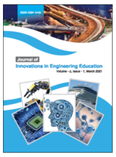

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Finite element analysis of Epoxy/E-Glass composite material based mono leaf spring for light weight vehicle

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Abstract

A great deal of work is put into decreasing the fuel consumption of automotive vehicles, which may be accomplished by reducing the bulk of the vehicles. One component that may be explored is the leaf spring, which is extensively utilized in many sorts of cars, including electric ones. For the leaf spring, four distinct materials are considered: standard steel, Epoxy/E-Glass UD composite, Epoxy/E-Glass Wet composite, and Epoxy/S-Glass UD composite. The FEA study executed with the help of the ANSYS finite element code. Firstly, the 3-D model of the leaf spring with different thickness varying from 15mm to 65mm is designed using SolidWorks software which is then imported to the ANSYS software for the static analysis. Along with this, the finite element analysis under full load on 3-D composite multi leaf spring model is executed using ANSYS 2020 R1 by taking three different materials and then the result for the different static behaviour of the leaf spring are compared for all the materials assigned. In this paper we describe design and analysis of composite leaf spring. The leaf spring model used for this purpose is a rear leaf spring used in MAHINDRA 'MODEL-COMMANDER 650 DI'. When compared to traditional steel, the mass of hybrid composite material is 62% lower. Hybrid composite materials have 36% lower equivalent (Von-Mises) stress than steel. Utlimately, the hybrid composite material may be employed as a leaf spring, decreasing the total weight of automobiles.

1. Introduction

A leaf spring, otherwise known as a semi-elliptical spring, elliptical spring, or cart spring, is a simple type of spring most common in heavy vehicle's suspension system. Also known as carriage or laminated spring when it was first use. It consists of several thin arc-shaped steel bars longitudinal in nature and with rectangular cross section such that the elastic nature of steel can be fully used to yield the function of spring. The location of axle of the vehicle is typically at the center of the arc and the spring is attached to the vertical frame of the vehicle with the use of loops. The piling of the leaves or bars is done in a way that each layer sitting on top of the other is longer than the one below. The number of leaves used is proportional to the weight of the vehicle and the load to be borne by it. Leaf springs can be used for locating and, to a lesser extent have the function of springing as well as dampening. While the inter-leaf friction acts as a dampener. It is common knowledge that autos consume a substantial amount of gasoline each day, and researchers are working to lower this consumption in the automobile sector. The reduction in bulk of automobiles has a direct impact on the amount of gasoline utilized by the vehicles. As a result, attempts are made to lower the automobile's mass without compromising its efficiency. Leaf springs are a type of automobile component that is found in most trucks, SUVs, buses, earth moving heavy equipment vehicles, and other types of huge vehicles.

They have a significant mass that can be lowered in order to reduce vehicle mass and thus save energy. It

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is necessary to develop a new material that is less in weight but more efficient than existing materials. Several studies on the weight reduction of leaf springs have been published in the literature. ANSYS software is used to analyze the leaf spring built of C glass composite and traditional steel material [1]. When compared to steel leaf springs, the composite leaf spring weighed less and caused 64% less stress [2]. Replacing the construction material of leaf spring with boron aluminium, glass epoxy or carbon epoxy in place of steel was found to reduce the overall weight upto 90 percent [3].

Fatigue analysis was carried out for steel spring, and static analysis for steel leaf springs, composite leaf springs and hybrid leaf springs. The stress in composite spring was found to be less as compared to steel. The hybrid spring found to have values of stress in between that of steel and composite. The fatigue analysis of steel spring was carried out by four approaches, Soderberg's approach was found out to give better results for the analysis of life data for the leaf spring [4].

Under static loads, numerical simulation is performed. Findings showed that the mass was reduced upto 78 percent and the stresses experienced were lesser as compared with that of steel [5]. The composite materials are preferable than steel in terms of weight and induced stress [6]. The concept of multi leaf spring being constructed with hybrid composite material is not totally noble. Leevy used this concept and the results were found to favor the use of hybrid composite materials for leaf springs [7]. Simulations on hybrid composite leaf spring is carried out and it was observed that the weight reduction was considerable in this leaf spring when the conventional steel material was replaced. Study on the fatigue properties of a hybrid composite leaf spring resulted that it has good fatigue qualities [8]. Based on the literature research, it is clear that there is a significant requirement to bring the weight of components in an automobile down even further in order to save energy in the future.

2. Methods and methodology

2.1. Vehicle considered

Mahindra MODEL-COMMANDER 650 Di vehicle shown in Figure 1 is considered for the data required. This vehicle consists of 10 leaves rigid leaf spring suspension in the rear side.

2.2. Model of the leaf spring

For the leaf spring models, four several materials are chosen: traditional steel, Epoxy/E-Glass UD composite, Epoxy/E-Glass Wet composite, and Epoxy/S-Glass UD composite. The properties include weight and length of each leaf. There are 8 graduated and 2 full length leaves. The thickness and width of each leaf is 6 mm and 50 mm respectively. Dimension of graduated leaves are calculated using formula, centre load is taken as mentioned by Manufacturer Company of vehicle. Factor of safety is considered so that load may vary in the vehicle. The leaf spring model is created using the Solidworks software and the subsequent simulation is executed with ANSYS 2020 R1 finite element code. The properties of leaf springs with their formulas are presented in Table 1

Figure 1: Mahindra model - COMMANDER 650 Di [9]

Weight of conventional leaf spring is required to compare with that of composite leaf spring which is tabulated in Table 2.

2.3. Finite element analysis

The static structural domain of ANSYS 16 R1 is used to analyze all of the models. A full length leaf spring model is studied, as shown in Figure 2. The research takes into account static loading circumstances and assesses equivalent stresses, elastic strain, total deformation, and maximal main stresses. By examining different loading circumstances involving three distinct models, almost 48 results involving various parameters are produced. Only the equivalent stresses, equivalent elastic strain, total deformation, and shear stresses of the highest load (i.e. 3200 N) for each model are described here for the purpose of brevity.

For various loading situations, the Von-Mises stresses, principal stresses, deformation, and strain are the key parameters discussed in this article. For all of the materials evaluated in this FEA study, the same leaf spring model is used.

2.4. Meshing

The domain is discretized by creating a mesh, and the mesh quality is monitored closely in terms of maximizing accurate results for the given problem. Over the

Table 1: Properties of leaf springs with their formulas and values

Property	Calculation	Value
Overall length of the spring	$2L_1$	1150 mm
Width of leaves	50 mm	
Number of leaf springs	10	
Assuming factor of safety	1.33	
Number of graduated leaves	8	Ng
Number of full length leaves	2	Nf
Number of springs	10	(N_g+N_f)
Center load	2W	1910 kg
2W	1910*10*1.33	25403 N
2W	25403/4	6350.7 N
2W	$\frac{\text{Total load}}{\text{No. of spring}}$	6350.7 N
W	3200 N (approximately)	
Leaf spring Material selected	structural steel	
Bending stress	$\frac{6wl}{nbt^2}$	299 N/mm^2
δ_F	$\frac{12wL^3}{\epsilon bt^3(2N_g+3N_g)}$	67.5mm
Length of leaf spring	$\frac{\text{effective length}}{\text{number of leaf-1}}$ + in effective length [10]	
Effective length	1120mm	
Ineffective length	90mm	
Number of full length leafs	2	
Length of smallest first leaf	$\frac{1120}{10-1}$+90	214.45mm
Length of second leaf	$\frac{1120}{10-1}$*2+90	338.89 mm
Length of third leaf	$\frac{1120}{10-1}$*3+90	463.34 mm
Length of fourth leaf	$\frac{1120}{10-1}$*4+90	587.78 mm
Length of fifth leaf	$\frac{1120}{10-1}$*5+90	712.23 mm
Length of sixth leaf	$\frac{1120}{10-1}$*6+90	836.67 mm
Length of seventh leaf	$\frac{1120}{10-1}$*7+90	961.11 mm
Length of eight leaf	$\frac{1120}{10-1}$*8+90	1085.56 mm
Length of ninth leaf	1120 mm	
Length of tenth leaf	1120 mm	

domain, a fine unstructured mesh with 3 mm element size is produced.

2.5. Material selection and properties

Epoxy composite materials are extensively being used for numerous space applications. These materials are being used in various Engineering applications because they have favorable mechanical characteristics like near to or potential zero thermal expansion coefficient and high strength/high stiffness to weight ratio. Four different materials are selected in this study and relevant properties are as given in Table 3 and 4 respectively.

2.6. Boundary condition

In order to acquire correct findings from any analysis, adequate boundary conditions must be specified. At the

Table 2: Wight of different leaf springs

Weight of leaf	volume * density * acceleration due to gravity	Value
Weight of smallest leaf (leaf one)	0.00000785*214.45*6*50*10	5.05 N
Weight of second leaf	0.00000785*338.89*6*50*10	7.98 N
Weight of third leaf	0.00000785*463.34*6*50*10	10.91 N
Weight of fourth leaf	0.00000785*587.78*6*50*10	13.84 N
Weight of fifth leaf	0.00000785*712.23*6*50*10	16.77 N
Weight of sixth leaf	0.00000785*836.67*6*50*10	19.70 N
Weight of seventh leaf	0.00000785*961.11*6*50*10	22.63 N
Weight of eight leaf	0.00000785*1085.56*6*50*10	25.56 N
Weight of ninth leaf	0.00000785*1120*6*50*10	26.37 N
Weight of tenth leaf	-	26.37 N
Total weight of steel leaf spring	-	175.2 N

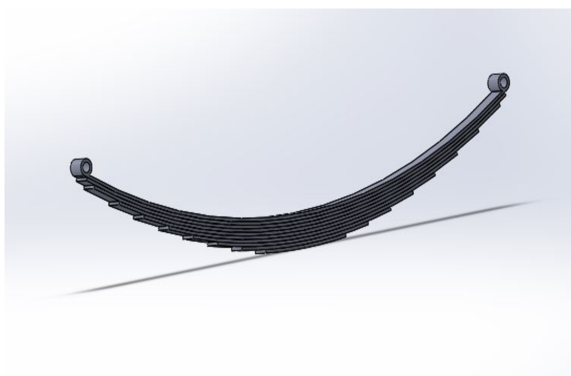

Figure 2: Leaf spring model

Table 3: Mechanical properties of steel

Properties	Symbols	Units	Values
Young's Modulus	E	Pa	2E+11
Density	ρ	kg/m^3	7850
Shear Modulus	G	Pa	7.692E+10
Bulk Modulus	K	Pa	1.6667E+11
Poisson's Ratio	μ	-	0.3

upper right tip, the leaf spring is fastened in the vertical direction (Y axis) yet free in the horizontal direction (X axis). The bottom left tip can only move vertically (on the Y axis), while restricting horizontal (X axis) motion. In both situations, rotation around any axis is restricted. To analyze different parameters for different leaf spring of different materials, a force of 3200 N is applied vertically.

3. Analysis result

First of all, all the parameters are found for Steel leaf spring which has 10 span. On the other side, single leaf spring is designed using different composite materials so that single leaf may replace the 10 span steel leaf spring. The parameters discovered under static load are

Table 4: Properties of composite materials from ANSYS

Properties	E Glass (UD)	S Glass (UD)	E Glass (Wet)
EX	4.5E+10	5E+10	3.5E+10
EY	1E+10	8E+9	9E+9
EZ	1E+10	8E+9	9E+9
PRXY	0.3	0.3	0.28
PRYZ	0.4	0.4	0.4
PRZX	0.3	0.3	0.28
GX	5E+9	5E+9	4.7E+9
GY	3.8462E+9	3.8462E+9	3.5E+9
GZ	5E+9	5E+9	4.7E+9
ρ	2000	2000	1850

then compared between structural steel and different composite materials. The research was carried out in ANSYS 2020 R1. The obtained results are depicted in the following Figures 3, 4, 5 and 6, as well as in tabulated form.

3.1. For steel

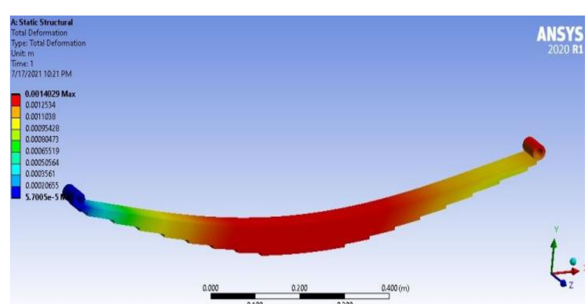

Figure 3: Total deformation in steel

The parameters seen from the ANSYS are tabulated in Table 5 and will be later compared to other materials.

Since, to minimize the weight of the composite leaf spring, several thickness of leaf are used to get the bet-

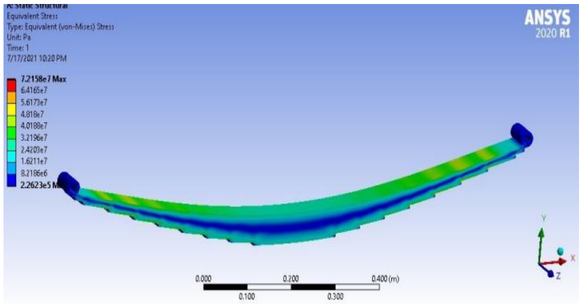

Figure 4: Equivalent (Von-Mises) stress while using steel

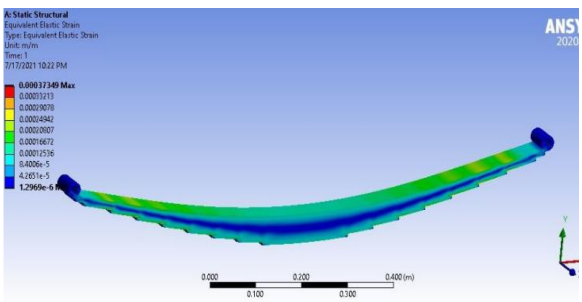

Figure 5: Equivalent elastic strain in steel

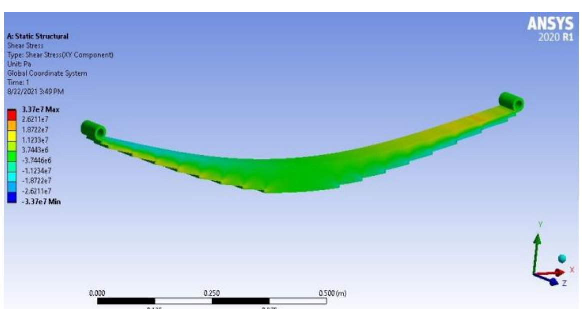

Figure 6: Shear stress in steel

Table 5: Summary of parameters for 10 span steel leaf spring

10 Span Spring	Steel
Equivalent Stress (MPa)	72.158
Total Deformation (mm)	14.03
Equivalent Elastic Strain	3.73E-4
Shear Stress (MPa)	33.7

ter result. Starting from 15mm thickness of the leaf, gradually, 25mm, 35mm, 45mm, 50mm, 55mm, 60mm, 65mm are taken to take the best result. Values of equivalent stress, deformation, equivalent elastic strain and shear stress are seen decreasing while increasing the width of the leaf, but for weight saving a break-even value is considered as 45mm. Figures 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17 and 18 shows the ANSYS plots and all values are tabulated in Table 6.

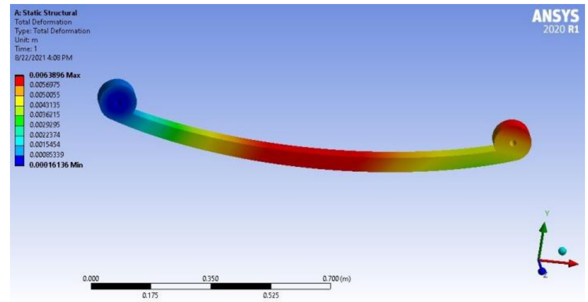

Figure 7: Deformation in epoxy s-glass UD

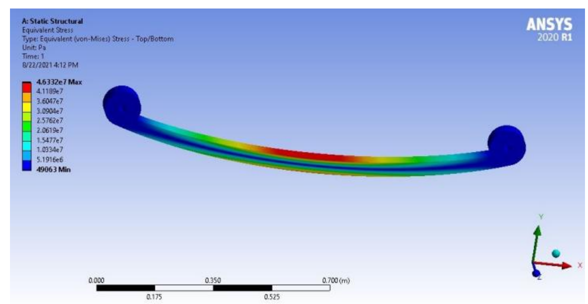

Figure 8: Equivalent (Von-Mises) stress in epoxy s-glass UD

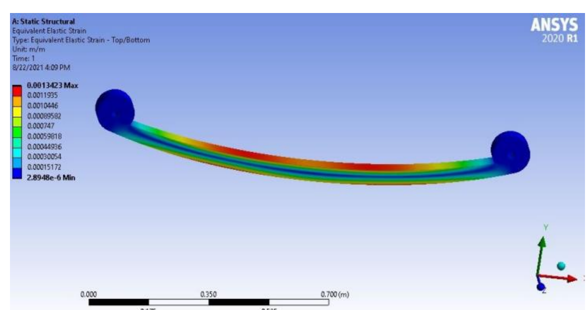

Figure 9: Equivalent elastic strain in epoxy s-glass UD

The equivalent (Von-Mises) stress for the spring made of standard steel is the largest whereas its elastic strain is the least among all the models, as evident from the data in Table 4. This is primarily owing to the significant mechanical differences between steel and composites. Steel has a much higher modulus of elasticity, tensile strength, and density than the glass epoxy composite. The largest distortion occurs in the middle of the leaf spring's span, and it gradually decreases towards the end. The highest strain is also found in the upper right corner of the master leaf.

Figure 19 shows comparison graph of the equivalent stress, equivalent strain, total deformation, and shear

Table 6: Summary of parameters for different composite material leaf spring

45mm mono leaf spring	Epoxy/S-Glass UD	Epoxy/E-Glass UD	Epoxy/E-Glass Wet
Total deformation (mm)	6.3896	6.9253	8.6003
Equivalent stress (MPa)	46.33	46.02	45.58
Equivalent strain	13.4E-04	13.8E-04	15.9E-04
Shear stress (MPa)	6.626	6.615	6.588

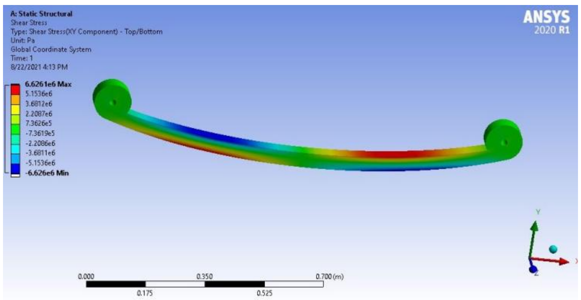

Figure 10: Shear stress in epoxy s-glass UD

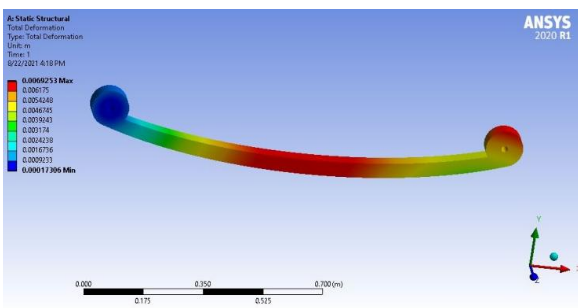

Figure 11: Deformation in epoxy e-glass UD

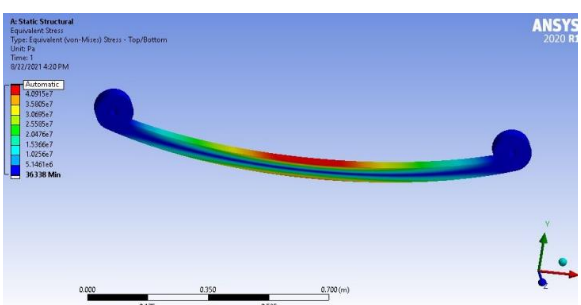

Figure 12: Equivalent (Von-Mises) stress in epoxy e-glass UD

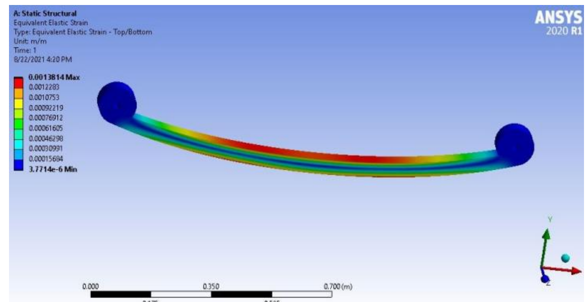

Figure 13: Equivalent eastic strain in epoxy e-glass UD

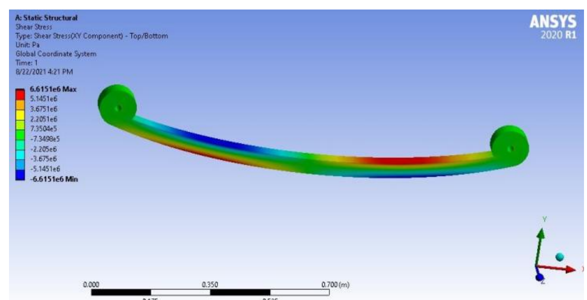

Figure 14: Shear stress in epoxy e-glass UD

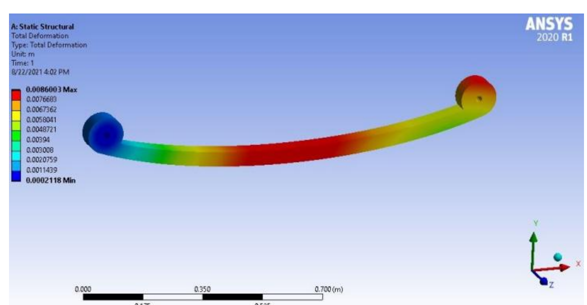

Figure 15: Deformation in epoxy e-glass wet

stress for conventional steel, Epoxy S - Glass UD, Epoxy E - Glass UD, and Epoxy E - Glass Wet under a load of 3200 N. So, from Figure 19, deformation in all composite mono leaf spring are less than that of conventional steel. The strain is more for all composite mono leaf spring, but the value is so low that this is neglected. The main factor during comparison i.e. Shear Stress favors Epoxy/S-Glass UD composite.

On the other hand, after validation from shear stress criteria, mass comparison is another main criteria for choosing the best composite material.

Table 7 shows the comparison in mass in which all the composite materials gives significant results. In comparison between the leaf spring types, Epoxy/S-Glass

Table 7: Mass comparison between models

Leaf Spring Type	Steel	Epoxy/S-Glass UD	Epoxy/E-Glass UD	Epoxy/E-Glass Wet
Mass (kg)	17.52	6.66	6.66	6.16
% mass saving	-	62	62	64.84

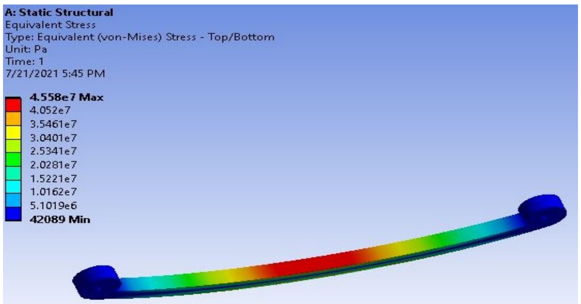

Figure 16: Equivalent (Von-Mises) stress in epoxy e-glass wet

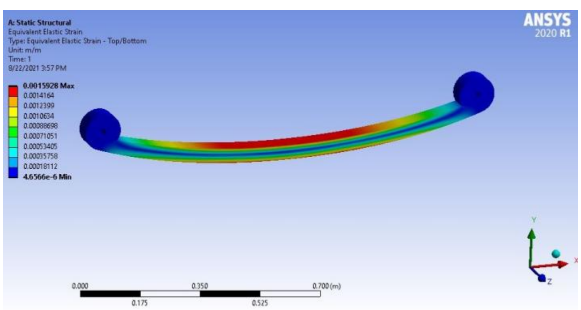

Figure 17: Equivalent elastic strain in epoxy e-glass wet

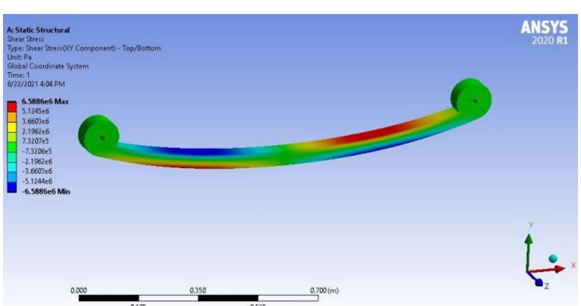

Figure 18: Shear stress in epoxy e-glass wet

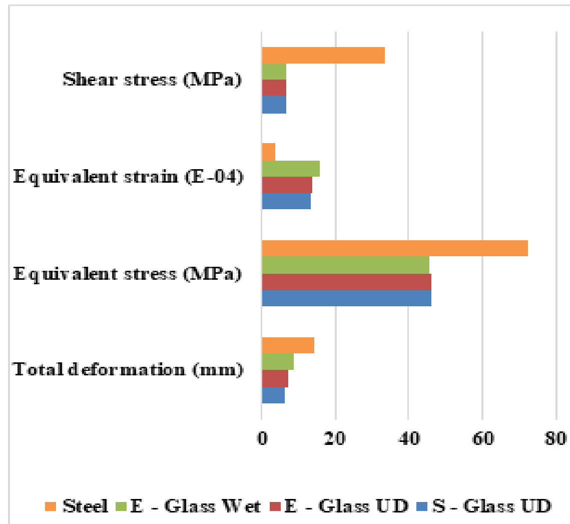

Figure 19: Graphical representation of Table 5 and Table 6

UD and Epoxy/E-Glass UD gives more favor.

4. Conclusion

The hybrid composite material is subjected to a finite element analysis to determine its suitability for use as a leaf spring material in an automobile vehicle. The following observations are made as a result of the analysis:

- The mass of Epoxy/E-Glass UD, Epoxy/S-Glass UD, and Epoxy/E-Glass Wet composite material are found to be respectively 62%, 62% and 64.84% lesser compared to conventional steel.
- When compared to normal steel, the three Epoxy composite materials yield about 80 percent lower shear stress.
- Epoxy/S-Glass UD at 40mm of thickness gives 54% less deformation compared to steel, which is better among the other composites.
- The equivalent (Von-Mises) stress of Epoxy/E-Glass UD, Epoxy/S-Glass UD, and Epoxy/E-Glass Wet composite material are found to be 36.22%, 35.79%, and 36.83% lesser than that of steel.
- The elastic strain of Epoxy/S-Glass UD composite material is less than that of other composite.

As a result, it can be inferred that Epoxy/S-Glass UD composite materials are employed as a material for leaf spring, lowering the gross weight of automotive vehicles.

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