a 4x4 strand](image)

**Figure 2.** The woven fibres in a 4x4 strand.

2.3. **Finite Element analysis of the Hybrid composite**

The simulation for the hybrid composite is done by using the FEA method on ABAQUS package. The design data received from the design software (CATIA) is imported in ABAQUS in a step by step manner, starting from the bottom layer of Aluminium. The material properties are assigned to each layer of the composite i.e. aluminium layer is assigned with Aluminium alloy-2024 series, similarly E-glass fibre is selected for the woven strands and the voids between the strands were filled with the epoxy resin. The material specifications of the following materials are mentioned in Table 1. Additionally, after assigning the material properties the design of each part is meshed by using sweep mesh and hex mesh. Then the parts of the composite are assembled in the same manner as it is assembled in the design software using parent and child method. Further the design is bonded using the tie constraint method in ABAQUS where each surface is tied with the adjacent other starting from the aluminium sheet at the bottom.

**Table 3.** Dimensions considered for designing the glass fibre strands in the hybrid composite structure.

| Number of Strands | Length of strands (mm) | Width of strands (mm) | Gap between strands (mm) | Thickness of strand (mm) | Volume fraction of fibre in epoxy composite |
|-------------------|------------------------|-----------------------|--------------------------|--------------------------|-------------------------------------------|
| C3                | 9.0                    | 2.0                   | 1.5                      | 0.4                      | 0.67                                      |
| C4                | 9.0                    | 1.5                   | 1.0                      | 0.4                      | 0.67                                      |
3. Results and discussions

A series of simulation for various loading conditions keeping the load of 100N constant were performed on the designed hybrid composite using the Abaqus package. The maximum stress and strain values were recorded for different loading conditions.

3.1 Bending

Bending also termed as flexure define the behaviour of a structural element exposed to an external load applied perpendicularly to a longitudinal axis of the element [23]. In composite design analysis of bending, stiffness is necessary, and it helps the designer to check whether the design is feasible or not. In this bending test a vertical load of 100 N is applied along a line on the top surface and placing two supports at the bottom of the block making the structure similar to three-point bending test for a simply supported beam. The top surface undergoes compression whereas the opposite side is subjected to tension. With the deformation tending to the upper side [24]. The structural analysis is done, and the results are observed for both C3 and C4 hybrid composites. The stress and strain values obtained from the FE analysis were further plotted in Stress vs Strain graph shown in figure 3 for C3 and C4. The simulated data for assembly stress distribution and assembly displacement is shown in figure 4 and figure 5 for C3 and C4 respectively. It may be noted here that the fabric layers were embedded into Epoxy Resin and all other layers and are assembled as a single unit. After analysis we can view stress and strain distribution over the whole structure defined as “Assembly stress distribution” and “Assembly displacement” respectively. The data plotted provide us with a straight line that depicts the stress-strain relationship of the particular hybrid composite till its yield point. It is observed that the C3 has shown a better flexural modulus than the C4 which is evident from the slope obtained from the corresponding graphs.

![Stress Vs Strain characteristics of the hybrid composite under bending load.](image)

**Figure 3.** Stress Vs Strain characteristics of the hybrid composite under bending load.
3.2 Compression

Compression is a balanced inward force of pressure or load which is given against an object at different points, surface or area to analyse the result of deflection occurred [11]. The analysis of compression force on the composite design is done by keeping the base fixed and by providing a compressive force of 100N on its top surface. The outcome of the FE simulation provided us with assembly stress distribution and assembly displacement for C3 and C4 hybrid composites. The stress-strain value thus obtained are plotted in a stress vs strain graph as shown in figure 6. The simulation model is shown in figure 7 and figure 8 respectively. A straight line is obtained in the graph representing the mechanical properties of each hybrid composite till their corresponding yield point. When the slopes of the lines are compared, an increase in strength is detected in the case of C4 in comparison to C3. This reflects the increase in strength with increase in number of strand count which in turn indicates that the rise of fiber content in the hybrid composite has enhanced the energy absorption capacity.
Figure 6. Stress Vs Strain characteristics of the hybrid composite under compressive load.

Figure 7. (a) Stress Distribution and (b) Assembly Displacement during compression in case of C3 composite.

Figure 8. (a) Stress Distribution and (b) Assembly Displacement during compression in case of C4 composite.
3.3 Cantilever

A cantilever is a rigid structural element, such as a beam or a plate, anchored at one end to a (usually vertical) support from which it protrudes; this connection could also be perpendicular to a flat, vertical surface such as a wall. When subjected to a structural load, the cantilever carries the load to the support where it is forced against by a moment and shear stress [22]. The analysis of applying a cantilever force is done to compare the feasibility of composite materials with various changes in the epoxy resin and E-glass fibre part. A uniformly distributed load of 100N is applied to the top surface of the cantilever beam keeping the one side fixed in the planer cross-section of the composite body and the resulting assembly stress distribution and assembly displacement are obtained by FEA for both C3 and C4 hybrid composites. The results extracted from the simulation are then plotted as stress vs strain curve shown in figure9, figure10 and figure 11 shows the result of the simulation done on the overall designed hybrid composite structure. Subsequently, a straight line is obtained up to the yield point of the corresponding composite structures. The stress-strain curve of both the composite structures is then compared with each other. It is observed that the slope defining the modulus of the structure varies significantly as 1216285 psi for C3 while 1036700 psi for C4. It is visible that the hybrid composite C3 shows a higher value of elastic modulus and hence possesses greater strength as compared to the hybrid composite C4. One plausible explanation for this phenomenon is that the change in the width of each strand impose significant changes in the mechanical properties of the overall structure of the hybrid composite. As the width of each glass fibre strand reduces from 2mm in C3 to 1.5mm in C4, there has been a reduction in the elastic modulus of the overall hybrid composite structure which indicates the reduction in strength of the overall structure.

![Stress Vs Strain characteristics of the hybrid composite under cantilever force.](image)

**Figure 9.** Stress Vs Strain characteristics of the hybrid composite under cantilever force.
Figure 10. (a) Stress Distribution and (b) Assembly Displacement under cantilever force in case of C3 composite.

Figure 11. (a) Stress Distribution and (b) Assembly Displacement under cantilever force in case of C4 composite.

Figure 12 and Figure 13 represent the comparison between the maximum stress and maximum strain values for C3 and C4 hybrid composites under the various loading conditions. It is evident from the figures that the maximum stress generated due to three different types of loading are lower for C3 (Figure 12), and this phenomenon is most significant in case of compression. Similarly, the maximum displacement is also less for C3 (Figure 13). The difference is most prominent in compression as before. This shows that wider strands of fibres are better for stress distribution. In such condition C3, though having same volume fraction of all the constituents, shall have better load bearing capacity compared to C4, due to its favourable fibre strands.
4. Conclusion
The mechanical properties of the designed hybrid composite are analysed through stress-strain graph by varying strand counts. It is evident from detailed finite element analysis that the variation in number of E-glass fibre strands significantly influence the strength of the hybrid composite under the action of various loading conditions, e.g. bending, compression and cantilever. Though the volume fraction and direction of the fibres are exactly same for both the cases (C3 and C4), but the stress distribution varies quite significantly only due to strand thickness.

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