Optimization and Weight Reduction of Hybrid Composite Leaf Spring

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Abstract. Weight decrease is one of the significant boundaries in plan of car segments. Such decrease helps to improve the eco-friendliness and execution of the vehicle, the variables which have specific importance in present situation of quickened non-renewable energy source consumption just as a dangerous atmospheric deviation concerns. The current work is aimed to design and analyse hybrid composite leaf spring, in commercial vehicles. For this reason, measurements of leaf spring used in broadly acclaimed business vehicle Tata 407 have been utilized. The goal is to compare the stress, deformation and weight decrease feasible through utilization of crossover/hybrid composite leaf spring when contrasted with regular leaf spring. The composite material selected for this purpose is glass fibre reinforced polymer (E-glass/epoxy). It has been observed that material combination of 2Eglass + 3EN45 results in weight reduction of 18.14 kg in one leaf spring, which is practically 50% of the conventional leaf spring. 1Eglass + 4² have 50% higher cost than the conventional spring but have lower stress value compared to conventional leaf spring & has achieved weight reduction of 14.77 kg in one leaf spring

Keywords: hybrid, composite, conventional, E-glass/epoxy, leaf spring.

1. INTRODUCTION

Springs such as leaf, torsional, coil & helical spring utilized in vehicle suspension system, must compensate irregularities of road surface, for better ride and comfort. Out of which leaf spring are widely used for heavy vehicles suspension system. A Leaf spring is a simple form of spring wherein number of arch leaves or plates (specific radius of curvature) are placed in a sequence of decreasing length pattern from top to bottom and then assembled directly with vehicle axles by U-bolt which is provided on master leaf. Leaf springs are also called semi-elliptical springs. According to load, number of leaves in leaf spring varies.

T.G. Loganathan et al. (2020) studied the fatigue and flexural behaviour of composite leaf springs. The materials used for this purpose are SAE5160 chrome steel and CFRP. The fatigue analysis was performed on ANSYS software by using the Goodman method to apply a load of 5000N. The results show that, compared with SAE5160 chromium steel, CFRP has
less weight and deformation, while the fatigue life and stiffness of CFRP are higher than SAE5160 chromium steel [1]. Jun Ke, Zhen-yu et al. (2020) discussed various design methods and manufacturing processes of composite leaf springs. According to reviews, the mixed material of carbon fiber and basalt fiber is an ideal material for composite leaf springs. By adding a rubber spindle or a woven fabric layer, the mechanical properties of the spring wire of the composite leaf spring can be improved. The ply angle of the composite leaf spring should be 45°. For comprehensive optimization, the dynamic performance of damping and fatigue life needs to be considered [2]. S. Seralathan, Hemanth Prasanna et al. (2020) through FEA analysis of Ansys, three different materials were compared. The materials used for comparison are conventional steel, glass epoxy composite and a mixture of steel and epoxy. A load of 3000N was applied when performing the analysis. The mass of the hybrid spring is 34% less than that of the traditional spring. Compared with steel, the stress generated by the hybrid spring is also 45% less [3]. Jun Ke et al. (2019) reviewed the work done on composite leaf springs. The design method of the spring is very mature, and the leaf spring can be optimized to suit different applications. Taking into account the cost of reproduction and environmental factors, natural fibers should be preferred as composite materials. The static and dynamic analysis of the composite leaf spring has also been systematically carried out. In most cases, it can be observed that the cost of composite materials is higher than that of traditional materials, but it can compensate for its better performance, comfort, ride quality and durability [4]. Jenarthanan M.P et al. (2018) analyzed conventional steel EN45 and carbon/glass epoxy resin. The goal is to reduce weight and improve vehicle performance. The dynamic analysis of the leaf spring during acceleration and deceleration was carried out. The overall weight is reduced by 79%, but it will be a little uncomfortable due to the large deformation [5]. Nishant Varma et al. (2020) studied the applicability of hybrid composite leaf spring combined with flax fiber and carbon fiber as reinforcement material. It was observed that by incorporating the fiber into the spring, both the strain and the safety factor were greatly increased. This is due to the high damping characteristics [6].

Ramakant et al. (2013) has performed fatigue analysis for steel leaf spring and static analysis for steel, composite & hybrid leaf spring. Material utilized for conventional leaf spring is 65Si7 whereas Eglass/Epoxy for composite leaf spring and alternative layers of both in hybrid Leaf spring. After comparing the static analysis, it was found that the stress developed in hybrid leaf spring is more than composite and steel leaf spring. Weight of steel leaf spring is higher compared to hybrid and composite leaf spring & cost for composite leaf spring is higher than the hybrid and steel leaf springs [7]. Paradhan and Rathore (2016) compared load capacity, stiffness and weight reduction by designing, analysis and fabrication of composite material thereby taking conventional material as a reference. Materials utilized for examination were 55Si2Mn90 and E-glass/Epoxy. A wide difference is observed under same load conditions for deflection and stress of composite leaf spring and steel leaf spring. Composite material shows less deflection than steel. Failure is observed at eye end of Conventional leaf Spring [8]. Ghanwat et al. (2017) describes the procedure of leaf spring analysis. The materials used are conventional steel and composite materials, such as E-glass/epoxy, carbon/epoxy, graphite/epoxy. The original size of Tata sumo is used for solid modeling and analysis is performed on ANSYS 12.1 software. They found that the strength of the composite material is much stronger than that of the steel leaf spring, and the weight reduction is considerably high for composite material [9]. Venu and Diwakar (2013) estimated the modal frequency, deflection and stress of the jeep leaf spring. The earlier material used is leaf springs, which will be replaced by composite materials. After observation and analysis, the stress of the composite eye is smaller than that of the steel eye, and the composite eye has a higher strength-to-weight ratio than the steel eye. Composite materials
have lower resistance to chipping in harsh environments, and some fibers may break in lower springs. Multi-leaf springs will be used instead of single-leaf springs, and composite materials will be used, which have higher strength, stiffness and stability than traditional leaf springs [10].

Saini et al. (2013) made a comparison between composite materials and leaf springs. The materials selected for composite materials are graphite/epoxy, glass/epoxy and carbon/epoxy, while steel is used for conventional materials. Use AUTOCAD 2012 for modeling and ANSYS 9.0 software for analysis. It is found that among the three composite materials, graphite/epoxy resin is much better than traditional materials. They found that the displacement of a given length is a uniformly distributed load, the stress of graphite/epoxy is higher than that of steel, and the percentage of weight loss of graphite/epoxy is high [11].

Smita C et al. (2014) described composite materials as an alternative to leaf springs. Software used for modeling and analysis are CATA V5R19 & ANSYS 2012. After checking the stress and deflection of various parameters of metal leaf spring (Mono) and Eglass / Epoxy material leaf spring through analysis and experiment, it is found that composite materials have lower stress values than steel, so composite materials are better than traditional ones with similar design specifications. Leaf springs are more effective and economical [12]. Mahesh Dasgaonkar et al. (2016) prepared two leaf spring models with different thickness values and used different materials, such as structural steel, titanium alloy, S glass fiber and E glass fiber for comparison. They found that the leaf spring model with S glass fiber and E glass fiber materials had lower mass than structural steel and titanium alloy. The total masses of S glass fiber composite material, E glass fiber composite material, titanium alloy, and structural steel with reference to model-1 are 12.51 kg, 7.06 kg, 4.09 kg and 3.95 kg, respectively. Compared with traditional leaf springs, E glass fiber and S glass fiber have greater deflection. Due to the lighter weight and higher deflection rate, the composite leaf spring provides higher comfort and a smoother ride. It can be seen that the strain energy of E-glass fiber composite is higher than that of other materials. This is due to its flexibility and strong energy storage capacity [13].

Prakash Shakti (2017) the author describes the vehicle leaf spring. The parameters to be checked are load, weight, stiffness, and the design parameters are stress and deflection. He checked the analysis results and experimental results of the composite multi-leaf spring. The characteristics of reduced mass concluded that the durability of the composite leaf spring is 5 times that of the traditional steel spring [14]. Mr.Nagabhushana.N. (2016) has analyzed three different materials as composite leaf springs for trucks. By analyzing the weight, stress, deflection, Poisson's ratio and other parameters of steel, electronic glass/epoxy, and carbon/epoxy under different loading conditions, the results show that carbon/epoxy is lighter in weight and stronger. Composite materials can replace conventional materials of the same specifications [15]. Anjish M George et al. (2017) used MAHINDRA "BOLERO" leaf spring for analysis. The modeling was done in CATIA, and the analysis was done in ANSYS 15.0. They used normal steel material for conventional material, and for the composite leaf spring, three different materials, such as E glass, flax fiber and banana fiber was considered. For composite steel plates, they have mixed all three composite materials and prepared composite hybrid leaf springs. Under the UTM test, good strength was observed for both E-glass banana and E-glass-linen hybrid leaf springs. If the leaf spring is replaced with an E-glass/linen/epoxy hybrid composite leaf spring, the weight is reduced by 88.49% [16].

Objective

Leaf springs used for commercial heavy vehicles should have high strength to withstand bumps and unevenness of the road. Similarly, if the weight of the spring is high, the weight of the unsuspended spring will increase, which directly affects the performance of the vehicle in
terms of fuel consumption and power. Composite materials are costly, but on the other hand, they are light and strong. Therefore, it is important to compare standard materials with composite materials. It was also observed that the combination of traditional materials and composite materials was never been done. Therefore, different combinations of materials with the same number of blades were prepared and analyzed. For further optimization, certain combinations were selected for analysis by reducing the number of leaves. Finally, compare the stress, deformation, weight reduction and cost to get the best results.

Leaf Spring Design

The leaf spring consists of full-length leaf and graduated leaves. When designing leaf springs, the combined strength and deflection characteristics should be considered. The leaves always appear in two groups, such as the main leaf containing the eyes and two full-length leaves forming one group, and another gradual leaf forming another group.

Load calculation:-

Gross Vehicle Weight (GVW) = 4450 kg
Kerb weight of the vehicle = 2200 kg
40% of kerb weight acts on the front leaf springs while 60% acting on the rear leaf springs.

Minimum Load

Both Rear leaf springs combined = 0.6 x 2200 = 1320 kg
For single rear leaf spring = 1320 / 2 = 660 kg = 6475N

Maximum Load

Both Rear leaf springs combined = 0.6 x 4450 = 2670 kg
For single rear leaf spring = 2670/2 = 1335kg = 13100N

Leaf spring specifications:-

For research, the TATA-407 light commercial vehicle was selected. It is composed of a multi-leaf spring made of manganese silicon steel (55Si2Mn90).

Table 1. Specification of Leaf Spring

| Properties                      | Values  |
|---------------------------------|---------|
| Span (2L1)                      | 1220 mm |
| Camber                          | 80 mm   |
| Width (b)                       | 70 mm   |
| No. of Full-length leaves (nf)  | 2       |
| No. of Graduated leaves (ng)    | 8       |
| Total No. of Leaves             | 10      |
| Inside diameter of the eye (d)  | 40 mm   |
| U-Bolt Centre Distance (l)      | 105 mm  |
| Poisson’s Ratio (ν)             | 0.3     |
| Young’s Modulus (E)             | 2 x 10^5 N/mm^2 |
| Yield Stress                    | 1470 N/mm^2 |
| Density (p)                     | 7860 kg/m^3 |
| Ultimate tensile stress         | 1962 N/mm^2 |

Length calculation: -

Ineffective length = 2/3*l = (2/3)*105 = 70 mm
Effective length (2L) = 2L1 – (2/3)*l = 1220–70 = 1150 mm
Length of smallest leaf = 1150/ (10-2)x 1 + 70 = 213.75mm
Length of 2nd leaf = 357.5 mm
Length of 3rd leaf = 501.25 mm
Length of 4th leaf = 645 mm
Length of 5th leaf = 788.75 mm
Length of 6th leaf = 932.5 mm  
Length of 7th leaf = 1076.25 mm  
Length of 8th leaf = 1220 mm  
Length of 9th leaf = 1220 mm  
(Master Leaf) Length of 10th leaf = $2L_l + 2\pi(d+t) = 1220 + 2\pi(40+7.5) = 1518.45$ mm  
Radius of curvature for spring (R) = 2365.625 mm  

**Modeling of leaf spring:**

![Fig. 1 CAD model of Leaf spring](image)

Figure. 1. Demonstrate the Leaf Spring CAD model in Solid Works 2014 software. All parts of the leaf spring (such as the main leaf, the graduated leaves, bolts and nuts) are manufactured according to specifications and assembled together.

**Material selection:**

For conventional materials, the selected materials are EN45 and SUP9, which are standard materials, and their properties are listed in Table 2. Compared with conventional materials, Eglass Epoxy was chosen as a glass fiber material which has high strength. See Table 3 for its mechanical properties.

| Properties                          | EN45  | SUP9   |
|------------------------------------|-------|--------|
| Young’s Modulus (Mpa)              | 2.1E+5| 2.1E+5 |
| Tensile Strength (N/mm$^2$)        | 1960  | 1962   |
| Poisson Ratio                      | 0.3   | 0.27   |
| Density (kg/mm$^3$)                | 7850  | 7850   |

| Properties | Values  |
|------------|---------|
| Ex (Mpa)   | 4.5E+10 |
| Ey (Mpa)   | 1E+10   |
| Ez (Mpa)   | 1E+10   |
| Px         | 0.3     |
| Py         | 0.4     |
| Pz         | 0.5     |
| Density (kg/mm$^3$)             | 2660    |

**Leaf Spring Analysis**

For the first three analyses, the same material is considered for all blades of the leaf spring, namely EN45, SUP9 and epoxy glass. Then, by alternately using materials or retaining the first or second leaf of composite material and the leaves of other conventional materials,
different combinations can be considered for analysis. Through this method, 17 different combinations of leaf springs were analyzed, and the stress and total deformation were found using ANSYS 18.1 software. Figures 2, 3, 4, 5, 6, and 7 show the analysis results of each combination and the results are listed in Table 4.

**Table 4. Analysis of all 17 Combinations**

| Sr. No. | Material Combination | Total Deformation | Von-Mises Stress |
|---------|----------------------|-------------------|-----------------|
| 1       | EN45 full            | 2.97              | 581.25          |
| 2       | SUP9 full            | 2.26              | 585.09          |
| No. | Material Combination            | Total Deformation | Von Mises Stress |
|-----|---------------------------------|-------------------|-----------------|
| 3   | Eglass Epoxy full               | 33.59             | 450.90          |
| 4   | Alternate EN45 & SUP9           | 2.95              | 579.36          |
| 5   | Alternate SUP9 & EN45           | 2.88              | 586.90          |
| 6   | Alternate E glass & EN45        | 34.51             | 461.77          |
| 7   | Alternate E glass & SUP9        | 34.23             | 460.28          |
| 8   | Alternate EN45 & E glass        | 3.80              | 626.26          |
| 9   | Alternate SUP9 & E glass        | 3.67              | 630.94          |
| 10  | 1st Eglass +9SUP9               | 34.97             | 465.86          |
| 11  | 1st Eglass +9EN45               | 34.94             | 465.53          |
| 12  | 2Eglass + 8SUP9                 | 34.78             | 463.29          |
| 13  | 2Eglass + 8EN45                 | 34.75             | 463.01          |
| 14  | 3 E glass + 7SUP9               | 34.45             | 460.27          |
| 15  | 3E glass + 7EN45                | 34.43             | 460.17          |
| 16  | 5E glass + 5SUP9                | 33.93             | 455.54          |
| 17  | 5E glass + 5EN45                | 33.92             | 455.46          |

![Material Combination vs Total Deformation](image1.png)

**Fig. 8.** Material Combination vs Total Deformation

![Material Combination vs Von Mises Stress (MPA)](image2.png)

**Fig. 9.** Material Combination vs Von-Mises Stress
Fig. 8 & Fig. 9 show graphical representations of the material combination as a function of Total deformation and von Mises stress.

**Design Optimization:**

The idea behind the optimization is to reduce the number of blades without changing the load-bearing capacity of the spring. This will reduce the weight of the spring and the overall weight of the spring. In this optimization, the number of leaves is reduced by considering different combinations, and an analysis is performed to find the deformation and stress values. Figures 10, 11, 12, 13, and 14 show the analysis of specific combinations selected for optimization, and the results are listed in Table 5.
Table 5. Analysis of Result with Reduced Number of Leaves

| Sr. No. | Material Combination | Total Deformation | Von-Mises Stress |
|---------|----------------------|-------------------|-----------------|
| 1       | 9 Eglass Epoxy       | 34.05             | 453.43          |
| 2       | 1Eglass+8en45        | 35.09             | 467.16          |
| 3       | 1Eglass+8sup9        | 35.12             | 467.44          |
| 4       | 3Eglass+6en45        | 34.62             | 462.09          |
| 5       | 3Eglass+6sup9        | 34.63             | 462.27          |
| 6       | 1Eglass+6en45        | 34.87             | 464.35          |
| 7       | 1Eglass+6sup9        | 34.90             | 464.7           |
| 9       | 5EglassEpoxy         | 40.59             | 606.41          |
| 10      | 1Eglass+4en45        | 33                | 519.13          |
| 11      | 1Eglass+4sup9        | 33.663            | 508.6           |
| 12      | 2eglass+3en45        | 36.32             | 600.72          |

Fig. 14. 5Eglass Epoxy

Fig. 15. Material Combination vs Total Deformation (mm)
Fig. 15 & Fig. 16 shows the graphical representation of variation of material combination with Total deformation and Von Mises Stress.

**Cost**

Conventional leaf spring: - Weight : 35KG , COST : 6100 RS  
Composite leaf spring: - Weight: 12KG , COST : 25700 Rs  
Taking best possible leaf spring pattern from above all analysis:

2. **RESULT**

It can be seen from Table 4 that compared with any subsequent composite materials, the von Mises stress of the conventional springs of EN45 and SUP9 is 18% higher. The deformation observed is that the composite material is higher than the conventional material. The design was optimized by reducing the number of blades, and the results are shown in Table 5. It can be found that compared with conventional springs, the stresses of all optimized designs are smaller. The results in Table 6 are tabulated, taking into account the best combination of von Mises stress, total deformation, weight, and cost in the above analysis. Compared with conventional materials, all other combinations have a lower weight. Among the following five possibilities, the weight of 9 Eglass Epoxy is much lower than all other combinations. Despite the high cost, reducing so much weight will reduce the unsprung weight and the overall weight of the vehicle, which will improve the performance of the vehicle.

**Table 6. Five Best Possibilities**

| Sr. No. | Material Combination | Total Deformation | Von-Mises Stress | Weight | Cost   |
|---------|----------------------|-------------------|------------------|--------|--------|
| 1       | 9 Eglass Epoxy       | 34.05             | 453.43           | 9.5    | 24650  |
| 2       | 5Eglass + 5EN45      | 33.92             | 455.46           | 18.2   | 22800  |
| 3       | 3Eglass + 7EN45      | 34.43             | 460.17           | 23.8   | 18700  |
| 4       | 3Eglass + 6en45      | 34.62             | 462.09           | 22.9   | 18200  |
| 5       | 1Eglass + 4sup9      | 33.663            | 508.6            | 20.2   | 9050   |
3. CONCLUSION

1. By comparing all possible combinations, it can be concluded that 9 Eglass Epoxy material will be the most effective in terms of the stress generated by the spring, and the weight is significantly reduced, but the total cost of spring development is high.

2. The material combination of 2Eglass + 3EN45 with a stress of 600.72Mpa is slightly higher than the traditional leaf spring, but it is safe due to the high tensile strength of the material. The weight of the spring is also 20.23kg, which means that the weight is reduced by 18.14kg, which is almost half of the conventional leaf spring. The cost will be twice that of the traditional leaf spring, but half of the composite leaf spring.

3. In order to further reduce the cost, the combination of 1Eglass + 4sup9 with a stress value of 508.6Mpa is lower than the traditional leaf spring material, and the weight is 16.86kg, i.e. the weight is reduced by 14.77kg. The cost of this combination is about RS 9050, which is 50% higher than traditional materials, but the weight of the four leaf springs in the vehicle is reduced by about 60 kg.

The natural frequency of the combination of leaf springs 1Eglass + 4sup9 and 2Eglass + 3EN45 is lower than the actual leaf spring.

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