International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 08, August-2022

Design And Analysis of Mono Composite Leaf Spring for Light Weight Vehicles

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Abstract:- **This work focuses on the replacement of steel or conventional leaf spring of a suspension system with composite material. Currently, automobile industry has shown interest in replacing most of existing components with glass fiber composite material, since the glass fiber composite has high strength to weight ratio and good corrosion resistance properties. Suspension system of vehicle significantly affects the way a vehicle perform in different driving conditions and control ride comfort and directional stability. One of suspension system component is leaf spring. Leaf spring is exposed to varying stress which leads to fatigue failure. As unsprung weight is minimized, the stress developed in the system reduces. The ride comfort as well as the fuel consumption is improved with a little amount of weight reduction in the system. In this work, the conventional steel leaf (multi-leaf) spring of Huanghai pick up is taken for modeling and analysis. E- glass Epoxy of mono leaf spring of composite was modeled and subjected exactly the same load as that of steel leaf spring. Constant cross section composite mono leaf spring is modeled in CATIA and deflection, stress, modal (natural frequency) safety factor and fatigue analysis of the model is performed using ANSYS software and results were analyzed. Analysis results of deflection, stress, fatigue life and weight of mono composite and existing leaf spring is found in a great difference. Thus, mono composite leaf spring has 73.24% reduced stress, 92.9% weight reduction, 5.3% lesser deflection and longer fatigue life than the existing leaf spring as well as increased safety factor is obtained. Natural frequency of composite leaf is also less than existing one but it is still greater than 12Hz (road frequency) which makes comfortable and resonance is also very much mitigated.**

Keywords: Carbon/Epoxy, composite material, composite leaf spring, conventional leaf spring, design and analysis

1. INTRODUCTION

Leaf spring is crucial suspension element which is used in the vehicle to minimize vertical vibrations and bumps impacts due to road irregularities as a result to create a comfortable ride. Leaf springs are widely used for rail road suspensions and automobiles. Impacts due to road irregularities and vertical vibrations of the vehicle should be absorbed or minimize by means of variations in the spring deflection. To meet the needs of natural resources conservation and economize energy, weight reduction has been the main focus of automobile manufacturer in the present scenario. Design optimization, use of better material, and better manufacturing processes can be applied primarily to achieve weight reduction. The introduction of composite materials in automotive industry made it possible to reduce the weight of the subject component without reducing load carrying capacity and stiffness. Material's strain energy is a decisive factor in spring design. Since composite materials have high strength to weight ratio and elastic strain energy storage capacity as compared with those of steel, multi- leaf steel spring are being replaced by composite leaf spring. Glass composite material offer substantial weight saving opportunities. Energy storage capacity of leaf spring assure a more comfortable suspension system.

The ever increasing competition of development and innovation in automobile industry tends to replace the existing materials by new and advanced materials products or modify old products. Ethiopia is in the stage of developing automotive industry, and believed that the industry is playing crucial role in the development of the country. However, most of the existing automotive industries except some import the components of the car and assemble it. This increase the initial the cost of the car and intelligence dependency will not be eradicated unless the company starts analyzing and designing the existing material or produce new alternative from other different material which is available nearby. Therefore, in order to improve the development of industry it is important to give emphasis towards replacing components which can easily produce locally having the same or more strength and stiffness. One of the methods to reduce the weight and cost of the car can be done by thoroughly analyzing and designing the existing component. This research focuses on replacing the conventional multi steel leaf spring with mono composite leaf spring. In the analysis, conventional steel leaf spring is tested for different load conditions and results will be compared with a virtual model of mono composite leaf spring. Leaf spring is modeled in CATIA V5 and imported in to ANSYS for better results. Results are compared on the basis of analysis reports produced by ANSYS software.

2. LITERATURE REVIEW

The literature review largely focuses on the replacement of the existing alloy steel spring with composite leaf spring which is made of glass fiber reinforced polymer.

Leaf springs are used for absorbing road shocks and bump loads and vehicle vibrations (induced as result of road irregularities) by means of deflection. For the same load and shock absorbing performance, steel leaf spring uses excess material which makes them substantially heavy. This can be improved by introducing composite material in place of steel leaf spring. Studies and researches were carried out on the application of composite material in leaf spring.

Amol Bhanage [1] has described design and simulation comparison of mono leaf spring using SAE1045-450-QT and E-Glass/Epoxy materials for automotive performance. This study presented comparative simulation results of E-glass epoxy mono composite leaf spring for different layup as well as for different thickness conditions and simulation results of SAE 1045- 450- QT steel material. ANSYS software was used for simulation results. Variation in thickness and layup thought to have effect on stress and deflection parameter; therefore, this will be helpful for the researchers for selecting the proper layup and thickness of leaf spring. M. Raghavedra et al. [2] described the analysis results of laminated composite leaf spring by applying static load using FEA. The existing mono steel leaf spring of a Maruti 800 passenger vehicle dimensions is taken for modeling and analysis of laminated composite mono leaf spring with three different composite materials namely, E-glass/Epoxy, S-lass/Epoxy and carbon/Epoxy. Analysis of the model has been done using ANSYS. Laminated composite mono leaf spring is found to have 25%- 65% higher stiffness, 47% lesser stress, 73%- 80% weight reduction. Achamyeleh et al. [3] described design of single composite leaf spring for light weight vehicle. Reducing weight of the vehicle and increasing or maintaining the strength of their spare parts are considered by replacing steel leaf spring with fiber glass composite leaf spring. Dimensions of steel leaf spring of TATA-Ace light weight vehicle were taken and 68.14% weight reduction was observed for the same dimension of fiber glass composite leaf spring as that of steel leaf spring. V. Pozhilarasu et al. [4] conducted performance comparison of composite and conventional leaf spring. Composite leaf spring and conventional steel leaf spring were analyzed using ANSYS software under similar conditions. Leaf spring was modeled by unigraphics NX4 software. The analysis result has shown that stress and deflection of composite leaf spring and steel leaf spring are found with huge difference under the same static load condition. Deflection of composite leaf spring is less as compared to steel leaf spring. Kumar Y. N. V. Santosh et. al. [36], this study indicated advantages of composite structures as replacement of conventional structures because of higher specific strength and stiffness of composite materials. Conventional leaf spring and composite was compared in several aspects such as weight, cost, and strength and load carrying capacity. A leaf spring modeled in Pro/E was imported to ANSYS and analyzed. On comparing, it was found that the deflection in the composite leaf spring is almost equal to the conventional leaf spring. It was also concluded that, the weight reduction was achieved by using composite material and reduced by 60.48% with good strength and load carrying capacity of the leaf spring. Patunkar M. M. et. al. [37], the objective of their work was to present modeling and analysis of composite mono leaf spring and compares its results. In this work conventional leaf spring was tested for the static load conditions and the material of the conventional leaf spring was 60Si7 (BIS). The tested results of the conventional leaf spring were compared with the virtual model of the composite material leaf spring. From the comparison it was found that the deflection of the composite leaf spring lesser than that of the conventional leaf spring. It was concluded that E-glass/epoxy leaf spring designed and simulated in this work having stresses much below the strength properties of the material satisfying the maximum stress failure criterion.

Mouleeswaaran Senthil Kumar et al. [6] in this work composite leaf is designed based on the fatigue failure. Theoretical equation has been formulated to predict fatigue life by using its degrading rate and fatigue modulus. Numbers of leaves and dimensions for both composite leaf spring and steel leaf spring are considered to be the same. The filament winding machine is used for fabrication of each leave. The testing of steel multi leaf spring and composite multi leaf spring are carried out with the help of an electro hydraulic leaf spring test rig. Design and fatigue analysis of composite multi leaf spring are carried out using data analysis. The result showed that composite leaf spring has 64.95% higher stiffness, 67.35% lesser stress, 126.98% higher natural frequency and also 68.15% weight reduction is achieved. J.P. Hou et al. [5] described freight rail composite leaf spring design evolution process. Three type of designs of spring eye end attachment of newly modeled composite leaf spring are described. Finite element analysis in static load condition has been carried out to obtain how the spring behaves. Strain measurement and deflection curves as a function of load for the three different spring eye designs have been plotted for comparison with FEA predicted values. delamination failure at the interface of the fiber that have passed around the eye and the spring body was the main concern associated with the first design, even though the design can still withstand one million cycles fatigue load and 150KN static proof load. Finite element analysis results showed that there is a high inter laminar shear stress concentration in the region. The second design feature is an additional transverse bandage around the region prone to delamination. Delamination was contained but not completely prevented. The third design overcomes the problem by making fibers end to the end of the eye section.

2.1 Composite

Composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the reinforcing phase and the one in which it is embedded is called the matrix. Composites are important materials that are now used widely, not only in the aerospace industry, internal combustion engines machine components; thermal control and electronic packaging and process industries [11, 13].

2.2 Suspension system

Suspension systems have been widely applied to vehicles, from the horse drawn carriage with flexible leaf springs to the modern automobile with complex control algorithms. The suspension of a road vehicle is usually designed with two objectives; to isolate the vehicle body from road irregularities and to maintain contact of the wheels with the roadway. Isolation is achieved by the use of springs and dampers and by rubber mountings at the connections of the individual suspension components. Roughly speaking, a conventional suspension needs to be soft to insulate against road disturbances and hard to insulate against load disturbances. Therefore, suspension design is an art of compromise between these two goals. The suspension systems basically consist of all the elements that provide the connection between the tires and the vehicle body. The suspension system requires an elastic resistance to absorb the road shocks and this job is fulfilled by the suspension springs. Spring is defined as an elastic machine element, which deflects under the action of the load and returns to its original shape when the load is removed. Springs are manufactured for many different applications such as compression, extension, torsion, power, and constant force. Depending on the application, spring may be in a static, cyclic or dynamic operating mode. Leaf springs can serve both damping as well as springing functions. The leaf spring can either be attached directly to the frame at both ends or attached at one end usually the front with the other end attached through a shackle, a short swinging arm. The shackle takes up the tendency of the leaf spring to elongate when compressed and thus makes softer springiness. Leaf spring consists of flat leaves or plates of varying lengths clamped together so as to obtain greater efficiency and resilience. Figure 1 shows leaf spring.

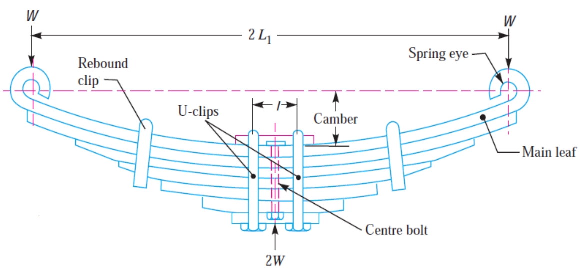

Fig. 1. Leaf spring

One of the important considerations in spring design is the choice of the spring material. Springs are usually made from alloys of steel. The most common spring steels are music wire, oil tempered wire, chrome silicon, chrome vanadium and stainless. Other materials can also be formed into springs, depending on the characteristics needed.

3. METHODOLOGY AND MATERIAL SELECTION

3.1 Material selections

Selection of the suitable material is a key aspect in automobile manufacturing industry. Materials of the leaf spring consist of nearly 60%-70% of the unsprung weight. Even a small amount in weight reduction of the vehicle, may have a wider economic impact. Composite materials are proved as suitable substitutes for steel in connection with weight reduction of the vehicle. The material which is capable of storing more energy in the form of elastic strain would be preferred for leaf spring. Specific elastic energy is given by: $S = 1/2(\sigma^2/\rho E)$ Where σ is the allowable stress, ρ is density and E is elastic modulus [23]. Composite materials have higher strain energy (energy storing capacity) as compared with metals because of their lower elastic modulus and low density. Hence, the composite materials can be selected for leaf spring design. Fiber reinforced polymer (FRP) composite materials consisting of fibers of high strength and modulus embedded in or bonded to resins with distinct interfaces between them. In general, fibers are the principal load carrying members, while the surrounding resins keep them in preferred location and orientation. The material composition selected for mono composite leaf spring are E-glass, Epoxy resin, in which E-glass as fiber material because of which is used as standard reinforcement fiber for almost all the present systems well complying with mechanical property requirements and low cost [19].

3.2 Specifications of existing steel leaf spring

Computer model of parabolic leaf spring of existing multi leaf spring is produced as exact replica of the physical specimen. Existing multi leaf spring and designed mono parabolic leaf spring is modeled in CATIA V5 in part design. The computer model is shown in Fig. 2 below based on the measured values in table 1.

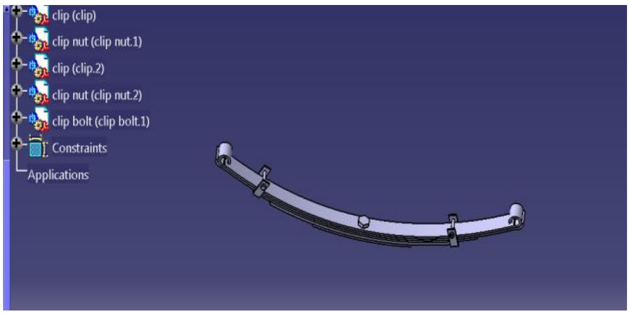

Fig 2. Existing steel leaf spring CATIA model

Table 1. Existing steel leaf spring measured dimensions

No.	Length	Radius of curvature(mm)	Width (mm)	Thickness (mm)
First leaf	115cm	160	62	8.5
Second leaf	115cm	168.5	62	8.5
Third leaf	89cm	177 mm	62	8.5
Forth leaf	75cm	185.5 mm	62	8.5
Fifth leaf	39cm	194 mm	62	8.5
camber	160mm			
Graduated leaves	3			
Full length leaves	2			

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 08, August-2022

Table 2. Mechanical properties of 55SiMn90

Parameter	Value
Material selected - steel	55si2Mn90
Tensile yield strength	1500 MPa
Tensile strength ultimate	1962 MPa
Young's modulus(E)	210 GPa
Poisson's ratio	0.3
Density	7850 Kg/m^3
Thermal Expansion	11×10^{-6} ℃

Material properties of E- glass Epoxy

Table 3. Mechanical properties of E-glass Epoxy [21, 40]

No.	Properties	value
1	Tensile modulus along X- direction (Ex), MPa	34000
2	Tensile modulus along Y- direction(Ey), MPa	6530
3	Tensile modulus along Z- direction(Ez),MPa	6530
4	Tensile strength of material, MPa	900
5	Compressive strength of material, MPa	450
6	Shear modulus along XY- direction, (Gxy), MPa	2433
7	Shear modulus along YZ- direction (Gyz), MPa	1698
8	Shear modulus along ZX- direction (Gzx),MPa	2433
9	Poisson ratio along XY – direction (Nuxy)	0.217
10	Poisson ratio along YZ- direction (Nuyz)	0.366
11	Poisson ratio along ZX – direction (Nuzx)	0.217
12	Mass density of the material(ρ), kg/mm^3	2.6×10^{-6}
13	Flexural modulus of the material, MPa	40000
14	Flexural strength of the material, MPa	1200

4. ANALYSIS RESULTS AND DISCUSSION

Finite element analysis (FEA) is a computing technique that is used to obtain approximate solutions to the boundary value problems in engineering. It uses a numerical technique called the finite element method (FEM) to solve boundary value problems. FEA involves a computer model of a design that is loaded and analyzed for specific results. Stress analysis is performed using quadrilateral meshing element and plane strain finite element model. A plane strain solution is considered because of the high ratio of width to thickness of a leaf. Analysis for both conventional leaf spring and mono composite leaf spring is done by using ANSYS 12.0, and analysis results of stress, deflection, natural frequency, fatigue failure (life prediction) are done.

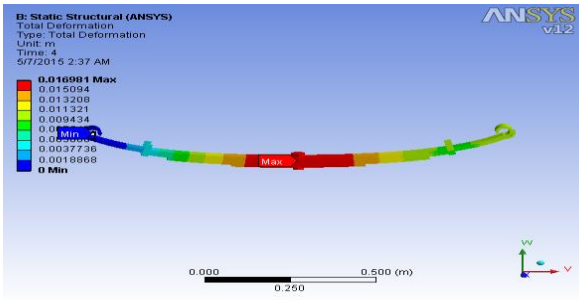

Fig. 3. Total deformation of steel leaf spring

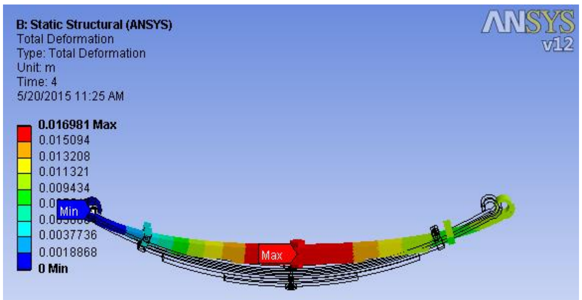

Fig. 4. Un-deformed and deformed shape

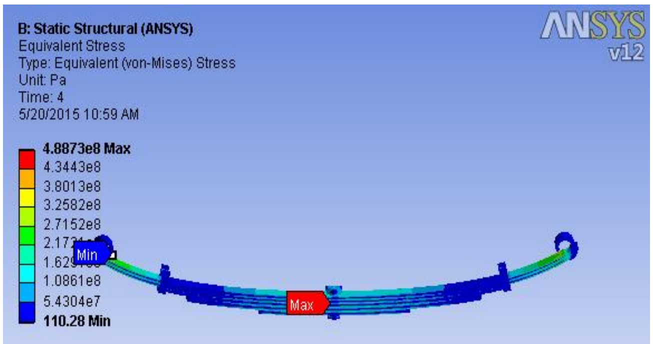

Fig. 5. Equivalent von- mises stress

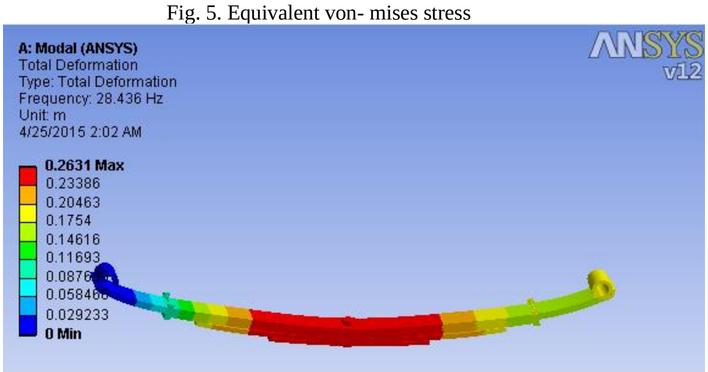

Fig. 6. First natural frequency and mode shape

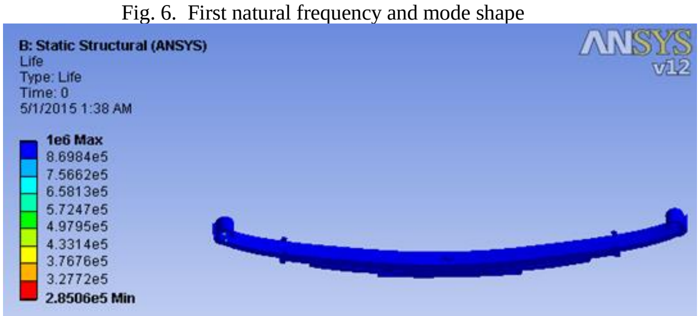

Fig. 7. Fatigue life

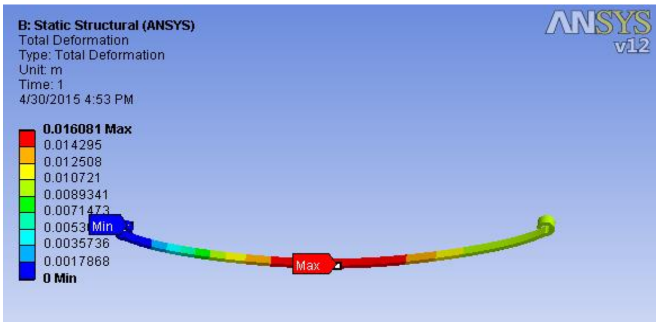

Fig. 8. Total deformation of composite leaf

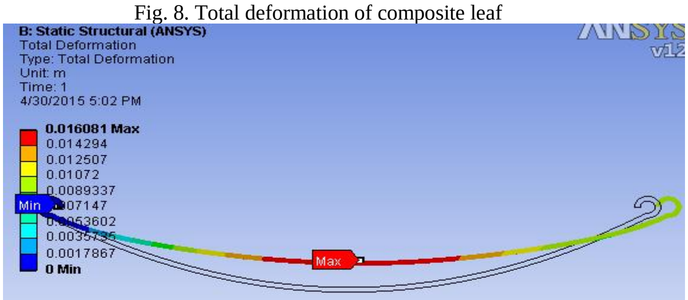

Fig. 9. Un-deformed and deformed shape of composite leaf

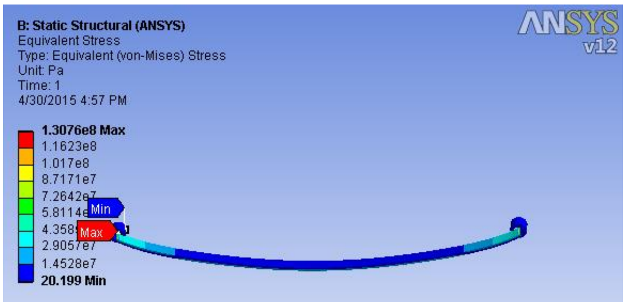

Fig. 10. Equivalent stress (von-mises) of composite leaf

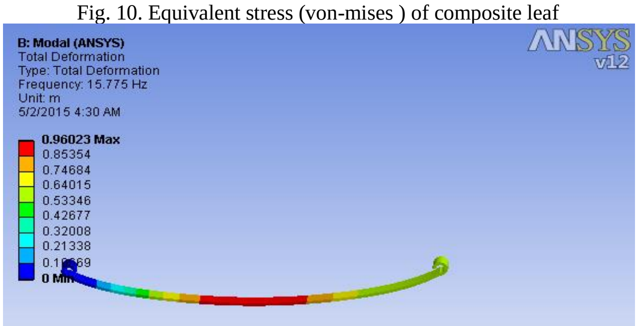

Fig. 11. First natural frequency of composite leaf

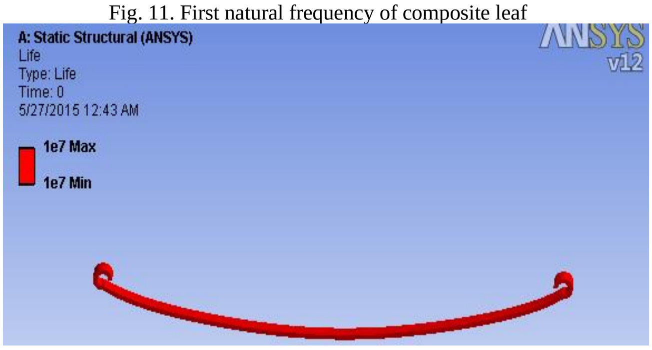

Fig. 12. Number of cycles to fatigue failure of mono composite leaf spring

Existing and mono composite leaf spring analysis results comparison

Table 4. Stress and deflection comparison between steel and composite leaf spring

Parameter	FEA results of steel spring	FEA results of composite leaf spring	Variation %
Load (N)	6796	6796	Nil
Deflection (mm)	16.981	16.081	5.3%
Bending stress (MPa)	4.8873×10^8	1.3076×10^8	73.24%
Mass (kg)	21	1.4799	92.9%

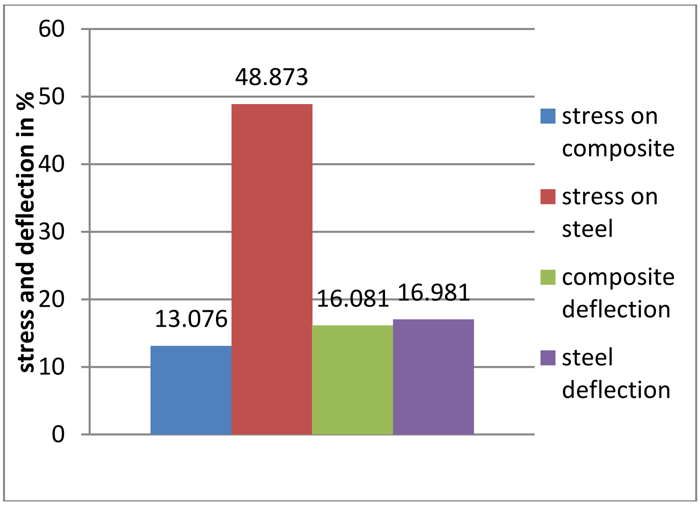

Fig. 13. Stress and deflection of leaf springs

Table 5. Frequency comparison of existing steel leaf spring and composite leaf spring results

No. of mode	Existing steel leaf natural frequency (Hz)	Mono composite leaf natural frequency (Hz)
1	28.436	15.775
2	76.064	45.82
3	85.561	58.362
4	197.48	96.494
5	230.86	157.04
6	308.66	158.16

Table 6. Fatigue analysis results

parameter	Existing steel(55si2Mn90)	E-glass epoxy
Maximum fatigue life (cycles)	1×10^6	1×10^7
Safety factor	0.83505	1.0726
High cyclic stress($\frac{N}{m^2}$)	1.7387×10^8	1.1466×10^8

Table7. Harmonic response amplitude results

Materials	Amplitude of response	Equivalent (von-mises)stress
55si2Mn90	5.11×10^{-3}	4.14×10^8
E-glass Epoxy	5.12×10^{-3}	4.4593×10^7

5. CONCLUSION

The numerical analysis of Huanghai pickup DD1022T steel leaf spring is done and based on the analysis results, mono composite leaf spring made of e-glass epoxy is designed. Both multi steel leaf spring and mono composite leaf spring are modeled in CATIA V5 and imported into ANSYS workbench in the form of IGS file for better analysis results. The different analysis namely, stress analysis, deflection analysis, fatigue analysis, harmonic and modal analysis are performed using ANSYS. Analysis results of conventional multi leaf spring and mono composite leaf spring is compared. Based on the results of analysis it is concluded that:

- Composite leaf spring is more economical on production processing cost than that of conventional steel leaf spring, since production of conventional leaf spring should passes through different production process tools which is very expensive.
- Conventional steel leaf spring is found to be heavier then E-Glass/Epoxy mono leaf spring
- E-Glass Epoxy mono leaf spring reduces the weight by 92.9% over existing steel leaf spring.
- Compared to conventional, composite mono leaf spring has lesser stress, weight, vibration, and increasing fatigue life, strength and comfort ride.
- Using the constant amplitude loading, the fatigue stress and life of the spring has been predicted, E-glass epoxy leaf spring has 1×10^7 cycles and existing steel (55siMn90) leaf spring has 1×10^6 cycles of fatigue failure. Therefore, e-glass epoxy has increased fatigue life than existing leaf spring.
- Steel has less amplitude than e-glass epoxy and they both have almost similar amplitude versus frequency graph that shows the harmonic response of the material.
- Equivalent stress in composite leaf spring due to harmonic response is less than its strength indicating that it is safe.
- The strength to weight ratio is higher for composite leaf spring than conventional steel spring.

The study demonstrated that composites can be used for leaf springs for light weight vehicles and meet the requirements, together with substantial weight Savings. Therefore, it can be concluded that mono composite leaf spring is an effective replacement for the existing steel leaf spring in light vehicles.

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