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Static structural analysis of composite material parabolic leaf spring for TATA ACE mini loader truck using FEA software

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Abstract- This research work done for the replacement of conventional steel EN-45 spring with a Composite spring using combined materials like E-Glass/epoxy UD, carbon/epoxy UD, kevlar/epoxy UD fiber. the parabolic spring CAD models design parameters were selected using reversed engineering method and validate data using conventional design method and analysis with the target of minimizing weight of the composite parabolic leaf spring as compared to the steel EN-45 spring. The spring was modeled in Pro/E and thus the analysis was done using ANSYS software.

1.Objective of the research work

The purpose of the present investigation is to reduce the stress acting in the spring in order to reduce the vibration of vehicle objectives of this work are -

i.To do Finite Element Modeling of the parabolic steel leaf spring and composite parabolic leaf spring.

ii.Analysis of CAD models of parabolic leaf spring with the help of finite element method on ANSYS-14 software.

iii.To choose the optimum parabolic leaf spring which have lower stress.

As we discussed the problem identified and solution methods through the various literature, now the objective of the research thrust is to replace the existing conventional steel EN45 material through the composite material.

ASSUMPTIONS

we make the following assumptions:

1. Automobile is assumed to be stationary.

2. Finite element modeling and analysis is performed for rear single parabolic leaf spring.

4. The conventional parabolic leaf spring material is steel EN45.

5 E-glass/epoxy, carbon/epoxy, and Kevlar/epoxy are used to design and analysis of parabolic leaf spring. For achieving the objective of the work. a flow chart is prepared which shows various steps taken in to consideration.

2. Methodology

Reverse Engineering
(To take dimension from the existing PLS)

↓

CAD Model Generation
(From Creo parametric 2.0)

↓

Static Analysis (With Conventional Steel and Composite material in ANSYS-14)

↓

Result
(Max. Deflection, equivalent von-mises stress, Max. principle stress, stiffness and weight)

3. Design data for design parabolic leaf spring

Length of the main leaf (L)	1072mm
Length of the second leaf(L)	1072mm
Length of the third leaf(L)	1072mm
Width of leaf (b)	60mm
Camber height (C)	95.4mm
Tip inserts	50mm dia.
Centre rubber pad	100mm×50mm×5 mm
Thickness of leaves (t)	8mm

4. FE modeling of parabolic leaf spring

4.1 Introduction

In this section application of FE analysis is discussed, FEA tool is the mathematical idealization of real system. Is a computer based mathematical method that breaks CAD geometry into nodes and element. It is useful for complicated geometry and boundary conditions where exact analytical solution are difficult to obtain. The static FE analysis is carried out in this section. FEM general purpose software ANSYS -14 is used for the analysis of parabolic leaf spring.

4.1.1 Pre processing

4 .1.1.1 Parabolic Leaf Spring Model

CAD modeling of the spring components is the first step of finite element analysis. CAD modeling of the parabolic leaf spring using conventional steel EN45 and composite materials has been done according to the dimensions suggested by different-different researchers in solid modeling software Pro/Engineer creo-2.

4.1.1.2 Importing the Geometry to the ANSYS-14

CAD model of the parabolic leaf spring is saved as IGES format in Pro/Engineer creo-2. Then, this IGES CAD file imported into ANSYS-14 for further analysis.

4.1.1.3 Material Properties

There are four parabolic leaf springs on which the analyses are going to perform, one is conventional steel EN45 parabolic spring and other three are composite parabolic leaf spring. The mechanical properties of the traditional steel material being used in this analysis and therefore the mechanical properties of composite material which can be taken as per ANSYS-14 standard material library.The above mentioned three composite materials are wont to perform the finite element analysis and compared with the conventional steel EN45 material for better improved mass and low stress and low total deformation.

4.2 Meshing

4.2.1 Mesh convergence test

A check point is tested on the assembly by using mesh convergence test so as to simplify and justify the analysis result. during this process the von- misses stress level is tested on assembly by taking different size of element during meshing. With the help of ANSYS-14 software, the respective mesh sizes with corresponding von- misses stresses are given within the table 4.1 below. The load value is same for every mesh size 2700 N. We observed that below the mesh size of 5.5 mm there are small variations within the value of von- misses stresses. therefore the mesh size of 5mm is taken in this study for meshing of the parabolic leaf spring.

Mesh element size in mm	Equivalent von-mises stress Mpa
7.5	102.96
7	108.92
6.5	126.81
6	114.76
5.5	142.79
5	156.44
4.5	151.58
4	138.81
3.5	159.17
3	167.70

Fig -4.1Variation in von mises stress value with respect to the mesh size

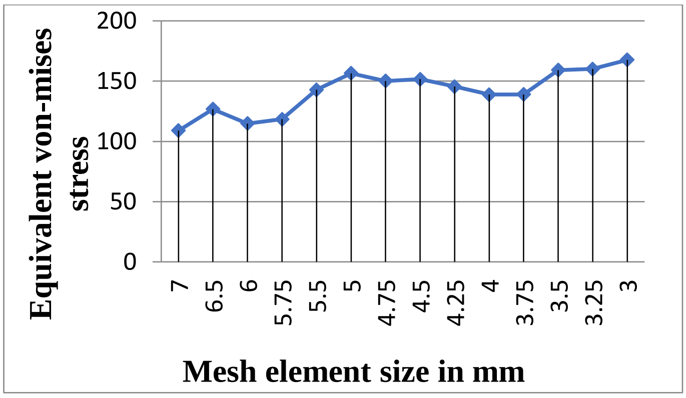

Table no- 4.1 meshing size and equivalent (von-mises stress)

Tetrahedral elements are used for all the components of parabolic spring . Tetrahedral elements better approximate the form with minimum error as compared to brick elements. consistent with the mesh convergence test, Size of the tetrahedral elements are 5mm for all the components of parabolic spring and a total no. of 78959 nodes and 26982 elements are generated after the meshing. Meshed parabolic spring model is shown in fig. 4.2

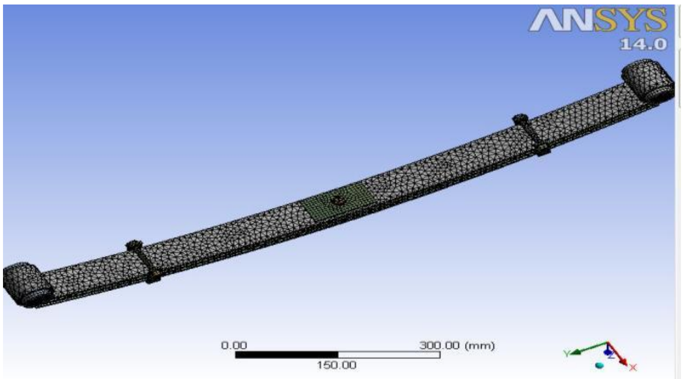

Fig.4.2 Meshed parabolic leaf spring model

4.2.2 Contact Interfaces

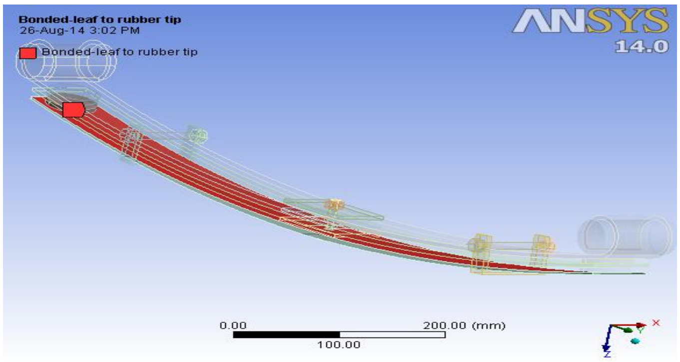

Fig-4.3 show bonded contact between parabolic leaf and rubber tip

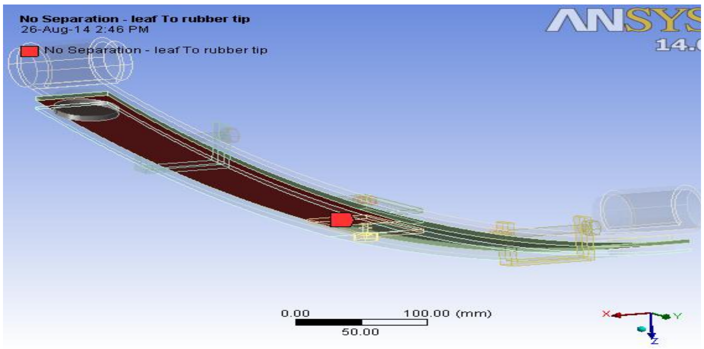

Fig-4.4 show no separation contact between parabolic leaf and rubber tip

4.2.3 Loading and boundary condition

the parabolic spring (steel EN45 and composite) which is shown in Fig.4.3 and fig.4.4 After load is applied of magnitude 500 to 5600 N within the upward direction at the center of the parabolic leaf spring. This specific computation of load to be applied has been completed on the idea of Gross Vehicle Weight (GVW). This has been clearly shown the Fig.4.5

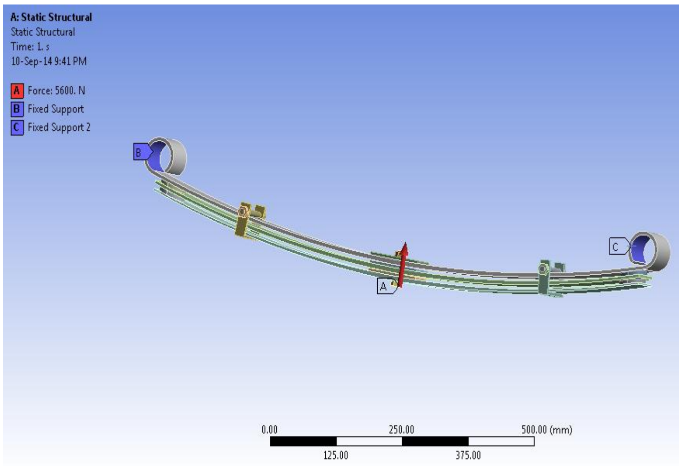

Fig 4.5 show loading and boundary condition of parabolic leaf spring

4.3 Static analysis of the parabolic spring

4.3.1 Introduction

Static analysis of the parabolic spring (conventional steel EN45 and composite material) is performed using ANSYS-14 software to find the von-misses stresses, maximum principle stresses, equivalent elastic strain and deflection. The Analysis involves the subsequent discretization called meshing, boundary conditions and loading. A virtual model of every parabolic leaf is modeled separately, then it is assembled together using pro-E creo 2.0 (figure 4.5).This model is then imported into ANSYS- 14 for conducting static analysis. Same model is employed for the static analysis with four different materials steelEN45,E-glass/epoxy, carbon/epoxy, and Kevlar epoxy. These materials are selected within the Ansys-14 software by inserting the appropriate material properties.

In this section the conventional steel EN45 and composite parabolic leaf spring will be analyzed to see the various results from the static analysis The software used to perform the analysis is ANSYS -14,The different comparative results of steel leaf spring and composite leaf spring are obtained to predict the advantages of composite leaf spring for a vehicle.

4.3.2 Post- processing

4.3.2.1 Equivalent Von-misses stress-

The results of 4 materials are shown in fig 4.6, 4.7, 4.8, 4.9 the utmost Von-Misses stress generated in conventional steel leaf spring is 322.62 Mpa, E-Glass/Epoxy material is 271.1 Mpa, Carbon-Epoxy material is 494.75 Mpa and Kevlar-Epoxy material is 438.19 Mpa. After having same meshing, Boundary and loading condition.

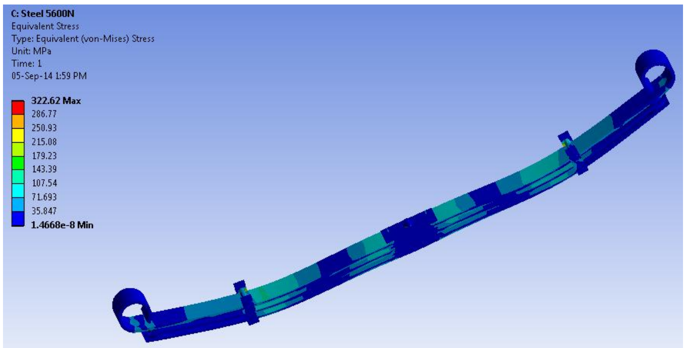

Figure 4.6 Von-mises stress distribution on steel EN45 parabolic leaf spring at 5600 N

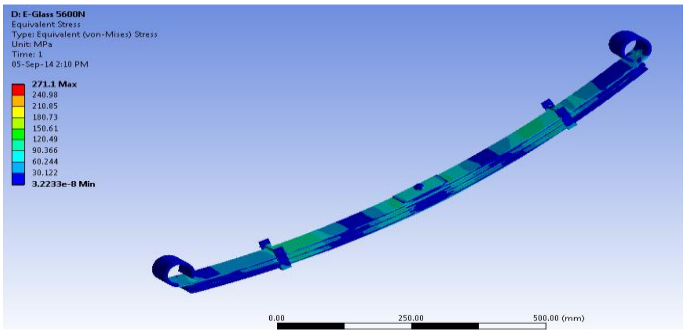

Figure 4.7 Von-mises stress distribution on E-glass/epoxy parabolic leaf spring at 5600 N

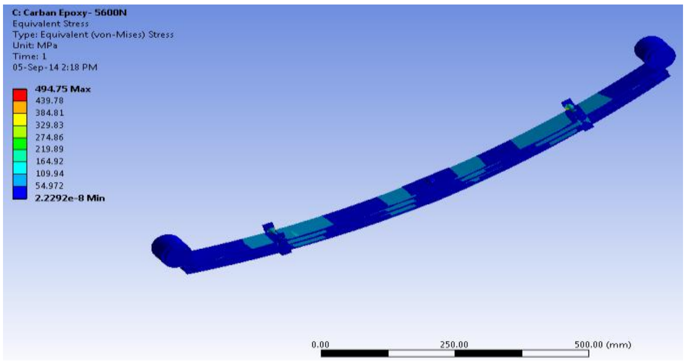

Figure 4.8Von-mises stress distribution on carbon/epoxy parabolic leaf spring at 5600 N

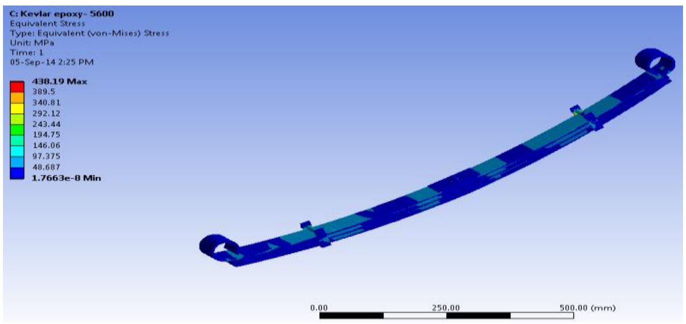

Figure 4.9 Von-mises stress distribution on Kevlar/epoxy parabolic leaf spring at 5000 N

4.3.2.2 Total deformation

The results of 4 materials are shown in fig 4.10, 4.11, 4.12, 4.13 the utmost deflection generated in conventional steel leaf spring is 14.06 mm, E-Glass/Epoxy material is 37.25mm, Carbon-Epoxy material is 30.91mm and Kevlar-Epoxy material is 24.63 mm. After having same condition.

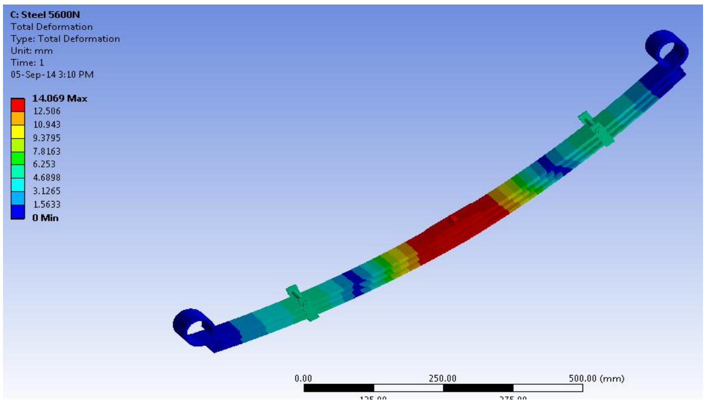

Figure 4.10 total deformation steelEN45 parabolic leaf spring at 5600

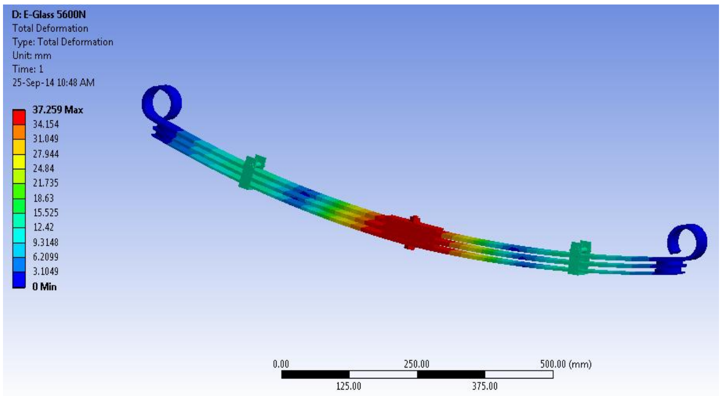

Figure 4.11 total deformation E-glass/epoxy parabolic leaf spring at 5600N

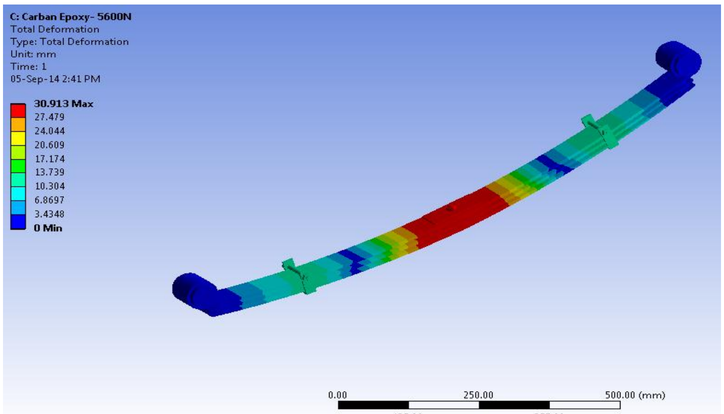

Figure 4.12 total deformation carbon/epoxy parabolic leaf spring at 5600 N

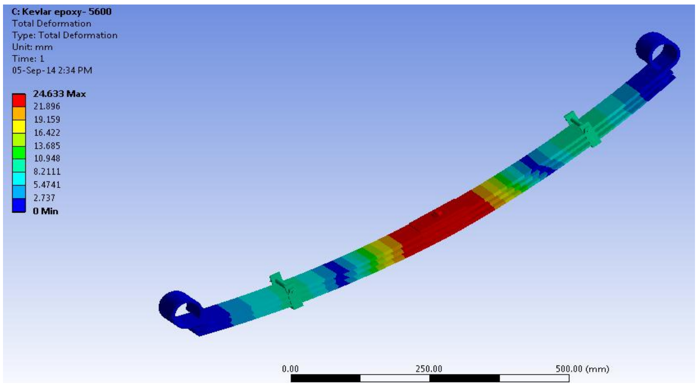

Figure 4.13 Total deformation Kevlar/epoxy parabolic leaf spring at 5600 N

4.3.2.3 Maximum principle stress

The results of four materials are shown in fig 4.14, 4.15, 4.16, 4.17 The maximum principle stress generated in conventional steel leaf spring is 303.74 Mpa, E-Glass/Epoxy composite material is 376.64 Mpa, Carbon-Epoxy composite material is 433.97 Mpa and Kevlar-Epoxy composite material is 455.35 M.pa. After having same meshing and boundary condition.

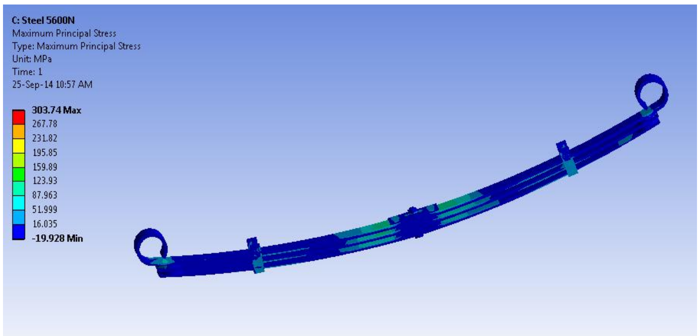

Figure 4.14maximum principle stress steel EN45 at 5600N

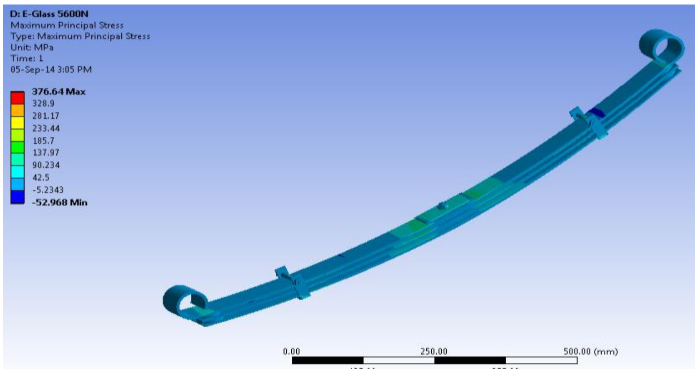

Figure 4.15 maximum principle stress E-glass/epoxy at 5600N

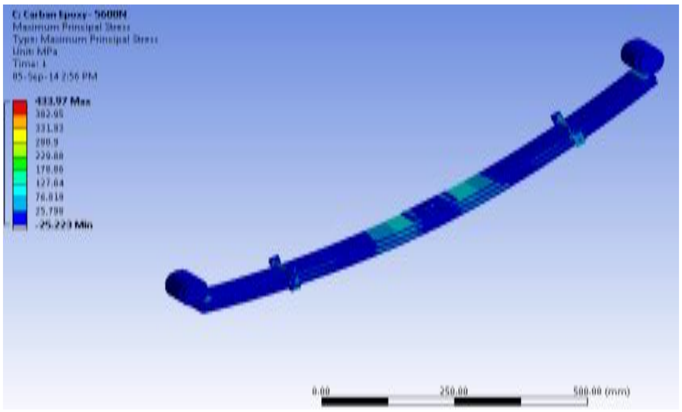

Figure 4.16 maximum principle stress carbon/epoxy at 5600N

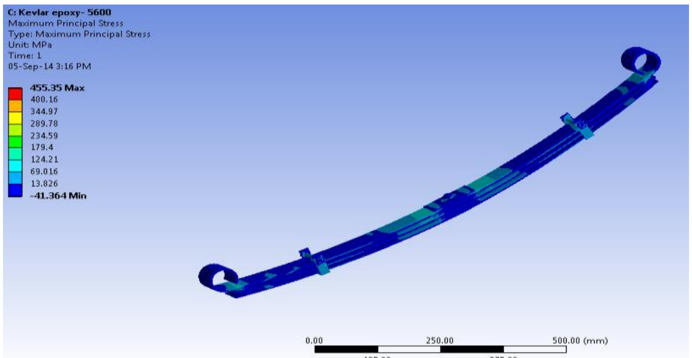

Figure 4.17 maximum principle stress kevlar/epoxy at 5600N

5.3.2.4 Equivalent elastic strain

The results of four materials are shown in fig 4.18, 4.19, 4.20, 4.21The equivalent elastic strain generated in conventional steel leaf spring is 0.0155, E-Glass/Epoxy composite material is 0.0357, Carbon-Epoxy composite material is 0.0419 and Kevlar-Epoxy composite material is 0.0361. After having same meshing and boundary condition.

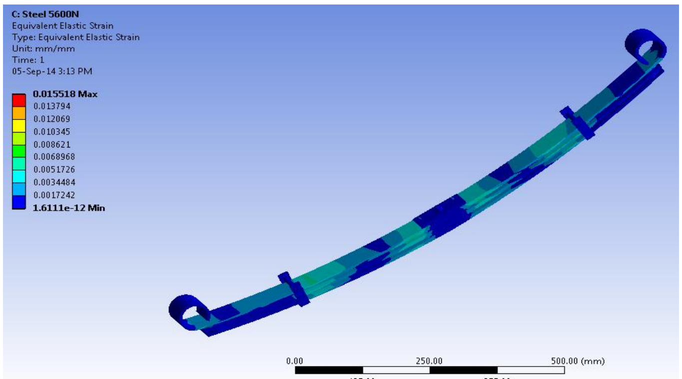

Figure 4.18 Equivalent elastic strain steel EN45 at 5600N

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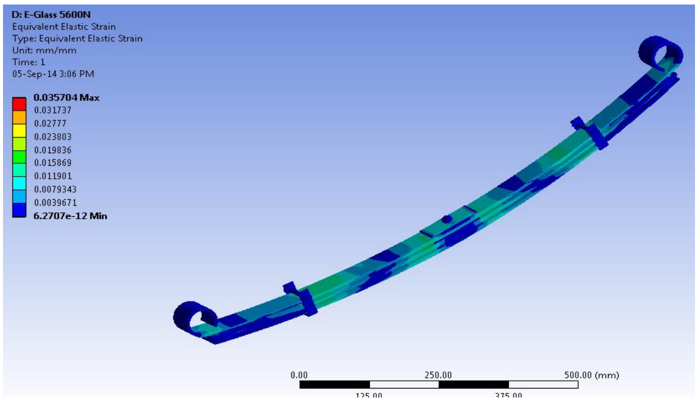


Figure 4.19 Equivalent elastic strain E-glass/epoxy at 5600N

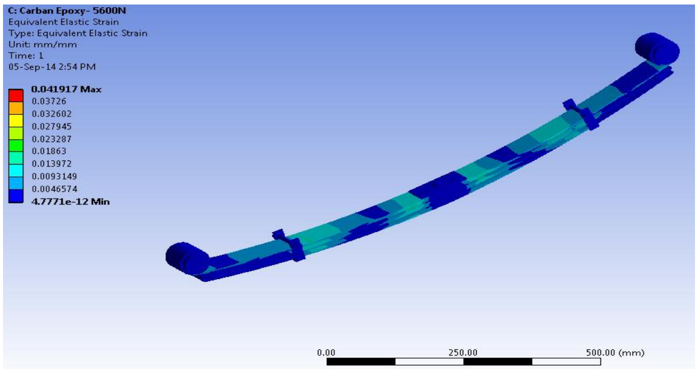


Figure 4.20Equivalent elastic strain carbon/epoxy at 5600N

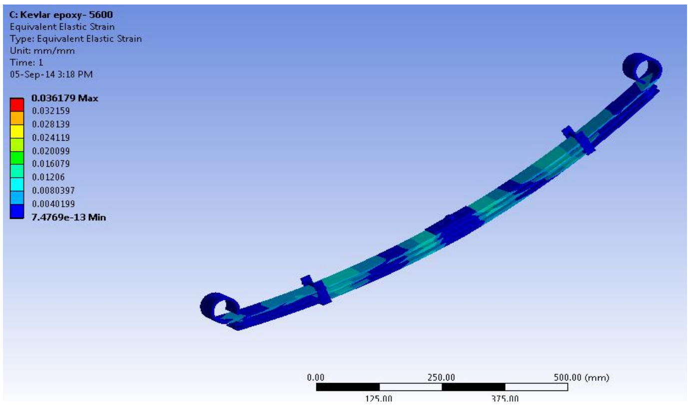
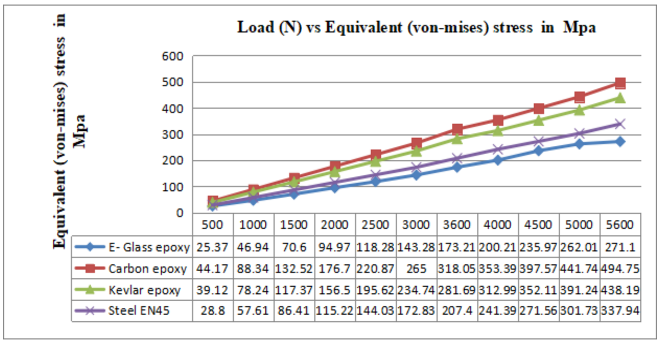


Figure 4.21 Equivalent elastic strain kevlar/epoxy at 5600N

5. Static analysis results and discussion

5.1 Load Verses Stress

Von-misses stress is widely employed by to check whether their design will withstand a given load condition, using this information we will say design will fail.

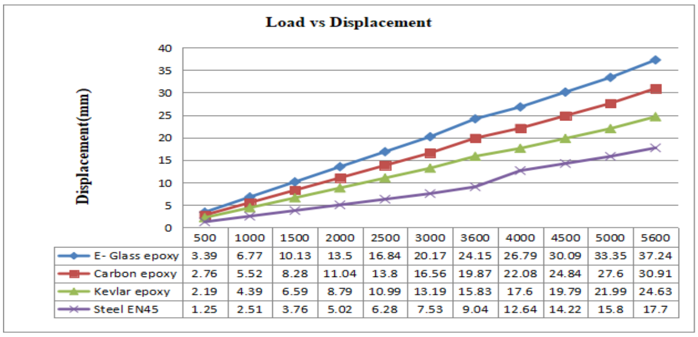


	500	1000	1500	2000	2500	3000	3600	4000	4500	5000	5600
E- Glass epoxy	25.37	46.94	70.6	94.97	118.28	143.28	173.21	200.21	235.97	262.01	271.1
Carbon epoxy	44.17	88.34	132.52	176.7	220.87	265	318.05	353.39	397.57	441.74	494.75
Kevlar epoxy	39.12	78.24	117.37	156.5	195.62	234.74	281.69	312.99	352.11	391.24	438.19
Steel EN45	28.8	57.61	86.41	115.22	144.03	172.83	207.4	241.39	271.56	301.73	337.94

Figure- 5.1 shows Load Vs Equivalent (Von-Mises) Stress

5.2 Load Verses Deformation

The rate of deformation is a function of the material properties, and therefore the applied load depending on the magnitude of the applied stress and its duration. Figure-5.2 shows the comparison of load verses deformation of both steel and composite leaf springs. it's found that the deformation in composite leaf springs is higher than steel leaf spring for the given loading conditions.



	500	1000	1500	2000	2500	3000	3600	4000	4500	5000	5600
E- Glass epoxy	3.39	6.77	10.13	13.5	16.84	20.17	24.15	26.79	30.09	33.35	37.24
Carbon epoxy	2.76	5.52	8.28	11.04	13.8	16.56	19.87	22.08	24.84	27.6	30.91
Kevlar epoxy	2.19	4.39	6.59	8.79	10.99	13.19	15.83	17.6	19.79	21.99	24.63
Steel EN45	1.25	2.51	3.76	5.02	6.28	7.53	9.04	12.64	14.22	15.8	17.7

Figure- 5.2 shows load vs displacement

5.3 Load verses maximum principle stress

According to maximum principle stress criterion the material of the parabolic leaf spring will be safe, if the ultimate tensile strength of the material is greater than maximum principle stress. Figure-5.3 shows the deviation of principle stress is very low at minimum load condition and the deviation of principle stress increases when the magnitude of applied load increases.

	Material	Weight of the parabolic leaf spring	% weight saving
1	Steel EN45	13.298kg	-
2	E-glass/epoxy	5.573 kg	58.13%
3	Carbon/epoxy	4.97 kg	62.63%
4	Kevlar/ epoxy	4.784 kg	64.03%

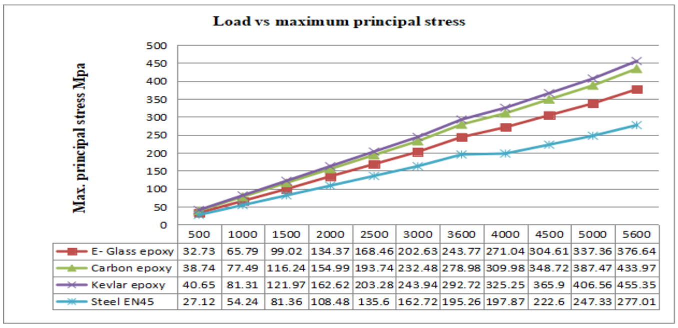


Figure- 5.3 Shows load vs maximum principle stress

5.4 Load verses stiffness

Stiffness is that the rigidity of an object, extent to which it resists deformation in response to an applied force. The complementary concept is flexibility or reliability, the more flexible an object is, the less stiff. The stiffness of a body could even be a measure of the resistance, offered by an elastic body to deformation. modulus of elasticity is required when flexibility is required . Figure-5.4 shows the comparison of load verses stiffness of both steel and composite leaf springs within the graph the load is taken on the x-axis. Where as the stiffness of steel and composite material are taken on y-axis. From the graph it's we'll see the variations in the respective stiffness of both materials. It is found that the stiffness of steel EN45 is higher than composite material parabolic leaf springs.

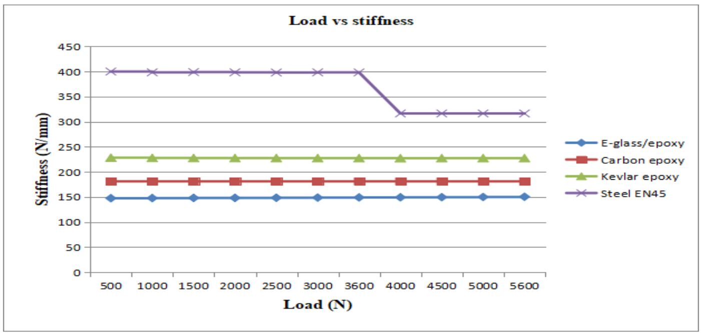
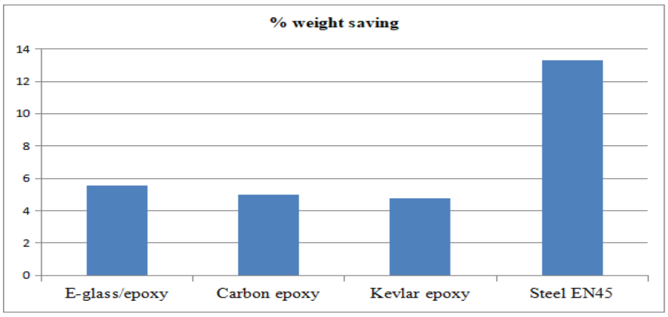


Figure 5.4 Shows load vs stiffness

4.5 Comparison of weights

The bar chart drawn below shows the comparisons in parabolic leaf spring weight (Kg) in case of steel and composite material. Blue bar is the weight of steel leaf spring and composite leaf springs. From this comparison of bar chart it is easily observed that the weight reduction in parabolic leaf spring. For steel leaf spring weight is 13.29 kg and for composite leaf spring.E-glass/epoxy weight is 5.57 kg, carbon epoxy weight is 4.97 kg, and Kevlar epoxy weight is 4.78 kg. Table shows the % saving of weight by using composites instead off steel EN45.



6.Conclusion and future scope

6.1 Conclusion

In this research work, a parabolic spring is meant and analyzed for TATA-ACE mini loader truck. The parabolic spring is meant for the load of 5600N. Theoretical calculations are calculated for parabolic spring dimensions at different cases like varying thickness, camber, span and no. of leaves by mathematical approach. during this work analysis has been done by taking materials Steel EN45, E-glass/epoxy, carbon/epoxy, and Kevlar/epoxy.Static analysis are conducted on total assembly of parabolic spring . The results show: The stresses within the composite parabolic spring of design are much less than that of the allowable stress.

A comparative study has been made between composites and steel EN45 parabolic spring for deflection, strain energy and stresses. From the results, of static analysis we observed that the composite parabolic spring is lighter and more economical than the traditional steel EN45 spring with similar design specifications. We observed that the weight savings of the composite parabolic spring made of Kevlar/epoxy fiber, is reduced by 64.03% compared to spring made from steel EN45, by using material E-glass/epoxy Fiber it's reduced by 58.13% compared to spring made up of steelEN45.by using material carbon/epoxy fiber it's reduced by 62.63% compared to spring made up of steelEN45.The introduction of composite materials was made it possible to reduce the weight of the parabolic leaf spring without any reduction on load carrying capacity and stiffness. Since the composite materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to those of steel EN45.we observed that the fabric shows more deflection and strain energy than that of steel, for fewer weight of the parabolic leaf spring mechanical efficiency will be increased. By observing the static analysis result, E-glass/epoxy Fiber is best than carbon/epoxy and Kevlar/epoxy.the foremost disadvantages of composite parabolic leaf spring are the matrix material has low chipping resistance when it is subjected to poor road environments which may break some fibers in the lower portion of the spring. this might end during a loss of capability to share flexural stiffness.

But this relies on the condition of the road. In normal road condition, this sort of problem will not be there. Composite parabolic leaf springs made from polymer matrix composites have high strength retention on ageing at severe environments.

6.2 Scope of future work

After completing the present work, it's found that the following things can be added as an extension to this work-

1.As analysis of composite parabolic spring and steel EN45 parabolic leaf spring is validated by the analytical results, so one can validate with manufacturing of actual prototype of composite and steel EN45 parabolic spring by testing on universal testing machine(UTM).

2.As this analysis is under static load condition, so one can choose the analysis of composite and steel EN45 parabolic leaf spring under dynamic loading condition.

3.one can do Vibration analysis of parabolic leaf springs.

4.Experimental procedure also used for performing and obtaining the good results.

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