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Experimental And Numerical Analysis of Impact Strength of Fiber Metal Laminates Made of Aluminium with GFRP

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Abstract - The benefits of fiber-reinforced matrix systems and metallic materials are combined in fiber-metal composite technology. The usage of fiber metal laminates is a result of the growing need for lightweight materials. In our work, fiber metal laminates are created utilizing aluminum-6061. Glass fiber that is single, double, or triple layered is bonded using the hand layup process and Epoxy-LY556 and Hardener-HY951. In this work, a single layer, double layer, and triple layer GFRP specimen made of aluminum, glass, and epoxy fiber metal laminate (FML) was created in accordance with ASTM D 7136 standards. A low velocity impact testing equipment was used to examine the impact behavior of specimens made of aluminum, glass, and epoxy fiber metal before experimental findings were obtained. The experimental results demonstrate that the impact strength of the composite will change as the number of GFRP layers increases. Utilizing ANSYS software and the ACP Pre post and Transient Structural Analysis Method, another numerical simulation was carried out. ABACUS analysis was used for material optimization, and the outcomes of the model and optimization were compared in order to validate the suggested numerical model. Due to its strong strength and low density, FML is frequently employed in the aerospace industry and wind turbine blades.

Keywords: FML, Aluminium, GFRP, Resin, Impact Strength, Numerical Analysis.

1. Introduction

The composite materials are used in many engineering applications due to their excellent properties. The sandwich composite materials replace the metals owing to their excellent strength with low weight. Many of the literature deals with the combination of steel or aluminium reinforced with the Glass Fiber Reinforced Polymers materials (GFRP). The carbon fiber finds application in aerospace and related fields. The cost of fabrication is reduced by using sandwich structures. The aluminium and glass fiber are used in order to form a Fiber Metal Laminates (FMLs) and it has excellent qualities such as overall reduced weight, corrosion resistance and environment friendly. The aircraft materials are developed based on fiber metal laminates which needs the improved crack growth properties. Competing materials like advanced aluminium alloys and fiber reinforced composites have potential to increase the cost effectiveness of the structure. Fiber metal laminates have hybrid composite structures based on thin sheets of metal alloys and plies of fiber reinforced polymeric materials. The concept is usually applied to aluminium with aramid and glass fibers, also it is applied to other constituents. Several articles have shown that, FMLs possess both the wonderful impact resistance characteristics of metals and the attractive mechanical properties of fiber reinforced composite materials. Lightweight construction is an everlasting matter in the aviation of automotive industries. Efficient lightweight construction can be achieved by using appropriate materials with their particular merits each in parts with locally varying mechanical requirements. Therefore, an increasing use of material mix constructions is to be expected in the future.

2.1 Objective of Project

Fiber Metal Laminates (FMLs) are advanced composite materials composed of alternating layers of metal sheets and fiber-reinforced polymers. FMLs aim to combine the best properties of metals and fiber-reinforced polymers. They offer high strength-to-weight and stiffness-to-weight ratios, providing excellent performance under various loading conditions. One of the main objectives is to enhance fatigue resistance. FMLs are designed to withstand cyclic loading better than traditional materials, making them ideal for aerospace and other high-stress applications. FMLs aim to reduce the weight of structures while maintaining or improving mechanical performance. This is particularly critical in aerospace applications where weight reduction leads to fuel savings and increased payload capacity.

2.2 Fiber Metal Laminates

Fiber Metal Laminate (FML) composed of several very thin layers of metal (usually aluminium) interspersed with layers of Glass-fiber Pre-preg, bonded together with a matrix such as epoxy. The Uni-directional pre-preg layers may be aligned in different directions to suit predicted stress conditions.

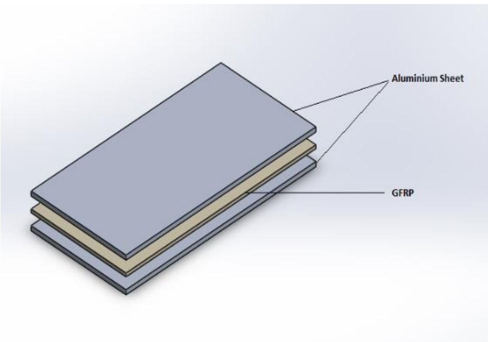

Fig -1: FML Laminates

2.3 6061 Aluminium Alloy

6061 is a precipitation-hardened aluminium alloy, containing magnesium and silicon as its major alloying elements. It has good mechanical properties, exhibits good weld ability, good formability, and is very commonly used in forging. 6061 is an alloy used in the production of extrusion long constant cross section structural shapes produced by pushing metal through a shaped die. 6061 is an alloy that is suitable for deep drawing. This particular alloy is suitable for open die forgings. Automotive parts, ATV parts, and industrial parts are just some of the uses as a forging. Aluminium 6061 can be forged into flat or round bars, rings, blocks, discs and blanks, hollows, and spindles. 6061 can be forged into special and custom shapes other colors. It can be etched to a matte finish, polished to a sparkling brightness or textured to resemble wood and painted.

2.4 Glass Fiber Reinforced Polymer

Fiber Reinforced Polymers (FRP) is a composite material made of a polymer matrix reinforced with fibers. The fibers are usually glass. The resin epoxy is molded with glass fiber in order to produce Glass Fiber Reinforced Polymers (GFRP) with a desired shape. It is also called Fiber Reinforced Polymer. Fiberglass Reinforced Polymers, FRP, is an excellent choice of material for the construction of chemical storage tanks, piping systems, apparatus and other types of industrial process equipment. The FRP material properties beat many conventional materials, such as steel when it comes to chemical and corrosion resistance.

2.5 Epoxy LY556

The Epoxy Resin LY 556 is extensively used as a reinforcing material due to its medium viscosity and chemicals resistivity. Property of this resin can easily be modified within wide limits with the use of fillers and hardeners. The composition of this resin is based on Bisphenol-A which makes it suitable for high-

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performance FRP composite applications such as pultrusion, pressure molding, filament winding and so on. Epoxy resin is known for exceptional mechanical, good fiber impregnation and thermal & dynamic properties. Also, the Epoxy Resin LY556 is having a low tendency to crystallize, that's why it is preferred for aircraft and aerospace adhesives.

2.6 Hardener HY951

Hardeners are almost always necessary to make an epoxy resin useful for its intended purpose. Without a hardener, epoxies do not achieve anywhere near the impressive mechanical and chemical properties that they would with the hardener. The correct type of hardener must be selected to ensure the epoxy mixture will meet the requirements of the application. Research should always be done on both the resin and the hardener to make sure the final epoxy mixture will perform satisfactorily. Common examples of epoxy hardeners are anhydride-based, amine-based, polyamide, aliphatic and cycloaliphatic. Hardeners are used to cure epoxy resins. However, simply adding a hardener to an epoxy resin may not cause the epoxy mixture to cure quickly enough. If this is the case a different hardener may be required. Also, hardeners with certain additives can be used. These hardener additives serve as catalysts that speed up the curing process.

2.7 Open Mold Laminating

Open mold laminating of Fiber Reinforced Plastics is achieved utilizing a single "open" top or bottom semi-rigid concave or convex mold. The desired "finished side" of the part dictates the orientation of the mold. In starting the manufacturing process, the mold is cleaned and prepped with a release agent. If a cosmetic surface finish is required, the mold surface is covered with a gel coat and allowed time to cure. The laminate structure (typically fiberglass) is "loaded" in the mold, combined with a thermoset catalyzed resin, and formed to the shape of the mold. At this stage, the molding process utilized to complete the part varies based on part dynamics and specifications.

2.8 Hand Lay-Up

In the hand lay-up process, the laminate structure, commonly a single continuous strand glass mat, a woven glass mat or an advanced composite mat is manually "hand- laid" in the mold. The catalyzed thermoset resin is introduced, and the materials are formed to fit the mold surface using a "roll-out" process, as well as a number of specialized laminating tools. Additional layers of reinforced mat can be added to key structural points to enhance rigidity and performance. The Hand lay-up process is most effective when molding complex surfaces, and is commonly used in the transportation, recreation, medical, and agricultural markets.

Fig -2: Preparation of Laminates

2.9 Low Velocity Impact Test

A low velocity impact test is a type of mechanical test used to evaluate the impact resistance or toughness of materials, components, or structures under conditions where the impact energy is relatively low. Here are some key points about low velocity impact tests, The test is conducted to assess how a material or structure behaves when subjected to impacts of relatively low energy levels. This is important in various industries to understand the durability and reliability of materials in real-world scenarios where impacts are common. Typically, a low velocity impact test involves dropping a

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weighted object (impactor) from a specified height onto a test specimen. The impact energy is controlled and measured to ensure consistency across tests. Parameters measured during the test may include impact force, absorbed energy, deformation characteristics, and damage assessment of the specimen. There are various standards and protocols that dictate how low velocity impact tests should be conducted, depending on the application and industry. Examples include ASTM standards for different materials and aerospace-specific standards for aircraft components. Low velocity impact tests are widely used in industries such as aerospace, automotive, construction, and sports equipment manufacturing. They help engineers and designers ensure that materials and products can withstand impacts without catastrophic failure. Data from low velocity impact tests are analyzed to determine the impact resistance and toughness of materials. This information is crucial for making decisions about material selection, product design improvements, and safety considerations.

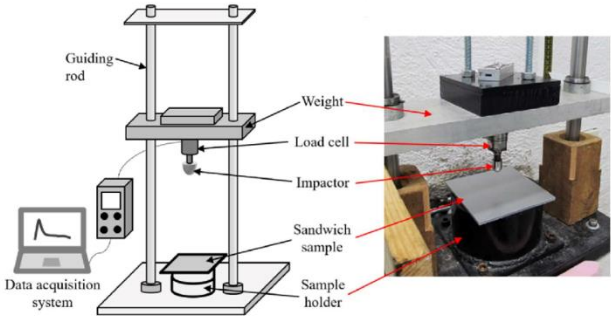

Fig -3: Low Velocity Impact Tester

2.10 Experimental Result

The Experiment was conducted in the low velocity impact testing machine the experimental result of fiber metal laminates with various layers namely Single, Double and Trible layer GFRP was obtained. The fiber metal laminates with single layer GFRP have 6.237 J of strain energy and double layer GFRP have 2.983 J strain energy and also fiber metal laminates with triple layer GFRP have strain energy of 1.572 J. Finally, all the three combinations of fiber metal laminates with experimental result were tabulated and compare the all the three results. To validate the effect of increasing of GFRP Layers in the fiber metal laminates with the help of graphical representation drawn by number of layers and strain energy in J.

Table -1: Experimental Result

Description	**Height of Fall (mm)**	**Total Strain Energy (J)**
Single Layer	300	6.237
Double Layer	300	2.983
Triple Layer	300	1.572

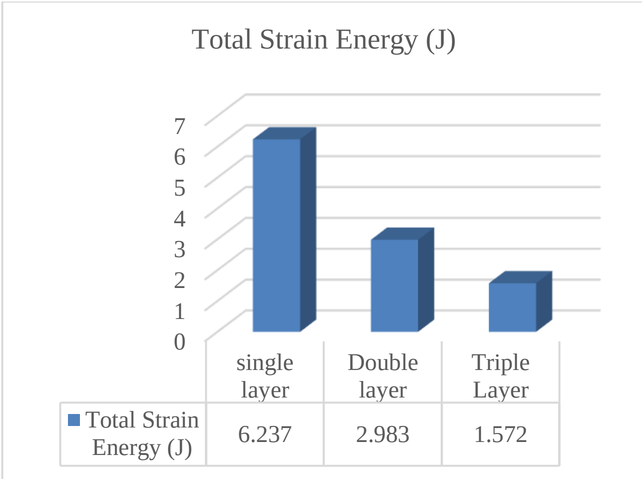

Fig -4: Experimental Result

2.11 Theoretical Deformation

$$\delta = 2\,U / F \qquad \text{in mm.}$$

Table -2: Theoretical Deformation

Description	**Height of Fall (mm)**	**Total Deformation (mm)**
Single Layer	300	**0.09291**
Double Layer	300	**0.0345**
Triple Layer	300	**0.0159**

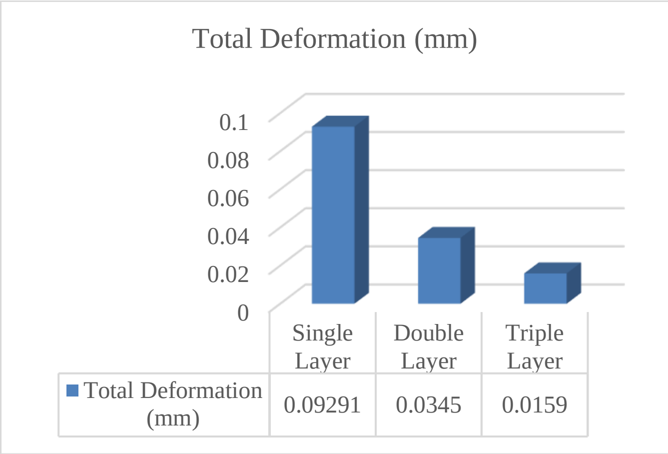

Fig -5: Theoretical Deformation

2.12 Finite Element Simulation

In Engineering data, we have to add the material properties. In that, there are some standard properties of materials is already available in data source. Using the data source, we can take the properties of a material which we need. In our test, we have selected some materials namely Aluminium 6061, GFRP, epoxy resin, Nanocomposite. For the selected material we have added the material properties like tensile strength, density young's modulus, etc. Similarly, we have taken the data for epoxy resin from the data source which is available in software. Create a geometry using the given dimensions. The top layer and bottom layer of that sheet have Aluminium and at the center we are placing a GFRP. Both the materials are attached using the epoxy resin. This is done in the ACP. In this setup, creating the composite layer for FML with different Nanoparticle percentage of the ply materials. This orientation is done using the tool stackups.

2.13 Ansys Schematic Work

The analysis of Impact strength is done through the ANSYS workbench software. This software package is based on the finite element analysis and basic steps involved in this are as follows Preprocessing, Solution Phase and Post processing.

2.14 Results Obtained

Select the solution – right click – insert – Energy – Strain Energy - evaluate all results.

2.14.1 Single Layer

Following post-processing, a single-layer fiber metal laminate product was produced. The numerical analysis yielded a minimum strain energy of 4.645 x e^{-5} J and a maximum strain energy of 7.010 x e^{-9}J in this single layer. The total deformation measured was **0.0425 mm.**

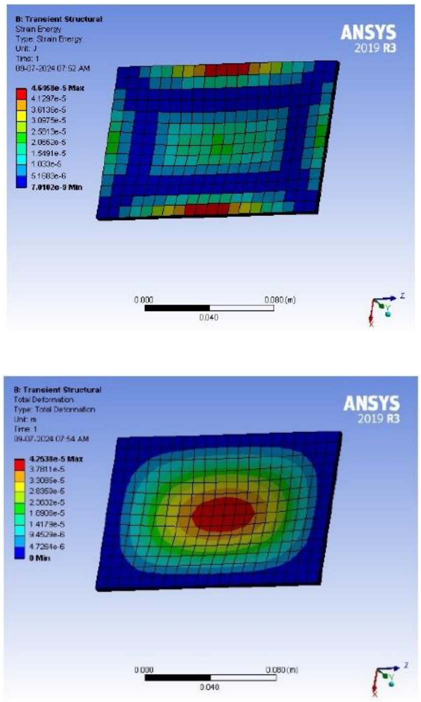

Fig -6: Strain Energy & Deformation

2.14.2 Double Layer

Following post-processing, a double-layer fiber metal laminate product was produced. The numerical analysis yielded a minimum strain energy of 3.914 x e^{-9} J and a maximum strain energy of 1.727 x e^{-5} J in this double layer. The total deformation measured was **0.0191 mm**.

2.14.3 Trible Layer

Following post-processing, a Trible-layer fiber metal laminate product was produced. The numerical analysis yielded a minimum strain energy of 5.404 x e^{-9}

J and a maximum strain energy of 7.972 x e^{-6} J in this single layer. The total deformation measured was **0.0107 mm.**

2.15 Numerical (Ansys) Result

Ultimately, a tabulation and comparison of all three combinations of fiber metal laminates with numerical results was performed. Using a graphical representation based on the number of layers and strain energy in J, to verify the impact of adding more GFRP layers to fiber metal laminates.

Table -3: Numerical (ANSYS) Result

Description	Total Strain Energy in J	Total Deformation in mm
Single Layer	6.573	0.0425
Double Layer	3.053	0.0191
Triple Layer	1.772	0.0107

2.16 Analysis with Abacus

Abacus is typically known for its software in the field of structural analysis and design for civil engineering applications. If you're looking for "Abacus optimization software," it likely refers to software tools designed to optimize structural designs, perform finite element analysis (FEA), or simulate various engineering scenarios. Here are a few points that might clarify what such software could entail. Some versions of Abacus software may include optimization capabilities. These algorithms can automatically adjust design parameters to achieve the best-performing structure based on predefined criteria, such as minimizing material usage while meeting safety standards. Mathematical Optimization**:** These tools can solve complex mathematical problems such as linear programming, nonlinear optimization, integer programming, etc., which can be visualized in terms of the abacus's ability to handle numerical calculations efficiently.

2.17 Result

Select the Jobs – right click – Summit – Running – Completed - evaluate results.

2.17.1 Single Layer

After the fiber metal laminates with GFRP layer were examined, the outcome of the single-layer fiber metal laminates was discovered. The highest deformation in this single layer was measured at **0.0164 mm.**

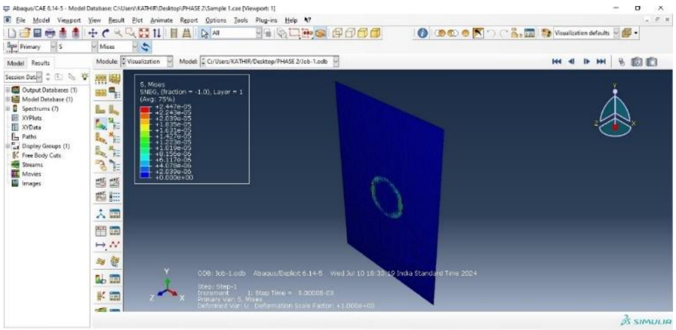

Fig -7: Total Deformation – Single Layer

2.17.2 Double Layer

The fiber metal laminates with GFRP layer were examined, the outcome of the double-layer fiber metal laminates was discovered. The highest deformation in this double layer was measured at **0.0102 mm**.

2.17.3 Trible Layer

The fiber metal laminates with GFRP layer were examined, the outcome of the Trible-layer fiber metal laminates was discovered. The highest deformation in this Trible layer was measured at **0.0070 mm**

Table -4: Numerical (ABACUS) Result

Description	Total Deformation in mm
Single Layer	0.0164
Double Layer	0.0102
Triple Layer	0.0070

2.18 Result and Discussion

In this study, impact tests for FML were used to record strain energy in (J) versus Number of layers, which was then compared with associations found by numerical and experimental studies. In general, the relationship between strain energy in (J) and the number of layers found through experimental and numerical analysis for the studied fiber metal laminates demonstrates their similarity. Here used two different analytic methodologies to gather data from the study and came to the conclusion that the ABACUS analysis closely matched the experimental results.

Table -5: Comparison of Strain Energy

Description	Experimental Result	Numerical Result (ANSYS)
	Total Strain Energy in J	
Single Layer	6.237	6.573
Double Layer	2.983	3.053
Triple Layer	1.572	1.772

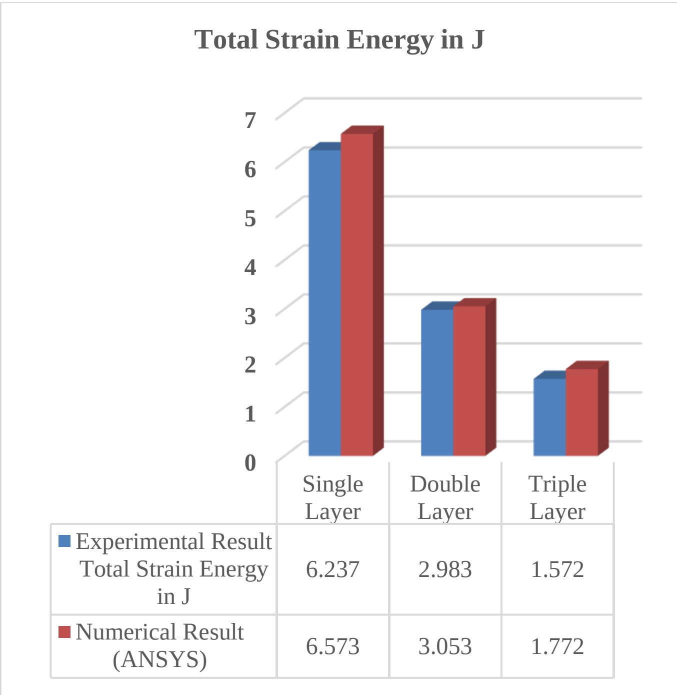

Fig -8: Comparison of Strain Energy

Table -6: Comparison of Total Deformation

Description	Theoretical Deformation	Numerical Result (ANSYS)	Numerical Result (ABACUS)
	Total Deformation in mm		
Single Layer	0.0929	0.0425	0.0164
Double Layer	0.0345	0.0191	0.0102
Triple Layer	0.0159	0.0107	0.0070

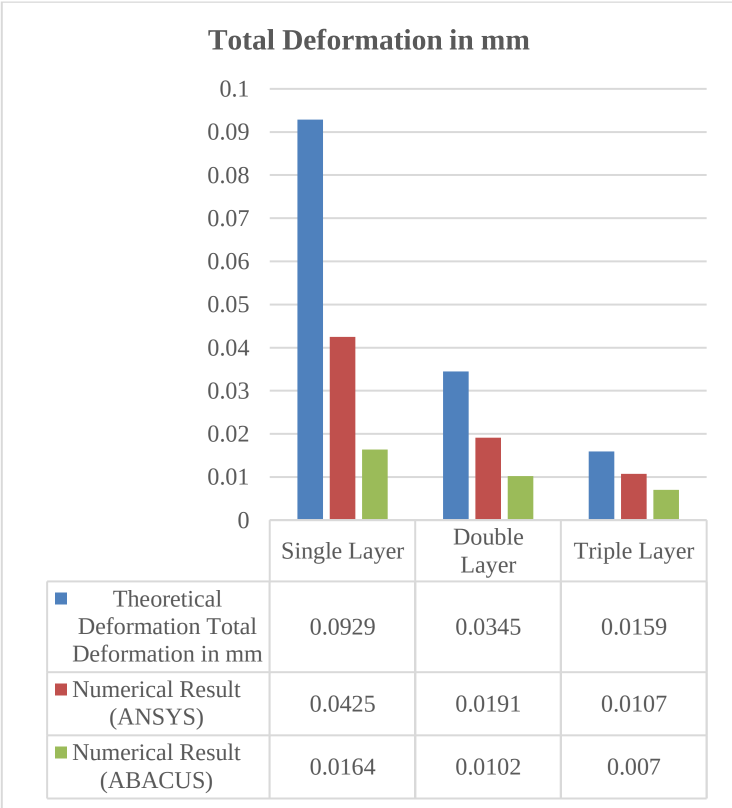

Fig -9: Comparison of Total Deformation

3. Conclusions

This work discusses how FML's impact is characterized in both experimental and numerical evaluations. Aluminum 6061 is used in our work to create fiber metal laminates. Glass fiber that is single, double, or triple layered is bonded using Epoxy LY556 and Hardener HY951 through the hand layup method.

Total Strain energy and Total Deformation of fiber-metal laminates with different layers were determined through both numerical and experimental analysis. This clearly shows that total strain energy increases when GFRP layers are added to fiber metal laminates, and total deformation decreases as GFRP layers are added to fiber metal laminates. Additionally, the results of the numerical analysis performed using the ABACUS software are superior than the ANSYS analysis method. Thus, it can be concluded that the obtained composites will acts as a low cost, lightweight composites to be used for various purpose, on account of their better mechanical and physical characterization.

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