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Fem Analysis of Leaf Spring for Different Composite Materials at Full Load Condition

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Abstract : *The Paper deals with the analysis of composite leaf spring on vehicles and their advantages. Efforts have been made to reduce the weight of composite leaf spring to that of steel leaf spring. The weight reduction of the leaf spring with adequate improvement of the mechanical properties has made composite spring a very useful material for convectional steel. Materials have selected based on the cost and strength factor. The design method is selected on the basis of design feasibility and requirement, as it is seen that the composite leaf spring is comparative less weighted & has high strength than convectional leaf spring. The literature has indicated a growing interest in the replacement of steel spring with composite leaf spring. The suspension system in a vehicle significantly affects the behaviour of vehicle, i.e. vibration characteristics including ride comfort, stability etc. In this paper the comparison between EN45, E-glass/ epoxy, carbon/epoxy, and Kevlar epoxy*

Keywords: *Composite materials, spring, suspension systems, stability, vibration*

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I. Introduction

During service, any vehicle is subjected to loads that cause stresses, vibrations and noise in the different components of its structure. This requires appropriate strength, stiffness and fatigue properties of the components to be able to stand these loads. Above all, quality of a vehicle, as a system, which include efficient energy consumption, safety and comfort to the user are highly desired.

All the above largely demand refined and complex design and manufacturing procedures involved during the production stage. This requires good understanding of the internal systems of the vehicle and the characteristics of the different body structures in reaction to static and dynamic loads. Different researches have been carried out regarding the performance, the response of components to static and dynamic loads, crashworthiness, safety and others by different institutions and automotive companies. Particularly, with the growing simulation capability using computers, researches are facilitated which are aimed to achieving better quality products.

The application of computer aided engineering (CAE) analysis to problems of this sort, in combination with prototype development and testing, enables to achieve structures having longer fatigue life, reduced cost, light weight and improved comfort. In light of this purpose, as stated earlier, advancements in the area are growing further. The components of the suspension system are parabolic leaf spring. Here they perform isolation task in transferring vibration due to road irregularities to driver's body. Increasing competition and innovations in automobile sector, tends to modify the existing products and replacing old products by new and advanced material products, more efforts are taken in order to increase the comfort of user, to improve the suspension system and hence many modifications have taken place over the time. Inventions of parabolic leaf spring and use of composite materials, for these springs are some of the latest modifications in suspension system.

We can reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness due to the introduction of composite materials. Therefore composite materials are now used in automobile industries to replace metal parts. Elastic strain energy capacity is also high in composite materials. As compared to steel, they also have high strength-to-weight ratio. Composite materials offers opportunity for substantial weight saving. Spring are design to absorb and store energy and then release it hence strain energy of material and shape becomes major factors in designing the spring. The spring allows the movement of wheel over obstacles and then after, returns the wheel to its normal position. This work is mainly focused on the implementation of composite materials specially (FRP composites) by replacing steel in conventional parabolic leaf springs of a suspension system. They have presented an artificial genetics approach for the design optimization of composite leaf spring. To meet the needs of natural resources conservation, automobile manufacturers are attempting to reduce the weight of vehicles in recent years. To interest in reducing the weight of vehicle parts has necessitated the use of better material, robust design and manufacturing processes[1]. The suspension leaf spring is one of the potential elements for weight reduction in automobiles as it leads to the reduction of spring weight of automobile. Different methods are in use for design optimization, most of which use mathematical programming techniques. Use GA, the optimum dimensions of a composite leaf spring have been obtained, which contributes towards achieving the minimum weight with adequate strength and stiffness. In the present work analytical and Finite element method has been implemented[2]. This was to modify the existing leaf spring with consider the dynamic load effect. Leaf spring manufactured by Awachat industries Pvt. Limited has been selected for stress analysis. One of the important areas where one can improve the product quality while keeping the cost low is the design aspect. One can design the part in such a way that its performance and quality increases while the customer has to pay min amount as compared to the same product of other companies. Material and manufacturing process are selected upon on the cost and strength factor whereas the design method is selected on the basis of mass production. We could get a correct approach to designing the leaf spring is ensured by finite element method and ANSYS tool. Thus, they epitomize the quality of the product that are essential for the manufacturing. They have Introduced the analysis and optimization of a composite leaf spring a four-leaf steel spring used in passenger cars is replaced with a composite spring made of glass/epoxy composites[3]. The existing analytical and experimental solutions are being verified by the finite element results. They show stresses and deflections. With the results of the steel leaf spring, a composite is being prepared from fibre glass. Now, the epoxy resin is being designed. And then it is optimized using ANSYS software. Main consideration is given to the optimization of the spring geometry. The main objective was the shape optimization of the spring to give the minimum weight. The results have implied that the optimum spring width decreases hyperbolically. It also tells us that the thickness increases linearly from spring eye towards the axle seat. As compared to the steel spring the stresses in the composite leaf spring are much lower. They have analyzed mono Composite Leaf Spring for Light Weight Vehicle – Design, End Joint Analysis and Testing. Single leaf with variable width and thickness and constant cross sectional area of glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties as the multi-leaf spring, was designed [4]. It was then fabricated (hand-lay-up technique) and tested. Computer algorithm using C-language has been used for the design of constant cross-section leaf spring. The results showed that a spring width decreases hyperbolically. From the spring eyes towards the axle seat the thickness increases linearly. The finite element results are being produced using ANSYS software. Hence, stresses and deflections are verified. They are being verified with analytical and experimental results. The design constraints were stresses (Tsai-Wu failure criterion) and displacement. The composite spring has stresses that are much lower and the natural frequency is higher as compared to that of the steel spring. Hence, spring weight is nearly 85 % lower with bonded end joint and with complete eye unit.

The aim of this paper is to present a low cost fabrication of complete mono composite leaf spring and mono composite leaf spring with bonded end joints. With this the aim is to perform general study on the analysis and design [5]. A single leaf with variable thickness and width for constant cross sectional area of unidirectional glass fibre reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multi leaf spring. It was first designed and then fabricated (hand-lay- up technique) and then finally tested. has been used for The design of constant cross-section leaf spring is being performed by computer algorithm using C-language. It has been observed that the spring width decreases hyperbolically. Also thickness increases linearly from the spring eyes towards the axle seat. The finite element results are being produced using ANSYS software. It shows that stresses and deflections were verified. They were being verified with analytical and experimental results. The design constraints were stresses (Tsai-Wu failure criterion) and displacement. When we compared composite spring with the steel spring the composite spring has stresses that are much lower. Hence, the natural frequency is higher. Also the spring weight is nearly 85 % lower with bonded end joint and with complete eye unit.

In current model they design the non-linear analysis of a parabolic leaf spring have tapered cantilever beams [6]. This is traditionally termed as leaf springs. It is for the large deflections in comparison to a beam of constant cross-section that takes the domain of geometric in the form of nonlinearity. The shape of leaf spring in parabolic here assumed to be made of highly elastic steel. Numerical simulation was carried out using both the small and large deflection theories to analyse the stress and the deflection of the same beam. There is a significant effect of non-linear analysis on the beam's response under a tip load. The actual bending stress at the fixed end is found to be nonlinear theory. It is 2.30-3.39 % less in comparison to a traditional leaf spring having the same volume of material. Far away from the fixed end of the designed parabolic leaf spring region the maximum stress occurs. The investigation is to improve the eye-end design to overcome the problem of the delimitation failure. Three designs of eye-end attachment for composite leaf springs are described. The material used is glass fiber reinforced polyester, static testing and finite element [7].

Analysis has been carried out to obtain the characteristics of the spring. The load–deflection curves and strain measurement have been plotted for comparison with FEA predicted values. This is done as a function of load for the three designs tested. The main concern associated with the first design is the delimitation failure at the interface of the fibres that have passed around the eye and the spring body. The design can withstand 150 KN static proof load. Also the design can bear one million cycles fatigue load. The FEA results have confirmed that there is a high inter laminar shear stress concentration in that region. The second design feature is an additional transverse bandage around the region prone to delimitation. Delimitation was contained but not completely prevented. The problem with the third design is overcome by ending the fibres at the end of the eye section. In this paper we have focused on the response of a leaf spring of parabolic shape and it is assumed to be made of highly elastic steel [8]. This simulation analysis was carried out using both the small and large deflection theories to analyse the stress and the deflection of the same beam. There is a significant effect on the beam's response under a tip load by the non-linear analysis. The actual bending stress at the fixed end which is calculated by nonlinear theory is 2.30-3.39 % less. The maximum stress is being observed at a The region which is far away from the fixed end of the designed parabolic leaf spring experiences the maximum stress.

II. Design Selection

The leaf spring behaves like a simply supported beam. In this the flexural analysis is done. It is done by considering it as a simply supported beam. This beam is subjected to both bending stress and transverse shear stress. They both are important parameters in the leaf spring design.
Here Weight and initial measurements of a Tata 207 Light commercial vehicle is taken-

SPECIFICATIONS

ENGINE		**FUEL TANK**	
Model	: TATA 497 SP	Capacity	: 60 liters
Type	: Water-cooled, Direct Injection, Diesel	**DIMENSIONS**	
Capacity	: 2956 cc	Wheel Base	: 3150 mm
Max.Output	: 65 HP @ 2800 rpm	Overall Length	: 5182 mm
Max Torque	: 18 mkg @1500-2000 rpm	Overall width	: 1860 mm
CLUTCH	: Single plate dry friction diaphragm type	Front Track	: 1537 mm
GEAR BOX	: GBS-76-514.1	Rear Track	: 1577 mm
Type	: Synchromesh on all gears	**MINIMUM GROUND**	
	: 5 forward and 1 reverse	**CLEARANCE**	: 210 mm Laden
STEERING	: Power steering	**LOADING AREA**	
BRAKES		**Load Body**	
Type	: Vacuum assisted independent Hydraulic	Length	: 2440 mm
	: with Tandem Master Cylinder	Width	: 1675 mm
Front Brakes	: Disc brake	Height	: 415 rnm
Rear Brakes	: Drum brake	**WEIGHTS**	
SUSPENSION		Max GVW	: 2950 Kg
Front & Rear	: Reid Suspension with Semi-elliptical	Kerb Weight	: 1940 Kg
	: Leaf Spring	**SEATING CAPACITY**	: Driver + 1
WHEELS AND TYRES			
Tyres	: 7.00 x 16 12PR		

Figure 1 Tata 207 DI RX Specification

Weight of vehicle= 1940kg

Maximum Gross Vehicle Weight= 2950 kg

Maximum Load carrying capacity of a vehicle = 2950- 1940 = 1010 kg including Driver)

Taking factor of safety (FS) = 2

Acceleration due to gravity (g) = 9.81 m/s^2

Therefore; Total Weight = 2950 × 9.81 = 28939.5 N

Since the vehicle is 4-wheeler, a single leaf spring corresponding to one of the wheels takes up one 4th of the total weight.

$$\frac{28939.5}{4} = 7235\ N$$

Load acted on the leaf spring is divided by the two because of consideration of the cantilever beam.
But 2F = 7235 N, F = 3617.5 N
Span length, 2L = 852 mm, L= 426 mm.
Now the Maximum Bending stress of a leaf spring is given by the formula-

$$\sigma = \frac{6 \times f \times l}{n \times b \times t^2}$$

$$\sigma = \frac{6 \times 3617.5 \times 426}{7 \times 76.2 \times 11.3^2}$$

$$\sigma = 135.756\ \mathrm{N/mm^2}$$

The Total Deflection of the leaf spring is given by -

$$\delta = \frac{6 \times f \times l^3}{E \times n \times b \times t^3}$$

$$\delta = \frac{6 \times 3617.5 \times 426^3}{2.1 \times 10^5 \times 7 \times 76.2 \times 11.3^3}$$

$$\delta = 10.3819\ mm$$

Data of the above stated light weight four wheeler vehicle.
Straight length of the parabolic leaf spring (L) =852 mm
The ratio of camber length of parabolic leaf spring is given by manaspatnaik et al (2012)

$$\frac{C}{L} = 0.089$$

$$C = 0.089 \times 852$$

$$C = 75.828\ mm$$

By analyzing half of the leaf spring is enough. The half of the applied force would have been taken, but here we took as it is to account over loadings of the vehicle and flexures of the leaf spring.
Hence,

$$\frac{L}{2} = 426\ mm$$

F=3617.5 N t=? b=?

Calculation for "t" and "b" dimensions which are capable of withstanding the loading behaviour of the conventional and composite parabolic leaf spring is the result of this design. From elementary equation we can find out thickness and width of the spring.
Now to find out bending stress we use the formulae,

$$\sigma = \frac{6 \times f \times l}{n \times b \times t^2}$$

Now the total deflection of the leaf spring is being given by,

$$\delta = \frac{6 \times f \times l^3}{E \times n \times b \times t^3}$$

S
After solving the above two equations the result obtained is:

$$\sigma = \frac{6 \times 3617.5 \times 426}{7 \times b \times 11.3^2}$$

$$974.54 = \frac{6 \times 3617.5 \times 500}{3 \times b \times 8^2}$$

b= 76.2 mm

Hence the thickness of the leaf spring is obtained by putting total deflection with stress:

$$145 = \frac{6 \times 3617.5 \times 500^3}{2.1 \times 10^5 \times 7 \times 76.2 \times t^3}$$

t=11.3mm

At no load, Partial load, Full load, over load and at level of FOS condition are considered in the analysis 2500 N, 3000N, 3617.5N, 4000N and 4855.95 respectively.

III. Design Data For Design Parabolic Leaf Spring

Length of the main leaf (L)	852 mm
Length of the second leaf(L)	851.83 mm
Length of the third leaf(L)	758.1 mm
Length of the fourth leaf(L)	624.41
Length of the fifth leaf(L)	508.68
Length of the six leaf(L)	374.61
Length of the seven leaf(L)	239.87
Width of leaf (b)	76.2 mm
Camber height (C)	75.828 mm
Tip inserts	25 mm dia.
Thickness of leaves (t)	11.3mm

a. Modelling of parabolic leaf spring

CREO is a feature-based, parametric solid modelling system with many extended design and manufacturing applications. Three dimensional model of parabolic leaf spring are prepared by using 3D modelling software CREO 3.0 after design and direction of load applied is presented in contour plot.

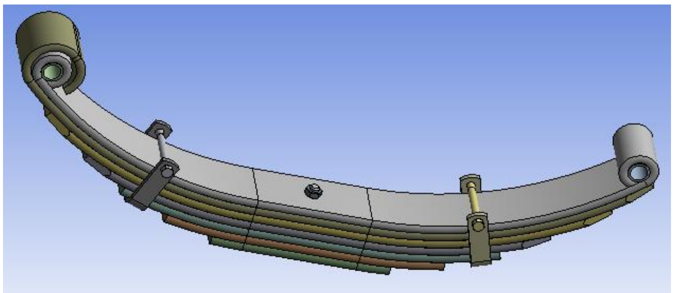

Fig-2 CAD model of parabolic Leaf spring

Meshing of the parabolic leaf spring model was done after defining the material properties and assigning each material to each of the component. Mesh convergence test is first performed for deciding the element size for meshing of the model.

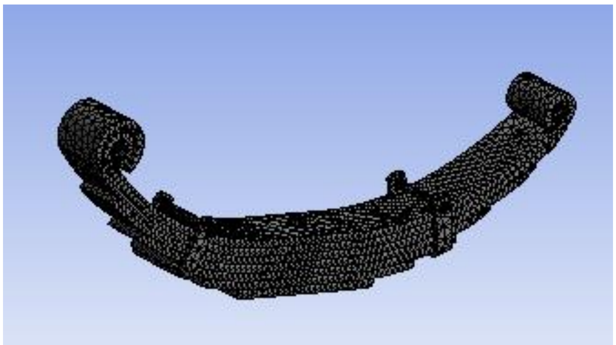

Fig -3 mesh element

Tetrahedral elements are used for all the components of parabolic leaf spring. Tetrahedral elements better approximate the shape with minimum error as compared to brick elements. According to the mesh convergence test, the final Size of the tetrahedral elements for all the components of parabolic leaf spring and a total no. of 607575 nodes and 304886 elements are generated after the meshing which is almost more than 15 times of initial generated mesh

IV. Result Analysis

a. Equivalent Von-mises stress-

The results of four materials are shown in fig 4,5,6 and 7 The maximum Von-Mises stress generated in conventional steel leaf spring is 32.44 Mpa, E-Glass/Epoxy composite material is 51.82 Mpa, Carbon-Epoxy composite material is 38.92 Mpa and Kevlar-Epoxy composite material is 206.94 Mpa. After having same meshing, Boundary and loading condition.

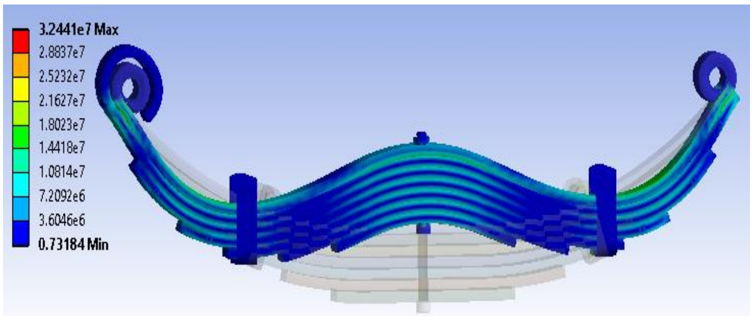

Figure 4 Von-mises stress distribution on steel EN45 parabolic leaf spring

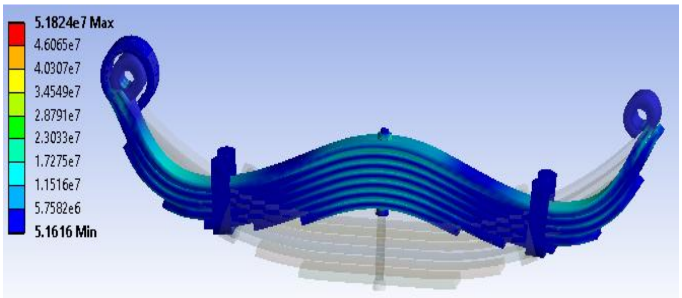

Figure 5 Von-mises stress distribution on E-glass/epoxy parabolic leaf spring

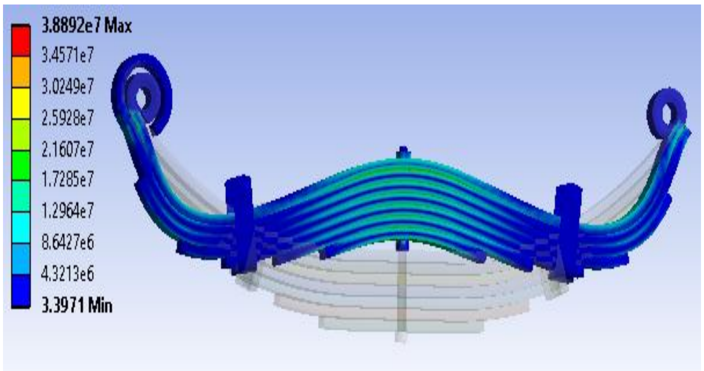

Figure 6 Von-mises stress distribution on carbon/epoxy parabolic leaf spring

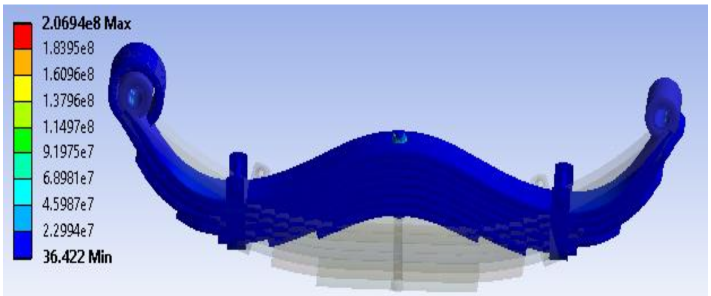

Figure 7 Von-mises stress distribution on Kevlar/epoxy parabolic leaf spring

b. Total deformation

The results of four materials are shown in fig 8, 9, 10, 11. The maximum deflection generated in conventional steel leaf spring is 1.93 mm, E-Glass/Epoxy composite material is 39.09 mm, Carbon-Epoxy composite material is 40.81mm and Kevlar-Epoxy composite material is 36.24 mm after having same meshing, boundary and loading condition.

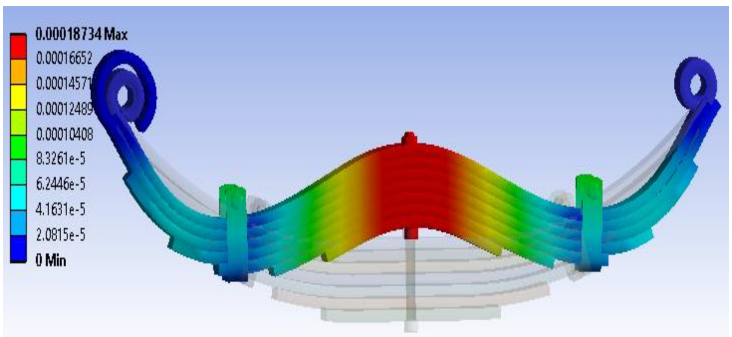

Figure 8 Total deformation steelEN45 parabolic leaf spring

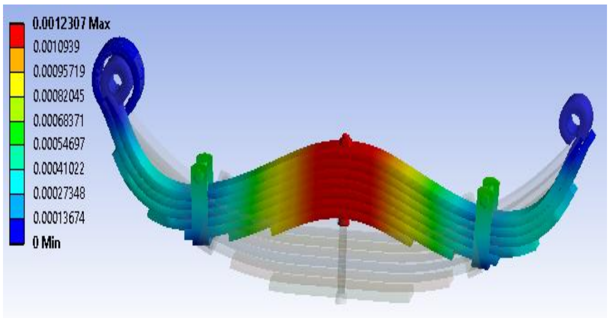

Figure 9 Total deformation E-glass/epoxy parabolic leaf spring

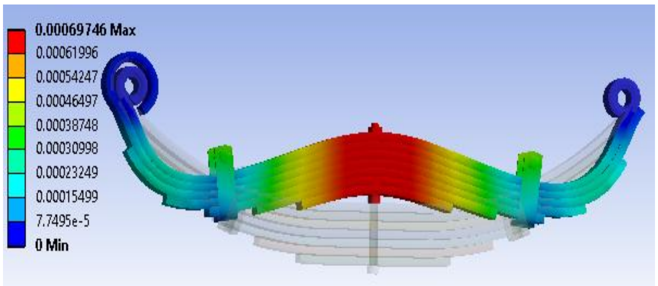

Figure 10 Total deformation carbon/epoxy parabolic leaf spring

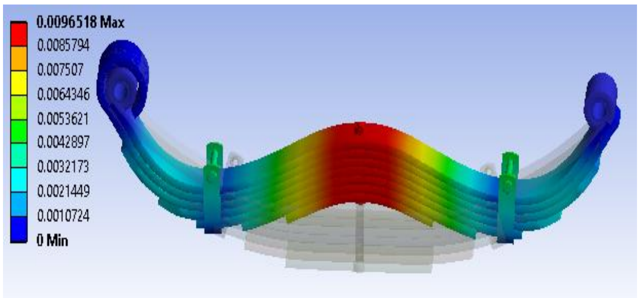

Figure 11 Total deformation Kevlar/epoxy parabolic leaf spring

c. Maximum principal stress

The results of four materials are shown in fig 12, 13, 14, 15. The maximum principal stress generated in conventional steel leaf spring is 26.721 Mpa, E-Glass/Epoxy composite material is 53.34 Mpa, Carbon-Epoxy composite material is 29.18 Mpa and Kevlar-Epoxy composite material is 236.95 Mpa, after having same meshing and boundary condition.

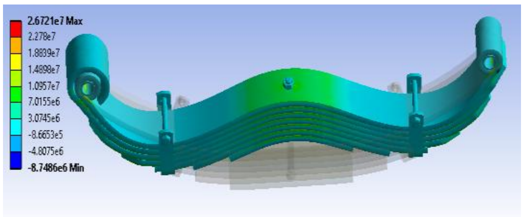

Figure 12 maximum principal stress steel EN45 leaf spring

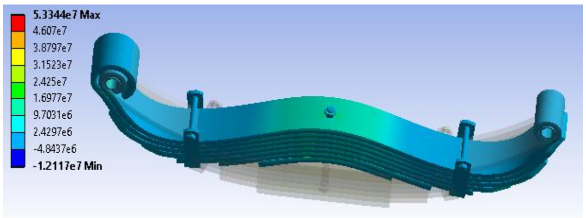

Figure 13 maximum principal stress E-glass/epoxy leaf spring

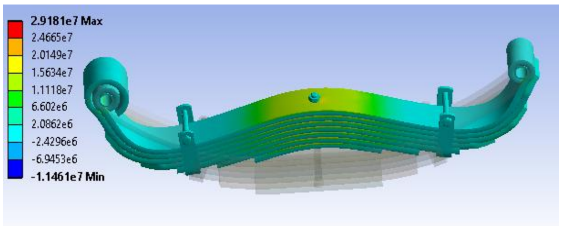

Figure 14 maximum principal stress carbon/epoxy

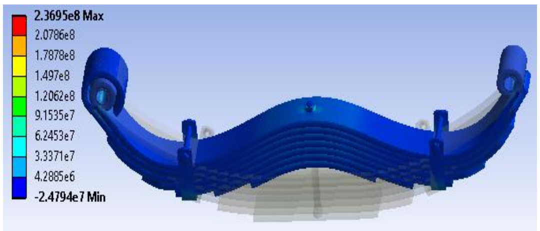

Figure 15 maximum principal stress kevlar/epoxy

d. Equivalent elastic strain

The results of four materials are shown in fig 16, 17, 18, 19. The equivalent elastic strain generated in conventional steel leaf spring is 0.00016576, E-Glass/Epoxy composite material is 0.0019017, Carbon-Epoxy composite material is 0.00152 and Kevlar-Epoxy composite material is 0.009, after having same meshing and boundary condition.

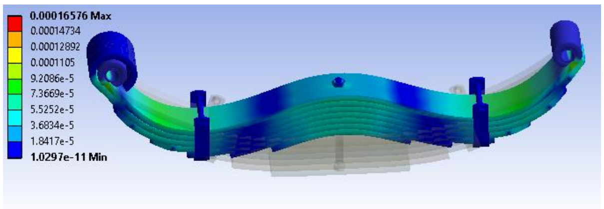

Figure 16 Equivalent elastic strain steelEN45

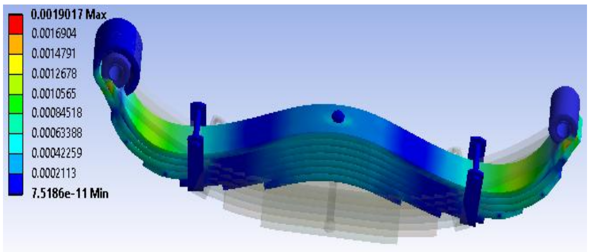

Figure 17 Equivalent elastic strain E-glass/epoxy

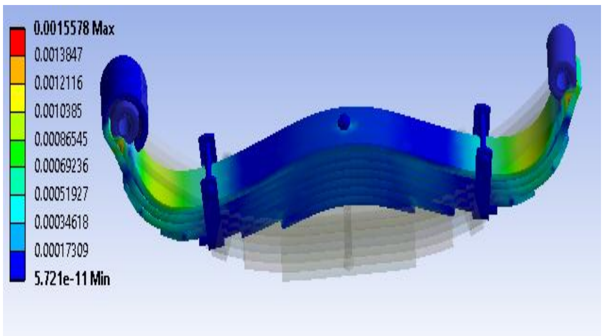

Figure 18 Equivalent elastic strain carbon/epoxy

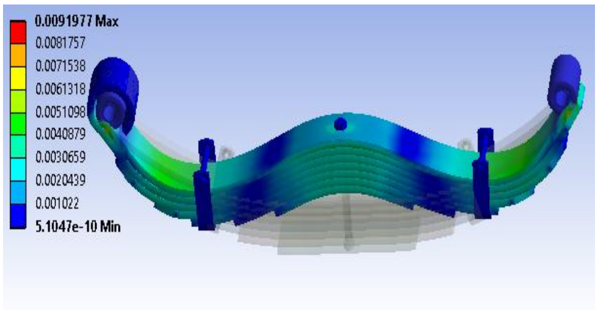

Figure 19 Equivalent elastic strain kevlar/epoxy

e. Load Verses Stress

Von-mises stress is widely used in industries to check whether their design will withstand a given load condition, using this information we can predict the design failure, if the maximum value of von-mises stress induced in the material is more than strength of the material. In analysis process we can see that von-mises stress is at maximum towards the fixed end of the parabolic leaf spring, and the value is less than yield point value of steel EN45 and composites. So the design of parabolic leaf spring is safe. Figure 20 shows the comparison of load verses stress of both steel and composite leaf springs. It shows the load is taken on the x-axis. Whereas the stress for steel and composite material is taken on y-axis. Observation of the graph indicates the difference level of stress of four different materials. The variation of stress against the load applied for the material under consideration. It is observed that the stresses linearly increase with the applied load maximum.

Table 1 Load vs Von-mises stress for various materials

VON MISES STRESS					
S.NO.	LOAD (N)	STEEL EN45 (MPa)	E-GLASS/EPOXY (MPa)	CARBON/EPOXY (MPa)	KEVLAR/EPOXY (MPa)
1	2500	22.42	35.815	26.878	6.215
2	3000	26.9	42.977	32.253	7.16
3	3617.5	32.441	51.824	38.892	7.3
4	4000	35.871	57.3	43	8.11
5	4856	43.548	69.556	52.2	9.12

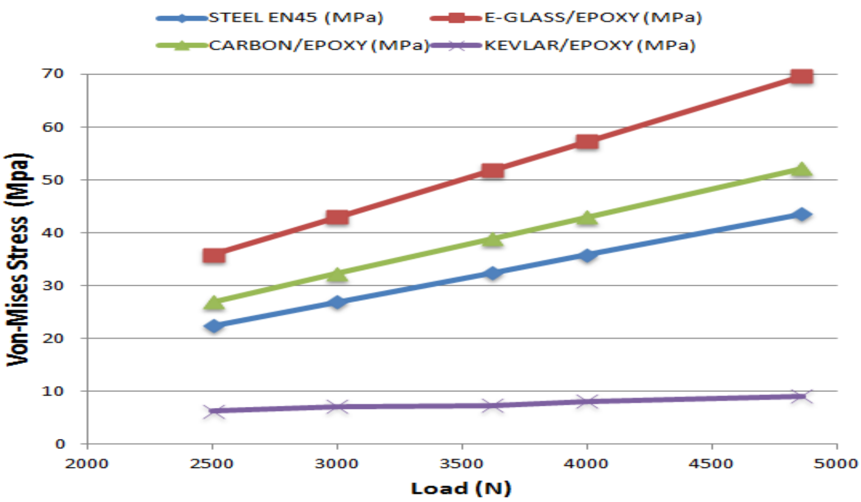

Figure 20 Load vs Von-mises Stresses graph for various materials

V. Conclusion

In this thesis, a parabolic leaf spring is designed and analyze for a certain automobile. The parabolic leaf spring is designed for the load of 3617.5N. Theoretical calculations have been calculated for parabolic leaf spring dimensions at different cases like varying thickness, camber, span and no. of leaves by mathematical approach. In this thesis, analysis has been done by taking materials Steel EN45, E-glass/epoxy, carbon/epoxy, and Kevlar/epoxy. Static and fatigue analysis are conducted on total assembly of parabolic leaf spring. The results show: The stresses in the composite parabolic leaf spring of design are much lower than that of the allowable stress

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