OPTIMIZATION OF MONO PARABOLIC LEAF SPRING

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ABSTRACT
The intent of 21st century for automotive sector is fuel economy and emissions; due to this the automotive designers are revisiting automotive systems and parts for reducing the mass of the vehicles. For suspension system, leaf spring is one of the key targets for weight reduction because it adds in unsprung mass; which affects the ride of the vehicle. To move further, we are going to optimize the parabolic mono leaf spring for the material as composite and the best possible design parameters to design lightest spring meeting all design constraints as length, width, suspension travel and various design stresses. The basic theory for leaf spring design has been rechecked for authentication with advanced finite element analysis. This paper gives the automotive designer to find out better design for parabolic leaf spring implementation in place of present mono leaf spring on vehicle. The results of this paper give good values for the automotive manufacturer to standardize the design and optimization methodology.

KEYWORDS: *MonoLeaf Spring, Composite, static analysis, Weight reduction*

I. INTRODUCTION

Today automotive manufacturers are faced with several complex challenges. In a highly competitive market, customers are demanding more for their money. Motorists wish cars that propose high performance, comfort, refinement, safety as well as increased vehicle customisation. The automotive industry is also faced with Governments who are consistently introducing legislation that demand improvements in fuel efficiency, reduced emissions, increased recycling and greater safety for both pedestrians and occupants. The circumstances facing the auto industry is most excellently summarised by quoting an article in the Polymotive magazine [1] "Far-reaching efforts to achieve components that are rigid, strong, safe and at the same time, as light as possible are needed in order to survive in automotive manufacturing".

In order to preserve natural resources and cost effects, weight minimization has been the major focus of automotive industries. Now a day’s weight minimization can be achieved generally by the replacement of better material, design optimization and enhanced manufacturing process. Springs are important suspension essentials on any vehicle, essentially to reduce the vertical vibrations, impacts and bumps due to road abnormalities and made a cosy ride. The leaf spring suspension holds about 10-20% of vehicle unsprung mass. Thus it becomes an essential component for weight minimization [4]. The mass minimization can be accomplished by selecting better materials and optimized design of leaf spring etc. [7-9].

There are various types of springs available for suspension system. A leaf spring can be considered as the simple type of spring, normally used for the suspension in vehicles. It’s generally like a slender arc-shaped having some length of a steel spring of rectangular cross-section. The axle is placed at the center of the arc, at the end eyes are used for attaching to the vehicle body. From the time 1970s Leaf springs were very general on automotives. The key characteristic that gives the smoothness of a vehicle is its suspension. Now a day’s extensively used suspension systems in automotives are the Leaf springs. It is also called as a semi-elliptical spring or cart spring, which is similar to an arc-shaped length of a steel spring with a rectangular cross-section. We can fasten a leaf spring directly at both ends (eyes) of the frame or directly to the one end usually the front end, whereas the other end is attached with the shackle, a short swinging arm. For the smooth riding in very heavy vehicles, a leaf spring prepared out of multiple leaves in multiple layers stacking at the top of each other often started with gradually shorter leaves is used to provide ease in riding in very heavy vehicles as shown in fig. 1.

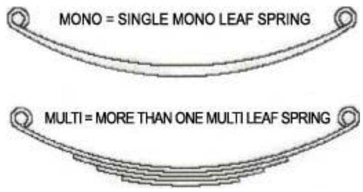

Fig. 1 Types of leaf spring

The automotive manufacturer tends to enhance soothe of user and achieve appropriate stability of comfort riding virtues and economy. The researchers are very fascinated in the replacement of steel leaf spring by some composite leaf spring because of high strength to weight ratio. On the other hand, there is a restriction for the amount of applied loads in springs. The amplification in applied load creates complexity at geometrical arrangement of vehicle height and erodes other parts of vehicle. So, springs design in concerned of strength and toughness is enormously significant. Minimization of spring mass is also key parameter in enhancement of car dynamic. By substitution of steel leaf spring with composite leaf spring will minimize spring mass in addition to resistance increase under the effect of applied loads. Increasing opposition and innovations in automotive field tends to alter the existing products or replacing old products by new and sophisticated material products. A suspension system of automotive is one of the areas where these innovations are carried out regularly. Leaf springs are generally used in suspension systems to absorb shock loads in automotives like light vehicles, heavy duty trucks and in rail systems [2].

Organization of manuscript:

Sec. 2 explains the problem identification formulation; sec. 3 shows the objective part and sec. 4 states some of the assumption taken for this paper. Problem formulation is presented in Sec. 5; Sec. 6 covers the methodology part and Analyses with corresponding results are given in Sec. 7 and sec. 8 to illustrate the applicability of the proposed material. Concluding remarks and some directions for future research are presented in Sec. 9 and 10 respectively.

II. PROBLEMS IDENTIFICATION

After reviewing the literatures, we identify some of the problem which generally occurs in case of leaf spring. The usual steel leaf spring has various problems identified which are listed as follow:

1. Maximum deformation: because of continuous running of the vehicle there is a declination in the level of soothed offered by the spring.
2. Low strength: It is observed that the leaf springs be likely to break and deteriorate at the eye end segment which is extremely near to the shackle and at the middle.
3. High weight: The usual steel leaf spring having more weight, which additionally influences the fuel efficiency.

III. OBJECTIVES

As we discussed the problem identified and solution methods through the various literatures, now the objective of the research thrust is to replace the existing conventional steel (55Si2Mn90) material through the composite material to reduce the weight and increase the strength.

IV. ASSUMPTIONS

In order to achieve the above listed objectives, we make the following assumptions:

1. Automobile is assumed to be stationary.
2. There are 4 parabolic leaf spring two at rear axle and two at front.
3. Static study is performed for rear single parabolic leaf spring.
4. The conventional leaf spring Material is 55Si2Mn90 (IS).

5. The composite material is not a laminated one.

V. PROBLEM FORMULATION

The problem identification, objective and hypothesis has been prepared in previous sections now to devise the problem the parabolic leaf spring (PLS) taken into consideration is that of a mini loader truck (TATA-ACE-HT) having the following specifications as [13]:

1. Kerb Weight [15] : 815 kg

It is the definite weight of the truck exclusive of any cargo or passengers on it. It's the basic weight that is used in exclusion to estimate the entire weight of the vehicle with cargo and passengers.

2. Loading Capacity [15] : 1 Tonnes

It is the maximum load, which can be carried by the vehicle.

3. Max Gross Vehicle Weight (GVW) [15] : 1550 kg

It is the entire weight of the loaded vehicle. This comprises the vehicle itself and the cargo that is loaded inside that vehicle.

4. Material : EN45(English System) / 55Si2Mn90(IS)

The material plays a vital role towards the design of the product. The spring steels have different nomenclatures [14] based on different systems and it has been shown in Table 1. The chemical composition of various elements in the existing conventional leaf spring steel (55Si2Mn90/EN45) has been shown in Table 2. The mechanical properties [18] of the existing conventional leaf spring material are shown in Table 3.

Table 1 Nomenclature corresponding to current PLS

International Standard	Equivalent Grades			
	IS	DIN	BS	AISI
EN45	55Si2Mn90	55Si7	250A53	9255

Table 2 Composition of various elements in 55Si2Mn90

Grade	C %	Si%	Mn%	Cr%	Mo%	P%	S%
55Si2Mn90	0.55	1.74	0.87	0.1	0.02	0.05	0.05

Table 3 Material Properties of existing PLS (55Si2Mn90) [18]

PARAMETER	VALUE
Young's Modulus (E)	200GPa
Poisson's Ratio	0.3
Tensile Strength Ultimate	1962 MPa
Tensile Strength Yield	1500 MPa
Density	7850 kg/m3
Thermal Expansion	11×10^{-6} / ºC

The parabolic leaf spring taken into consideration is of TATA-ACE-HT having a Max Gross Vehicle Weight of 1550 kg.

Total weight acting downwards (i.e at full load)

= Gross Vehicle Weight × gravity

= 1550 x 9.81 = 15205.5 N.

There are four suspensions two at the front and two at the back. So, Load on one suspension = 15205.5/4 = 3801.4 N or 3800 N approx.

Factor of safety = Ranges (2 - 2.25) for a leaf spring.

Through the above mentioned problem formulation, the design space will be created and then analysis will be performed.

VI. METHODOLOGY

For achieving the objective of the paper a flow chart is prepared which shows various steps taken in to consideration. The flow chart is shown in figure 2.

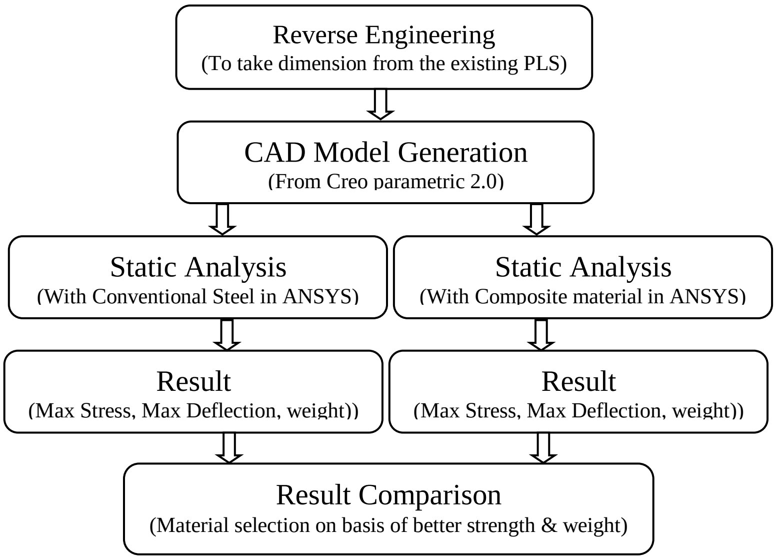

Fig.2 Flow chart to achieve the objective

VII. ASSESSMENT OF LEAF SPRING

In this section the conventional steel and composite parabolic leaf spring will be analysed to see the various results from the static analyses. The software used to perform the analysis is ANSYS® 14.5. ANSYS software is used to analyze the stresses by performing static analysis for the given leaf spring specification and to determine the stiffness in leaf springs.

Material properties

There are four leaf springs on which the analyses are going to perform, one is conventional steel leaf spring and other three are composite leaf springs. The properties of the conventional steel material 55Si2Mn90 [18] being used in this analysis are shown in Table 3.
Table 4 shows the mechanical properties of composite (E-Glass/Epoxy) material, which can be taken as per Ansys Standard material library.

Table 4 Mechanical Properties of E-Glass/Epoxy_UD composite PLS[25]

Properties	**Value**
Tensile modulus along X-direction (Ex), Pa	4.5E+10
Tensile modulus along Y-direction (Ey), Pa	1E+10
Tensile modulus along Z-direction (Ez), Pa	1E+10
Shear modulus along XY-direction (Gxy), Pa	5E+09
Shear modulus along YZ-direction (Gyz), Pa	3.8462E+09
Shear modulus along ZX-direction (Gzx), Pa	5E+09
Poisson ratio along XY-direction (NUxy)	0.3
Poisson ratio along YZ-direction (NUyz)	0.4
Poisson ratio along ZX-direction (NUzx)	0.3
Mass density of the material (ρ), kg/mm^3	2000

Table 5shows the mechanical properties of composite (Carbon/Epoxy) material, which can be taken as per Ansys Standard material library.

Table 5 Mechanical Properties of Epoxy_Carbon_UD_395GPa_Prepreg composite PLS[25]

Properties	**Value**
Tensile modulus along X-direction (Ex), Pa	2.09E+11
Tensile modulus along Y-direction (Ey), Pa	9.45E+09

Tensile modulus along Z-direction (Ez), Pa	9.45E+09
Shear modulus along XY-direction (Gxy), Pa	5.5E+09
Shear modulus along YZ-direction (Gyz), Pa	3.9E+09
Shear modulus along ZX-direction (Gzx), Pa	5.5E+09
Poisson ratio along XY-direction (NUxy)	0.27
Poisson ratio along YZ-direction (NUyz)	0.4
Poisson ratio along ZX-direction (NUzx)	0.27
Mass density of the material (ρ), kg/mm^3	1540

Table 6 shows the mechanical properties of composite (Kevlar/Epoxy) material, which can be taken as per ref [27].

Table 6 Mechanical Properties of Kevlar/Epoxy composite PLS[27]

Propertie	**Value**
Tensile modulus along X-direction (Ex), Pa	9.571E+10
Tensile modulus along Y-direction (Ey), Pa	1.045E+10
Tensile modulus along Z-direction (Ez), Pa	1.045E+10
Shear modulus along XY-direction (Gxy), Pa	2.508E+10
Shear modulus along YZ-direction (Gyz), Pa	2.508E+10
Shear modulus along ZX-direction (Gzx), Pa	2.508E+10
Poisson ratio along XY-direction (NUxy)	0.3400
Poisson ratio along YZ-direction (NUyz)	0.3700
Poisson ratio along ZX-direction (NUzx)	0.3400
Mass density of the material (ρ), kg/mm^3	1402

The above mentioned three composite materials are used to perform the finite element analyses and compared with the conventional steel material for better improved mass and low stress and low total deformation.

Boundary and loading Conditions

The leaf spring is placed on the axle of the vehicle; the frame of the vehicle is attached to the ends (by eyes) of the leaf spring. The ends of the leaf spring are produced in the form of an eye. The front eye of the leaf spring is attached straightly with a pin to the frame so that the eye can revolve without restraint about the pin but no translation is takes place. The back eye of the spring is linked to the shackle which is a flexible link the next end of the shackle is linked to the frame of the vehicle. One eye of the leaf spring is reserved fixed (cylindrical support) and the other eye is given certain degree of rotation to allow the leaf spring to deflect by some amount along its length to meet the actual conditions for both the leaf spring (steel and composite) which is shown in Fig. 8. After this load is applied of magnitude 3800 N in the upward direction at the centre of the PLS. This specific computation of load to be applied has been completed on the basis of Gross Vehicle Weight (GVW). This has been clearly shown the Fig. 8.

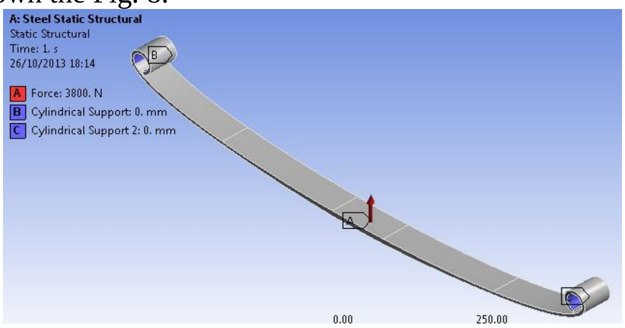

Fig.8 Loading and boundary condition for leaf spring

Static Analysis

After providing the material to the model, meshing and loading as well as boundary condition now we have to solve the design space created for the four leaf spring models and then perform the assessment for the selection of the better material. The comparison is based on the material weight, the maximum von-mises stress generation and the value of maximum total deflection. The results of von-mises stresses for four the materials are shown in fig 9.

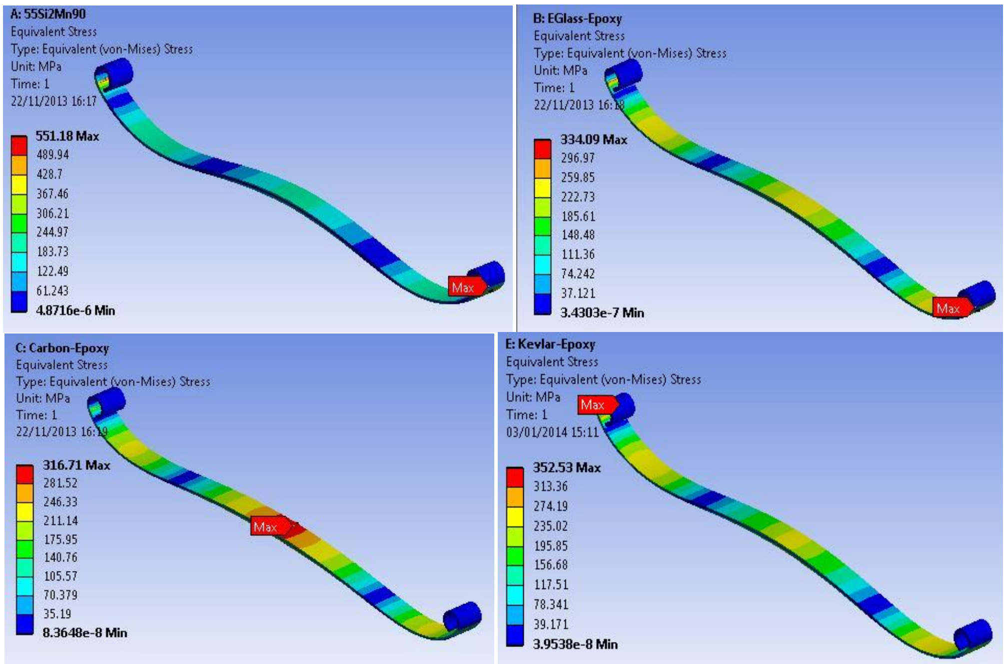

Fig.9 Von-Mises Stress generated for 55Si2Mn90, EGlass-Epoxy, Carbon-Epoxy, Kevlar-Epoxy Leaf Spring

As per the results shown above the maximum Von-Mises stress generated in conventional steel leaf spring is 551.18 Mpa, EGlass-Epoxy composite material is 334.09 Mpa, Carbon-Epoxy composite material is 316.71 Mpa and Kevlar-Epoxy composite material is 352.71 Mpa. After having same meshing, boundary and loading condition the results for the value of maximum total deflection are shown in fig. 10.

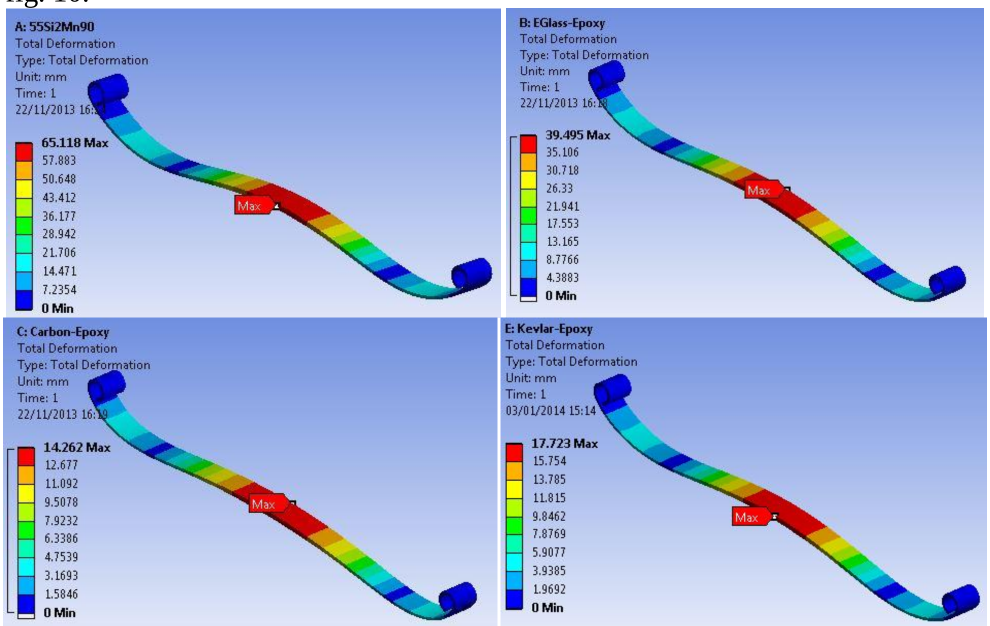

Fig.10 Total Deformation generated for 55Si2Mn90, EGlass-Epoxy, Carbon-Epoxy, Kevlar-Epoxy Leaf Spring

The above result shows the improved strength and comfort level as low deflection for the leaf spring which is better in case of Carbon-Epoxy composite material, but we are still looking for the possible weight reduction. The mass of the conventional leaf spring is 4.613 kg, EGlass-Epoxy composite leaf spring is measured as 1.175 kg and the mass for the Carbon-Epoxy composite leaf spring is measured as 0.905 kg, which means Carbon-Epoxy composite leaf spring reduce the weight about 80% from conventional one.

VIII. Results And Discussion

As presented above, we discussed the modelling and analyses of the conventional steel and three composite leaf springs with the same loading and boundary conditions. The results of the analyses are shown in the previous chapter. The results are tabulated in the Table 7.

Table 7 Comparison between steel and three composite leaf springs

Parameter	**55Si2Mn90 steel leaf spring**	**E-Glass/Epoxy composite leaf spring**	**Carbon Epoxy prepreg**	**Kevlar/Epoxy composite leaf spring**	**Reduction by Carbon Epoxy prepreg**
Von-Mises Stress (MPa)	450.73	338.03	316.71	352.53	30%
Total Maximum Deflection (mm)	65.118	39.495	14.262	17.232	78%
Total Mass (Kg)	4.613	1.175	0.905	0.823	80%

Through the comparative assessment of steel and three composite material leaf springs the maximum total deflection is reduced by 78% through composite material, Von-Mises stress generation is reduced by 30% and the weight is also reduced by 80% by using the Carbon Epoxy prepreg composite material as shown in fig. 11.

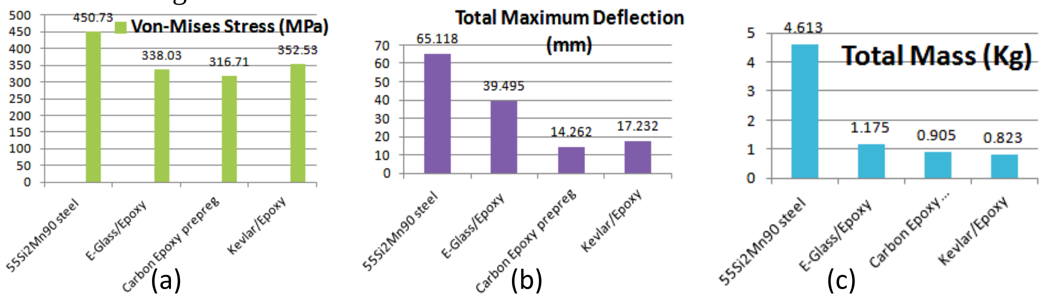

Fig 11 Comparison of four materials on basis of (a) vonmises stress (b) Total maximum deformation (c) Total mass

IX. Conclusion

As shown in the paper, we confer a relative study for a variety of materials of parabolic leaf spring (PLS). As per the outcome shown above, we can say that by substituting the usual (55Si2Mn90) steel material by composite material (Carbon- Epoxy) we can decrease the stress produced in the leaf spring and moreover we anticipate that by substituting the material the enhanced comfort level throughout the spring can be accomplished or in other word it concentrated the total deflection of the leaf spring.

Another significant characteristic is weight, which is also concentrated in case of Carbon- Epoxy composite leaf spring, which can consequence in enhanced design of the leaf spring material. The composite material accumulates up to 80% of the entire weight as compare to the usual steel material. So as conclusion it can be said that the current work is established that Carbon- Epoxy composites can be used for leaf springs for light weight vehicles and convene the necessities, along with considerable weight reductions.

By the reduction of weight and the less stresses, the fatigue life of Carbon- Epoxy composite leaf spring is to be higher than that of steel leaf spring. In totally it is found that the Carbon- Epoxy composite leaf spring is the better that of steel leaf spring. Which means the proposed new (Carbon-Epoxy composite) material can be used to satisfy the objective.

X. FUTURE SCOPE

For future work, we anticipate that the further reduction in weight is possible by means of applying the modern shape optimization techniques to achieve an effective shape of the leaf spring.
Based on these investigations will be further performed and in future the shape optimization can lead us to a proper shape of the composite leaf spring.

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