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DESIGN & OPTIMIZATION OF COMPOSITE LEAF SPRING TO BE USED IN LIGHT WEIGHT AUTOMOBILE VEHICLES

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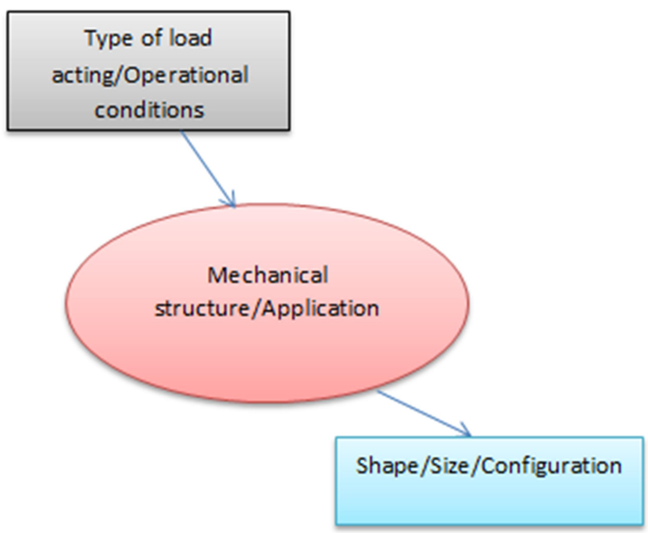
Abstract
Composite leaf spring is used as replacement to conventional leaf spring due to versatile advantages offered by it such as, light weight, compact construction, easy to assemble and dismantle, high stiffness, high strength to weight ratio etc. and this is the reason, though cost of design and manufacturing of composite leaf spring is more, it is widely recommend in to suspension application. The balance, stability, reliability and efficiency are other few advantages can be added to the account of leaf spring. Day by day research are undertaken to enhance the design and spring and thus make it available to customer at lowest affordable price with similar and constant performance maintained throughout the operation.Paper describes one such aspect of design of composite leaf spring which will be used in light weight automobiles. The design of spring is carried by considering assumptions and formulas usually applicable under static loading circumstances. The basic intention of the paper is to obtain basic dimensions of spring by using stress-strain relationship, the equation of bending also called in to picture to obtain require dimensions of spring. The dimensions obtaining have proceeded in iterative way, the iterations were continued till last possible value of spring dimensions. The dimensions include length, width, thickness of laminate, number of plies, ply thickness, fibre orientation, fibre and matrix volume fraction etc.
Key words: Leaf spring, composite material, lamina, laminate, ply, stress, strain etc.

1. Introduction: Application of composite material now days looking for the replacement of metal structure in civil, mechanical and marine engineering, to most of the extent experiments have ran successfully offering several benefits over metallic structure, still complete replacement of metals by composite or any other alternative material is not possible. Design of compose stands for integrating the structure so as to hit the set objective. Term optimization in design stands for precise selection of shape, size and thus control on associated cost of idea implementation. Design involves configuration and material selection, forces analysis, mechanism and motion selection etc. though design of composite material is tricky aspect than design of conventional material and designer needs to focus on things precisely such as, properties of constituent material, material anisotropy, variations in strengths etc. apart to this designer must have an idea about probable behaviour of structure and its mode of failure if keep operate under similar working conditions.

Process of design: Process of design starts keeping in mind objectives to hit or achieve. The basic objective to hit generally is, load sustaining and reliability, if deign is centric to mechanical engineering components. The material and its constituents, the methodology used in processing and moulding of that material, ageing are few other parameters which can be considered responsible let structure to enable to sustain said amount of load for expected period of time.

The shape & Size of that structure added extra advantage to achieve set objective in more precise way.

The process of design can averagely depicts through following chart,



2. Load distribution happened through 0, 45 and 90 degree ply: As already mentioned about anisotropic behaviour of composite material, the behaviour of material goes difficult comparative to conventional steel or metals, difference in strength added further difficulty to this task, and thus designer experience, intellectual would help him to predict/guess an average behaviour of composite which would lead to address design requirement possibly.

The basic difference between conventional material and composite is, conventional material is continuous bulk which had put forth for forming operation and now it is about to process for certain shape through best chosen manufacturing process. It is continuous structure of metal matrix and thus manufactured in single attempt only. But manufacturing of composite is different and required to address ply wise, each ply is imbibe with definite percentage of fibre and matrix volume, so the geometry, orientation and packing of fibres in matrix is next decision to take, and one such complete ply will be stacked over the other, then next ply and then next, and finally it forms the integrated composite structure which would be capable enough to address set objectives by designer or by organization on the behalf of designer.

The behaviour of various plies into laminate retains their unique importance, the plies oriented in 0 degrees good in longitudinal loading, the plies oriented in 90 degrees exhibits good strength in transverse direction, the plies oriented in 45 degree imparts good shear strength to laminate structure. The lamina orientation starts changing/increasing from 0 degree onwards the longitudinal strength goes decreasing and at 90 degree it was noted highest. The lamina oriented for 45 degrees retains good shear strength and support the structure to avoid bending due to external loading.

Sometimes behaviour of laminate is beyond understanding. This behaviour can be explained as, consider laminate with ply of 0 and 90 degrees stacked one above the other, now structure is subjected to loading in longitudinal direction, the strength of 0 degree lamina is more than 90 degree lamina as per longitudinal loading is concern, thus 0 degree lamina share its strength with 90 degree lamina and sharing of strength continues until strength of both the lamina won't be equal, sometimes, this load sharing reduces strength of 0 degree lamina to the extent that its strength leads to become less than strength of 90 degree lamina and finally failure tends to occur in lamina with highest strength, i.e. 0 degree lamina.

a. **Composite structural design:** The structural design term associated with finding of an optimum dimensions to support the said loading conditions economically.

b. **Laminate design:** While designing or addressing a design process, few parameters are necessarily required to be focused to address remaining process of product design and development, and thus achieve the said objectives. Those such parameters can be listed as, weight, reliability, manufacturing ease, production cost, strength, stiffness, density, stability, wear etc. few parameters needs to consider at early design stage, few needs to consider during manufacturing and rest need to focus at production and inspection stage. The right and precise parameter configuration chosen during design stage would minimize the risk of going something wrong at downstream and like this process of product design and development starts gaining accuracy over the years of practicing. Stacking of several lamina's for definite fibre orientation, fibre and matrix volume fraction to sustain the load of said magnitude, the resultant structure with all these features imbibe is called as Laminate Structure. The lamina or laminate structure is basically composed of, fibre reinforcement and resign, thickness of layer will be same or different, and due to different combination of imbibed constituents the laminate properties would also varies. Physical properties also varies with change in orientation of fibres occurred. There are few forces which need to consider on very prior basis while designing of composite structure let to avoid structure failure kind virtue of such forces.

c. **Estimation of shear force:** Apart from bending and normal load, designer also needs to focus on shear force/load which leads to happen phenomenon of ply delamination in the case inter laminar shear stress exceeded the maximum shear stress sustaining capacity. The distribution of shear stress across laminate structure usually noted linear.

d. **Stiffness & Deflection:** In some cases such as aircraft control surface, leaf spring of automobile, needs minimum deflection under heavy/intensive loads, the maximum permissible deflection will be the criteria of design in such cases and structure deflects beyond set limit undergoes the failure, such structure supposed to design with material having high stiffness which would deform/deflect less under high intensive loadings. To let occur minimum possible deflection, structure is supposed to design with fibres such as, carbon, Kevlar, aramid and born etc.

e. **Strength:** It is an ability of material to sustain load without undergoing for failure, the load sustaining capacity can be considered against statics or dynamics load. The fibres such as, S-glass, boron is generally recommended in to heavy applications as they possess high strength comparatively others. Carpet plots are specifically used to obtain first-hand information stating orientation of ply, percentage of fibres with specific orientation etc.

f. **Deflection:** Elastic modulus of laminates composed of conventional fibres is less and thus they shows large amount of deflection for small magnitude of loadings, thus it is essential to design a laminate which would show minimum deflection under applied load, or at least shows the defection in prescribed limits.

Composite design for In-plane combined load: This load will be possible combination of tension, compression and shear. The maximum load sustaining capacity of plate/structure decided based on magnitude of principal stresses induced and maximum stress sustaining capacity of same material at yield point.
Composite design for buckling load: This load is considered from stability point of view and so the design of laminate/composite plate structure would steers.

3. Problem Definition: It is required to design composite leaf spring for a light weight vehicle. The load acting on vehicle under static loading condition considered is, 2500*9.81 N. the vehicle has maximum seating capacity of 8+1 peoples. The proposed design of composite leaf spring to be used as replacement for conventional steel leaf spring should possess an advantages such as, light weight, high stiffness, high strength in static and dynamics loading, low deflection and deformation, easy manufacturing & assembly etc.

4. Objectives:

1. To design a composite leaf spring for “Mahindra Bolero Automobile Vehicle” to be used as a replacement for conventional steel leaf spring.
2. To determine an exact dimensions of spring.

3. To suggest an appropriate material as a replacement to the conventional steel.

5. Methodology: Following methodology have adopted to achieve/reach the above stated objectives.

1. First of all, the magnitude of total load acting on leaf spring is calculated, the maximum seating capacity of vehicle considered is, (8+1).
2. Based on direction of load acting the orientation of composite fibres have set, as discussed above the 0 degrees fibres have chosen to imbibe into structure as maximum load acting and carrying happened in longitudinal direction only.
3. Based on total load sustaining strength required, total number of plies has calculated. All plies carry 0 degree orientation, maximum load sustaining requirement have arisen in that particular direction only.
4. Thickness of ply considered 0.1 mm at initial level, the load sustaining capacity at this thickness checked, on not found satisfactory iteration keep moving every time taking new/next value to exhibit better load sustaining capacity, thickness of ply tried to maintain as minimum as possible, so the overall size of laminate would be less.
5. Length and width of laminate/lamina have determined based on linear and bending stresses equation.
6. The laminate structure design is carried for static load sustaining capacity, later it is analysed for dynamics loading too.
7. Point load acting on laminate structure carried away in the direction of length, so all plies have considered to organize into structure with fibres orientated in 0 degrees.

6. Design process:

1. The design variables are thickness of ply, overall thickness of laminate, length and width of ply/laminate etc.
2. The load acting on leaf spring considered for static and dynamics separately, for static, it is, 2500*9.81 N and for dynamics it is considered in varying range i.e. -2500*9.81 N to +2500*9.1 N.
3. Three materials have considered under analytical investigation, such as, carbon/epoxy, glass/epoxy and Kevlar/epoxy etc. the process of design and dimensions obtaining is explained for carbon/epoxy and summarized result for other materials which are obtained following similar design approach, finally presented in tabular form in result, conclusion and discussion part.
4. Number of plies in laminate structure is calculated through following relation,

N (Number of Plies) = Load acting/Material elasticity*thickness of ply

Load acting is, 2500*9.81 N;
Material elasticity = 1500 MPa;
Initial thickness considered is, 0.1 mm;

The repetitive iteration let to sustain load of said magnitude entails 16 plies each of thickness 0.25 mm to be assembled into laminate structure.

5. Thickness of lamina finalized at the end of above iteration process is, 0.25 mm for each ply.
6. Number of ply assembled in to structure will be limited to 16 to sustain the load of acting magnitude without undergoing for failure.
7. The fibre and matrix volume fraction are considered for standard value and remains same throughout all the iterations, the values considered are,
   i) ***Fibre volume fraction*** = 0.7
   ii) ***Matrix volume fraction***= 0.3

8. The fibre geometry considered is cylindrical; fibres are continuous and long, arranged in regular pattern of array.
9. All laminas exhibits 0 degree's fibre orientation, and stacking sequence of various laminas assembled into structure is, $[0]_{16}$.
10. Bending stress equation as stated below,

$$\sigma_b = \frac{M_b}{I} * y$$

Equation is used to establish relationship between width of lamina length and width.

The process goes as follows,

Maximum bending moment = (Magnitude of point load acting on the mid of spring * length of spring)/2

Distance of extreme fibre (Top or bottom of leaf spring) from Neutral axis/Central axis = Overall thickness of spring/2

Moment of inertia of spring = Width of spring *(Overall depth/thickness of spring)^3/12

Putting the above values in to equation of bending stress, exhibits relationship as mentioned below,

Length of spring = 13.33* Width of spring

Let assume some initial value/base value/Reference value for the width of spring and find out corresponding length of spring.

The length of spring obtained has cross check for bending safety by using bending stress equation as stated above. And result yields following dimensions for the length and width of spring,

Length of spring = 800 mm;
Width of spring = 60 mm.

7. The composite leaf spring prototype model manufactured for testing:

Fig (7.1): Prototype of composite leaf spring manufactured considering above obtained dimensions.

The leaf spring manufactured above used as replacement to conventional leaf spring which usually made of steel or brass. The automobile suspension system imbibe of composite leaf spring offers several advantages over conventional leaf spring which can be listed as, lees weight, high stiffness, high strength, greater stability, high operational efficiency, enhanced fuel efficiency etc.

8. Result, Discussion & Conclusion:

1. The suitable material for the replacement of conventional steel leaf spring is carbon/epoxy, glass/epoxy and Kevlar/epoxy etc.
2. The design of carbon/epoxy leaf spring is processed in current research paper.

3. Thickness of ply is initiated from 0.1 mm which finally sets to 0.25 mm with satisfying all design criterions.
4. The number of plies arranged into laminate structure is 16, with thickness of each ply is marinated constant.
5. Orientation of each ply is considered in 0 degrees, as load acting and carrying taken place in longitudinal direction, thus fibres of all plies have set to orient the load in said direction.
6. The fibres choose to fix into matrix are regular, long cylindrical fibres, length of fibres equal to length of lamina/laminate.
7. Fibre and matrix volume percentage in composite structure is considered standard i.e. 70 and 30% respectively.
8. The spring design is carried based on hypothesis/assumptions/equations considered which are generally applicable to static deign.
9. The maximum load acting on spring is considered one forth of total load acting on vehicle.
10. In another paper life of leaf spring with respect to changing/varying magnitude of load is calculated by using S-N Curve approach.
11. The changing load magnitude, or, increased tenure of load acting lead to reduce life of spring by considerable amount.
12. Length and width of spring obtained satisfying all design conditions is, 800 and 60 mm respectively.
13. Equation of maximum permissible bending moment and linear stress are used to find required length and width of the spring.
14. The laminate configuration/Structure of leaf spring can define in terms of configuration, $[0]_{16}$.
15. While designing of spring, failure is considered due to excessive bending load and stress induced because of that load only, the failure due to ply delamination, fibre pull out, fibre-matrix de-bonding, fibre slipping etc., haven't considered at all.
16. The failure of spring is considered priority under the impact of dynamics/fluctuating load, where, design is carried by static load acting approach.

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