International Journal on Interactive Design and Manufacturing (IJIDeM) (2022) 16:239–252
https://doi.org/10.1007/s12008-021-00831-8

ORIGINAL PAPER

A methodological study of leaf spring by material comparison and Taguchi's DOE

Sagarsingh Kushwah[1] · **Shreyashkumar Parekh**[1] · **Harsh Mistry**[1] · **Meet Bhatt**[1] · **V. K. Joshi**[1]

Received: 25 April 2021 / Accepted: 24 December 2021 / Published online: 10 January 2022

Abstract

The automotive sector showed a great interest in the composite leaf spring as a substitute for steel springs due to high strength-to-weight ratios. The better mechanical properties, lower density, and manufacturing feasibility of composites in aviation, marine, and automotive industries also have a broad acceptance. The aim is to evaluate the effect of the leaf spring when the composite is applied as a substitution. This study observed static conduct for a composite leaf spring in comparison to that of a steel leaf spring concerning deformation, load-bearing, stresses, and weight savings. Deformation and stresses were taken as design constraints. The specification and dimensional were optimized using Taguchi's technique. To study the static behaviour, Finite Element Analysis (FEA) is done using ANSYS workbench 19.2. To simulate operating conditions by modelling the Leaf spring in the 3-D modelling software SOLIDWORKS. To validate the results of the software, the results were compared to the numerical method. For the Design of Experiments (DOE), Minitab software was used. Moreover, the outcome of the study represents the performance of composite material in leaf spring along with the design optimization. The composite material was found to give better performance over conventional material. Furthermore, the stress-induced in it was minimum i.e., 448.32 MPa, 491.32 MPa, 488.32 MPa in carbon epoxy, S glass epoxy, and E glass epoxy compared to 496.98 MPa in plain carbon steel and the deformation was optimum. Also, the weight of the composite material is less i.e., 3.884 kg, 4.338 kg, 2.506 kg in S glass epoxy, E glass epoxy, and Carbon epoxy compared to 12.217 kg in plain carbon steel.

Keywords Composite material · Finite element analysis · Taguchi's DOE · Leaf spring

1 Introduction

Springs are quite different mechanical elements from others, it deforms significantly when put under loading conditions; their principles allows them to store readily recoverable mechanical energy [1]. When a wheel collides with an obstacle in a suspension system of the vehicle, the spring allows to move off the wheel over any obstacle and then the wheel regains its original position. Springs are also used in force–displacement transducers, such as weighing scales, where an easily discernible displacement is applied to calculate an alteration in the force [2, 3].In contrast to the constant cross-section beam, the leaf spring is stressed almost continuously along its length because the linear increase in bending moment from either simple support is matched by the beam's widening rather than its deepening, as longitudinal. The terminology of leaf spring is depicted in Fig. 1 [4, 5].

Leaf springs are critical components in the suspension systems of vehicles like SUVs, trucks, and railroad vehicles [6]. For the evaluation of braking performance, ride comfort, stability, and vibration characteristics, accurate modelling is required. Though it appears simple, a leaf spring causes numerous modelling issues [7]. Vehicles are typically modelled using a multi-body-systems approach for dynamic simulation (MBS) [8, 9]. The majority of wheel/axle suspension systems can be represented by standard multi-body-system elements such as rigid bodies, links, joints, and

---

✉ Sagarsingh Kushwah
sagarsinghkushwah123@gmail.com

Shreyashkumar Parekh
shreyashparekh08@gmail.com

Harsh Mistry
harshmistry540@gmail.com

Meet Bhatt
meetbhatt5272@gmail.com

V. K. Joshi
vkj.fetr@gmail.com

[1] Mechanical Engineering Department, R. N. G. Patel Institute of Technology, Bardoli, Surat, Gujarat 394620, India

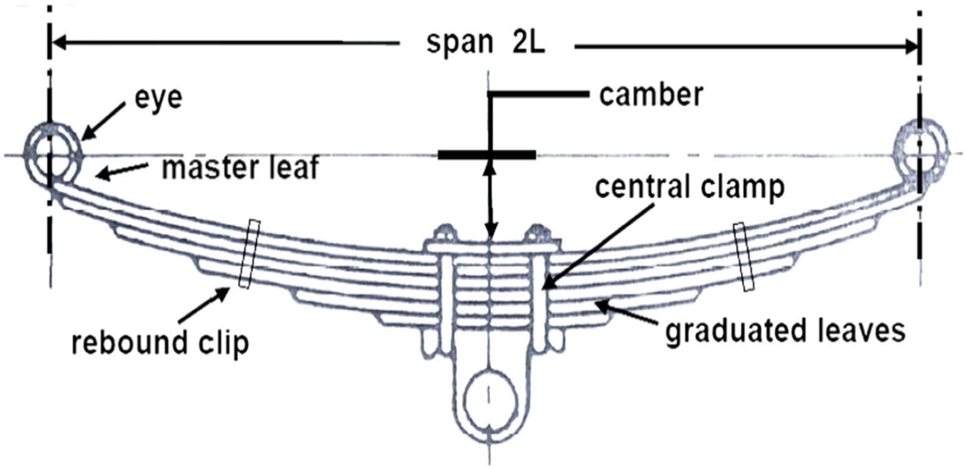


Fig. 1 Leaf spring model [44]

force elements [10]. Poor leaf spring models approximate the guidance and suspension properties of the leaf spring by using rigid links and separate force elements [11]. For realistic ride and handling simulations, the deformation of the leaf springs must be taken into account [12].

To conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturers in the present scenario [13]. Weight reduction can be achieved primarily by the introduction of better material, design optimization, and better manufacturing processes [14]. The suspension leaf spring is one of the potential items for weight reduction in the automobile as it accounts for ten to twenty percent of the unsparing weight. This helps in achieving the vehicle with improved riding qualities [15, 39].

Composite materials were the key that has the potential to decrease the weight of the leaf spring while maintaining the stiffness and the load-carrying capacity [16]. Because it has a higher capacity to store the elastic and a higher strength-to-weight ratio than steel [17]. The definition states that “Composite materials (or composites) are engineered materials composed of two or more constituent materials with significantly different physical or chemical properties that remain separate and distinct on a macroscopic level within the finished structure” [18]. A composite material is usually composed of reinforcement (fibres, particles, flakes, and/or fillers) embedded in a matrix (polymers, metals, or ceramics). The matrix holds the reinforcement in place to form the desired shape, while the reinforcement improves the overall mechanical properties of the matrix. When properly designed, the new combined material outperforms either material alone in terms of strength [19, 32].

The purpose of this study is to evaluate the performance of leaf springs made from composite materials as a substitute for conventional materials. Deformations and stresses were also observed for a composite leaf spring compared to a steel leaf spring in this study. Moreover, the focus was also diverted towards the weight-saving aspects. Most of the study focuses only on technical aspects, however, the current study compared the composite and conventional materials considering both technical as well as commercial aspects. Taguchi’s technique was utilized to optimize the specification and dimension parameters. Therefore, the effect of composite material study along with optimized designed parameters was carried out in the present work. Besides, few researchers have carried out the studies over leaf spring considering the composite materials that are discussed here.

B. Vijaya Lakshmi et al. [20] evaluated the Static and dynamic analyses of composite leaf springs used in heavy vehicles were carried out in this article. The purpose was to measure the load-bearing power, stiffness, and weight savings of composite leaf springs to steel leaf springs. Stresses and deflections posed architecture restrictions. The measurements of an existing traditional steel leaf spring from a heavy commercial vehicle were used to manufacture a composite multi-leaf spring using unidirectional laminates E GLASS/EPOXY, C- GLASS/EPOXY, and S- GLASS/EPOXY. The modelling was done using Pro/Engineer, and the research was done in COSMOS.

H.A. Al-Qureshi [21] presented a general experiment on composite spring analysis, design, and fabrication. The suspension spring of a small vehicle, "a jeep," was chosen as a prototype from this perspective. A single leaf spring made of variable thickness glass fibre reinforced plastic (GFRP) with geometrical properties similar to a multi-leaf Steel spring was planned, fabricated (hoop wound), and tested. The research was carried out in a laboratory setting and was proceeded by a road test. A contrast was made between the performance of GFRP and multi-leaf steel springs.

M. M. Shokrieh et al. [22] ANSYS V5.4 program was used to study a four-leaf steel spring used in the rear suspension system of light vehicles. The finite element analysis showed stresses and deflections, confirming previous analytical and experimental results. ANSYS was used to build and refine a composite leaf spring made of fibreglass and epoxy resin, based on the findings of the steel leaf spring. The optimization of the spring geometry was assigned top priority. The purpose was to bring spring with the minimum possible weight that could withstand given static external forces without failing. The stresses (Tsai-Wu failure criterion) and deformations were the architecture constraints. The findings show that from the spring-eyes to the axle seat, the optimal spring diameter decreases hyperbolically while the thickness increases linearly. The optimized composite spring had much lower pressures, a higher normal frequency, and a spring weight without eye units that was almost 80% lower than the steel spring.

Bulent Ekici [23]compared the test results to the three-link leaf-spring model The model was established to be built by forecasting aim is to improve. Normal experiments were carried out to determine the relationship between torque and angular displacement to complete this mission. After that, the ADAMS solver was used to produce the corresponding three-link model. The parameters involving the acceleration for the driver seat were programmed using an ANOVA system after achieving the optimum mode! The length of the leaf spring, its material properties, and the stiffness of the springs connected to the front panel were the parameters. The reduced acceleration for the driver seat was presented by the response surface regression method.

Abdul Rahim Abu Talib et al. [24] Based on the spring rate, log life, and shear stress parameters, the material, and design of the composite elliptical spring are optimized. Both theoretical and experimental, the effect of the ellipticity ratio on the output of woven roving-wrapped composite elliptical springs was studied. The study found that composite elliptical springs would significantly reduce the weight of heavy and medium vehicles. The ellipticity ratio has an enormous effect on the design parameters and the results. The best spring parameters are considered in composite elliptic springs with an $a/b = 2$ ellipticity ratio.

nil Kumar Malaga et al. [25] show that, For the same load-carrying capability and stiffness, a mono composite leaf spring was used instead of a multi-leaf steel spring because composite materials have a higher elastic strain energy efficiency ability and a higher strength-to-weight ratio than steel. The weight of the leaf spring may be reduced without sacrificing load-carrying capability or stiffness. Limiting stress and displacement were the design constraints. ANSYS software was used to model and analyze both the steel and composite leaf springs.

Venkatesan et al. [26] identified the construction and experimental study of a glass fibre reinforced polymer composite leaf spring. The goal was to equate composite leaf spring load-carrying capability, stiffness, and weight savings to steel leaf spring. Stresses and deflections were the design parameters. The dimensions of a light commercial vehicle's current traditional steel leaf spring are determined. E- Glass/Epoxy unidirectional laminates were used to fabricate a hybrid multi-leaf spring of the same dimensions as a traditional leaf spring. ANSYS 10 was also used to do a static study of a 2-D model of a traditional leaf spring, which was contrasted to experimental observations.ANSYS 10 had been used to carry out a full finite element analysis on a 3-D model of composite multi-leaf spring, and the analytical and experimental results were compared. In comparison to a steel leaf spring, the composite leaf spring had 67.35 percent less stress, 64.95 percent higher stiffness, and 126.98 percent higher natural frequency. Using an integrated composite leaf spring, a weight reduction of 76.4 percent was achieved.

Joo-Teck Jeffrey Kueh et al. [27] Using the ANSYS V12 program, the study examined the static and fatigue behaviour of steel and composite multi-leaf springs. We used the dimensions of a light commercial vehicle's internal traditional leaf spring. The same dimensions were used to create a composite multi-leaf spring for the two components, E-glass fibre/epoxy and E-glass fibre/vinyl ester, which sparked the transportation industry's interest. The effects of material structure and fibre orientation on the static and fatigue behaviour of leaf springs were the main focus of this study. Bending stress, deflection, and fatigue life were the design parameters. Compared to the steel leaf spring, the designed composite spring was found to have much lower bending stresses and deflections and higher fatigue life cycles.

Mehdi Bakhshesh et al. [28] studied steel helical spring related to light vehicle suspension system under the effect of a uniform loading and finite element analysis was compared with the analytical solution. Afterwards, the steel spring was replaced by three different composite helical springs including E-glass/Epoxy, Carbon/Epoxy, and Kevlar/Epoxy. Spring weight, maximum stress, and deflection were compared with steel helical spring and a factor of safety under the effect of applied loads was calculated. It was shown that spring optimization by changing spring material caused a reduction of spring weight and maximum stress considerably.

B. Raghu Kumar et al. [29] For the design and manufacturing of a total mono composite leaf spring, the best composite material was suggested. Modelled and studied as a single leaf spring made of composite material with variable thickness and width with a constant cross-sectional area of various composite materials with identical mechanical and geometrical properties to the multi-leaf spring. The analytical findings were compared to the finite element results obtained with ANSYS tools, which showed stresses and deflections. Stresses and relocation were the design limits. The composite spring was found to have significantly lower stresses and deflection than the steel spring, and the spring weight is nearly 78 percent less.

Shivashankar et al. [30] replaced the steel leaf spring with a Genetic Algorithm based optimally designed composite leaf spring. The Genetic Algorithm based optimization techniques provided robust solutions. The replacement of steel with optimally designed composite leaf spring provided a 93% weight reduction. Moreover, the composite leaf spring was found to have lower stresses compared to the steel spring.

Trivedi Achyut v. et al. [31] The aim of this study was to compare the load-enhancing capacity and weight savings of composite leaf springs to those of traditional steel leaf springs. Light design calculations on the proportions of an actual traditional steel leaf spring. inertia Analysis commercial software is used to analyze a 3-D design of a conventional leaf spring. Those dimensions are often used for composite multi-leaf springs made of carbon/Epoxy and graphite/epoxy composites. For a traditional steel leaf spring, the constraints are stress and deformation, or the weight of the composite leaf spring. Composite leaf springs have a higher strength-to-weight ratio than traditional steel leaf springs. In addition, carbon leaf springs are about 400% lighter than traditional steel leaf springs. It can be inferred from a modal study that e leaf spring is healthy as it will not experience a resonance effect.

Ryan Gaylo et al. [32] investigated a design optimization approach for mono-composite leaf springs developed with a hybrid fibre-layup. To begin, a detailed topology optimization based on the Tsai-Wu failure model was performed to optimize the geometry of the leaf spring. This process resulted in a one-of-a-kind spring design that reduced the mass of the spring by twenty-nine percent compared with the original non-optimized spring and by eighty to ninety percent compared to a spring made of steel. Following that, the design is further optimized by replacing low-stress reinforcement with lower modulus, high modulus, cost-effective materials to improve overall vehicle mass, operation, and efficiency.

A review of the literature suggests that several studies have been carried out to study the leaf spring. However, there are some knowledge gaps in the research reported so far. Though much work has been carried out to study a wide variety of composite leaf materials i.e. components used for the manufacturing of composite leaf spring are E-glass, c-glass, and s-glass. The static performance shows a great advantage for composite leaf spring, analysis of failure in the midsection of leaf spring, modifications of a thickness of spring leaves to make a cost-efficient. However, there is no proper investigation report on the dynamic performance of composite leaf springs. Several research efforts have been devoted to studying and investigating load carrying capacity, stresses, deflection, and weight savings of composite leaf spring with that of steel leaf spring. However, the design variable (thickness and width) of steel and composite leaf springs has not been clarified. Also, the comparative study is not clarified by changing various dimensions parameters with a variety of materials in leaf springs. Furthermore, the reduction of stress and deflection is not optimized by any researcher.

Based on the problems and previous research gap analysis, the objective of the study is to compare the load-carrying capacity, stress, deflection, and weight savings of the composite leaf spring with that of the steel leaf spring. This goal is pursued by paying attention to composite materials by replacing steel with conventional leaf springs with a suspension system to minimize stress, to study the ride characteristics and passenger comfort, economical feasibility, compare with the current state of art design parameters from Taguchi's design of experiments (DOE), to study the effect of composite materials on the leaf spring and comparing with conventional material.

2 Taguchi's Design of Experiments (DOE)

The definition of Design of experiments (DOE) can be said as "it is the branch of applied statistics concerned with the planning, execution, analysis, and interpretation of controlled tests to evaluate the factors that influence the value of a parameter or group of parameters." DOE is a powerful data collection and analysis tool that has a wide application in various experimental scenarios. Multiple input factors can be manipulated and their effect on the desired output/response can be determined. DOE can identify important interactions that may not be possible when experimenting with a single factor by manipulating multiple inputs simultaneously. Any combinations (full factorial) or only part of the potential combinations can be examined (fractional factorial) [33, 38].

The orthogonal array of Taguchi, also known as the Taguchi Method or Taguchi Technique, or the robust design method adopted to DOE. It is the kind of factorial design DOE method. Taguchi method is the statistical method, established for the improvement of the quality of produced goods by Genichi Taguchi, and recent applications are for engineering, biotech, marketing, and publicity. The Taguchi approach is one of the best experimental methods for finding a minimum number of tests to be conducted within the allowed limits of factors and levels [34].

This procedure uses a particular array called orthogonal arrays. It specifies how the minimum of experiments can be conducted which can provide complete information about all factors affecting the performance parameter. The key point of the array method is to choose the level of combinations for each experiment of the input design variables. For instance, if the effect of four distinctive independent variables with three-set values (level values) for each variable is to be understood, then the orthogonal array L9 may be right. The orthogonal array L9 is intended to understand the effect of four independent factors with three-factor levels, each. This array assumes

Table 1 Layout of L9 orthogonal array

L_9 (3^4) Orthogonal array					
	Independent variable				Performance parameter value
Experiment	Variable 1	Variable 2	Variable 3	Variable 4	
1	1	1	1	1	p1
2	1	2	2	2	p2
3	1	3	3	3	p3
4	2	1	2	3	p4
5	2	2	3	1	p5
6	2	3	1	2	p6
7	3	1	3	2	p7
8	3	2	1	3	p8
9	3	3	2	1	p9

The L9 orthogonal array is displayed in Table 2. There are a total of 9 experiments to be performed

Fig. 2 3 D model of leaf spring

that two factors are not interactive. In many cases, although no assumption of an Interaction Model is valid, some cases show clearly an interaction [35] (Table 1) (Fig. 2).

3 Methodology

3.1 3D Modelling

First of all, 3D modelling (Fig. 3) of the leaf spring used in "Tata Ace Gold" (Commercial vehicle) was done. The dimensions like the length of the master leaf, width, thickness, and eye diameter of the leaf spring were taken from the real master leaf (Table 2), which was bought which is shown in Fig. 2. The length of graduated leaves was calculated using the following equation [36]:

$$Length\ of\ smallest\ leaf = \frac{Effective\ Length}{(n-1)} + ineffective\ length \quad (1)$$

$$= \frac{2L}{(n-1)} + l \quad (2)$$

$$Length\ of\ next\ leaf = \frac{2L}{(n-1)} \times 2 + l \quad (3)$$

$$Length\ of\ (n-1)^{th}\ leaf = \frac{2L}{(n-1)} \times (n-1) + l \quad (4)$$

3.2 Finite element analysis

FEA is a numerical method for predicting how a part or assembly will behave under certain conditions [37, 38]. It serves as the foundation for modern simulation software, assisting engineers in identifying weak points, areas of tension, and other flaws in their designs [39]. The results of an FEA-based simulation are typically depicted using a colour scale that shows, for example, the pressure distribution over the object. ANSYS 19.2 software was used for FEA. The first step was to import the geometry into ANSYS and assign the material to it.

3.2.1 Material selection

Plain carbon steel is the conventional material used in leaf springs. The composite materials used for comparison are S glass epoxy, E glass epoxy, and Carbon epoxy. Most of the literature compared various composite materials and concluded the above respective materials as a better alternative to conventional materials in their respective study. Therefore, in the present study, better materials are being studied to get better from better materials. The mechanical properties of all the materials are shown in Table 3 [42, 43].

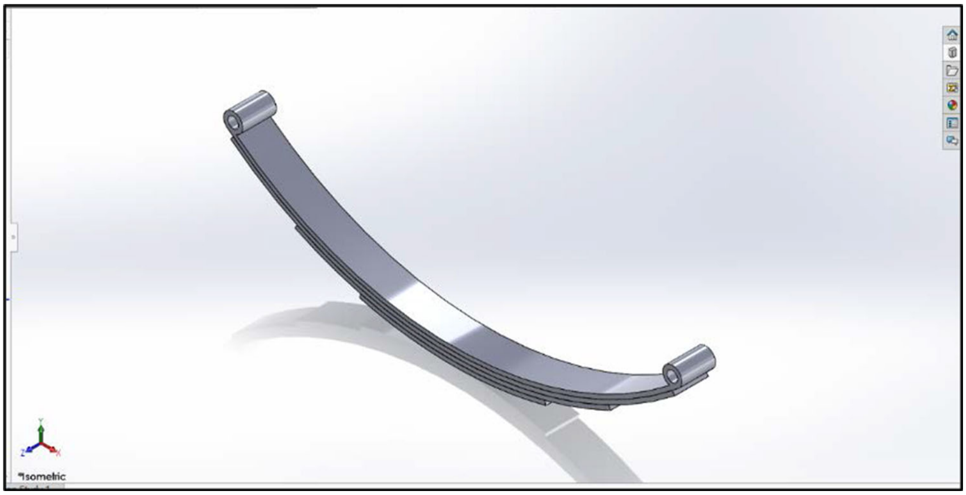


Fig. 3 Tata Ace Gold Master leaf

Table 2 Dimensions of leaf spring

Aspect	Dimensional parameters	Unit
Length	850	mm
Thickness	8	mm
Width	65	mm
Ineffective Length	110	mm
No. of Leaves	2 extra full length, 2 Graduated Leaves	–

3.2.2 Meshing

After assigning the materials, the mesh was created. The goal of Finite Element Analysis (FEA) is to simulate some physical phenomena using a numerical technique known as the Finite Element Method (FEM). Any continuous object has infinite degrees of freedom (DOF), making hand calculations impossible. As a result, in FEM, we create a mesh that divides the domain into a discrete number of elements from which the solution can be calculated. The data is then interpolated over the entire domain. Figure 4 shows the example of meshing done in leaf spring. The size of the meshing was kept at 5 mm. The nodes and elements of the model were 67,360 and 13,728 respectively.

3.2.3 Boundary conditions

After Meshing, applying the boundary conditions is the crucial step. One eye was constrained the displacement and rotation in all directions except the rotation along the z-axis was given to let the eye rotate as shown in Fig. 5. Whereas, the other eye is connected to a shackle, which allows the displacement in the x-direction. Therefore, the second eye has constrained the displacement and rotation in all directions except the rotation along the z-axis and displacement in the x-direction as shown in Fig. 6. The force of 4905 N was given at the bottom of the spring as shown in Fig. 7. The loading condition (amount of load) was calculated in the following way. The approximate weight of the vehicle (Tata ace gold) is 1200 kg and the capacity of the vehicle is 800 kg which makes a total of 2000 kg. Converting it into newton, 19,620 value is obtained. However, the load is divided by 4 that making the total load 4095 N.

Table 4 Taguchi's orthogonal array

Array	Length (mm)	Thickness (mm)	No. of Leaves
L1	840	7	3
L2	840	8	4
L3	840	9	5
L4	850	7	4
L5	850	8	5
L6	850	9	3
L7	860	7	5
L8	860	8	3
L9	860	9	4

In the next step, the results of bending stress, deformation, and von mises stress were obtained which were validated by numerical method. The optimum material was selected to apply it into the dimensional parameter to optimize the dimension by the Taguchi technique. The results are discussed in the next section. The following equations were used for validation of software results:

$$\delta = \frac{12PL^3}{Ebt^3\left(3n_f + 2n_g\right)} \tag{6}$$

$$\sigma_b = \frac{6PL}{nbt^3} \tag{7}$$

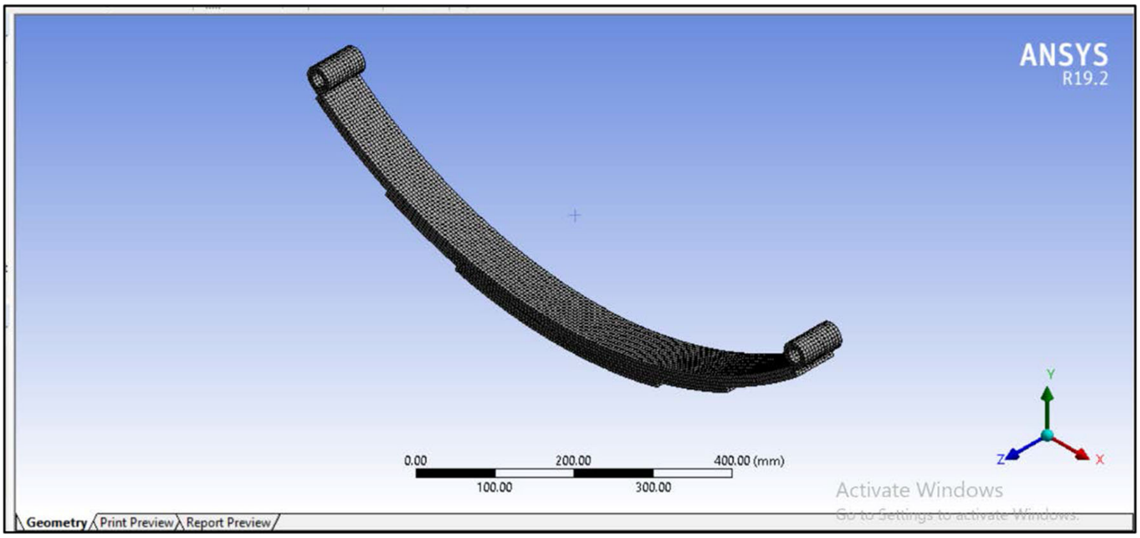


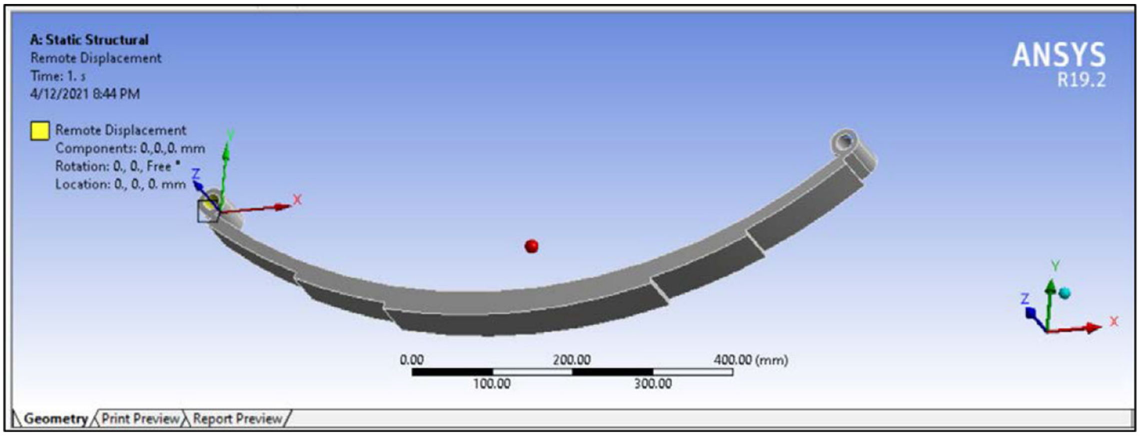
Fig. 4 Meshing

3.3 Taguchi technique

A detailed explanation of this technique is given in the previous section. There were three factors considered i.e., Length, Thickness, and the number of leaves. The number of levels was also 3 i.e., Length: 840 mm, 850 mm, and 860 mm; Thickness: 7 mm, 8 mm, and 9 mm; Number of leaves: 3, 4, and 5. The other dimensions (levels) were decided by the standard dimensions given in the machine design data book

Table 3 Material properties

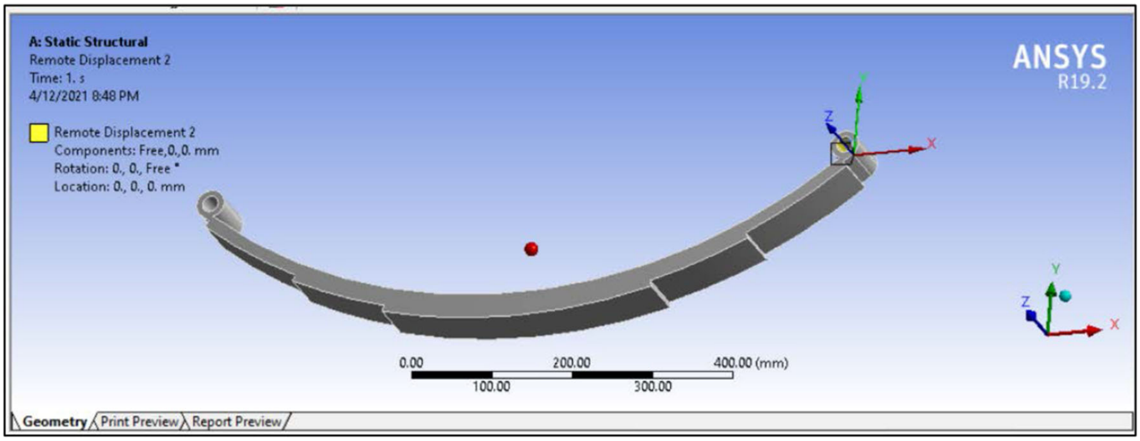
Materials	Plain carbon steel	S Glass Epoxy	E Glass Epoxy	Carbon Epoxy
Density (mmˆ-3t)	7850	1815	1815	1352
Young's Modulus (MPa)	2.12E + 11	-	-	-
Young's Modulus X direction (MPa)	-	50,000	45,000	1.21E + 05
Young's Modulus Y direction (MPa)	-	8000	10,000	8600
Young's Modulus Z direction (MPa)	-	8000	10,000	8600
Poisson's ratio	0.29	–	–	–
Poisson's ratio XY	–	0.3	0.3	0.27
Poisson's ratio YZ	–	0.4	0.4	0.4
Poisson's ratio XZ	–	0.3	0.3	0.27
Tensile (MPa)	761	–	–	–
Tensile X direction (MPa)	–	1700	1100	2231
Tensile Y direction (MPa)	–	35	35	29
Tensile Z direction (MPa)	–	35	35	29
Compressive X direction (MPa)	–	− 1000	− 675	− 1082
Compressive Y direction (MPa)	–	− 120	− 120	− 100
CompressiveZDirection (MPa)	–	− 120	− 120	− 100
Shear (MPa)	8.2171E + 10	–	–	–
Shear XY	–	80	80	60
Shear YZ	–	46.154	46.154	32
Shear XZ	–	80	80	60
Bulk Modulus (Pa)	1.6825E + 11	–	–	–



A: Static Structural
Remote Displacement
Time: 1. s
4/12/2021 8:44 PM

🟨 Remote Displacement
Components: 0.,0.,0. mm
Rotation: 0., 0., Free °
Location: 0., 0., 0. mm

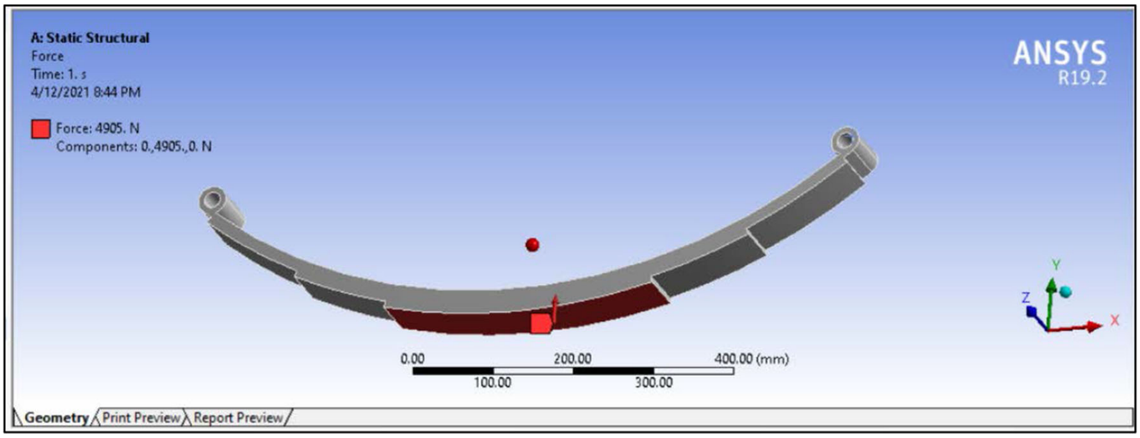
Fig. 5 Boundary Condition in one eye



A: Static Structural
Remote Displacement 2
Time: 1. s
4/12/2021 8:48 PM

🟨 Remote Displacement 2
Components: Free,0.,0. mm
Rotation: 0., 0., Free °
Location: 0., 0., 0. mm

Fig. 6 Boundary condition at another eye



A: Static Structural
Force
Time: 1. s
4/12/2021 8:44 PM

🟥 Force: 4905. N
Components: 0.,4905.,0. N

Fig. 7 Loading Condition

by V B Bhandari [45]. The orthogonal array formed is shown in Table 4.

The array L1 to L9 is the number of experiments to be performed. The FEA analysis was done as explained earlier. Same as before the mash size was kept 5 mm. The nodes and elements of all the arrays are shown in Table 5.

The software (FEA) results were validated by numerical method to obtain the optimum results by Eqs. 6 and 7.

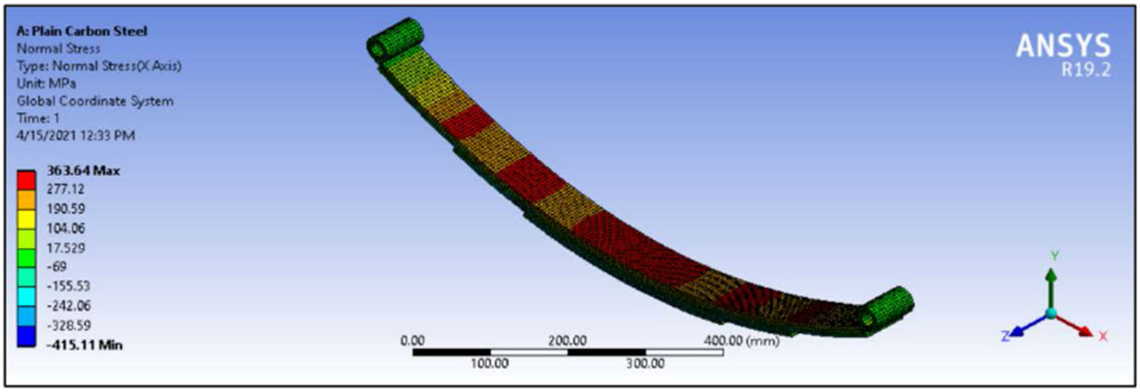


Fig. 8 Bending stress in plain carbon steel

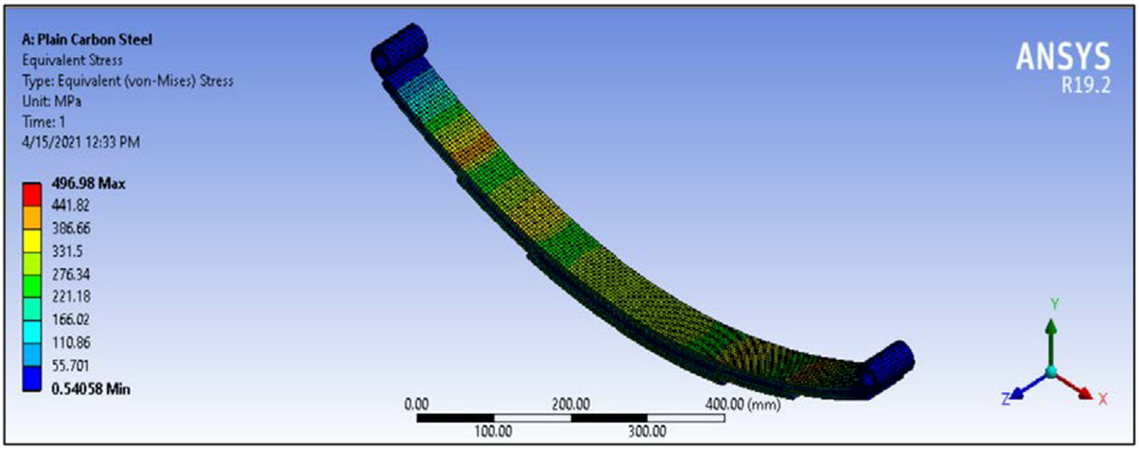


Fig. 9 Von misses stress in plain carbon steel

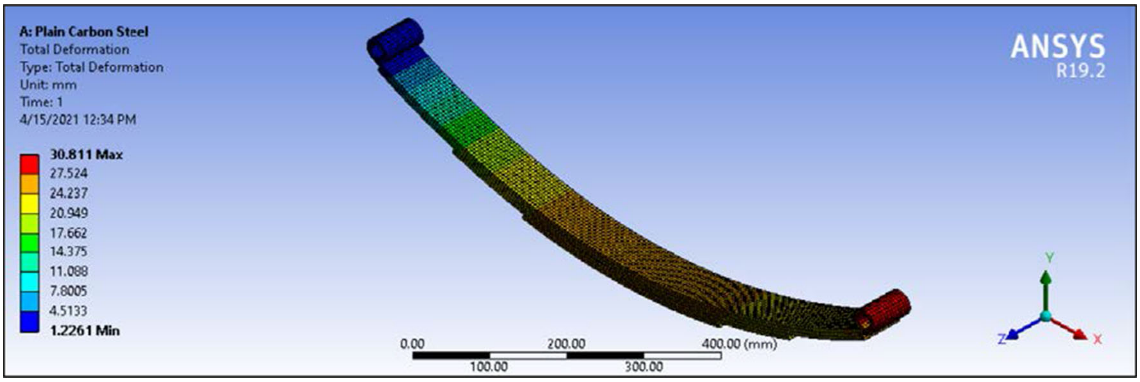


Fig. 10 Deformation in plain carbon steel

4 Results and discussion

4.1 Material comparison

The results of FEA for the comparison of conventional material (Plain Carbon Steel) and composite material (E glass epoxy, S glass epoxy, and carbon epoxy) are discussed below in respective sections. The output of FEA was deformation, bending stress, and von missed stress obtained. The results of FEA for plain carbon steel is shown in Figs. 8, 9, and 10. The same was carried out for other materials.

Figure 11 shows the output of FEA for all the materials. The comparison and percentage error between software output and numerical method is shown in Tables 6 and 7. Based on Von misses stress and deformation, the carbon epoxy was found to be a better material among them. The critical stress

Fig. 11 FEA results of materials

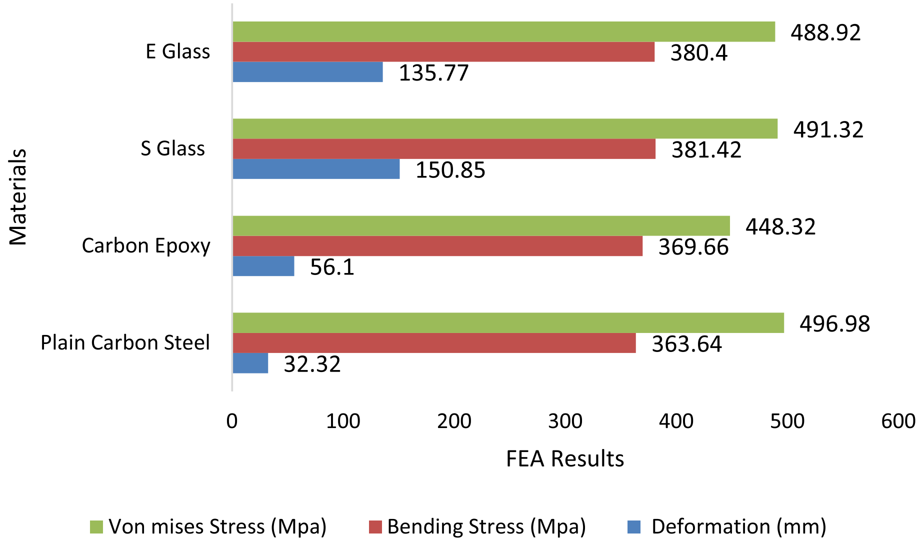


Table 5 Nodes and elements of Taguchi array

Array	Nodes	Elements
L1	51,908	25,688
L2	64,451	41,415
L3	42,797	24,315
L4	57,773	36,604
L5	75,167	49,028
L6	61,922	39,168
L7	37,095	20,618
L8	55,960	35,286
L9	26,037	15,929

Table 6 Comparison of software and numerical deformation

Materials	Software deformation (mm)	Numerical deformation (mm)	Percentage Error
Plain Carbon Steel	30.811	32.32	4.66
Carbon Epoxy	52.451	56.1	6.5
S Glass	155.11	150.85	2.82
E Glass	135.2	135.77	0.41

region in the leaf spring (Fig. 8) is in the middle of the spring. The sping can be straightened or can be failed from the middle section. Besides, the eye that is allowed to rotate and displace in the x-direction can also fail as there is much deformation and stress generation.

4.2 Taguchi array

Now, here 9 experiments are performed from L1 to L9 to optimize the specification of leaf spring. The material taken in the analysis is carbon epoxy because it was found to be the optimum material in the previous results. The results of the L1 array is shown in Figs. 12, 13, and 14. The same was carried out for array L2 to L9.

Table 7 Comparison of software and numerical stress

Materials	Software Stress (Mpa)	Numerical Stress (Mpa)	Percentage Error
Plain Carbon Steel	363.64	375.83	3.24
Carbon Epoxy	369.66	375.83	1.64
S Glass	381.42	375.83	1.48
E Glass	380.4	375.83	1.21

Figure 15 shows the output of FEA results of all the orthogonal arrays. The comparison and percentage error between software output and numerical method is shown in Tables8 and 9. Whereas Table 10 shows the weight and cost comparison of leaf spring.

5 Conclusion

After the comparison of conventional and composite materials, and Design of Experiment (DOE) by Taguchi technique, based on Finite Element Analysis (FEA) results, the following concluding remarks were made:

- Based on stress parameters and deformation, carbon epoxy was found to be the optimum material among plain carbon steel, e glass epoxy, and s glass epoxy. The Stress-induced in it was minimum and the deformation was optimum.
- Besides, the weight of the carbon epoxy is also less compared to all the materials considered in the present work.

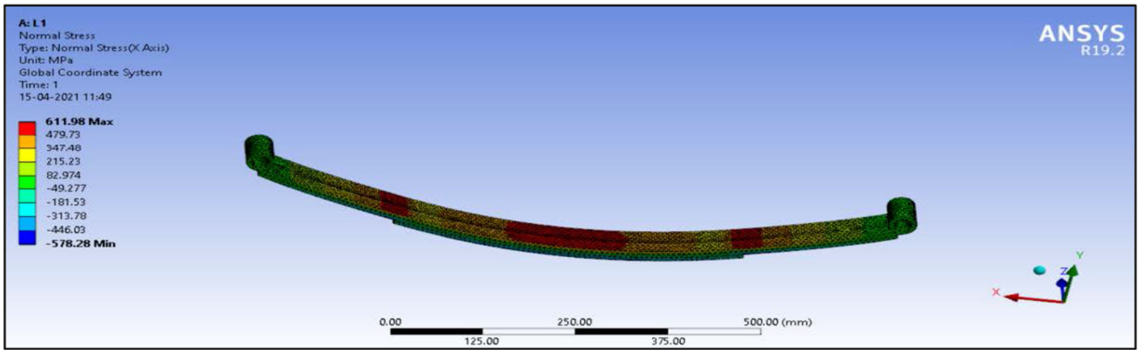


Fig. 12 Bending stress in L1 array

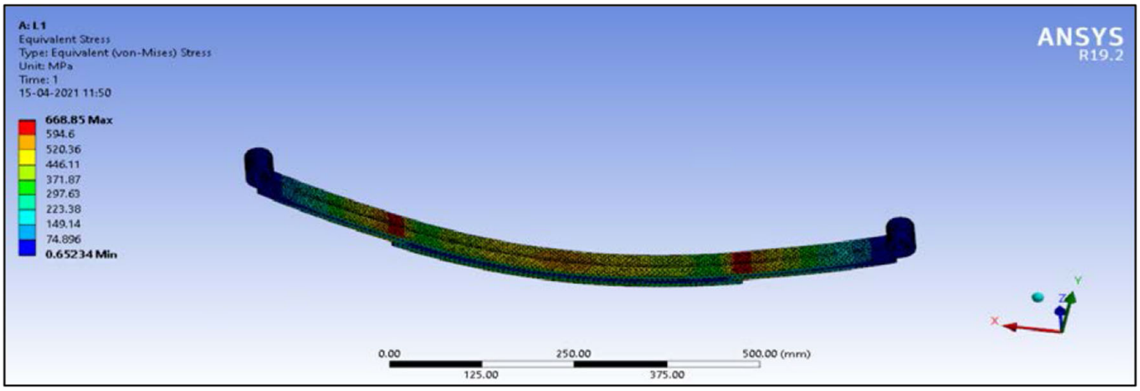


Fig. 13 Von missesstress in L1 array

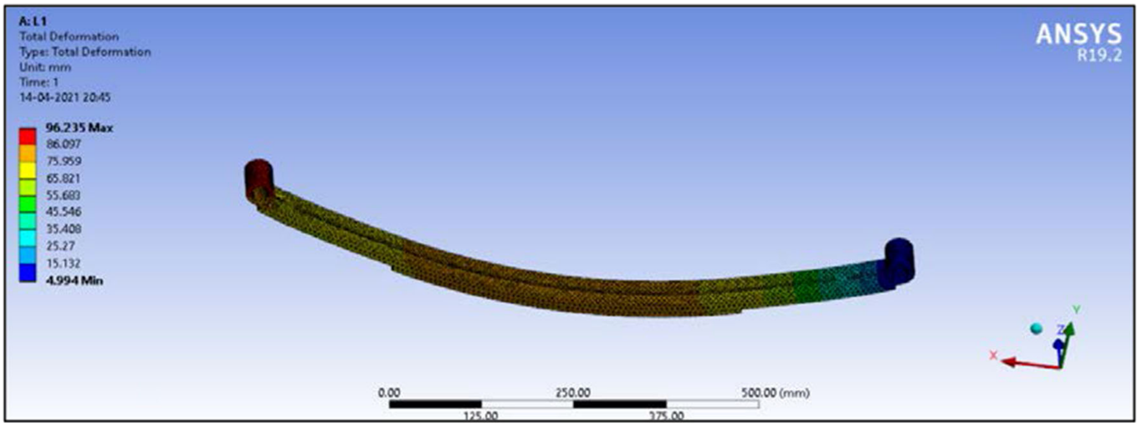


Fig. 14 Deformation in L1 array

- Therefore, the composite material was found to give better performance over conventional material.
- However, carbon epoxy is less feasible than plain carbon steel in terms of economical feasibility.
- In addition, from Taguchi's DOE, comparing design parameters, the stress in the L3 array was minimum. i.e., for configuration Length: 840 mm; Thickness: 9 mm, and No. of leaves: 5.
- Also, while comparing to current design parameters, the

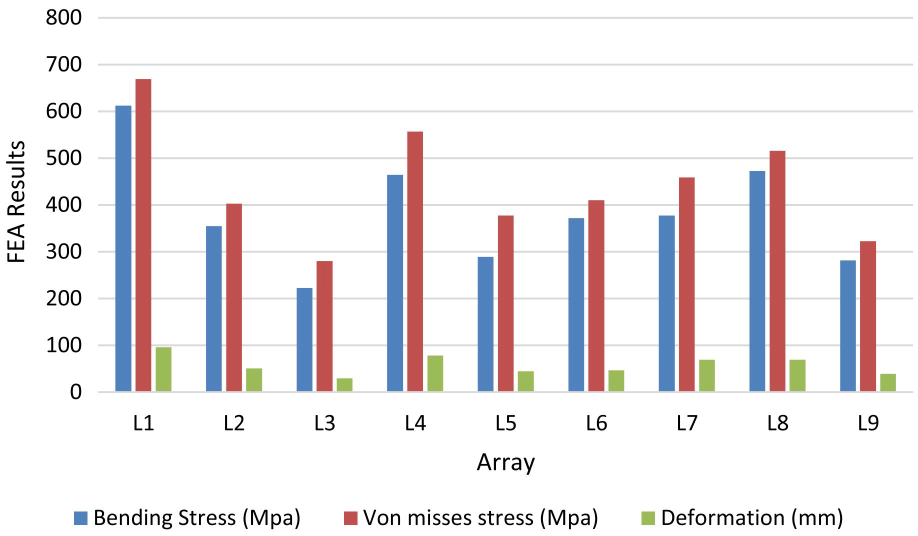


Fig. 15 FEA results of orthogonal array

Table 8 Comparison of software and numerical stress

Orthogonal Array	Numerical Bending Stress (MPa)	Software Bending stress (MPa)	Percentage Error	Von misses stress (MPa)
L1	646.813	611.98	5.38	668.85
L2	371.41	354.88	4.45	402.74
L3	234.769	222.53	5.21	279.88
L4	490.885	464.32	5.41	556.52
L5	300.667	289.2	3.81	377.08
L6	395.94	372.15	6	410.08
L7	397.328	377.36	5.02	458.62
L8	507.007	472.8	6.74	515.64
L9	300.449	281.27	6.38	322.36

Table 9 Comparison of software and numerical deformation

Orthogonal Array	Numerical Deformation (mm)	Software Deformation (mm)	Percentage Error
L1	101.031	96.235	4.74
L2	54.1463	51.05	5.71
L3	31.6906	29.885	5.69
L4	83.746	78.312	6.48
L5	46.7527	44.58	4.64
L6	49.2539	46.743	5.09
L7	72.2805	69.361	4.03
L8	72.6334	69.383	4.47
L9	40.8102	38.989	4.46

L9 array was found to induce lesser stress. i.e., for configuration Length: 860 mm; Thickness: 9 mm, and No. of leaves: 4.

Table 10 Weight and cost of leaf spring

Material	Weight (Kg)	Estimated Cost per Kg (Rupees)	Approximate cost of material (One leaf spring) (Rupees)
S glass epoxy	3.884	380	1475.92
E glass epoxy	4.338	200	867.6
carbon epoxy	2.506	800	2004.8
plain carbon steel	12.217	68	830.756

- The stress generated in the L5 array is nearly equal to current leaf spring specification i.e., for configuration Length: 850 mm; Thickness: 8 mm, and No. of leaves: 5.

References

1. Ke, J., et al.: A review on material selection, design method and performance investigation of composite leaf springs. Composite Struct. 111277. (2016)
2. Yu, W., Kim, H.: Double tapered FRP beam for automotive suspension leaf spring. Compos. Struct. **9**, 279–300 (1988)
3. Kurmi, S., et al.: Design and static structural analysis of leaf spring using FEA. Int. J. Res. Appl. Sci. Eng. Technol. (IJRASET) (2018)
4. Chavhan, G., et al.: A review on stresses and displacement in leaf spring. Des. Aanal. Leaf Spring Using Composite Mater. (2018)
5. Jain, V., et al.: Analysis of leaf spring conditions for heavy duty vehicle, Research, and Development (IJAuERD) ISSN 2277–4785, 97–104 (2013)
6. Solanki, P., et al.: A review on composite material mainly use in leaf spring. Study Rev. Leaf Spring (2015)
7. Noronha, B., Yesudasan, S., Chacko, S.: Static and dynamic analysis of automotive leaf spring: a comparative study of various materials using ANSYS. J Fail. Anal. Preven. **20**, 804–818 (2020). https://doi.org/10.1007/s11668-020-00877-y
8. Jamadar, N.I., Kivade, S.B., Tati, P.: Prediction of residual fatigue life of composite mono leaf spring based on stiffness degradation. J Fail. Anal. Preven. **18**, 1516–1525 (2018). https://doi.org/10.1007/s11668-018-0548-8
9. Duan, L., Song, C., Yang, S., et al.: High-precision modeling and simulation of the taper leaf spring of tandem suspension of commercial vehicles. J Mech Sci Technol **30**, 3061–3067 (2016). https://doi.org/10.1007/s12206-016-0614-7
10. Wu, Wj., Zhu, Lm., Yu, X. et al.: Novel method for equivalent stiffness and Coulomb's damping ratio analyses of leaf spring. J. Mech. Sci. Technol. 26, 3533–3538 (2012). https://doi.org/10.1007/s12206-012-0866-9
11. Kim, B.M., Kim, J.W., Moon, I.D., et al.: Optimal combination of design parameters for improving the kinematics characteristics of a midsize truck through the design of experiment. J Mech Sci Technol **28**, 963–969 (2014). https://doi.org/10.1007/s12206-013-1167-7
12. Aydin, E., Dutkiewicz, M., Öztürk, B., et al.: Optimization of elastic spring supports for cantilever beams. Struct Multidisc Optim **62**, 55–81 (2020). https://doi.org/10.1007/s00158-019-02469-3
13. Krużelecki, J.: Parametrical optimization of compression helical springs against instability. Struct. Optim. **12**, 135–141 (1996). https://doi.org/10.1007/BF01196947
14. Qin, Y., Wang, Z., Yuan, K., et al.: Comprehensive analysis and optimization of dynamic vibration-absorbing structures for electric vehicles driven by in-wheel motors. Automot. Innov. **2**, 254–262 (2019). https://doi.org/10.1007/s42154-019-00079-9
15. Wang, L., Wang, Z.: Failure analysis of the longitudinal composite leaf spring. J Fail. Anal. Preven. **20**, 1437–1444 (2020). https://doi.org/10.1007/s11668-020-00961-3
16. Hocine, A., Maizia, A., Chérifi, M., Chapelle, D.: A contribution of the reliability-based approach for a cylindrical composite of sensitivity analytical design. Adv. Mater. Process. Technol. **3**(3), 428–437 (2017). https://doi.org/10.1080/2374068X.2017.1336883
17. Khatkar, V., Behera, B.: Experimental investigation of textile structure reinforced composite leaf spring for their cyclic flexural and creep behavior. Compos. Struct. **258**, 113439 (2021). https://doi.org/10.1016/j.compstruct.2020.113439
18. Lakho, M., Bhatti, T., Rajpar, A., Khoso, M., Qazi, I.: Comparative tensile behavior study of locally developed jute reinforced composite materials with conventional composite materials. Adv. Mater. Process. Technol **4**(3), 370–377 (2018). https://doi.org/10.1080/2374068X.2018.1440867
19. George, A., et al.: A review on hybrid composite material more efficient than steel. Des. Anal. Leaf Spring Hybrid Composite Mater. (2017)
20. Lakshmi, B., Satyanarayana, I.: Static and dynamic analysis on composite leaf spring in a heavy vehicle. Int. J. Adv. Eng. Res. Stud. (2012)
21. Al-Qureshi, H.: Automobile leaf springs from composite materials. J. Mater. Process. Technol. (2001)
22. Shokrieh, M., Rezaei, D.: Analysis and optimization of a composite leaf spring. Composite Struct. (2003)
23. Bulent, E.: Multi-response optimization in a three-link leaf-spring model. Int. J. Vehicle Des. (2005)
24. Talib, A., Ali, A., Goudah, G., Lah, N., Golestaneh, A.: Developing a composite based elliptic spring for automotive applications. Mater. Des. (2010)
25. Malaga, A., Charyulu, T., Ramesh, C.: Design optimization of leaf spring. Int. J. Eng. Res. Appl. (2012)
26. Venkatesan, M., Devaraj, D.: Design and analysis of composite leaf spring in light vehicle. Int. J. Modern Eng. Res. (2012)
27. Kueh, J., Paris, T.: Finite element analysis on the static and fatigue characteristics of composite multi-leaf spring. J. Zhejiang Univ. (2012)
28. Bakhshesh, M., Bakhshesh, M.: Optimization of steel helical spring by composite spring. Int. J. Multidiscipl. Sci. Eng. (2012)
29. Raghu, B., Vijaya, R., Ramesh, N.: Static analysis of mono leaf spring with different composite materials. J. Mech. Eng. Res. (2013)
30. Shivashankar, G., Vijayarangan, S., Rajiv, D., Pradeep, R.: Genetic algorithm based optimal design of mono composite leaf spring and testing.
31. Trivedi, A., et al.: Static and dynamic analysis of automobile leaf spring (TATA ACE). IJSTE: Int. J. Sci. Technol. Eng. pp. 2349–784X (2015)
32. Gaylo, R., Farahani, S., Schmueser, D., et al.: Optimization of a mono-composite leaf spring using a hybrid fibre-layup approach. Int J Interact Des Manuf **14**, 407–421 (2020). https://doi.org/10.1007/s12008-019-00636-w
33. Pundir, R.,Chary, G., Dastidar, M.: Application of Taguchi method for optimizing the process parameters for the removal of copper and nickel by growing Aspergillus sp.. Water Resour. Ind. 20:83–92 (2018). https://doi.org/10.1016/j.wri.2016.05.001.
34. Mitra, A., Jawarkar, A., Soni, T., Kiranchand, G.: Implementation of Taguchi method for robust suspension design. Proc. Eng. **144**, 77–84 (2016). https://doi.org/10.1016/j.proeng.2016.05.009
35. Tamizharasan, T., Senthilkumar, N., Selvakumar, V., et al.: Taguchi's methodology of optimizing turning parameters over chip thickness ratio in machining P/M AMMC. SN Appl. Sci. **1**, 160 (2019). https://doi.org/10.1007/s42452-019-0170-8
36. Ke, J., et al.: A review on material selection, design method and performance investigation of composite leaf springs. Compos. Struct. **226**, 111277 (2019). https://doi.org/10.1016/j.compstruct.2019.111277
37. Zeng, D., Ethier, C.: A semi-torsional spring analogy model for updating unstructured meshes in 3D moving domains. Finite Elem. Anal. Des. **41**(11–12), 1118–1139 (2005). https://doi.org/10.1016/j.finel.2005.01.003
38. Amalu, E., Ekere, N., Zarmai, M., Takyi, G.: Optimisation of thermo-fatigue reliability of solder joints in surface mount resistor assembly using Taguchi method. Finite Elem. Anal. Des. **107**, 13–27 (2015). https://doi.org/10.1016/j.finel.2015.08.004
39. Berselli, G., Bilancia, P., Luzi, L.: Project-based learning of advanced CAD/CAE tools in engineering education. Int J Interact Des Manuf **14**, 1071–1083 (2020). https://doi.org/10.1007/s12008-020-00687-4
40. Lafarge, B., Cagin, S., Curea, O., et al.: From functional analysis to energy harvesting system design: application to car suspension. Int

J Interact Des Manuf **10**, 37–50 (2016). https://doi.org/10.1007/s12008-015-0284-1

41. Khalkhali, A., Nikghalb, E., et al.: Multi-objective optimization of hybrid carbon/glass fibre reinforced epoxy composite automotive drive shaft. Int. J. Eng. Trans. A **28**, 583–592 (2015). https://doi.org/10.5829/idosi.ije.2015.28.04a.13
42. Tamrakar, S.: Characterization of S-glass epoxy composite interface under various rates of loading, university of Delaware, (2018) http://udspace.udel.edu/handle/19716/23606
43. Ramakant, U., Sowjanya, K.: Design and analysis of automotive multi-leaf spring using composite material. IJMPERD2249–6890 3(1): 155–162 (2013)
44. Elsheltat, S., et al.: Modeling and finite element analysis of leaf spring using pro-engineer and ANSYS Softwares. In: Proceedings of First Conference for Engineering Sciences and Technology (CEST), September 25–27, (2018)
45. Bhandari, V.B.: Machine design data book. McGraw Hill (2019)