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Research Article

Design and Experimental Study of Composite Beam with Cantilever Loading

Kiran More[#*], Sachin R. Kale[#], Sudhanwa Kulkarni[#], Prakasa Babu. M^,

[#]Department of Mechanical Engineering, Savitribai Phule PuneUniversity,MIT College of Engineering, Pune, India.
^Department of Mechanical Engineering, Savitribai Phule PuneUniversity ,Alard College of Engineering & Management, Pune, India

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Abstract

In daily used cars the fuel used is gasoline i.e. petrol which is depleting with time. So to save this gasoline various research works are being done. In many of the research works the main criteria is to increase the efficiency of the vehicle, by increasing the mileage of the vehicle. The mileage of vehicle is mainly dependent on the power of the engine and weight of the vehicle. This project work focuses on reducing the weight of the vehicle. So the focus of this project is to replace the heavy steel leaf spring by some other material which will reduce the weight and will possess same or more strength than the steel material. In western countries in many of the aircraft applications metal parts are either replaced or repaired by composite materials or fiber metal laminates. For automobiles if we use such materials or laminates instead of metals that will help to reduce the weight as composites possess less mass density than the metals.

Keywords: *Steel Leaf Spring, Composite Material, Fiber Metal laminate, Mass density*

1. Introduction

A composite is a mixture of two or more distinct constituents or phases. However this definition is not sufficient and three other criteria have to be satisfied before a material can be said to be a composite. First, both constituents have to be resent in reasonable proportions, say greater than 5%. Secondly, it is not only when a constituent phases have different properties of the constituents that we have to come to recognize these materials as composites. For example plastics, although they generally contain small quantities of lubricants, ultra violet absorbers, and other constituents for commercial reasons such as economy and ease of processing, do not satisfy either of this criteria and consequently are not classified as composites. Lastly, a man made composite is produced by intimately mixing and combining the constituents by various means. Thus an alloy which has two phases microstructure, which is produced during solidification from a homogeneous melt, or by a subsequent heat treatment whilst a solid, is not normally classified as a composite.

We know that composite have two (or more) chemically distinct phases on a microscopic scale, separated by a distinct interface, and it is important to be able to specify these constituents. The constituent that is continuous and is often but not always, present in the greater quantity of a composite is termed as matrix. The normal view is that it is the properties of the matrix that are improved on incorporating another constituent to produce a composite. A composite may have ceramic, metallic or polymeric matrix.

As a generalization polymer have low strengths and Young's moduli, ceramics are strong , stiff and brittle, and metals have intermediate strengths and moduli together with good ductility's, i.e., they are not brittle. The second constituent is referred to as the reinforcing phase, or reinforcement, as t enhances or reinforces the mechanical properties of the matrix. In most of the cases reinforces is harder, stronger and stiffer than the matrix, although, there are some exceptions; for example, ductile metal reinforcement in a ceramic matrix and rubberlike reinforcement in a brittle polymer matrix.

The geometry of the reinforcing phase is one of the major parameters in determining the effectiveness of the reinforcement; in other words, the mechanical properties of the composites are function of the shape and dimensions of the reinforcement. We usually describe the reinforcement as being either fibrous or particulate. Particulate reinforcements have dimensions that are approximately equal in all directions. The shape of reinforcement particles may be spherical, cubic, platelet or any regular or irregular geometry. The arrangement of the particulate reinforcement may be random or with a preferred orientation, and this characteristic is also use a part of classification scheme.

*Corresponding author: **Kiran More**

In single-layer composites long fibers with high aspect ratios give what are called continuous fiber reinforced composites, whereas discontinuous fiber composites are fabricated using short fibers of low aspect ratio. The frequently encountered preferred orientation in the case of continuous fiber composite is termed unidirectional and corresponding random situation can be approximated to by bidirectional woven reinforcement. Multilayered composites are another category of fiber reinforced composites. These are classified as either laminates or hybrids. Laminates are sheet constructions which are made by staking layers in a specified sequence. A typical laminate may have between 4 to 40 layers and the fiber orientation changes from layer to layer in a regular manner though the thickness of the laminate, e.g., a $0/90^0$ stacking sequence results in a cross ply composite.

Hybrids are usually multilayered composites with mixed fibers and are becoming commonplace. The fibers may be mixed in a ply or layer by layer and these composites are designed to benefit from the different properties of the fibers employed. For example, a mixture of glass and carbon fibers incorporated into a polymer matrix gives a relatively inexpensive composite, owing to the lost of glass fibers, but with mechanical properties enhanced by the excellent stiffness of carbon. Some hybrids have mixture of fibrous and particulate reinforcement.

The fabrication and properties of composites are strongly influenced by the proportions and properties of the matrix and the reinforcement. The proportions can be expressed either via the weight fraction, which is relevant to fabrication, or via the volume fraction which is commonly used in property calculations. Composites materials have fully established themselves as workable engineering materials and are now relatively commonplace around the world particularly for structural purposes.

Fiber Metal Laminates (FML) are the hybrid composite laminates made by stacking the metal layers with Fiber Reinforced Plastic layers. FMLs offers excellent fatigue strength, impact resistance, residual and blunt notch strength, flame resistance, high strength/stiffness and good damage tolerance, etc. The fiber layers act as barriers against corrosion of inner metallic sheets, whereas the metal layers protect fiber layers from picking up moisture. Composite material provides low weight and excellent strength. Following figures shows layup structure of fiber metal laminates;

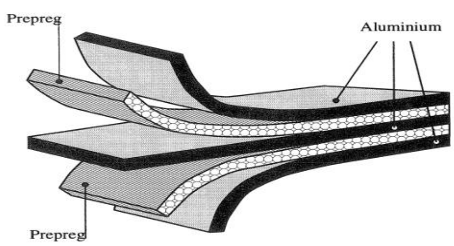

Fig.1 Layup structure of FML

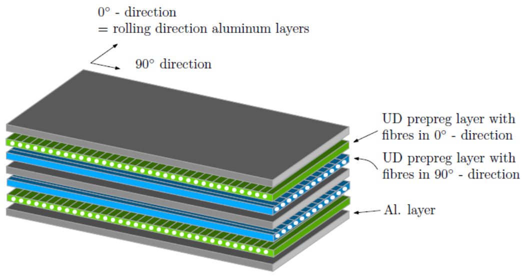

Fig.2 Typical lay-up of a fiber-metal laminate: Glare 3-2/1 laminates

2. Literature review

L Santosh Sreekanth and M Kumaraswamy studied that, cracks induced in the structural elements like high speed machineries, aircrafts and light weight structures composite beams causes serious failure and monitoring of these cracks is essential. The occurrences of these cracks influences the dynamic characteristics like natural frequencies, modes of vibration of structures, buckling loads has been the subject of many investigations. This work studied the effects of various parameters like crack location, crack depth and fibers orientations upon the changes of the buckling loads of the beam using ANSYS. Concluded that buckling load of a cracked composite beam decrease with increase of crack depth for crack at any particular location due to reduction of stiffness. When, angle of fibers increase the values of the buckling loads decrease. This is due to the fact that for 0 degree orientation of fibers, the buckling plane normal to the fibers is of maximum stiffness and for other orientations stiffness is less hence buckling load is less. Buckling loads of two beams in cracked and non cracked conditions decrease with increase in fiber angle. It is clearly understood that rate of change of buckling loads of graphite fiber reinforced polymide is more compared to E-glass fiber reinforced polymide.

K.Veeraswamy and V.VenkataSudheerBabu have worked on Composite Beam for Side Impact Protection of a Car Door. Side impact crashes are dangerous because there is no room for large deformation to protect an occupant from the crash forces. Fuel efficiency, safety and gas regulation of the passenger cars are important issues in contemporary world. The best way to increase the fuel efficiency without sacrificing the safety is to employ composite materials in the body of the cars because the composite materials have higher specific strength than those of steel. Increase in the usage of composite material directly influences the decrease in the total weight of car and gas emission. Carbon/Epoxy AS4/3051-6 is used as composite material for side impact beam which has sufficient load carrying capacities and that it absorbs more strain energy than steel. In this study compared the total energy absorption of the beam with steel and composite material and concluded that there is considerable reduction in the weight of the Composite beam. Composite beam can absorb more deformational energy than steel and more effective. The reduction in weight is 65%.Composite beam is more effective for FMVSS 214 side impact protection standards. Although the composite beams fail by buckling during impact loading, by proper design, fiber orientation and fiber matrix combination buckling failure can be reduced.

Jayalin.D and Prince Arul raj. G have worked and developed Finite Element Model to analyze the beams with openings. The openings in the beams are provided for utility ducts and pipes. Generally cracks will develop due to the stress concentration around the openings. Studied beams strengthened by Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) Concrete sheets. Concrete was modeled using solid 65 element and rebars were modeled using beam 188 elements. Thirteen beams were modeled, one beam is the reference reinforced concrete beam without any opening. Six beams with openings retrofitted with CFRP fibers and six beams with opening retrofitted with GFRP were also analyzed. Three out of six beams had openings in the shear zone and the other three had openings in the flexure zone. Studied the load deflection relationship, crack pattern and crack at ultimate load were obtained and comparison was done for CFRP and GFRP beams. It was observed that, performance of beams retrofitted with CFRP was better than that of the beams retrofitted with GFRP. To improve the ultimate load carrying capacity of beams, strengthening with CFRP and GFRP sheets around and inside the opening was found more effective.

T.Subramani and J.Jayalakshmi Analytical and experimental study has been carried out to investigate the behavior of concrete beams bonded with strengthened Glass Fiber Reinforced Polymer (GFRP) sheets on all sides with different thickness of the plate under loading. Studied the behavior of concrete beams strengthened with GGFRP unidirectional composite laminates. GFRP pasted beams behaves better than the RCC beam. The finite element program ANSYS has been used to study the Strengthened behavior of a beam. Deflections in the beams retrofitted with GFRP are less than RCC beam. Failure has occurred in the rehabilitated beam due to the delaminating of GGFRP plate. The delaminating is occurred due to the stress concentration at the ends of the plate. Finite element analysis shows that RCC with GFRP has higher stiffness than all other cases. For the same load the RCC beam with GFRP have the less stresses and strains. Compared both experimental and analytical results and results are well correlating. Hence the FEA software ANYSYS can be used effectively for the beam analysis.

Pankaj Charan Jena and Dayal R. Parhi Presented on theoretical, experimental and numerical (finite element methods) analysis of fibers composite beams with transverse crack subjected to free vibration by using Epoxy- glass fibers (unidirectional) material. This study presents the evaluation of changes in natural frequencies and corresponding mode shapes curvature for different boundary conditions by varying crack positions and crack depth. Compared the experimental, analytical and finite element analysis investigation and observed that with increase in crack depth, the relative frequencies reduce in order due to drop in stiffness of the composite beam. The study concludes that structure with crack can be diagnosed by using vibration signatures and it help to monitoring the health of beam type structures.

A. Kurşun, M. Tunay Cetin, E. Cetin, and H. Aykul: Studied an elastic stress analysis of Woven steel fiber reinforced thermoplastic cantilever beam loaded uniformly at the upper surface. Composite beam material contains of low density polyethylene as thermoplastic and woven steel fibers. Poly ethylene granules are put into the molds and they are heated up to 160°C by using electrical resistance and the material is held for 5min under 2.5 MPa at this temperature. The temperature is decreased to 30°C under 15 MPa pressure in 3min. found closed form solution and satisfying both the governing differential equation and boundary conditions. Studied orientation angle effect on stress distribution of composite cantilever beams. The results shows that, maximum stress values are observed on both upper and bottom surfaces of the thermoplastic cantilever composite beam. The stress is high for orientation angle equals to zero at upper side of composite beam. The tensile stress observed at upper side while it is compressive at lower side, and it is linearly distributions along to thickness of composite beam.

Yousif K. Yousif: Worked on the composite material (Polyester & Silicon-Carbide) with cantilever loading. Force applied at the free end of the beam with different values. Experimental results shows the maximum deflection occurs at the point of application. The slope and deflection of beam are analyzed by using the FEM modelling. MAT lab is used to assemble the equations, vector and matrix of FEM and solving the unknown variables (deflection and slope) at each node. ANSYS software used to compare the results with the theoretical and experimental data. The numerical methods are used to compare the results with the theoretical and experimental data. Good correlation was observed between the analytical, theoretical and experimental methods. experimental results shows that Increasing the volume fraction of Silicon Carbide particles, decreasing the deflection of beam for the same applied force & increasing the modulus of elasticity of composite material with increasing the volume fraction of particles.

V. Tita, J. de Carvalho and J. Lirani studied the dynamic behavior of components manufactured from fiber reinforced composite materials. Composite materials are well known by their excellent combination of high structural stiffness and low weight. Their inherent anisotropy allows the designer to tailor the material in order to achieve the desired performance requirements. Some beams were made using the hand-lay-up process followed by a molding under pressure and heating. Experimental dynamic tests were carried out using specimens with different fiber orientations and stacking sequences. The objective of this work is better understanding of the dynamic behavior of components mage from the fiber reinforced composite beam materials. Results shows that changes in the laminate stacking sequences yield to different dynamic behavior of the component, that is , different natural frequencies and damping factor for the same geometry, mass and boundary conditions. From this, designers can easily design the laminate with more possibility of changing fiber orientations in order to get a more damped structure. This possibility also makes to obtain the desired natural frequencies and damping factors without increasing mass or changing geometry.

Mohammed Waseem H.S and Kiran Kumar N: Studied the delamination techniques by using VCCT and CZM which are implemented in commercial software ANSYS workbench. Delamination is one of the most commonly observed failure modes in laminated composites. Presence of delamination in a structure can significantly reduce the stiffness and strength of the structure. The analysis carried by two different methods. Virtual crack closure technique (VCCT) and cohesive zone method (CZM). VCCT is a fracture mechanics approach which is widely used to compute energy release rates. CZM is a progressive event governed by progressive stiffness reduction of the interface between two separating faces which uses bilinear material behavior for interface delamination and fracture energies based debonding to analyze delamination of unidirectional Double Cantilever Beam (DCB) specimen. These methods are correlated with the benchmark results. The load-displacement response predicted by CZM correlated well with the benchmark results. VCCT approach also successfully simulated the load-displacement response curve but this method overestimated the critical load.

3. Problem Statement

To find out the optimum design of fiber metal laminated beam by considering various combinations and different ply angles of fiber material. After optimizing the design of fiber metal laminated beam, the same beam is to consider as cantilever beam under the load applications. Compare the results like stress and deflection of the beam with the results of steel beam under same loading conditions.

3. Objectives

- The primary object of the project is to find the stress and deflection of the fiber metal laminated composite beam considered as cantilever beam.
- To compare the results with the steel beam.

Beam specifications are as shown in following fig: 3 (L=350mm, b=70mm, t=10mm)

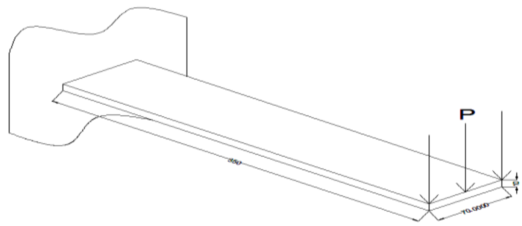

Fig. 3

4. Methodology

- For all three approaches i.e. analytical, finite element and experimental approach, the beam will be considered as cantilever beam and formulae of same will be used.
- As per discussion with expert for finite element analysis the fiber material will be considered as orthotropic material while metal material will be considered as isotropic material.
- The loading conditions are kept as 500N and 1000N and experimentally can be achieved on universal testing machine.
- The fabrication method will be done by hand layup technique.
- Validation of the results will be done by all three approached results.

5. Material Selection

As this project work is related to replace the steel leaf spring with the other nonmetal material leaf spring the very first criteria for the nonmetallic material is to possess same or high strength than steel material. As leaf spring is used for suspension purpose so the material used should have high rigidity as well. If we use only composite laminate then the rigidity will be the criteria of concern. The replaced leaf spring with high rigidity and high strength and less weight can be achieved with the fiber metal laminate.

Table.1 Selection of FML types and FML constituents applied and investigated in the past decades

FML Type	Metal Constituents	Fiber/Polymer Constituents
Arall	Aluminum 7075-T6	Aramid/BSL-312-UL Aramid/AF163-2
Glare	Aluminum 2024-T3 Aluminum 7475-T761	S2-Glass/FM94 S2-Glass/FM906
Carall	Aluminum 2024-T3	T300-Carbon/epoxy
TiGr	β Titanium Ti-15-3	IM7-Carbon/polyimide

Fiber metal laminate is the sandwiched laminate of metal layers and fiber layers. Fiber metal laminates offers excellent fatigue strength, impact resistance, residual and blunt notch strength, flame resistance, high strength/stiffness and good damage tolerance, etc. The fiber layers act as barriers against corrosion of inner metallic sheets, whereas the metal layers protect fiber layers from picking up moisture. In past decades previously used combinations of fiber metal laminates are tabulated in table 1.

In most of the aircraft applications fiber metal laminate is made of aluminum and fiberglass composite material. Fiberglass sheet is a composite since it is made of glass fibers imbedded in a polymer. Most commonly used fiberglass material is S2-glass for aircraft applications due its properties. The cost of S2-glass is higher than any other composite material. For leaf spring to be economical S2 glass is not preferable, hence between the other composite materials the second mostly used fiberglass is E-glass fiber material. E-glass properties are not same as like S2-glass but the considering the cost factor S2-glass is 10 times costlier than E-glass. For automobile application E-glass fiber with aluminum metal combination is preferable. Aluminum is with the fiber is mostly used combination as aluminum has less density (ρ ~ 2.70) than steel (ρ ~ 2.70). The available aluminum alloy i.e. aluminum alloy AA1050 is selected. Also aluminum has corrosion resistance properties than other metals. The bonding between aluminum and glass fiber with epoxy resin and hardener has good resistance against delamination. Carbon fiber is having highest strength in the fiber family but carbon-aluminum laminate possesses an inherent disadvantage of low resistance to galvanic corrosion due to good electrical conductivity of carbon fibers. With all such properties of aluminum and E-glass fiber, both the materials are selected to form fiber metal laminate with the adhesive material epoxy resin which has high adhesive strength and high mechanical properties

6. Results and discussion

The optimized design of the beam is decided depending upon the results of the beam when it is loaded as cantilever beam. The thickness of all beams kept as 6 and 10 mm. Firstly the results of steel cantilever beam are found by analytical and finite element analysis method for same thicknesses. Then various combinations of composite laminates and fiber metal laminates are compared with the steel beam. The load acting on the beam is taken as 500 N and 1000 N. This load is kept same for all the beams. The deflection for this beam is found by analytical and finite element analysis and then these results are validated with the experimental results shown in following table.

Table.2 Fiber metal laminate results

S No	Laminate/ Beam (Thickness)	Load, N	Deflection, mm		Stress, N/mm²
			Analytical	FEA	
1	$[Al_3/E_{0,14}]$ (10mm Thickness)	500	49.12	41.97	397.34
2	$[Al_3/E_{0,14}]$ (10mm Thickness)	1000	98.24	83.95	794.69
3	Steel (6mm Thickness)	500	54.01	53.71	921.31
4	Steel (6mm Thickness)	1000	108.02	102.35	1843
5	Steel (10mm Thickness)	500	11.67	11.628	328.47

Conclusion

The optimum design for the fiber metal laminated beam is found by using various combinations of fiber and metal layers and also using different ply orientations of the fiber layer. For this purpose analytical method is used. The results of the analytical analysis then validated with the finite element analysis results. For finite element modeling and analysis Ansys 11.0 software is used. The optimized beam results will finally validated by experimental results. For analytical purpose the equations are developed by using classical lamination theory. From the results following conclusions can be drawn;

1) The fiber metal laminated beam gives better results under loading conditions compared to steel beam.
2) The steel beam of 6 mm thickness deflects ~54 mm for same loading conditions the fiber metal laminated beam of 10 mm thickness deflects ~42 mm.
3) The stress on steel beam is ~922 MPa is higher than the stress on fiber metal laminated beam, which is ~398 MPa.

Steel beam results, load applied 500N (6 mm thickness)

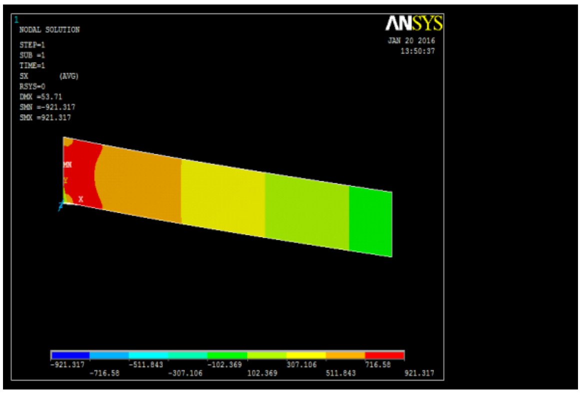

Fig.4: Stress in 10mm Steel beam

2. [$Al_3/E_{0, 14}$] (t=10mm) laminate results, load applied 500N

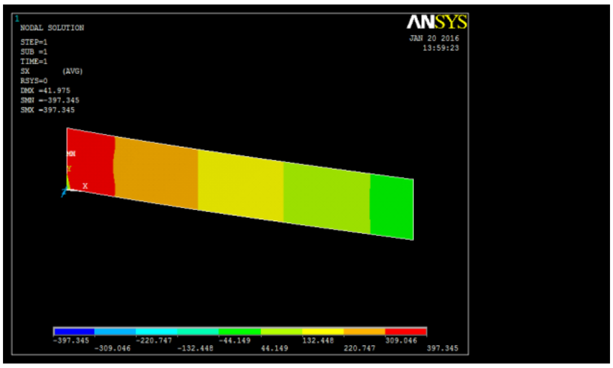

Fig.5: Stress in 10mm $Al_3/E_{0, 14}$ beam

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