# Design, Static And Fatigue Testing/Experimentation of Composite Leaf Spring To Be Used In Light Weight Automobile Vehicles As A Suspension System

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***Abstract-*** *Composite leaf spring now days used as a replacement for conventional leaf spring due to several advantages offered by it, few of them can be listed as reduced weight, high strength to weight ratio, high stiffness, high energy storage capacity etc. suspension system contributes 20% of total weight of vehicle, reduced in weight of it leads to increase operational efficiency of system, which would be helpful to cut down on cost of fuel/save on fuel expenditure. Enhanced strength for similar spring dimension leads to increase spring stamina let to withstand for fatigue loading which is unpredictable all time.*

*Paper describes one such aspect of design & development of composite leaf spring to be used in light weight automobile which will serve the intention of replacement of conventional spring to gain the benefit of above stated advantages. Followed by this initial work, leaf spring stability and strength is tested in terms of static and dynamic/fluctuating/fatigue loading and results are compared with simulation results.*

***Keywords***- Leaf spring, composite, static, fatigue, automobile etc.

## I. INTRODUCTION

A mechanical spring is a well-known element/component in the field of mechanical engineering and at general too. The purpose of element is to absorb the energy (Strain Energy) which generates due to conversion of load, shocks, impacts and vibration etc. store it for some time and same amount of energy will be released on removal of load. Energy dissipation to surrounding will be happened in the form of sound, heat and light. The operation cycles thus work in the sequence, absorption of energy, store it for some time and release it in different energy format, once energy is given out, spring will be ready to receive fresh form of energy and cycle continues. In similar operational context, leaf spring can be defined as, "It is mechanical element which absorbs the energy, deform elastically, store the energy momentarily and energy will be given out once applied load will be released, thus it provides vehicle safety, passenger comfort, driving stability etc." as per structure of conventional leaf spring is concern, it is made of high carbon or medium carbon steel. The structure is assembled in the form of multiple leaves, few of them are long, few of them are short and one is longer in all. The short length leaves are called as "Graduated Lead" where long length leaf is called as, "Master Leaf". Leaves are bent for specific radius of curvature which will be chosen based on need of that particular application. On application of load, spring with set radius of curvature bend in opposite direction the direction of its already set initial bending, absorbing whole load which then transmitted from wheel to axle and then axle to spring, the load is absorbed by spring thus stopped from letting it further transfer to vehicle body or passenger seated inside of it, on releasing of load spring gain its original shape, size and cycle of operation continues.

Talking about structure of leaf spring, the graduated length leaves bent for certain radius will be supported by master leaf from downside, the master leaf one can say supports the entire structure of spring. Master leaf ends are bent to form eye shaped geometry, the front eye is fixed into vehicle frame/chassis where back eye is fixed into shackle or pin, which is expandable in nature and slight load acts on it expand to absorbs the effect of that load, on removal of load it gain back its shape and size. Shackle is the flexible link. The rear axle is supported by means of leaf spring, thus whatever road irregularities the wheel would be come across transferred in the form of shocks and vibrations to leaf spring, the whole effect of such shocks and vibrations will be absorbed by spring and left nothing to transfer to vehicle frame/body, thus vehicle component safety against damage as well the passenger comfort seated inside will be maintained forever.

The short and long leaves are held together by means of nut and bolt assembly/fasteners. The structure of plates further held together and supported by clips which assist in avoiding of inter leaf spring friction, if it continue for long time, wear and tear action of it would make structure unable to fulfil its objective and replacement will be only the option left to address the problem. However, interleaf friction is beneficial aspect some time as it performs the function of damper and absorbs the impact of load which otherwise if transmitted to vehicle body/frame would either leads to damage the component or will interfere with passenger comfort and vehicle stability.

Conventional leaf spring with its accessories increases overall weight of structure and thus total weight of vehicle also goes increase. Many years investigation of problem and efforts made towards betterment of system enabled the designer to use alternative material which would address drawbacks arrived from conventional leaf spring, few of the advantages offered by composite spring after immediate implementation of it are observed as, reduced weight, high strength, high fatigue resistance, increased stiffness etc. this made designer to keep system optimized and upgrade time to time and thus more value added research have been added into context of newness which has ever enhanced performance of spring to best possible extent still the research work is going on and will keep going.

While briefing to composite leaf spring structure first important point come to highlight is, one piece and continuous structure which is formed by placing layer of materials one above the other and bind together by means of resin, and thus interleaf friction problem which further give rise to wear and tear action will be eliminated totally. The fibre are stiff element which either present in continuous cylindrical geometry or whisker type speared into matrix structure, the load received by matrix transferred to fibre and fibre are capable enough to withstand for the said magnitude of load either acting gradually or suddenly. The more percentage of fibre into matrix would be beneficial as it increases load sustaining capacity of structure but beyond one limit packaging of fibre into matrix is not possible else structure rather offering an advantage turned brittle and rather sustaining load/responding load, fails immediately.

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.

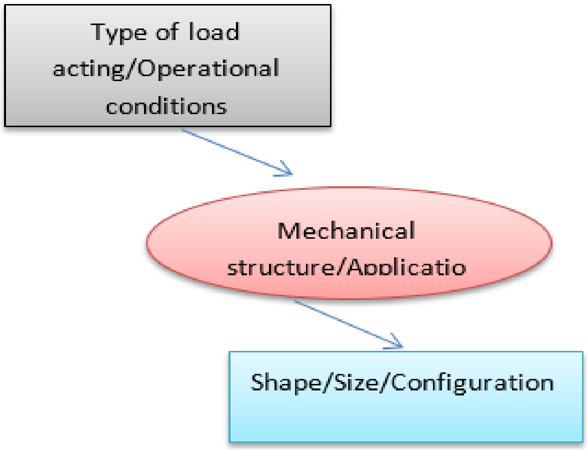
Paper describes one such aspect of design of composite leaf spring which will be used in light weight automobiles. The design of spring is carried by considering assumptions and formulas usually applicable under static loading circumstances. The basic intention of the paper is to obtain basic dimensions 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.

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,




## II. 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. **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.

## III. 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.

## IV. OBJECTIVES

1. To design a composite leaf spring for “Light weight automobile vehicles having seating capacity, (8+1)” 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.

## V. METHODOLOGY

Following methodology has 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.

## VI. 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,

   1. ***Fibre volume fraction*** **=** 0.7
   2. ***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.

- **Key point discussion to the end of Mathematical Modelling & Analysis:**

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.

- **Dimensions of leaf spring:**Load acting on vehicle leaf spring=2500*9.81N,, Length=800mm, width=60mm, thickness=8mm, total number of layers=16, thickness of each layer/ply=0.5mm, fibre orientation=0 degree, fibre volume fraction=0.7, matrix volume fraction=0.3, fibre geometry: long, continuous and cylindrical, radius of curvature= 1040mm

- **Geometry of leaf spring:** Rectangular, uniform cross sectional.

- **Car Model/Vehicle Model & Type:** Four Wheeler, Light weight Vehicle, (08+01) Seating Capacity.

## VII. MANUFACTURING OF LEAF SPRING:

Manufacturing of spring is possible by methods such as, contact molding, hand layup, pressure molding etc.

This research method recommends manufacturing by hand lay-up method. The layer of glass fibre placed one above the other till structure is not built for said thickness. Thickness of each layer is same, after finishing of each layer, the coating of resin is applied by brush and next layer of material is placed, the process continues until structure wont exhibits said thickness. Same procedure is continued for carbon and Kevlar fibres, and samples formed are put forth for testing.

The specimen geometry with said dimensions and features, finished after hand layup method and ready for further testing and validation purpose is shown below,

**Fig. (3.1):**Composite leaf spring structure formed after molding/hand layup method

## VIII. STATIC TEST

The vehicle under idle condition, the load of vehicle and passenger seated inside of it will be treated as static load and outcome result with respect to this loading can be considered as, deflection/deformation, stress, strain etc. apart from this, mass of spring, stiffness of spring are another parameters which can be added into this context of analysis.

The static test is performed on UTM (Universal Testing Machine), few tests are carried out on this machine, such as, ultimate load sustaining capacity of material, stress at corresponding ultimate load, deflection/deformation corresponding to ultimate load, and where few parameters such as strain, elongation can be calculated based on preliminary information obtained/recorded during experimentation and testing of samples.

The specification of UTM are discussed below,

- Measuring range: 0-400N
- Least count: 0.04 N
- Clearance between column: 500mm
- Ram stroke: 200mm
- Power supply: 3 Phase, 440V, 50 HZ AC
- Overall dimensions: 2100*800*2060mm
- Weight: 2300kg
- Clearance for tensile test: 50-700mm
- Clearance for compression test: 0-700mm

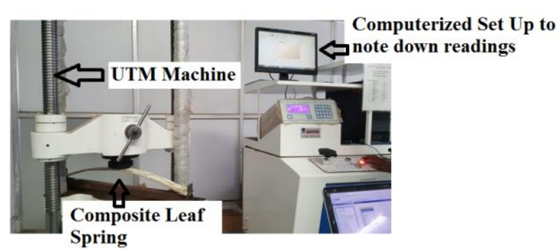
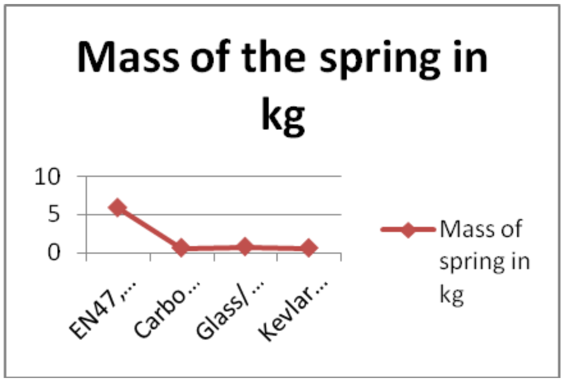
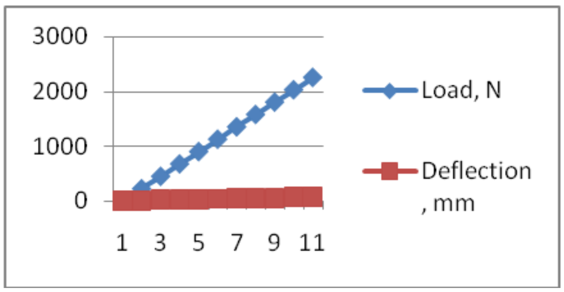



**Fig (8.1):** UTM (Universal Testing Machine) installed in laboratory and used for static testing



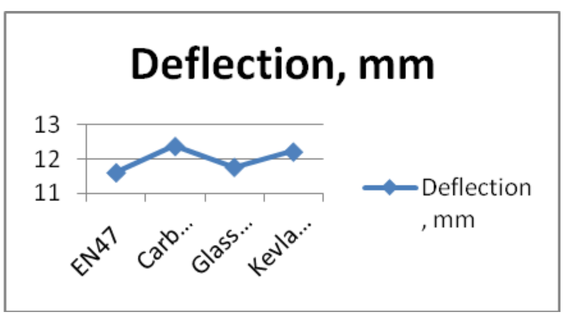

**Graph (8.1):** Mass comparison between steel and composite leaf spring.

Graph above depicts mass comparison between conventional steel and composite material, composite material mono leaf spring yields less mass compared to conventional springs.



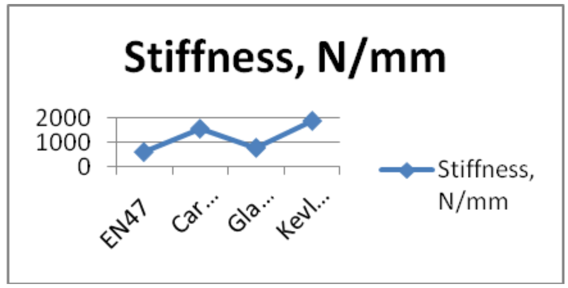

**Graph (8.2):**Load vs deflection, increased load leads to produce more deflection.

Load vs deflection behaviour studied for carbon/epoxy leaf spring, the deflection goes increase with increase in load, no failure is noted and that means composite spring structure has an ability to deflect more under increased loading conditions still exhibits no failure at all.



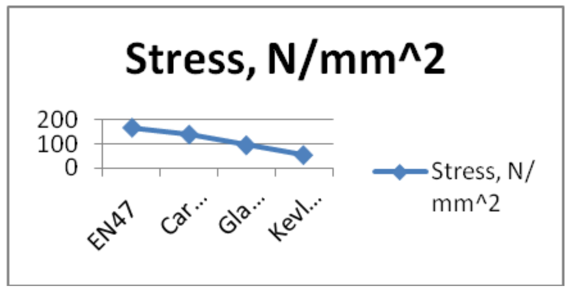

**Graph (8.3):**Deflection comparison between steel and composite material.

Deflection comparison between conventional steel and composite leaf spring, conventional leaf spring exhibits less deformation and more efforts to bend it probably lead it to fail, contrast to this composite springs are showing highest deflection and thus retains the capacity/stamina to deflect more showing highest load absorption capacity. Among composite, carbon/epoxy has highest deflection capacity.




**Graph (8.4):**Stiffness comparison between steel an composite materials.

Stiffness of conventional spring noted less, where, stiffness among composite noted highest in Kevlar/epoxy and carbon/epoxy second next.

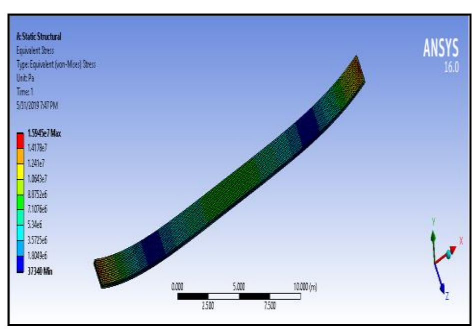



**Graph (8.5):**Stress comparison between steel an composite materials.

Graph above depicts, stress value is noted highest in conventional steel where among composite though it noted less compared to steel, it noted lowest in Kevlar/epoxy.

## IX. SIMULATION RESULTS

Conventional steel performance/behaviour is compared with carbon/epoxy and same is depicted through following snapshots.



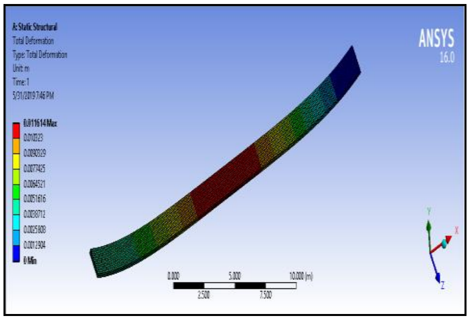



**Fig (9.1):**Stress and deflection analysis respectively in conventional steel leaf spring.

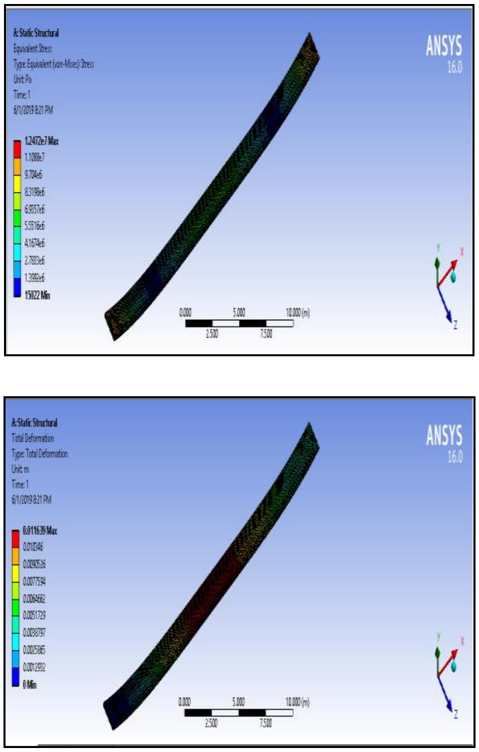



**Fig (9.2):**Stress and deflection analysis respectively in composite leaf spring.

Though deflection in both the materials (Steel and composite) is noted highest in the middle of spring, it is noted high in conventional compared to composite carbon/epoxy leaf spring. The stress affected zone in composite spring is less where in conventional steel this zone is seems to be speared widely. Highest magnitude of stress is noted at the extreme end of the spring which will be acting as a supporting end, the resultant magnitude of stress noted at these end may be the contact reaction stress and thus certainly equal magnitude of force spring must be acting on the frame which do supporting it.

## X. DYNAMIC TESTING

Unlike static test, dynamic testing is the virtual effect created in which repetitive force of nearly same or different magnitude and nature will be acting on spring at same or different location, the frequency of this load acting will be different, sometime it is more than mean and some time it is less than mean.

The experimental set up consists of Pneumatic Cylinder & Solenoid valve. Pressure with varying intensity released through cylinder stimulates solenoid valve which further acts variable load on leaf spring for every alternate cycle. The set-up is similar to the loadings which act when vehicle runs over irregular road conditions. The picture below depicts more about same,

**Fig. (10.1):**Pressure gauge and solenoid valve equipped with electronics circuit


**Fig. (10.2):**Solenoid Valve/Piston reciprocates up and down, acting point load of different magnitude on composite leaf spring.

Detailed description of loading acting on composite material of different category is summarized and depicted through table below,

**Table (10.1):** Details of fluctuating load acting on composite leaf spring for different span of time with different magnitude of intensity.

| Sr. No. | Name of Material | Material Specification, Modulus of Elasticity (MPa) | Load (N) and stress (MPa) details | Tenure of load |
|---|---|---|---|---|
| 1 | Carbon/Epoxy | $E_1$= 1500 | 400 | 75% |
| | | | 500 | 15% |
| | | | 600 | 10% |
| 2 | Glass/Epoxy | $E_1$= 1080 | 300 | 80% |
| | | | 375 | 15% |
| | | | 450 | 5% |
| 3 | Kevlar/Epoxy | $E_1$= 1280 | 300 | 75% |
| | | | 350 | 15% |
| | | | 430 | 10% |

Corresponding to above loading, following performance of samples were noted.

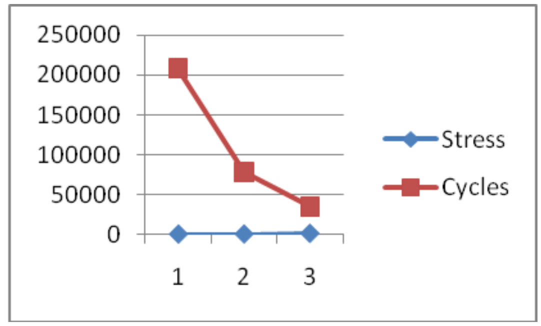
The loading magnitude, tenure of its acting, intensity of stress induced, fraction of component life consumed and resultant number of cycles specimen/sample/leaf spring could withstand before appearing of first crack on its surface is summarized in table below,

**Table (10.2):** Details of the cyclic loading and percentage/fraction of life consumptions happened during each such span/specification of load acting.

| Sr. No. | Load, N | Stress, MPa | Effective Cycles (Number) | Usage of specimen |
|---|---|---|---|---|
| 1 | 1500 | 172 | 3.1*10^6 | 0.07 |
| 2 | 2100 | 220 | 1.8*10^6 | 0.11 |
| 3 | 3200 | 330 | 6*10^6 | 0.17 |
| 4 | 4000 | 440 | 1.84*10^6 | 0.25 |
| 5 | 5100 | 556 | 4.50*10^6 | 0.4 |

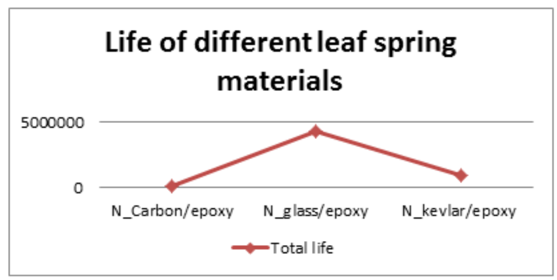
Table shows, maximum loading magnitude consumes great portion of effective life of component, if tenure of such load acting continues then also picture progresses similarly. Contrast to this, when less loading magnitude acting on component it consumes less life of component and even tenure of load increases slightly the effect of damage do not expand to that severe extent.

The crack under fatigue loading generally initiates at the places of dislocations and discontinuities which propagates either with respect to increase in the magnitude of load or tenure of load acting, and when the length of crack goes beyond critical limit, component failure acts by fatigue. It is interesting to note that, by the time of fatigue, failure stress is noted much lower than normal strength of component which generally driven out the component failure and yet failure of component is happened at this low level stress.Sometime grain structure, abrupt changes happened into area of cross section increases the effect of stress concentration and bring this sort of failure where whole strength of component is not utilized and failure of component due to fluctuating loading taken place much lower than the normal strength of component.




**Graph (10.1):**Effect of load/stress on effective life of specimen

Graph above depicts as magnitude of load/stress goes on increasing, or increase in tenure of load acting would leads to drag down the life of specimen.




**Graph (10.2):**Life of different material moulded and tested as a composite leaf spring.

Doubtlessly life of composite material as a leaf spring noted high than conventional steel, yet among composite, effective life cycle of glass/epoxy is noted high among all, next is of Kevlar and last is of carbon.

## XI. DISCUSSION AND CONCLUSION

Overall experimentation/testing and analysis work of leaf spring leads to following conclusion and discussion which still holds the scope for an improvement.

- The dimensions and geometry of leaf spring manufactured in composite material is compact and stable compared to conventional steel leaf spring.
- Inter laminar friction is totally eliminated in composite spring which otherwise quote the need of spring replacement on very frequent basis.
- Manufacturing of composite spring for said dimensions and geometry is taken place by hand layup method in

which layer after layer of composite fibre placed one above the other, which applied with resin by means of brush, the resin fill up the gap and dislocations, it also assist to hold different layers of spring firmly together in said sequence to fulfil the need of an idle or required structure.

- The deflection in composite material is noted high compared to steel which means it provide great scope of deformation under applied loading and thus ensures maximum load absorbing which further results in passenger comfort and component safety of automobile which other under severe impact of loading tends to get damage or leads to malfunction.
- The strength and load sustaining capacity of composite spring is again noted higher than steel leaf spring.
- Stiffness of composite is noted high than steel, it means, composite structure requires heavy load let to get deflect by an unity.
- Value of stress induced in spring is less compared to conventional steel which states that composite structure holds the great margin of deformation and yet stress value maintained within permissible limit and assures no failure of component at all.
- In fluctuating loading, highest magnitude stress even acted for small tenure leads to consume life of component by great extent contrast to this stress with low magnitude despite acted for long tenure leads to bring less damage into component leaving behind the scope to perform for longer.
- It has observed in fatigue loading, component failure is occurred below the normal strength, component yet hold the scope to perform and still its damage/failure is happened, and this sates that during fatigue failure of component happened below normal strength and whole utilization of component strength do not happened at all.
- Failure in fatigue loading is total and sudden, the crack initiates at the region of discontinuity and dislocations, it goes on increase with increase in loading magnitude, when length of crack goes beyond critical limit, component failure have been happened already below normal strength of component where component still hold the scope to perform.

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