IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 8 Issue 10, October 2021
ISSN (Online) 2348 – 7968 | Impact Factor (2020) – 6.72
www.ijiset.com

Design and Simulation of E-Glass/Epoxy Composite Mono Leaf Spring for passenger Vehicle Application

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Abstract

This study deals with the design and simulation of E-Glass/epoxy composite materials for the leaf spring of a Toyota land cruiser vehicle application. The aim being to replace the conventional multi-leaf with a single-leaf composite spring is to achieve a reduction in vehicle weight, ergonomic design, and to get a better fuel-efficient vehicle. The conventional multi-leaf spring specifications and dimensions of the Toyota land cruiser vehicle have been investigated and consequently, the leaf spring was designed for single leaf composite as well as the multi-leaf conventional steel springs. The designs were simulated by ANSYS simulation package and the results were compared for different strength and material properties. The static structural analysis predicts a 22% in stress reduction of the composite spring over the conventional spring and 61.35% overall significant weight reduction have been achieved.

KEYWORDS: *Mono leaf spring, Graduated leaf spring, ANSYS package**,** Epoxy resin**.***

1. Introduction

A higher car population and an increase in the concentration of poor quality second-hand cars have many negative consequences. First, as these old cars are made up of heavy materials, they consume a huge amount of fuel that increases fuel cost and air pollution. Second, they will increase the occurrence of unexpected and damaging car accidents. According to the world health organization, in 2014, road traffic accidents were 15,015, or 2.5% of total deaths in Ethiopia. This is one of the highest accidents in the world, which leads the country to be 68th in a road traffic accident in the world[1]. All these indicate that improving the transportation system and reducing car-related accidents and unexpected risks is mandatory. Many approaches are suggested as a solution for this. For example, road improvement, changing transport modalities, use of new vehicle technology, and use of less-weight vehicles that can consume minimum fuel are the main ones [2]. A suspension device is one of the most important components of a vehicle. The suspension device separates the axle from the vehicle chassis so that any road irregularities are not transmitted directly to the driver and the load on the vehicle. This is not solely allowing an extra-relaxed ride, and protection of the load from feasible damage, but it additionally helps to stop distortion and harm to the chassis frame[3]. Depending on the size and cars type, there are different types of suspension systems. Leaf spring suspension system is the common suspension system for medium and large cars.

A leaf spring normally used in automobiles is of semi-elliptical form. It is built up of the different sizes of leaves. The leaves are typically given preliminary curvature or cambered so that they will tend to straighten under the load. The leaves are held collectively making use of a center bolt passing by the center. The spring is clamped to the axle housing the use of U-bolts. The longest leaf recognized as the main leaf or master leaf has its ends formed in the structure of an eye through which the bolts are exceeded to tightly close the spring to its supports

Usually, the eyes, through which the spring is attached to the hanger or shackle, are provided with bushings of some anti-friction materials such as bronze or rubber. The other leaves of the spring are known as graduated leaves. To prevent digging in the adjoining leaves, the ends of the graduated leaves are trimmed in various forms. Rebound clips are positioned at intermediate positions in the length of the spring so that the graduated leaves also share the stresses triggered in the full-length leaves when the spring rebounds[4].

The advantage of leaf spring over helical spring is that the ends of the spring might also, in addition, be guided alongside a particular route as it deflects to act as a structural member in addition to the energy-absorbing device. Thus, leaf spring can additionally carry lateral loads, brake torque, driving torque, in addition to shocks. The functionality to take in and store more extent of energy ensures the comfortable operation of a suspension system. A notable variety of spring materials are available to the designer, inclusive of simple carbon steels, alloy steels, and corrosion-resisting steels, as nicely as nonferrous substances such as phosphor bronze, spring brass, beryllium copper, and several nickel alloys[3].

The material used for leaf springs is commonly carbon steel having 0.90 to 1.0% carbon. However, to gain larger strength, greater load-carrying capacity, and increased vary of deflection, and higher fatigue resistance using carbon steel the leaves need to be warmth dealt with after the forming process[1]. But this requires a large amount of human, material, and financial resources which is not easily affordable and accessible.

2. Methodology

2.1 Materials

Tow materials are chosen for this research work; one is a composite material and the second is conventional steel. Composite materials are fashioned through the mixture of two or more substances to attain properties (physical, chemical, etc.) that are most reliable to these of their constituents. The most important factors of composite materials are reinforcement (fibers) and matrix.

Table1 Properties of E-G lass Fiber (Reinforcement) Materials [5-8]

Glass fiber	
Density	2.45 g/cm^3
Longitudinale Tensile modules (E_1)	81 *GPa*
Trasverse Tensile modules(E_2)	81 *GPa*
Poison ratio (n_{12})	0.22
Shear modulus (G_{12})	30*GPa*
Longitudinal Tensile Strengths(σ_t)	3.450*MPa*
Compressive strength (σ_c)	0.45 *GPA*
Ultimate tensile strength(σ_u)	2500*MPa*

The fibers provide most of the stiffness and strength. The matrix binds the fibers collectively thus offering load transfer between fibers and the composite and the external masses and supports. In addition, it protects the fibers from environmental attack[6]. These unique behaviors provide the mechanical engineer with design possibilities no longer viable with ordinary monolithic (unreinforced) materials. Further, many manufacturing approaches for composites are properly adapted to the fabrication of large, complicated structures, which allows consolidation of parts, decreasing manufacturing costs[7].there are so many different types of composite materials and that offer a combination of strength and modulus that are better than any traditional metallic materials[8]. For this study, E - Glass material is used as a reinforcement and epoxy resin is as the matrix. By combining these materials E-Glass /Epoxy composite mono leaf spring is designed and simulated for land cruiser vehicle application.

Table 2 Properties of Epoxy Resin[9]

Properties	Values
Density (g/cm^3)	1.2
Elastic modulus(*GPa*)	3.33
Tensile strength (*GPa*)	0.13
Shear modulus (*GPa)*	1.25
Poisson's ratio	0.33
Flexural yield strength (*GPa*)	0.125
Compressive strength	0.19
Elongation at break	0.8
Glass transition temperature ^{0}c (*Tg*)	120 - 130

For the multi-leaf spring model conventional steel is selected and simulated to compare the different stress and deformation values with composite mono leaf spring. The properties of E-Glass fiber and Epoxy resins are presented in Tables 1 and 2 respectively and conventional steel materials are in table 4.

3. Analytical Design

To perform the analytical design of conventional steel and composite mono leaf spring, first, all the required information such as each dimension of leaf spring, number of graduated and master leaves, and weight of the vehicle are collated from land cruiser vehicle by directly observing and measuring each dimension. Their characteristics are tabulated in table 3 and the models of conventional steel and composite materials leaf springs are presented in figure1.in conventional steel, there are five graduates and one master leaves.

Table 3 dimensions of conventional steel leaf spring models

Parameters	Value in(*cm*)
Length of 1^{st} t leaf	143
Length of 2^{nd} leaf	141
Length of 3^{rd} leaf	116
Length of 4^{th} leaf	105
Length of 5^{th} leaf	95
Length of 6^{th} leaf	57
Width (equal for each) leaf	7
Thickness (equal for each) leaf	0.8
Width of U-bolt	12

Table 4 characteristic features of land cruiser vehicle

Features	Values
Mass of the vehicle	1400kg
Number of seats	8
The average mass of one person	80kg
The total mass of passengers	640kg
The capacity of the cargo	200kg
Total mass	2240kg
Acceleration due gravity (g)	$10m/s^2$
Factor of safety	1.8

Using the information mentioned in table 4, the total load exerted to the vehicle can be determined by multiplying the total mass of the vehicle by gravity and factor of safety. That becomes, 2240gk $*10m/s^2*1.8=$ 40320N therefore, Weight = 40320*N*

Since the vehicle is a four-wheeler and the load are exerted to four sides equally then it can be taking a single side of leaf spring corresponding to one of the wheels so, it should be 1/4 of the total weight of the vehicle become,

$$W = \frac{40320N}{4} = 10080N$$

Table 5 Properties of Steel Material[10]

Property	Values
Ultimate tensile strength (σ_t)	1272*MPa*
Tensile yield strength ($\sigma_{y)}$	1158*MPa*
Compressive yield strength (σ_c)	1158*MPa*
Modulus of elasticity (E)	$2.1*10^5 N/mm^2$
Shear modulus (G)	$7.69*10^9 MPa$
Density (ρ)	$7850 kg/m^3$
Poisons ration(v)	0.266
Shear strength of steel(τ)	1470*Mpa*
Flexural strength of steel (σ_b)	*653Mpa*

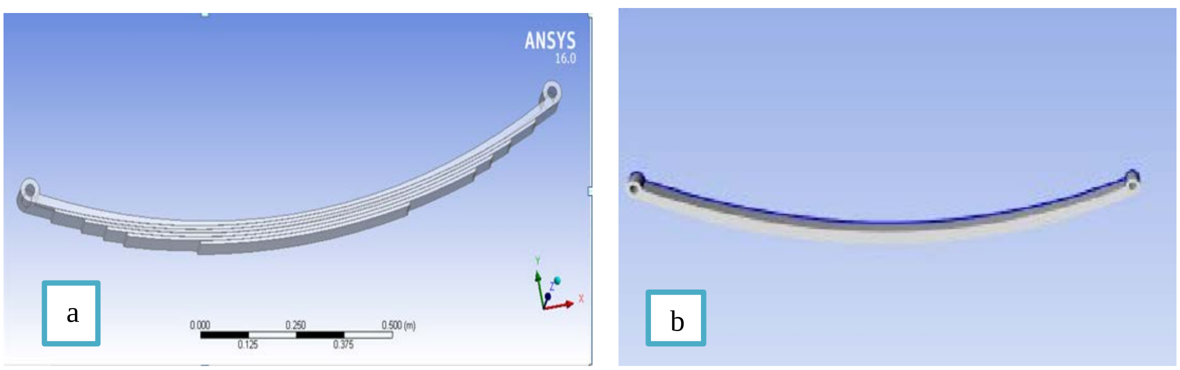

Figure 1 model of conventional steel (a) and E-Glass/Epoxy composite (b) mono leaf spring

4. Numerical and Finite Element Analysis

In this article, by applying similar amounts of load in the same boundary condition for both models of the leaf spring it can perform the static analysis. The solid models of the leaf springs are designed by solid work 2017 premium and the static analysis is done using Ansys 16. for the numerical and FEA of both leaf springs, von-misses stress, principal (alternating stress), and total deformations are considered as the main constraint. Figure1 (a) and (b) below shows the models of conventional steel and composite mono leaf spring respectively.

5. Boundary Condition:

5.1 Displacement Constraint:

By considering the actual behavior of leaf spring in the vehicle, one end of the leaf spring is rests on the shackle and the other end is on the chassis frame. Therefore, remote displacement of one end of leaf spring in X, Y, and Z components are fixed and in rotation constraint X, Y components are also fixed and Z components are free to rotate. The other ends of remote displacements of the X component are free, Y and Z components are fixed, in rotation X and Y are fixed and Z is free to rotate.

5.2 Force Constraint:

When observing the leaf spring mounting position concerning the exerting loads of the vehicle. The right and left sides of the wheels are connected by the axel and the whole structure or body of the vehicle is resting on the chassis and leaf spring of the vehicle. leaf spring of land cruiser vehicle is mounted on its center to the axel using U- bolts finally loads of the vehicle is rest at the center of the leaf spring through the axel in left and right sides. Regarding this characteristic, the load is applied at the center of the leaf spring. The front and the rear links (especially the shackle one) act as the flexibilities of the motion of the vehicle in vamp and speed breaker road as a suspension.

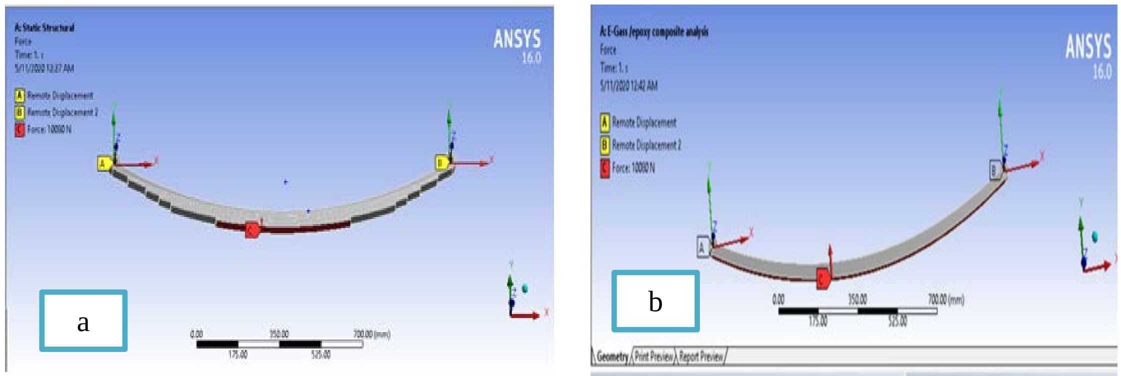

Figure2 force and displacement constraint for steel (a) and composite (b) leaf spring

6. Meshing or (Discretization) of Leaf Spring Models:

The total equation in the continuous body is six times infinite which results in infinite ($6*\infty = \infty$) and the solving times of the structures are infinite so, solving any infinite body is impossible using computer software. Therefore, the continuous domain of study should be replaced with a finite set of points, and the process is called discretization or meshing. The meshing of mechanical parts is the transferring of the continuous body, which has infinite points into discontinuous (discrete) points, which have finite nodes and elements. This is because the computer for the numerical solutions can give answers at only discrete points in the domain, called grid points. For this structure, the mesh has been generated using a triangular mesh method and by considering the computer CPU the types of mesh used are medium, as shown in figure 3(a). The number of elements used is 74686 and the number of nodes is 127487 for conventional structural steel leaf spring and in figure (b) Number of elements used for E-Glass/Epoxy composite is 13848 and the number of node is 25772.

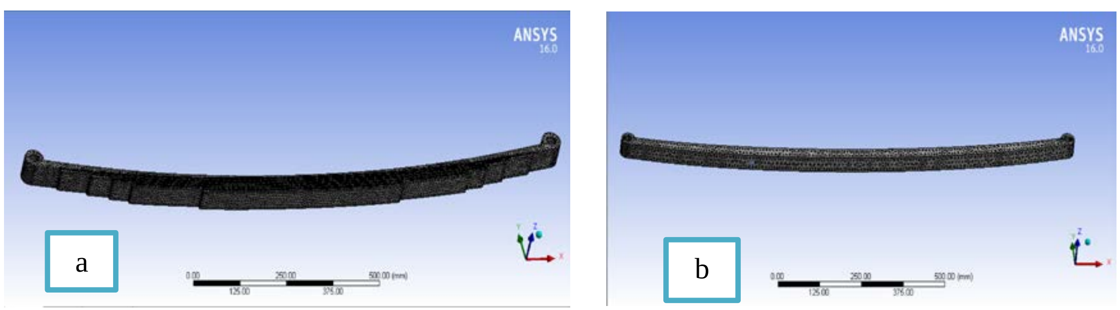

Figure3 mesh models of steel (a) and composite (b) leaf spring

7. Results and Discussion

This part describes all about results generated in the analysis of conventional steel and E-Glass/Epoxy composite mono leaf springs for land cruiser vehicle applications, which are obtained from static structural analysis.

Static structural analysis of composite material mono leaf spring and conventional steel multi-leaf spring is performed by way of making use of a load of 10080N for each leaf spring. as really observed from the layout and the Finite element simulation result above, for the equal capacity, equal Load, and the same boundary condition. The evaluation of all the noted constraint analysis results was carried and when comparing the design and simulation result of traditional steel multi-leaf spring and unconventional composite mono leaf spring, the overall performance of the composite mono leaf spring is better than that of the existed steel leaf spring in the preferred parameters and the stated constraints. These unique results acquired for both leaf springs are mentioned below.

7.1Weight Reduction:

As received from the numerical results, the weight discount got the usage of composite mono leaf spring and existing steel leaf springs are present in table 6. as mentioned so far, the major goal of this specific research is to decrease the consumption of fuel of the Toyota land cruiser vehicle by minimizing the weight and stress .so, 61.354% of weight reduction is executed using glass fiber composite mono leaf spring materials. It can prove that, after using composite materials mono leaf spring, the weight of the car and failure of the leaf spring to become decrease thereby it improves the fuel efficiency and load-carrying capacity.

7.2 Equivalent Stress:

By applying a load of 10080N in both leaf springs using the finite element method (FEM) in ANSYS16 analysis software to the same boundary condition, the maximum stress induced in E-Glass/epoxy mono leaf spring in figure 4 is smaller than that of the existing conventional steel multi-leaf spring figure 5 .which is 196.28mpa < 253.22mpa. Therefore, this result implies that composite mono leaf spring can replace conventional steel leaf spring for suspension application of light and medium vehicles.

7.3 Deformations:

observes from the analytical and the simulation result of ANSYS16 software, the values of total deformation at the center of each leaf spring is 7.68mm for steel present in figure 6, and mono leaf spring in figure7 is 11.8mm. Because steel leaf spring has different size graduate leaves and the structure is not uniform but the composite Leaf spring is a single leaf spring and uniform size throughout its length. Therefore, a composite mono leaf spring can replace the existing steel leaf spring. as indicated in Figure 8 and figure 9 respectively, simulation result of conventional steel and E-Glass/Epoxy composite mono leaf spring the alternating stress-induced in steel leaf spring is higher (242.82 MPa) than the alternating stress-induced in composite mono leaf spring (195 MPa).

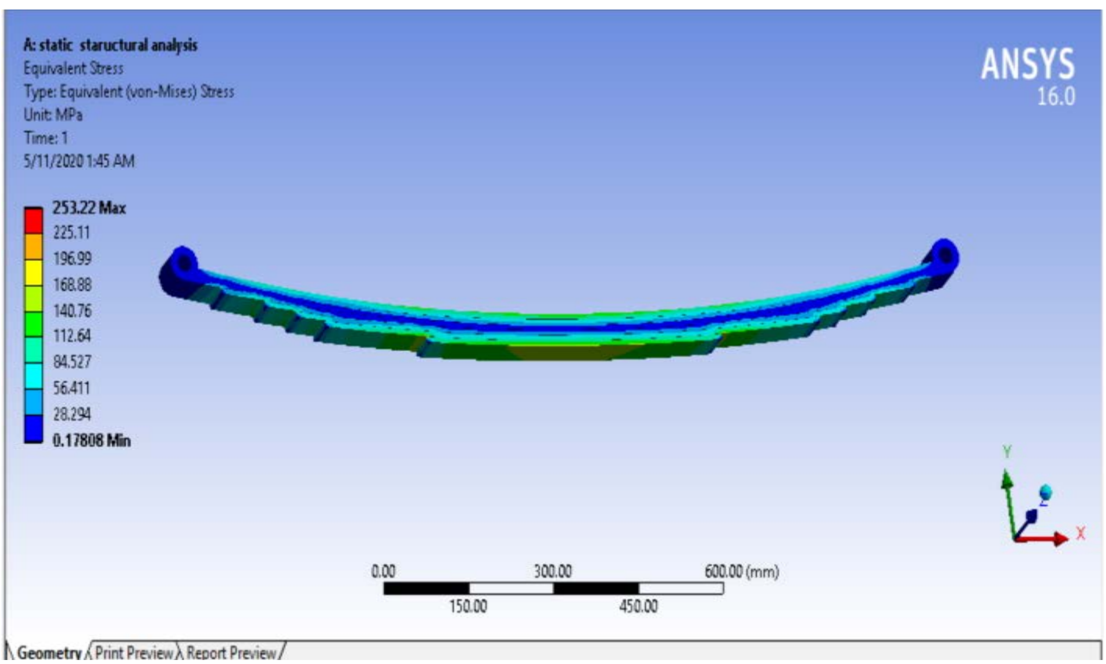

Figure 4 Equivalent (von-misses) stress of conventional steel leaf spring

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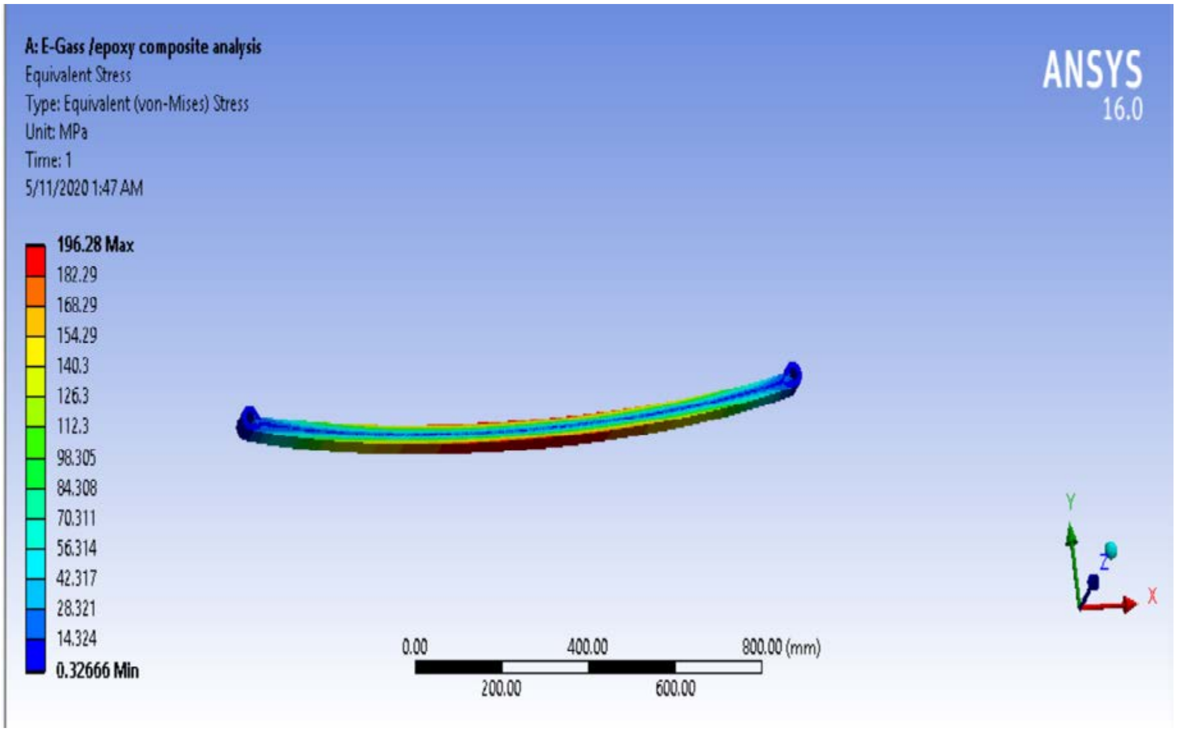

Figure 5 Equivalent (von-misses) stress of composite mono leaf spring.

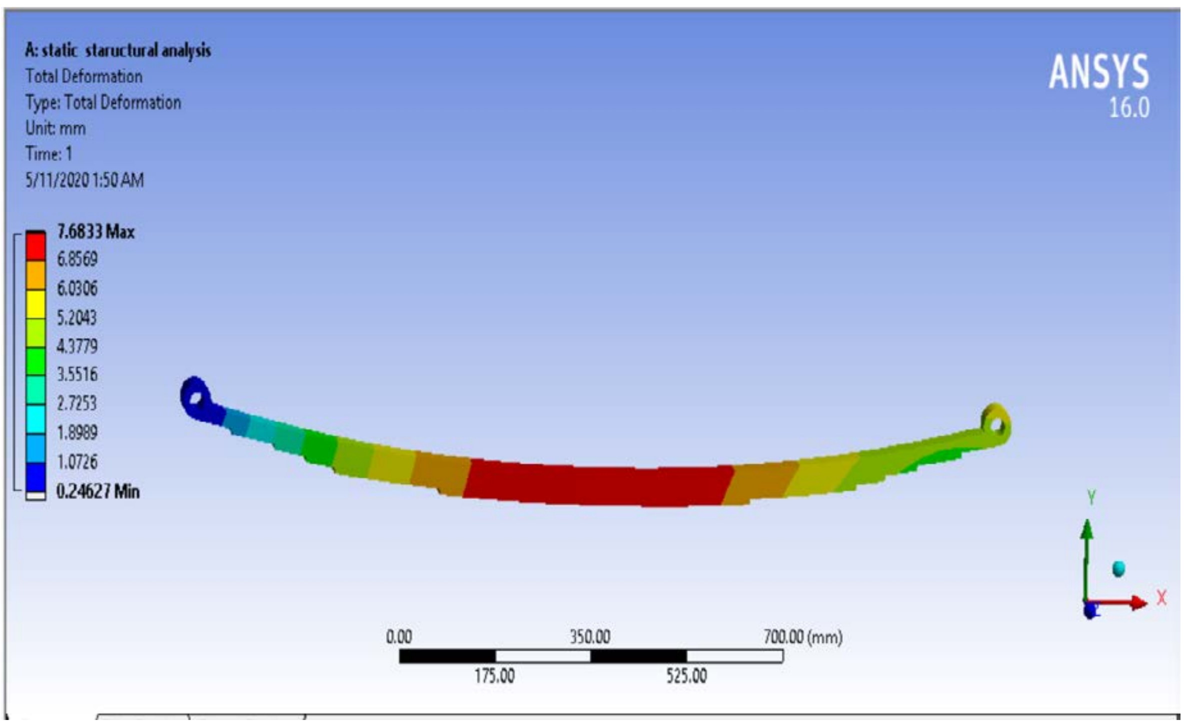

Figure 6 total deformation of conventional steel leaf spring

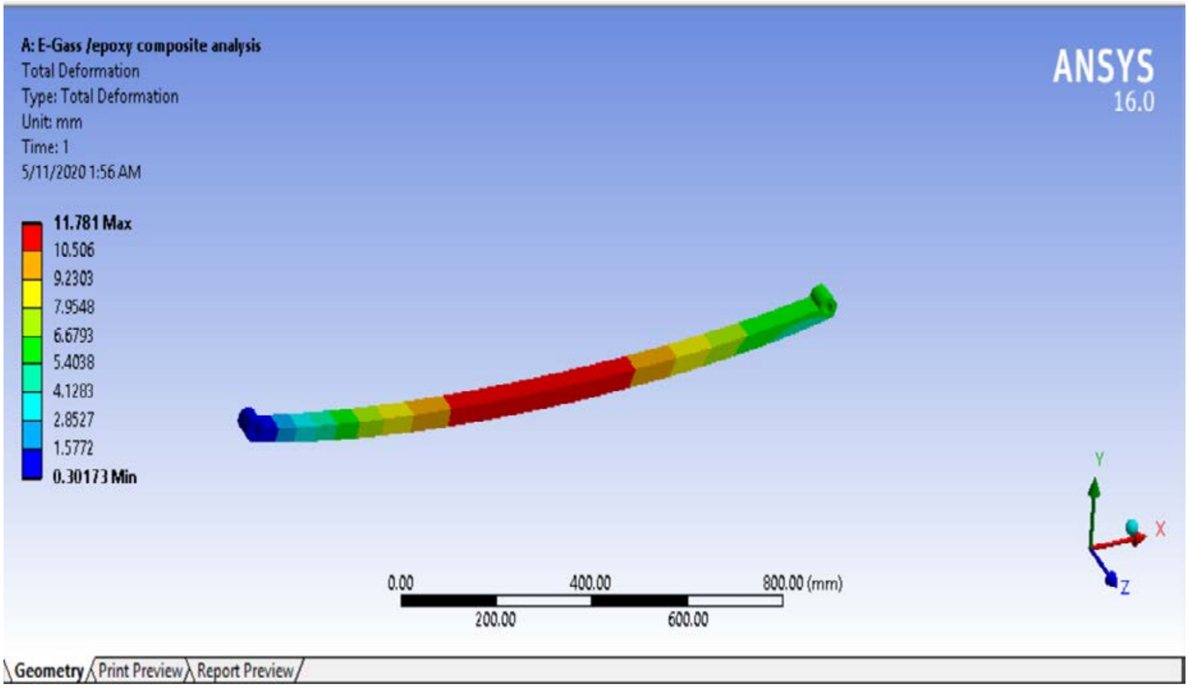

Figure7 total deformation of composite mono leaf spring

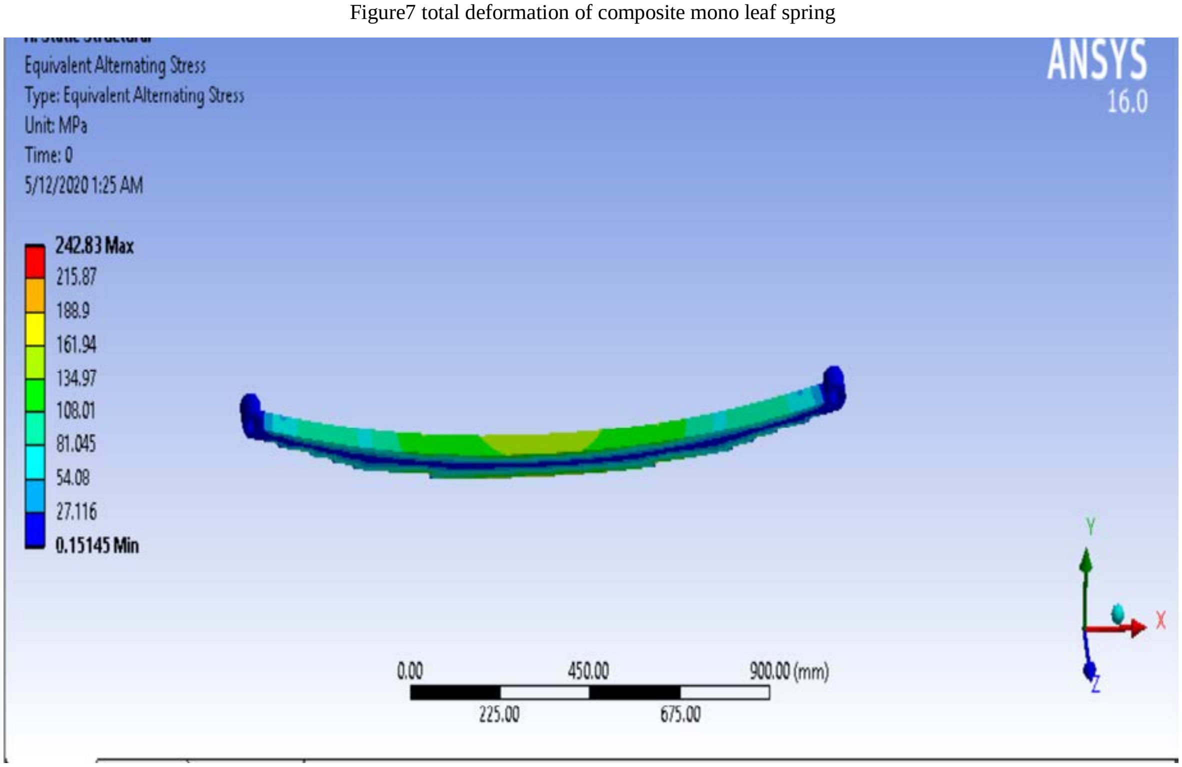

Figure 8 Equivalent alternating stress of conventional steel

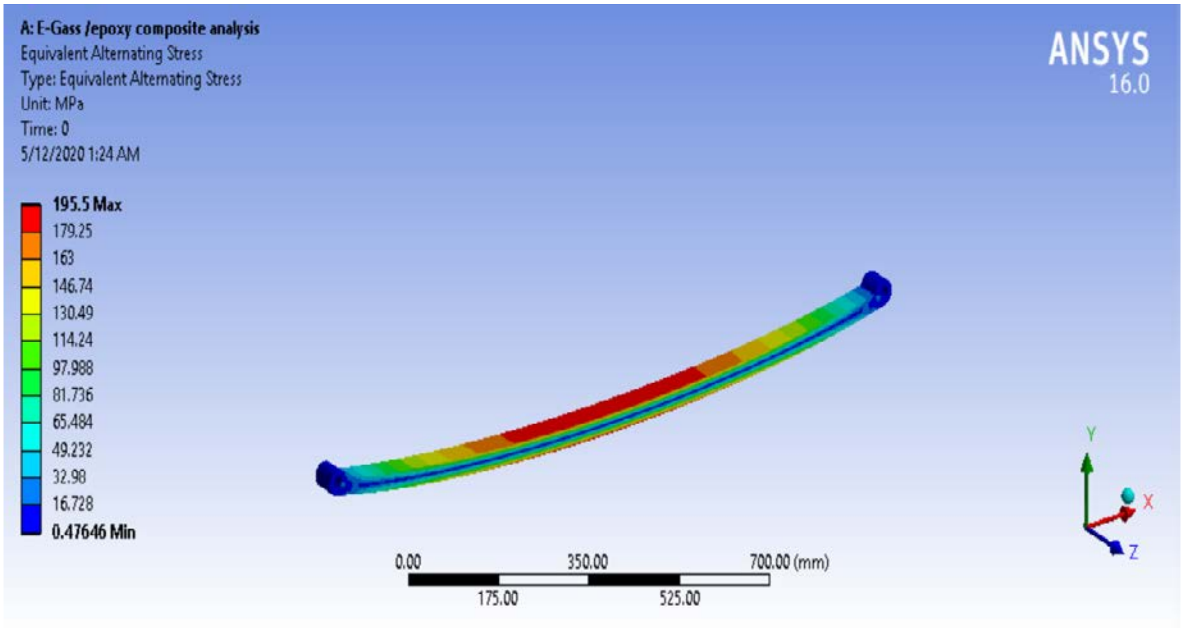

Figure 9 Equivalent alternating stress of composite mono leaf spring

Table6 summary of static structural analysis results

Leaf Springs	Maximum Equivalent stress (Mpa)	Maximum Total deformation (mm)	Alternating mean stress (Ma)	Weight in (N)
Conventional steel	253.22	7.68	242.83	288.7
E -Glass/epoxy	196.28	11.78	195.5	111.6
Percentage optimization	22.48%	34.8%	19.5%	61.35%

The chart below shows the comparison results of FEA of conventional steel and E-Glass/epoxy mono leaf springs.

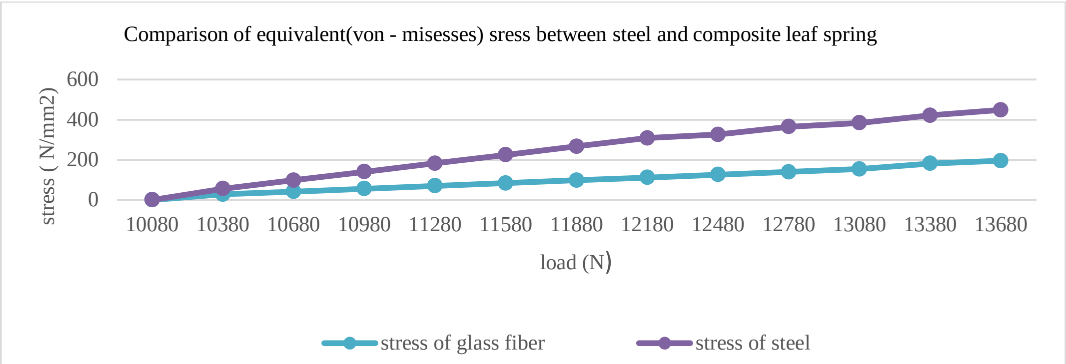

Figure 10 Comparison of equivalent stress of steel and composite leaf spring

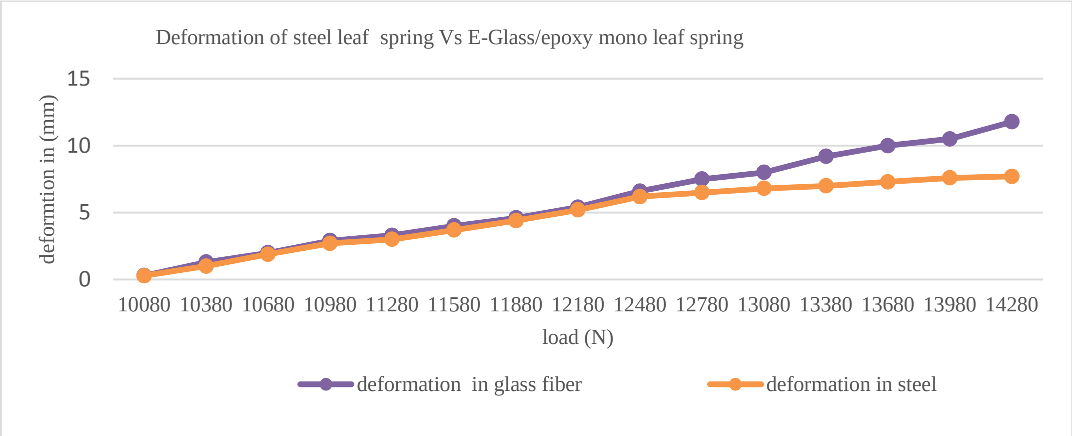

Figure11 Comparison of deformation for steel and E-Glass/epoxy mono leaf spring

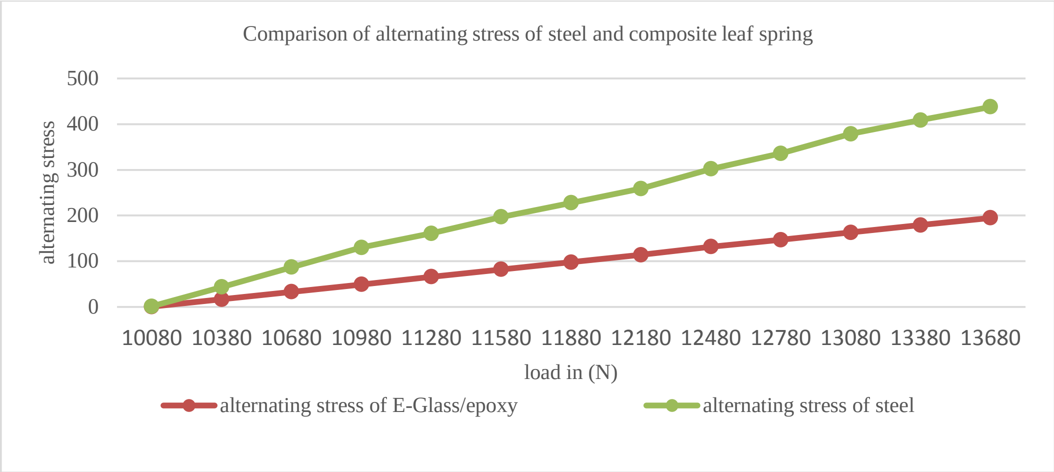

Figure12 Comparison of alternating stress of steel and composite leaf spring

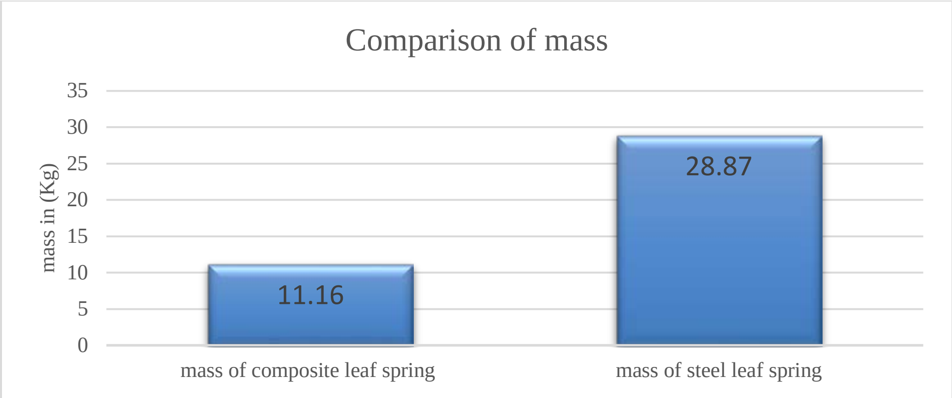

Figure13 Comparison of mass of steel and composite leaf spring

8. Conclusion

In this study, design and analysis of E-Glass/epoxy composite materials are conducted for the application of Toyota land cruiser passenger vehicle leaf spring. The static structural analysis was conducted by applying finite element methods between traditional steel and E-Glass/epoxy composite mono leaf spring using ANSYS workbench to evaluate the strength properties of these materials related to the utility of land cruiser leaf spring. In the static analysis, the stress-induced in conventional steel leaf spring are 253.22MPa whereas in composite mono leaf spring is reduced to 196.28MPa. These values indicate E-Glass/epoxy composite mono leaf spring is better for the applicability of leaf spring.

Finally, using composite materials for the leaf spring application has to be achieved a 61.35% of weight reduction over the existing steel leaf spring. This improves fuel consumption of the vehicles and it leads the vehicle industry to immerge confidently for mass production of fuel-saving vehicles and Thereby it reduces air prolusion.

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