International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 12 Issue 9 ǁ September 2024 ǁ PP. 77-84

Numerical Approach of Material Optimization of Multi Leaf Spring using Composite Material.

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Abstract:
All cars use leaf spring suspension. Fuel efficiency is an important factor when driving a vehicle. For the car to be affected, the weight of the car needs to be reduced by reducing the weight of the components to be more fuel efficient. Therefore, among many components, one of the components of the car, the leaf spring which is used to support the weight of the entire car, is best replaced with composite material instead of steel material. The material chosen for the paper spring is an e-glass/epoxy, carbon epoxy and graphite epoxy composite material that is more economical with mechanical and engineering properties similar to steel paper springs. A leaf spring is designed using both steel and composite materials for the same range of loads. Simulations were created for both models and FEA testing was performed, showing the stress and deflection analysis of steel and composite leaf springs. The springs were experimentally tested by tensile and bending tests and their results were validated by simulation results. A comparative study of the two materials was carried out, showing differences in dimensions, stresses and deflections.

Keywords: *Leaf Spring, Composite Material. Finite Element Analysis*

Date of Submission: 01-09-2024 Date of acceptance: 11-09-2024

I. INTRODUCTION

a. Suspension System :

Suspension system consist of shock absorbers, tires, springs, tire air, and the linkages. The linkages are used to connect a vehicle to its wheels and which allows relative motion between the tires and vehicle. Suspension systems support the ride quality and road holding capability. [4] The suspension also protects the vehicle itself and any vehicle luggage from damage and wear. Design of front and rear suspension of a car is different. The Suspension should be light in weight so that it reduces the weight of vehicle. Reduction in kerb weight of vehicle gives increase in mileage of vehicle. The suspension system acquires some weight in vehicle, hence optimizing the weight of vehicle can be done. The Most common Spring Suspension are,

1. Helical springs
2. Disc or Belleville springs
3. Special purpose springs
4. Laminated or leaf springs

b. Laminated Leaf or Leaf Spring Suspension System:

A leaf spring commonly used in automobiles is of semi-elliptical form. It consists of number of leaves which are arranged in semi-elliptical form and of gradually decreasing in length. The longest leaf is known as master leaf. All the other leaves are bounded together by U-clip and a center bolt. [5]

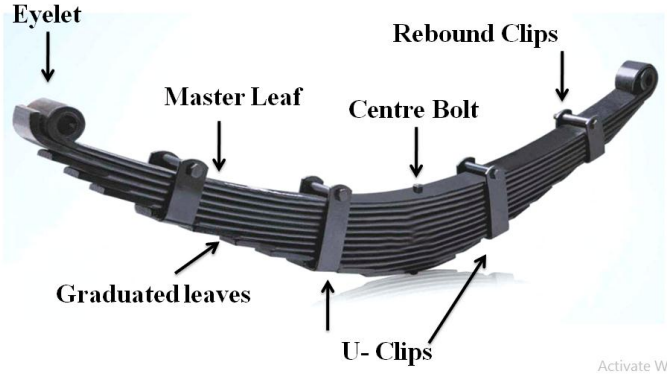


Figure 1 : Leaf Spring

The Leaf spring used in this case is of Mahindra MM540 Jeep. Mahindra MM540 Jeep is passengr type vehicle which is currently very popular in market. The total weight of Jeep is 1770 kg which on the whole can be said as 2KN. The material of spring is AISI 6150 Steel.

c. Material of Leaf Spring :

Table 1 Material Properties of Leaf Spring [4]

Material and Properties	AISI 6150 Steel
Ultimate Tensile Strength (MPa)	1015
Ultimate Yield Strength (MPa)	979
Young's Modulus (MPa)	$2e^5$
Poisson's Ratio	0.29
Density (kg/m^3)	7850

II. LITERATURE SURVEY :

Different types of composites -Polymer, ceramic and metal matrix composite have been discussed [1]. Analysis and optimization of a composite leaf spring used in the rear suspension system of light vehicles. The steel leaf spring is replaced by fiber glass. The design optimization is done considering the stress distribution criteria [2]. The paper focuses on replacement of design by composite multi leaf spring using carbon/Epoxy and Graphite/Epoxy unidirectional laminates [3]. The design of leaf spring is done using Ti-6Al-4V alloy and S-Glass fiber composite. Harmonic analysis is done and the results are compared showing titanium as best [4]. This paper focuses on the design & parametric optimization of heavy duty leaf spring with the analysis made in Ansys software. The spring is designed using Glass Fiber Reinforced Plastics followed by Fatigue test.[5]. The spring is optimized using factors of Bending stress, deflection, safety factor and fatigue strength. Experimental investigation is also done concluding the design safety of spring [6]. Design and optimization of Leaf Spring Using composites is done in order to satisfy the objective of comparing the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring. [7].The leaf spring is designed using all kinds of composite materials. The main objectives of this study are reducing the weight of the steel leaf spring by introducing composite material to increase the load carrying capacity [8]. Design of dual-cantilever thermoplastic spring in the rear which is very similar to double-wishbone geometry is done followed by optimization. Spring is designed using Steel and carbon fiber reinforced polymer [9]. The Analysis and size optimization of composite leaf spring using FEA analysis is done describing static analysis of steel and composite leaf spring. The spring is designed using load capacity, Strength, deflection and weight reducing factor.[10]. Design and material optimization of heavy vehicle leaf spring describing static and dynamic analysis of steel leaf spring and laminated composite multi leaf spring to compare displacement, frequencies, deflections and weight savings of composite leaf spring with that of steel leaf spring. Materials used are, S2 Glass/Epoxy and Kevlar/Epoxy [11]. Design and assessment of multi leaf spring is done using the steel leaf spring is replaced with the composite E-glass/Epoxy leaf spring to compare the load carrying capacity, stresses, deflection and weight savings of composite leaf spring with that of steel leaf spring [12]. This paper investigates the stresses in master leaf of leaf spring by fem and its experimental verification. In this work stresses in master leaf are evaluated by considering two approaches i.e. stress on graduated and full length leaves [13].

III. COMPOSITE MATERIAL

Composite materials are flexible and complicated shapes are easily generated. Composites are light in weight and can be used as replacement for steel due to high stiffness and strength ration. Composites are of three types, polymer matrix, ceramic matrix and metal matrix [1]. The concept used in this study is polymer matrix composites. The leaf spring is designed using S-Glass, E-Glass Epoxy, Carbon fiber and Kevlar.

Table 2 Properties of Polymer Matrix Composites [8]

Parameter	S-Glass	E-Glass	Carbon	Kevlar
σ_{sy} (MPa)	4587	767	1100	3727
σ_{yt} (MPa)	3250	300	900	2820
E (MPa)	$8.69e^5$	$3.69e^5$	$0.5e^3$	$1.12e^5$
μ	0.28	0.3	0.25	0.25
ρ (kg/m^3)	2480	1900	1600	1440

IV. MODELLING AND SIMULATION

The leaf spring is modelled in Creo 2.0 software. The terminology of joint is as shown below with all the dimensions of joint.

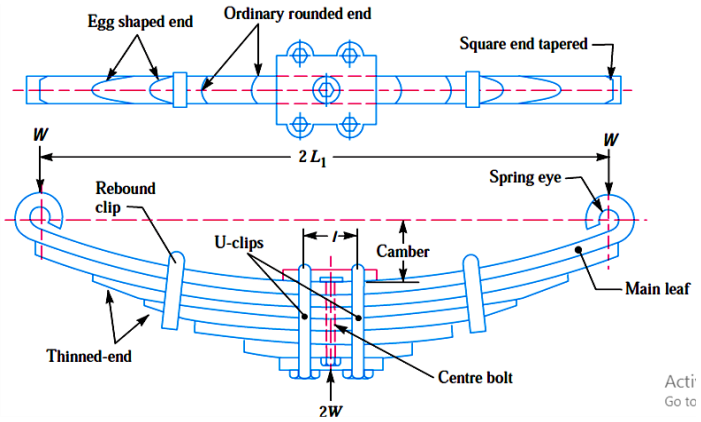
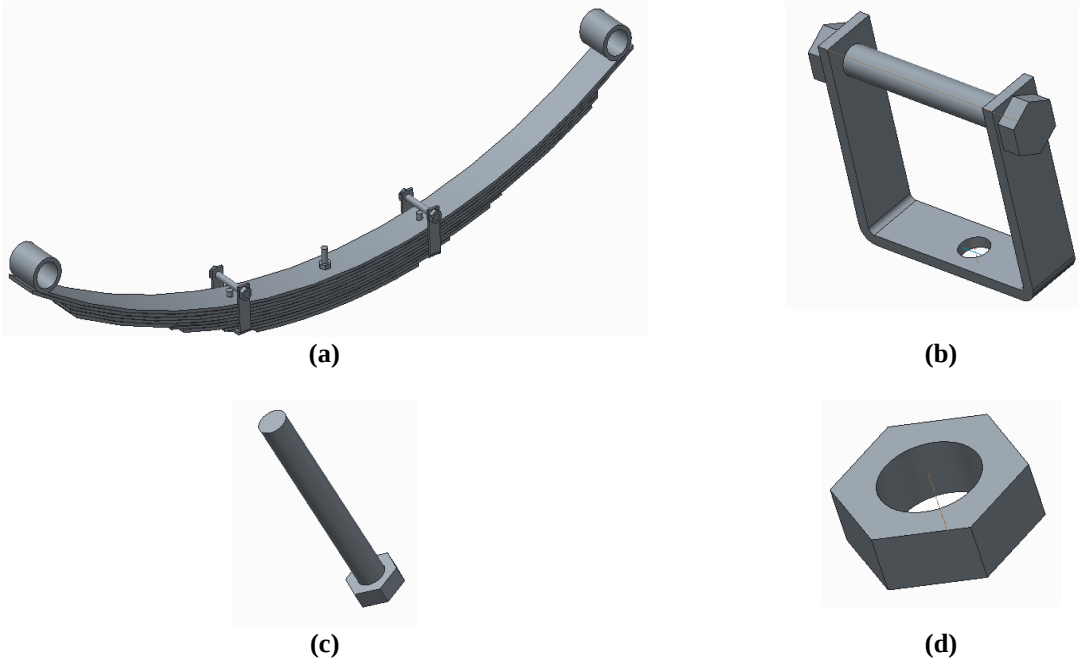


Figure 2: Terminology of Leaf Spring [5]

Table 3 Dimensional Parameters

Not.	Parameter	mm
W	Weight acting on Spring	4.3 KN
t	Thickness of each leaf	3.7 mm
T	Total Thickness of Spring	30 mm
b	Thickness of Knuckle Pin	47 mm
L	Effective Length	670 mm
2L1	Overall Length of Spring	850 mm
l	Distance centers of U-bolts	270 mm
n	Total number of leaves	10
nf	Number of full length leaves	2
ng	Number of graduated leaves	8
y	Camber distance in mm	128 mm



(a) **(b)**

(c) **(d)**

Figure 3: a. Assembly of Lead Spring, b. U-Clip, c. Bolt, d. Nut

V. FINITE ELEMENT ANALYSIS

The Finite element analysis is carried out using Creo 2.0 Software. The Model is subjected to 4.3KN which subjected on each spring. The FEA is done under Von misses Criteria for Maximum stress distribution and maximum displacement for Steel as well as all four composites, i.e. S-glass, E-glass, Carbon fibre and Kevlar.

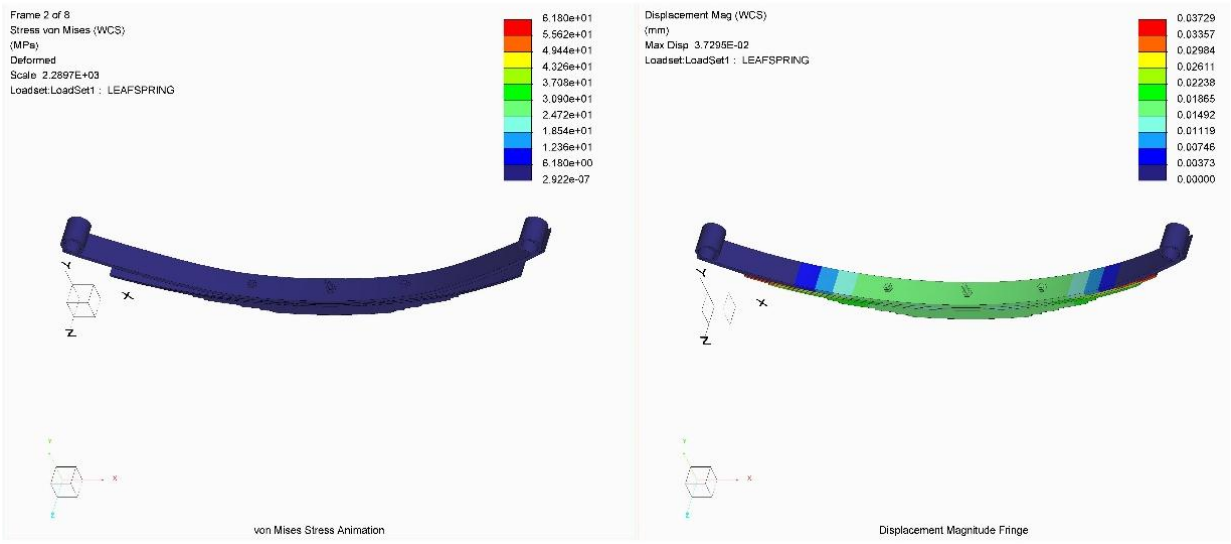


Figure 4: FEA of Leaf Spring made of S-glass Fiber

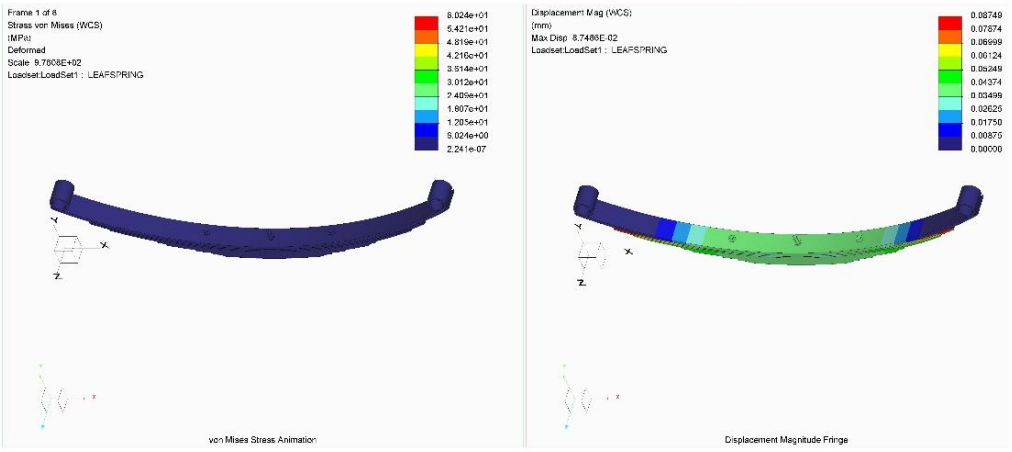


Figure 5: FEA of Leaf Spring made of E-glass Fiber

Figure 6: FEA of Leaf Spring made of Carbon Fiber

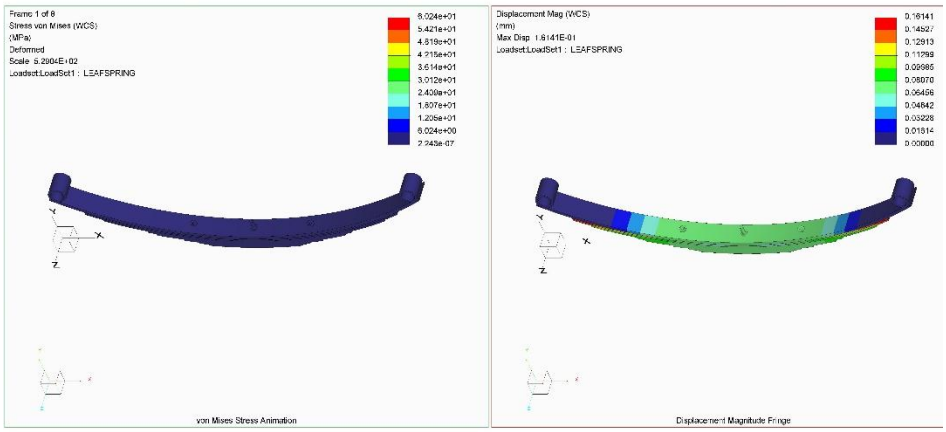


Figure 7: FEA of Leaf Spring made of Steel

The Finite Element Analysis was carried out using Creo software and the results of Deformations and Stress is determined. Figure 4, shows the response analysis of leaf spring using material S-Glass Fiber, followed by Figure 5 as the material for E-Glass fiber, figure 6 is the FEA of Leaf spring using Kevlar Fiber and figure 7 is the leaf spring using conventional material of AISI Steel.

VI. RESULT AND DISCUSSIONS

a. Response Analysis of Stress Distribution :

Table 4 Response Analysis of Stress Distribution

KN	S-Glass	E-Glass	Kevlar	Carbon	Steel
2	28.74	28.02	29.71	29.71	28.06
3	43.11	42.02	44.56	44.56	42.02
4.3	61.80	60.24	63.87	63.87	60.24
5	71.86	70.04	74.27	74.27	70.41
6	86.23	84.05	89.12	89.12	84.05

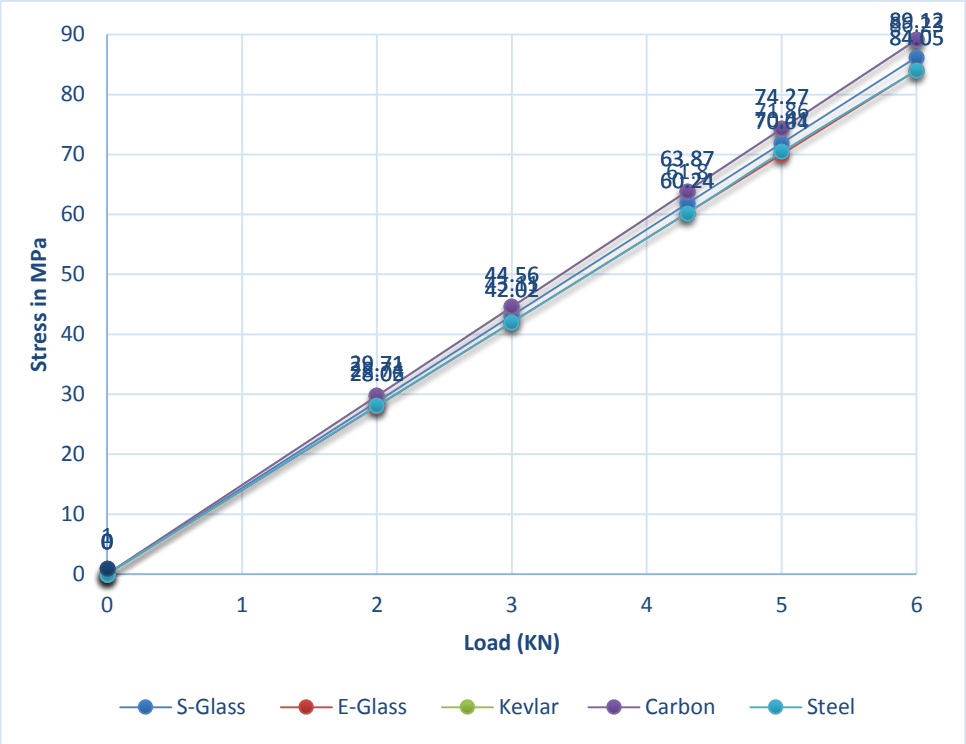


Figure 8: Comparative Analysis of Stress Distribution for Various Materials

a. Response Analysis of Deformation in mm:

Table 5 Response Analysis of Max. Displacement

KN	S-Glass	E-Glass	Kevlar	Carbon	Steel
2	0.01735	0.04	0.1359	0.303	0.0932
3	0.026	0.061	0.2032	0.455	0.1126
4.3	0.0372	0.0874	0.2913	0.6524	0.1614
5	0.0433	0.1017	0.3387	0.7587	0.1876
6	0.052	0.122	0.4064	0.9105	0.2252

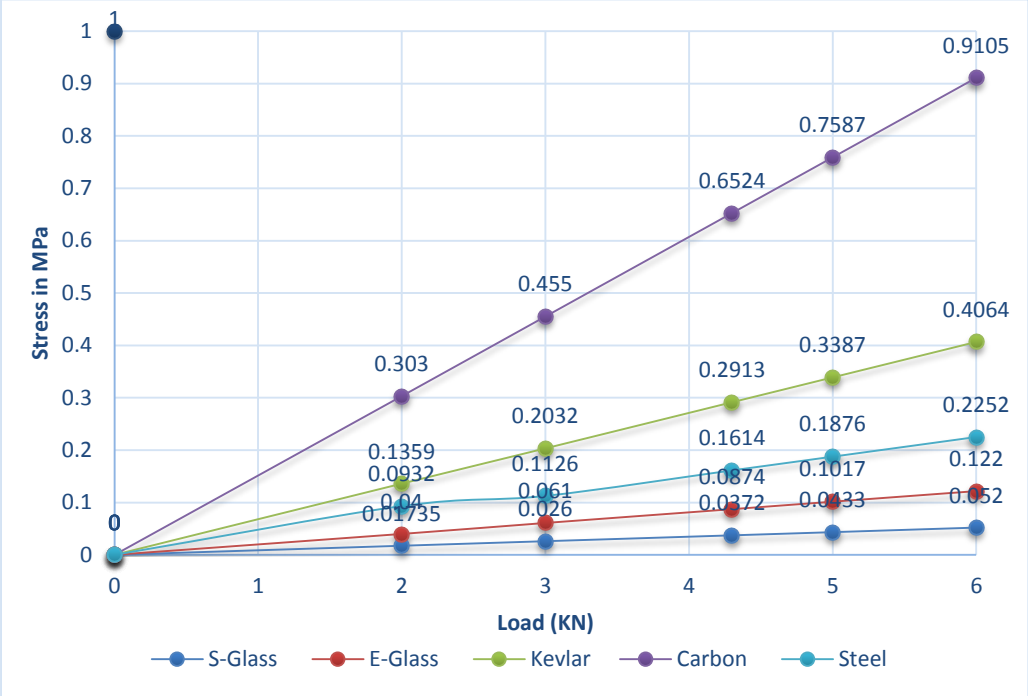


Figure 9: Comparative Analysis of Deformation for Various Materials

VII. CONCLUSIONS

- In this paper FEA of all the materials are carried, including the composites and steel, from which it can conclude that E-Glass Fiber gives 60% better results than steel with respect to maximum displacement and maximum stress distribution.
- Due to the strengths and stiffness of composite material, the results obtain are in favor E-Glass fiber.
- Use of E-Glass fiber is also optimal as it reduced the cumulative weight of joint up to 70%.
- As the weight of one leaf spring is by 70%, hence we can say that, there will enough decreases in weight of vehicle.
- This reduction in weight of vehicle can lead to economic performance of vehicle in terms of power and fuel consumption.
- Hence, in this way we can optimize the material and shape of leaf spring by replacing it with polymer matrix composite.

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