Size Optimization of Composite Leaf Spring for Light Commercial Vehicle

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Abstract *Due to rise in competition and prices of fuels, automotive industries has shown increased interest in reducing the weight of vehicles. Replacement of traditional materials with new and light weight materials is gaining importance. The aim of this research paper is to design, analyse and optimize composite mono leaf spring. A spring with constant cross section area was designed using* C^{++} *language. The composite leaf spring with constant width and varied thickness was analysed for static analysis and finally optimum size which satisfied condition of stress and deflection using FEA. It is observed that composite leaf spring with 24 mm was found optimized design compared to other thicknesses.*

Keywords*: Static analysis, FEA, Design Optimization, E-glass fiber/epoxy*

I. INTRODUCTION

The vehicle weight can be reduced by use of light weight materials, design optimization and efficient manufacturing process. To achieve above mentioned objective, automotive industry and many researchers are working on replacing steel parts with light weight materials like Aluminum alloys and composites. Composite can reduce weight of spring without reducing load carrying capacity and stiffness in automobile suspension system. The leaf spring absorbs vertical vibration due to irregularities by means of variation in the spring deflection so that potential energy is stored in the spring as strain energy and released slowly [1-4]. A double tapered beam has been designed and optimized for automobile suspension system[5]. It has been reported that by tapering leaf spring leaves in thickness and width direction, even distribution of stress can be also obtained. This design gave efficient material utilization and met stiffness requirement [6]. The analysis of composite leaf spring has become essential for comparative assessment with conventional steel leaf spring. Moreover, an attempt was also made to design and analyse the low cost mono composite leaf spring with bonded and without bonded end joints [9]. As size optimization is concerned with the thickness of a material and dimensions of cross-sections, it is particularly useful when designing composite components which are constructed from a number of layered plies of various thicknesses.. Usually optimization problem is solved numerically by iterative methods. However, it is a time consuming process. The aim of size optimization is to minimize weight of leaf spring and determine an optimal thickness. In addition a small amount of weight reduction in leaf spring will lead to improvement in passenger comfort as well as reduction in vehicle cost. Normally various approaches i.e. Genetic Algorithm, Neural system and Optistuct solver is utilized for optimization in product design. However, because of FEA, number of iterations is possible with the minimum errors, which reduce development time and cost and also, guide the manufacturing process. Therefore, in present work FEA method has employed to optimize size of composite leaf spring.

1.1 . Purpose and Objective

The objective of this research paper was to present: design, analysis and optimize size of mono composite leaf spring made of E-glass fiber.

2. RESEARCH METODLOGY

2.1 *Description of existing Steel leaf spring for Tata –Ace*

A commonly used leaf spring for Tata -Ace is of semi elliptical type which has built up with three graduated leaves. The leaves are initially given a curvature or camber of 90 mm so that they tend to straighten under load.

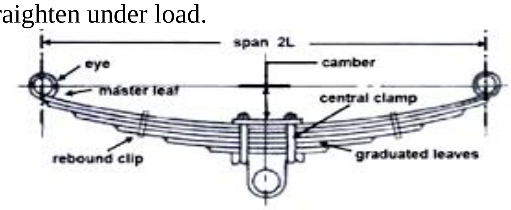


Fig. 1: Multi Steel Leaf Spring.

The spring is clamped to the centre of axle of vehicle at rear end by U-bolt. Fig. 1 shows multi steel leaf spring. Assume, permissible deflection of leaf spring ranging from 50 to 56 mm.

2.2 Specification of steel leaf spring

For this purpose Tata Ace (two tone) commercial vehicle multi steel leaf spring has been selected and with *d*esign parameters of existing multi steel leaf spring used in this work are : Material of leaf spring 65Si7; Total length (eye to eye) 860 mm; Arc height of axle seat (camber) 90 mm; spring rate 23.1 N/mm ; number of full-length leaves 01; number of graduated leaves 02;width of leaves 60mm; thickness of each leaves 08 mm ; full bump loading 4169N ; spring weight 10.5 kg ; Young's modulus

$2.1x10^5$(N/mm^2); Available space for spring width 40-45 mm

2.3 Properties of steel leaf spring

The material properties of existing leaf spring are : Material of leaf spring -65Si7, Young's Modulus2.1 x 105 MPa, Poissons ' ratio0.266, Tensile strength Ultimate1272 MPa, Tensile Yield strength-1158 MPa, Density-$7.86x10^{-6}$ kg/mm^3 , Allowable stress-540MPa.

2.4 Selection of fiber

However, Different kinds of fibers such as carbon fiber, C-glass, S-glass were used by many researchers in numerous applications. Even if, carbon/epoxy material was more suitable for leaf spring than other fibers, but carbon fiber is found to be too expensive. Because of its high cost, it has limited applications. Therefore, promising relations between cost and properties of a material can be attained with E-glass fiber/epoxy. E-glass fiber with (0/45/0/45)S is selected as the leaf spring material having following mechanical properties: modulus of elasticity ,E11, 34GPa and E22,6.53GPa; modulus of shear,G12, 2.4GPa; Poisson ratio,0.21;tensile strength ,σt ,900MPa; compressive strength , σc,610MPa; density, ρ, $2.6x10^{-6}$ kg/mm^3.

2.5 Design of composite leaf spring using Computer program C++

The final dimension selected using C-program satisfied all three conditions of stress, stiffness and deflection.

Fig. 2 shows Flow chart for design of composite leaf spring. Therefore, final dimension are:

Length of spring =860 mm,
Width of spring = 60 mm
Total thickness of mono spring = 24 mm

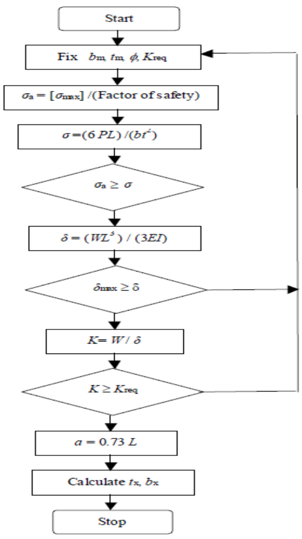


Fig. 2: Flow chart for design of composite leaf spring using C++

2.6 Theoretical Calculation of Thicknesses and Stress

We have,
Total weight = 16677 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.

F = 2084 N
Span length, 2L= 860 mm,

We have,

∴ Maximum bending moment in the center, = WL

$$\therefore \quad \sigma b = \frac{6FL}{bt1^2} \text{ and } \delta max = \frac{6FL^3}{nEb\,h^3}$$

Solving, for t1=23mm ,22,mm

The estimated thicknesses of composite mono leaf spring such as, t1 and, t2, has taken for development of CAD models of composite leaf spring for finding optimum thickness using FEA method. Nonetheless, these computed thicknesses have to be checked for stress and deflection point of view. This is done by calculating bending stress and deflection for obtained value of thickness.ie. t1 and t2 respectively.

$$\text{Let,} \quad \sigma_{b\,1} = \frac{Mx\ y}{I} \text{ and } I = \frac{bt1^3}{12}$$

∴ t1 and t2 Stress σ_{b1} = 169MPa,$\sigma_{b2=}$ 185 MPa less than Allowable stress .

Hence, these dimensions are found to be safe from stress point of view. Hence, this was taken in FEA for size optimization. Finally, CAD models with constant width and varied thicknesses such as, 23 and 22 mm were developed and then used for further analysis.

3. *Size optimization using FEA*

Firstly, FEA model was constructed using composite shell element. For modeling, the composite leaf spring an actual mounting condition of leaf spring on rear axle was considered. This was done by importing the CAD model of leaf spring in ANSYS. Appropriate loading and boundary condition were applied to composite leaf spring CAD models. Firstly, static analysis was performed at different load conditions ranging from 500 to 4169 N for three CAD models of composite leaf springs having varying thickness 22mm, 23mm, and 24mm respectively. Thickness of composite leaf spring was altered from its initial thickness value in CATIA V5R18 and thereafter, their IGES were called one by one in the analysis process and analysis was performed for various loads. Table1 shows comparative analysis made between the initial and optimized design of composite leaf spring on the basis of computed stress and mass.

Table 1 : Size Optimization using FEA

	(t= 24 mm)		(t1 = 23 mm)		(t2 = 22 mm)	
Load N	Deformation (mm)	Stress (Mpa)	Deformation (mm)	Stress (Mpa)	Deformation (mm)	Stress (Mpa)
500	4.98	28.48	5.56	31.18	6.45	32.79
1000	9.97	56.96	11.31	62.36	12.91	65.58
1500	14.96	85.44	16.97	93.54	19.37	98.37
2000	19.95	113.9	22.63	124.7	25.82	131.1
2500	24.93	142.4	28.29	155.9	32.28	163.9
3000	29.92	170.8	33.95	187.0	38.74	196.7
3500	34.91	199.3	39.61	218.2	45.20	229.5
4169	41.55	219.0	47.18	260	53.84	273.4

Table 2. : Weight comparison for initial and optimized design of Composite leaf spring using FEA

Weight of Composite Leaf Spring (kg)	Thickness of composite leaf spring		
	24mm	23mm	22mm
	3.125	2.898	2.729

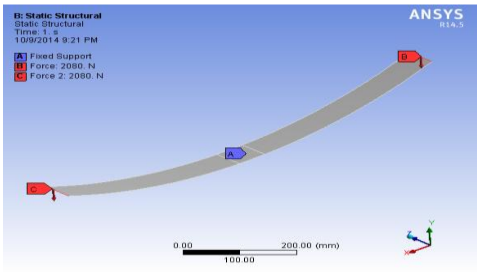


Fig. 3. Loading and boundary condition applied in the analysis

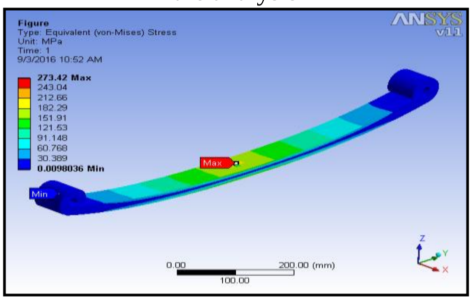


Fig.4 and 5 indicate stress and deflection contours for composite leaf spring at maximum load of 4169N.

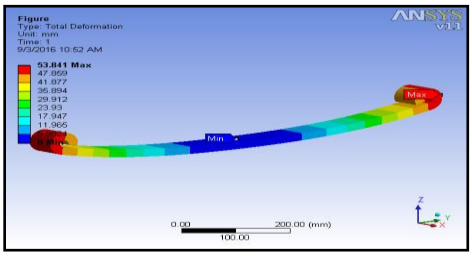
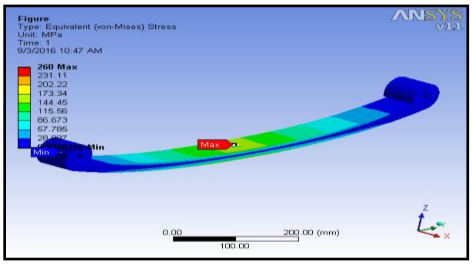


Fig. 4 : Stress and Deformation pattern of composite leaf spring at t2= 22mm



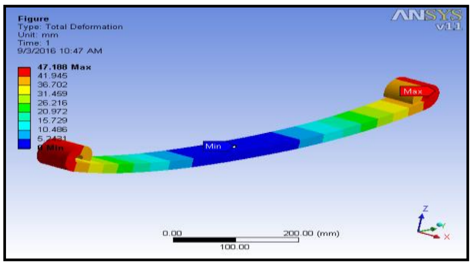


Fig.5 : Stress and pattern of Composite Leaf spring at t1= 23 mm for 4169N

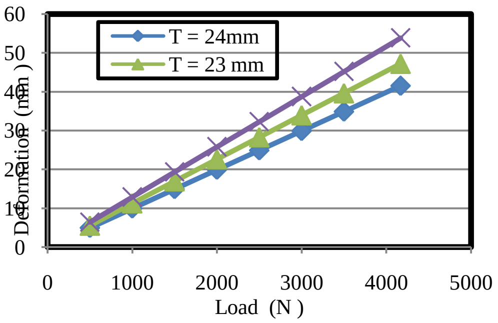


Fig. 6 : Deformation Vs Load

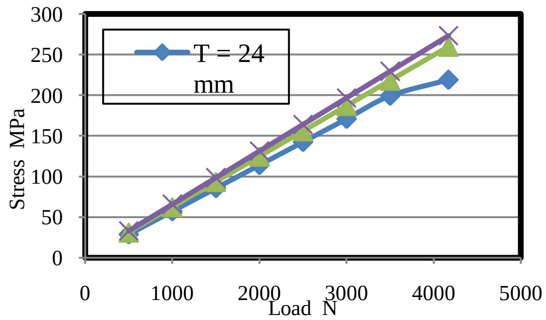


Fig. 7 : Stress Vs Load

4. RESULT AND DISCUSSION

Replacing steel leaf spring by composite leaf spring with thickness of 24mm reduced weight of composite leaf spring by 70 %. In case of composite leaf springs with 22 mm a reduction of 74.0 %.in was achieved compared to conventional steel leaf spring. Among the three composite leaf spring (CAD models) of varied thickness, the two composite leaf springs with 22mm and 23mm shows higher stress than design stress. Hence, this value was not safe as stress point of view. It is evident from Fig. that the measured deformation for three composite leaf spring models with different thickness varies linearly with applied load. It is obliviously noted that, the deformation for composite leaf spring with a thickness of 22 and 23mm was observed within permissible limit of deflection. Hence it has been observed that, the composite leaf spring with thickness of 24mm was found to be optimum thickness as it satisfied condition of stress and deflection. Even though the mass of the optimized composite leaf spring was not the lowest, however, the choice was done on the basis of maximum stress. It can be concluded that the weight saving of optimized design was achieved up to approximately 70 % as compared to the conventional steel leaf spring.

5. CONCLUSION

Composite mono leaf spring with constant cross sectional area has been designed using C^{++}. The 3D modelling of composite leaf spring having constant width and varied thickness was done and analyzed for size optimization using ANSYS. It is observed that composite leaf spring was lighter and more economical than multi steel leaf spring. It has been observed that, composite leaf spring with thickness of 22 and 23mm not satisfied condition of stress and deformation where as 24mm thickness was found to be safe with respect to stress and deformation. Hence, it has been observed that, the composite leaf spring with thickness of 24mm was found to be optimum thickness as it satisfied condition of stress and deflection. Even though the mass of the optimized composite leaf spring was not the lowest.

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