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Performance Analysis of Epoxy Resin based Composite C Shape Spring with E Glass Fiber for Improved Part Loading Functionality

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Abstract: -- **In present industrial scenario, the suspension system is the most important parameter in all type of vehicle. The automobile world has keenly emphasized on progressive rate spring unit as an alternative to steel leaf spring, because of its good minor to maximize shock absorption and better part loading properties compared to leaf spring. This project work focuses on designing special C shape spring instead of leaf spring which serves the purpose of protection of the vehicle and comfort to the passengers. C shape and leaf spring are modelled with the help of Pro-E 4.0 software and FEA is done with the help of simulation software Ansys 16.0. FEA reading shows that the C shape spring not only has better bending strength but also deflection compared with an existing suspension system. Hence provides better results as a suspension for the car and also use of composite material for C shape spring helps in reducing the overall weight of the vehicle.**

***Keyword*: Ansys, C shape spring, Deflection, FEA, Stress.**

I. INTRODUCTION

AUTOMOBILE suspension system are designed to react and to maneuver forces induced by laterally (side loads on tilted vehicle) and longitudinally (acceleration, braking) by tires, to resist roll of chassis so that proper balance of the vehicle is maintained. It is used to keep the tires in minimum load variations. The role of suspension system is vital in vehicles, as it functionally support the vehicle weight. Also, for the occupant smooth riding i.e. cushioning effect. Protect the vehicle from damage and wear. To gain traction it helps in keeping firm contact of the wheels to the ground. Suspension separates the car body from dynamic vibrations and road shocks that can be transferred to the occupants.

An advantage of leaf spring over the helical spring is that the ends of spring can easily be guided along the certain path with its deflection. Thus, the spring may act as a structural member and shock energy-absorption device. It can provide all the control for the wheels during acceleration, breaking, corning and general movements caused by the road surface.

Composite Material: A composite material has superior strength and stiffness than all other known structure materials. Also, it has high fatigue strength, temperature resistance strength, and other properties. The desired properties can be obtained by manufacturing particular material. Moreover, in this process the material can be shaped as to the form of final products. Composite materials are complex in nature as their components differ respect to each other in their properties, are insoluble or only little soluble and divided by defined boundaries. From above study it is found that the C shape spring is design with the consideration that it is like a beam. Because of its accuracy ANSYS is selected for the analysis. Constant cross section design Composite C Shape Spring is made by hand layup technique. The specimen is experimentation is done by bending test on universal testing machine. In given references conclude that composite material not only reduces but also gives many other advantages such as flattering noise reduction, increasing ride comfort and zero maintenance.

II. LITERATURE REVIEW

Anil Kumar and Ch. Ramesh [1] did the experimental and analytical comparison in the multi-leaf steel spring and mono leaf spring of composite material. They had done the work on same load carrying capacity and stiffness. They found that at same load the defection in composite material leaf spring was minor to that of steel leaf spring for all composite materials. Value of stresses and deflection were nearly equals to theoretical result. M. V. Jadhav and Y. R. Kharde [2] performed the experimental work on the leaf spring by using the composite materials like glass fibers C-

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glass and E-glass instead of the conventional steel material for leaf spring. They perform work on composite leaf spring under static loading condition. They used Pro-E 4.0 design software to make solid design and uses ANSYS 14.0 for the analysis.

They found that composite mono leaf spring having constant stress at any thickness point in parabolic type thickness of the spring.

Pankaj Saini and Ashish Goel [3] stated that the comparative analysis between the conventional steel leaf spring and composite material like polymer reinforced with glass fiber i:e Carbon epoxy, E-glass based epoxy and Graphite epoxy used for designing leaf spring. They done the modeling in the Auto-CAD 2012 software and ANSYS 9.0 used for analysis. the static analysis results shows that maximum displacement of conventional steel leaf is 10.16 mm and that for E-glass based epoxy is 15 mm for Graphite epoxy is 15.75 mm and for carbon/epoxy 16.21 mm the values of stress for conventional steel leaf is 67 N/mm and 163.22 Mpa, 663.68 Mpa, and 300 Mpa, for composite material resp. Out of that graphite epoxy has more stress the conventional material steel leaf so E-glass based epoxy leaf spring can be replaced from stress and strain point of view.

A.V. Amrute and R. K. Rathore [4] exchanged the conventional steel spring and used the E-glass based epoxy material leaf spring for experimental analysis of light commercial vehicle. They had done the CAE analysis of three full length leaves or strip. They found that under defined loading condition with same dimension of both leaf springs composite leaf has high strength to weight ratio, high stiffness lower weight reduces to 67.88% compared to leaf spring that means composite material spring is better option for the existing steel leaf spring.

T. B. Sonawane and S. S. Sarode [5] did V-shape and leaf spring comparative FEM analysis. They change the shape of leaf spring into V-shape spring with same width and thickness. Design of both spring is preferred using software Pro-E and using ANSYS the load is applied on both spring material selected for spring is 65si7 (65% Carbon and 7% Silicon). It observed that V-shape spring has more deflection i:e 16% and strain energy as 38.20% than that of steel material leaf spring from observation it find that V-shape spring can used only for part load condition only.

III. PROBLEM DEFINITION

Literature review shows that lot of work is been carried on conventional steel and composite leaf spring, the effect of suspension observed during full loading condition. It has also observed that various methodology and analyzing techniques are used to improve the performance and quality of suspension effect, this leads to a very important area for R & D field to enhance the effect of suspension system. As various parameters of spring like deflection, stress, etc. has been studied but seldom works done on part loading (i. e. not fully loaded), so this leads to a very important area for designing the special shape spring for part to full load condition with "Analytical, numerical, FEA & Fatigue investigation". Hence the present work is an attempt to study and workout theoretical calculations as per requirement for special shape spring that gives the solution for part loading condition.

Problem Objectives

1. FEA and Fatigue analysis of E-Glass/Epoxy Composite C shape spring.
2. Evolutions of stress value at different location for E-Glass/Epoxy C shape spring.
3. Evolution of greater load carrying capacity of E-Glass/Epoxy C shape spring compared with existing EN47 steel leaf spring.
4. Comparison of FEA and Fatigue analysis results of E-Glass/Epoxy Composite C shape spring.

IV. MATERIALS

A. Selection of Material:

Carbon, keviar, glass etc. are commonly used fiber material. Selection of the glass fiber based on cost impact and strength required. The glass fibers are classified as E-glass, C-glass and S-glass. The C-glass fiber gives excellent surface finish. S-glass fiber gives very high modular strength, important in aeronautic industries. The E-glass fiber is nothing but a high quality glass. It is standard reinforcement fiber which satisfies mechanical property requirements. Hence, E-glass fiber is perfectly suitable for this application.

Fiber reinforcement plastics (FRP) are made from different resins like polyester, vinyl ester, and epoxy resin. Out of all resins, epoxies bear better mechanical properties and high inter-laminar shear strength. Hence, epoxide is perfectly suitable for given application. Epoxy resins with hardener pairs are classifieds, based on their mechanical properties.

Out of all, epoxy resin selected grade is Dobeckot 520 F and hardener grade used for given application is 758. Dobeckot 520 F is an epoxy resin without solvent. In this hardener 758 is cured into hard resin. Hardener 758 is a polyamine with low viscosity.

B. Design Selection:

Types of spring design

1. Keeping Thickness Constant, Variable Width
2. Keeping Width Constant, Variable Thickness
3. Keeping Design of Cross-Section Constant

E-glass fibers are reinforced with Dubeckot 520F. Epoxy resin which chemically belongs to epoxide family serves as the matrix material. Commonly known as Bisphenol a Diglycidyl Ether. Hardener and low temperature curing epoxy resin are mixed in to each other in ratio of 1:10 by weight as recommended. The hardener and the epoxy resin are supplied by Dr. Nano NIC Ltd. E-glass fiber with epoxy resin has modulus of elasticity 53800 MPa and 17900 MPa respectively and has density of 2.6x10-6 kg/mm3, 1.1x10-6 kg/mm3 respectively. Weight percentage of E-glass fiber in composite is 60% for the samples.

C. Processing of the Composite:

Coarsely woven E-glass fiber having density 2.6x10-6 kg/mm3, maximum tensile strength, low cost and toughness is used. As the resin affects the economy of leaf spring for decreasing prize it is used. The resin Dobeckot 520 F and the hardener 758 is used in combination of 10:1 mass ratio. The mass ratio were calculated based on density of fiber and epoxy, size of mold and thickness of composite. Each percentage weight is prepared in separate jar with pot life of 2 h to facilitate wetting of fibers and epoxy resin.

D. Prototype Manufacturing:

Hand-lay-up method is selected to manufacture the prototype of a single Composite C Shape Spring. Cross section design is kept constant as it is quite suitable for hand lay-up manufacturing technique and accommodates continuous reinforcement of fibers. 0.4 mm layers of E glass fiber each are used to achieve 20 mm thickness. The prototype is manufactured as follows:

1. Preparation of moulds as per shape of leaf spring & set-up.
2. Preparation of clamping plates and stiffener pads.
3. Desired dimensions fiber preparation.
4. To facilitate ease of removal wax/gel is applied on the fiber side of the lower mould.
5. Dubeckot 520 F (epoxy resin) and hardener 758 (Hardener) mixture preparation in the 10:1 ratio.
6. Mixture application just above the wax.
7. Laying up the first ply with application of matrix on it, up to the desired thickness.
8. Mixture application on the topmost layer and Covering the upper mould after the wax application on its fiber side.
9. Stiffener application on the covered mould and clamping by plates and c-clamps.
10. Curing of C shape spring at room temperature.
11. Dismantling set up and trimming excess material.

V. METHODOLOGY

A. Analytical (Design of springs):

Leaf spring is considered first and designed as follows.
Here,
Weight and initial design data of measurements of "Swift Dzire" 4 wheeler and Light commercial vehicle is taken.
Vehicle weight= 837 kg [6]
Load carrying capacity Max. = 1200 kg
Combined total weight= 837 + 1200 = 2037 kg;
Number of full-length leaves (nf) = 1
Gravity acceleration (g) = 9.81 m/s2
Hence,
Combined total weight = 2037 x 9.81
= 19982.97~20000
As the vehicle has 4-wheels, each leaf spring takes up 1/4th of the total weight.
∴ 20000/4 = 5000 N
But, 2F = 5000 N
∴ F = 2500 N
i.e. F = 254.84Kg

TABLE I Properties Dimension of LEAF Spring

Sr. No.	Parameter	Value
1	Straight length (2L)	800 mm
2	Leaf thickness (t)	15 mm
3	Leaf width (b)	60 mm
4	Density of leaf material EN 47	7700 kg/m3
5	Modulus of elasticity (E)	2.1x105
6	Tensile strength	1158 Mpa
7	Yield strength	1034 Mpa

Deflection of Leaf spring

$$\delta = \frac{4FL^3}{Exbxt^3} \quad (1)$$

Bending Stress of Leaf Spring

$$\sigma_b = \frac{6FL}{bxt^2} \quad (2)$$

From the given formulae we can find out different values of stress with deflection for the leaf spring which are tabulated as follows.

TABLE II Analytical READINGS OF Leaf Spring

Sr. no.	Central load	Cantilever load	Deflection (mm)	Stress N/mm2
1	5000	2500	15.05	444.44
2	6000	3000	18.06	533.33
3	7000	3500	21.06	622.22

C Shape Spring Design is done as follows.

Here,

Weight and force acting on V-spring is taken same as for leaf spring and design data or dimension of V-spring as follows.

TABLE III
Specification or dimension of C Shape-spring

Sr. No.	Parameter	Value
1	Straight length (2L1) in mm	440
2	Thickness at outer end (t1) in mm	15
3	Leaf width (b) in mm	62
4	Density of leaf material E Glass/ Epoxy (kg/mm3)	2.6 X 10-6
5	Young's modulus in fiber direction,	45000
6	Young's modulus in transverse direction, E2 (MPa)	17900
7	Shear modulus, G12 (GPa)	8960
8	Tensile Strength in the fiber direction,	1100
9	Compressive Strength (MPa)	515

From the table the diagrammatic representation of the C shape spring is given as follows.

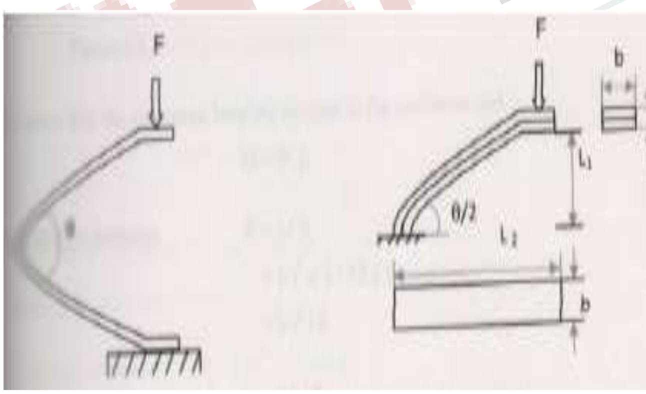

Fig. 1 Deflection of C shape spring

Deflection of C shape spring

$$\delta = \frac{FL^3}{3ExI} \quad (3)$$

Bending Stress of C Shape Spring

$$\sigma_b = \frac{6FLxsin\theta}{bxt^2} \quad (4)$$

From the given formulae we can find out different values of deflection and stress for the C shape spring which is tabulated as follows.

TABLE IV
Analytical reading of C shape spring

Sr. No.	Cantilever load (N)	Deflection (mm)	Stress (N/mm2)
1	3296.16	35.34	48.13
2	2943	31.55	42.97
3	2452	26.29	35.80
4	1962	21.04	28.65
5	1471.5	15.78	21.49
6	981	10.52	14.32
7	490.5	5.26	7.16

The final analytical results are compared in the subsequent table

TABLE V
Reading for EN47 and E Glass/Epoxy

Load N	Leaf Spring (EN 47)		C Shape (E Glass/Epoxy)	
	Deflection (N)	Stress (N/mm2)	Deflection (N)	Stress (N/mm2)
3296	15.05	444.44	35.34	48.13

B. Fatigue Life Calculations (Analytical):

Main factor that contribute the fatigue failures includes number of load cycles experienced, range of the stress and mean stress experienced in each load cycle and presence of local stress concentration. Testing of c-shape springs using the regular procedure consumes a lot of time. Hwang and Han have developed an analytical fatigue model to predict the number of fatigue cycles to failure for the components made up of composite material. They have proposed two constants in their relation on the basis of experimental results. It is proved that the analytical formula predicts the fatigue life of component with E-glass/epoxy composite material.

Hawang and Han Relation,

$$N = \left(B(1-r)^{\frac{1}{c}} \right) \quad (5)$$

Where,

N = No. of cycles to failure

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$$r = \frac{\sigma_{Max}}{\sigma_{UTS}} = Applied\ stress\ level$$

$$\sigma_{Max} = Maximum\ Stress$$

$$\sigma_{UTS} = Ultimate\ Tensile\ strength$$

B = 10.33; C = 0.14012 are the constant

Equation (5) is applied for different stress levels and fatigue life is calculated for the composite leaf spring. The results are obtained based on the analytical results. It is observed that the composite c-shape spring, which is made up of E-glass/epoxy is withstanding more than 10 million cycles under the stress level of 0.0465 as

$$\sigma_{UTS} = 1100 MPa\ for\ composite$$

$$N = \left(Bx\left(1-r\right)^{\frac{1}{c}} \right) = \left(10.33x\left(1-0.046547389\right)^{\frac{1}{0.14012}} \right)$$

$$N = 12292307.45$$

From the given formulae we can find out different values of life cycle and stress for the C shape spring which is tabulated as follows.

TABLE VI
Analytical reading of C shape spring fatigue life

Composite C shape Spring		EN47 Leaf Spring	
Stress	No. of Cycles	Stress	No. of Cycles
48.13	12292307	444.44	306882
42.97	12758907	418.21	419557
35.8	13432502	391.98	566119
28.65	14134446	365.75	754711
21.49	14868752	339.52	994987
14.32	15636718	313.29	1298310
7.16	16437406	287.06	1677972

The given results are validated through the FEA as well. The FEA fatigue tool (life) is used.

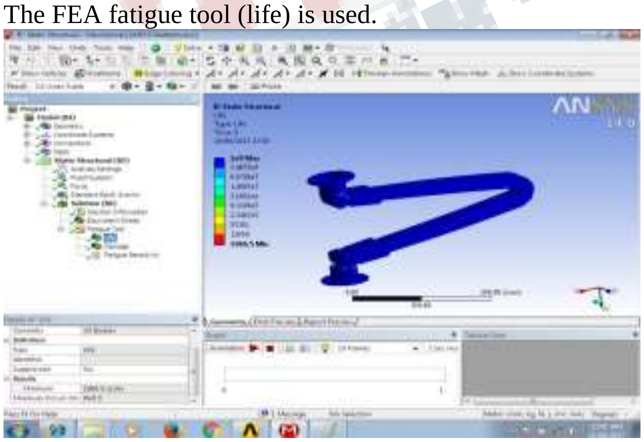

Fig. 2 Fatigue Life of Composite C-Shape Spring by FEA

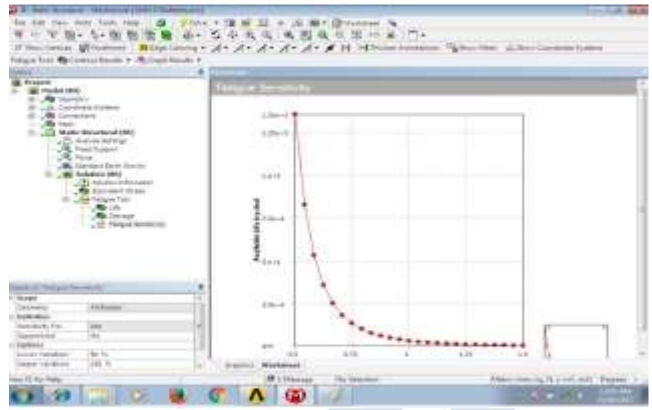

Fig. 3 S-N curve for Composite C-Shape Spring

Stress level of 0.0465. This is very much helpful for the determination of remaining number of cycles to failure using fatigue model. According to this fatigue model, the failure of the composite leaf spring takes place only after 10 million cycles. Since the composite leaf spring is expected to crack only after 10 million cycles, it is required to conduct the leaf spring fatigue test up to 10 million cycles for finding type and place of crack initiation and propagation. For completing full fatigue test up to crack initiation with the same frequency, nearly hour and hours of fatigue test is required.

Hence, it is found that the under the same loading condition the life of composite c-shape spring is much higher than that of steel leaf spring.

C. Finite Element Analysis:

Modelling of leaf and C shape spring are done with the help of Pro-E 4.0 software and the simulation are done with the help of Ansys 16.0 software. Procedure followed in FEA are:

Domain discretization.
Applying Boundary conditions.
System equations formation.
System equations solution.
Post processing the results.

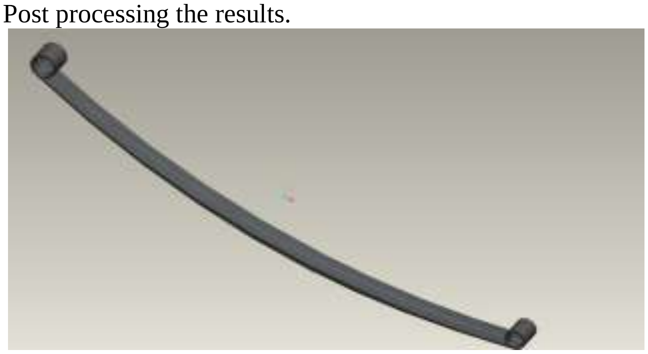

Fig. 4 Model of EN47 Leaf Spring in Pro-E 4.0

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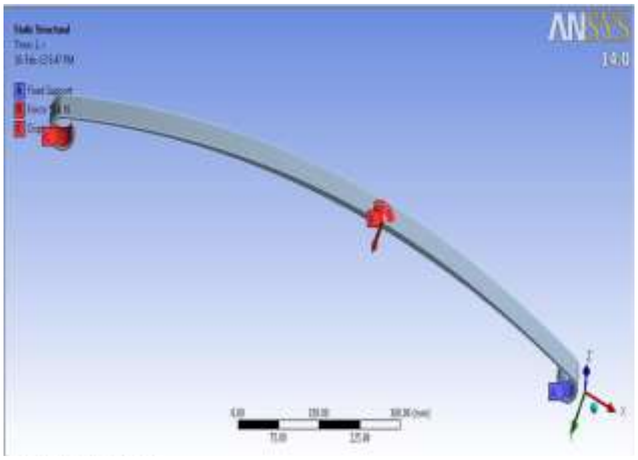

Fig. 5 Boundary Conditions and Loading for EN47 Leaf Spring

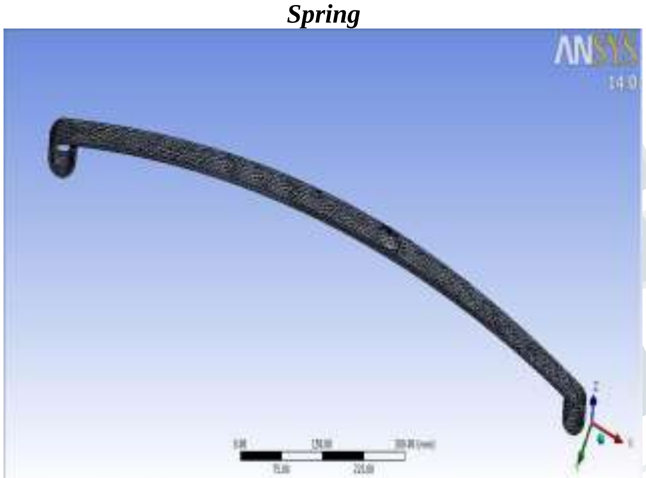

Fig. 6 Meshing of EN47 Leaf Spring

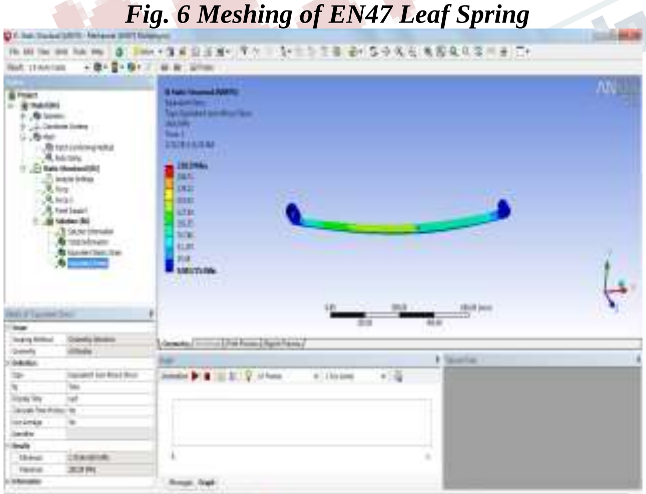

Fig. 7 Equivalent Von Mises Stress for EN 47 Leaf spring

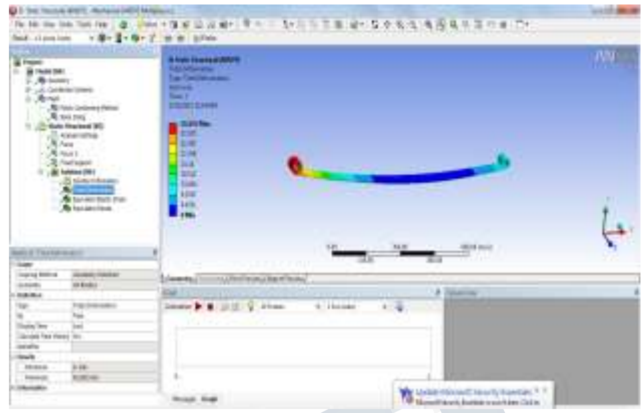

Fig. 8 Total Deformation of EN47 Leaf spring

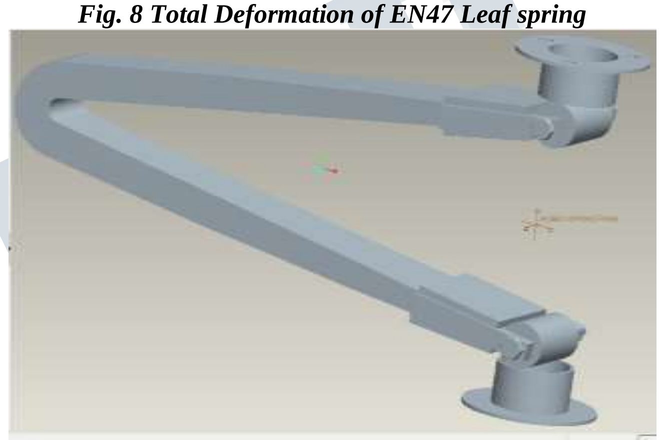

Fig. 9 Model of Composite C Shape Spring in Pro-E 4.0

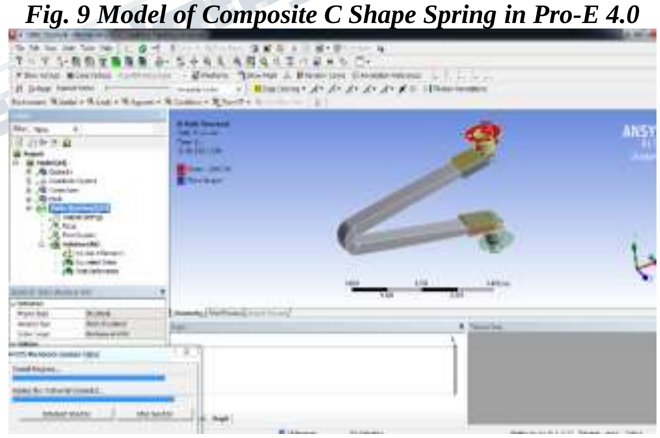

Fig. 10 Boundary Conditions and Loading of Composite C Shape Spring

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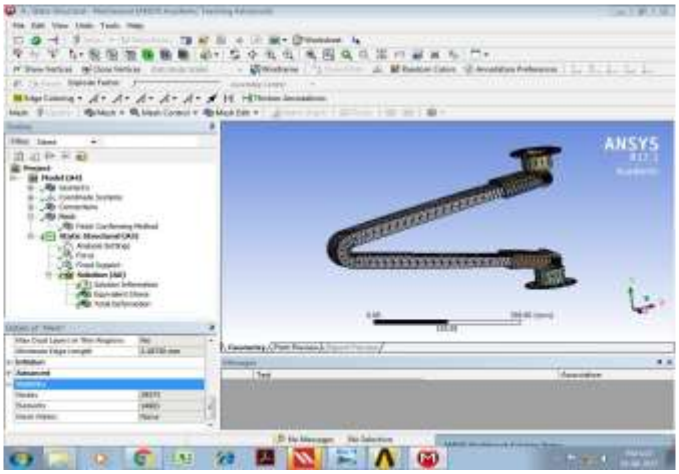

Fig. 11 Meshing of Composite C Shape Spring

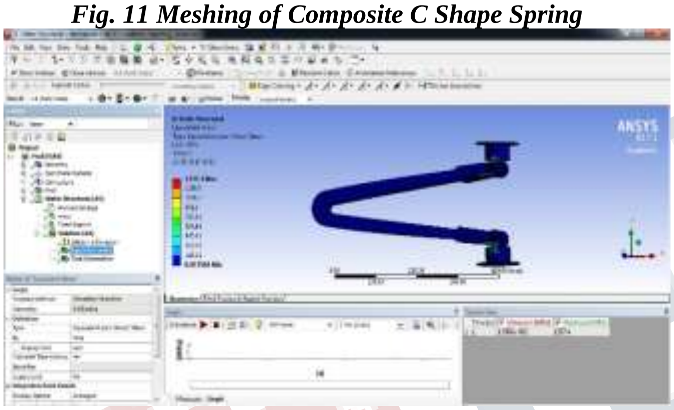

Fig. 12 Von Mises Stress for Composite C Shape Spring

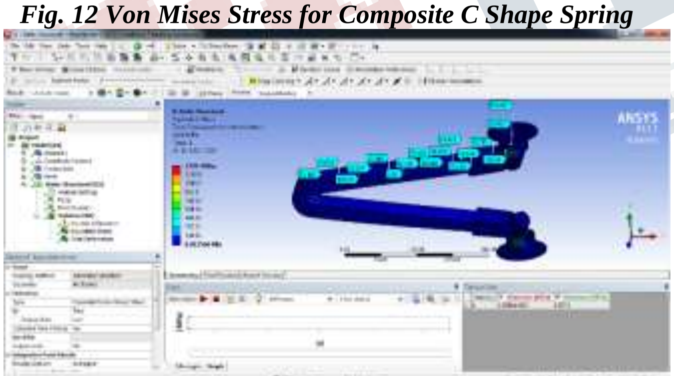

Fig. 13 Stress value at the different Location for Composite C Shape Spring

TABLE VII
Stress and Deflection for Various Loads by FEA

Load N	Leaf Spring (EN 47)		C Shape (E Glass/Epoxy)	
	Deflection (N)	Stress (N/mm2)	Deflection (N)	Stress (N/mm2)
3296	39	805	45	18

The force in z-axis doesn't produce any displacement. In FEA because of forces in y and x axis stress was created. Static stress values variation is quite high because spring's starting position is different than in the FEA. In the FEA, spring deformation is same to ideal deformation. The deviation between analytical and FEA results can be considerate acceptable. Where up to load of 3296.16N where deflection and stress value of EN47 and E-Glass/Epoxy leaf spring 805Mpa and 18Mpa for analytical reading and 444.44MPa and 48.13MPa for FEA and experimental reading shows stresses in E-Glass based Epoxy leaf spring lower as compare to EN47 leaf spring.
results and discussion
Thus, the Composite C Shape Spring can withstand with greater loads than steel leaf spring, also it shows near about the same deflection as far as damping is considered. In addition, the composite C Shape spring offers significant advantages over traditional steel leaf springs as mentioned below

1. Not requiring special mounting adaption or control arms for replacement.
2. Weight reduction of an equivalent spring rate leaf of 20 to 40 % in light vehicle applications.
3. Balanced compression and tensile strength than steel leaf spring.
4. The spring geometry is closer to a true constant stress beam.

TABLE X
Comparison of results for EN47 leaf spring and E-Glass/Epoxy C shape Spring

Parameter	Analytical		FEA	
	Steel leaf spring	Compo C Shape Spring	Steel leaf spring	Compo. C Shape Spring
Load (N)	3296	3296	3296	3296
Deflection (mm)	15.05	35.34	39	45
Bending Stress (N/mm2)	444.44	48.13	805	18

VI. CONCLUSION

The analytical, FEA and fatigue analysis of statistical behavior of E glass fiber with Epoxy resin based composites leads to the following conclusions:
1. E-Glass fiber with Epoxy resin Composite C shape spring withstands for greater load carrying capacity as

compared to EN47 material leaf spring for the similar conditions and result also in agreement with published results.
2. The analytical, FEA and fatigue results were compared and showed good agreement.
3. Deflection and stresses of EN47 steel leaf spring and E-Glass/Epoxy C shape spring are varying and showed E-Glass/Epoxy C shape spring has less stress value under the same static loading condition.
4. Under same loading condition we can conclude that the fatigue life of composite c-shape spring is much higher than that of steel leaf spring.

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