

Designed and Analysed of Three Distinct Composite Material-Based Mono Leaf Spring using ANSYS

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ARTICLE INFO

Article History:

Accepted: 05 April 2024

Published: 15 April 2024

Publication Issue

Volume 8, Issue 2

March-April-2024

Page Number

04-26

ABSTRACT

The leaf spring is an important component in vehicles because it provides a comfortable ride and stability to the vehicle. The need to replace leaf springs with stronger and more lasting leaf springs is a key challenge in the transportation and automotive industries. In addition to offering ride comfort and stability, traditional steel leaf springs have a significant impact on the weight of the car. Fibre reinforced polymeric composites, therefore, are appropriate materials for various applications due to their many exceptional properties, including high wear resistance, high strength, long fatigue life, corrosion resistance, and low density. Fiber-reinforced polymeric composites find extensive application in several technical sectors, such as automotive, aviation, military, and marine industries. The utilization of composite materials has become imperative in the automotive industry to attain weight reduction without compromising material strength, as fuel consumption and CO₂ emissions have to be reduced. In this paper, three different types of composite-based mono leaf springs were designed and examined. The results of the investigations showed that the 0° unidirectional glass fiber system was unable to correctly produce the required spring rate. Consequently, many combinations of carbon and glass hybrid systems were studied. The analysis showed that the desired spring rate was produced by the material configuration of [0°6G / 0°2C / 0°22G] S. When the final results were contrasted with the FEA findings, it was found that they concurred.

Keywords : Composite Material, Leaf Spring, ANSYS Software, Carbon Material, Glass Material

I. INTRODUCTION

The suspension system is an important element for providing protection and strength to the vehicle's structure. However, the suspension system is the area of concern for manufacturers in order to reduce the load of a vehicle by decreasing its suspension weight. Suspension system weights account for 16-21% of unsprung weight. Furthermore, automotive suspension systems are constantly evolving to give protection against impact loads, as well as to avoid chassis deformation and damage [1][2]. The leaf spring suspension systems are critical components for lowering weight in cars, which boosts fuel efficiency and ride comfort. The advantages of leaf springs are their simple and low-cost design. However, depending on the gross weight of the vehicle, several types of leaf springs are utilised in cars [3]. The form of a leaf spring distinguishes it from other varieties. The quantity of leaves heaped together in the parabolic leaf spring and conventional leaf spring is different [3].

The leaf spring is an important component in vehicles because it provides a comfortable ride and stability to the vehicle. The need to replace leaf springs with stronger and more lasting leaf springs is a key challenge in the transportation and automotive industries. The car was intended to be more dependable, comfortable, and quicker with this statistic. Because of its and modulus-to-weight ratio, higher strength-to-weight ratio and low density, Fibre reinforced polymer composites have been employed in numerous components in automotive, aerospace, and other technological areas to replace metallic materials. In addition to the aforementioned characteristics, many Fibre reinforced composite have good corrosion resistance and good fatigue strength [1].

Leaf spring systems, which determine the weight of the vehicles as well as stability and ride comfort, are

critical components of the vehicle. As a result, composite materials, which offer several advantages over metals, such as high strength, and high wear resistance, low density, and long fatigue life, are ideal for these applications [4]. When loaded, springs exhibit significant deformation. As a machine component, this is their primary design goal. As a result, the material and geometry of the springs become critical design elements [5]. In the automobile sector, leaf springs are commonly used to minimize the damaging effects of good shocks on car components, give ride comfort [2]. Materials with minimal modulus and maximum strength in both directions provide us increased specific strain energy, making composite materials an excellent choice for leaf spring applications [6].

The most prevalent failure mode in leaf springs is fatigue failure caused by strong dynamic loads. These dynamic stresses have a significant impact on the leaf spring, which bears the whole weight of the car. Because of the dynamic loads are created, unevenness of the road, causing the vehicle's wheels to move with irregular frequencies and creating recurrent stress on the spring [5] [8]. However, there are several methods for extending the fatigue lives of a typical leaf spring. The authors also exhibited many surfaces including shot peening, processing techniques, which is widely used for enhancing the strength of steel leaf springs due to its low cost and simplicity. To improve the fatigue strength of traditional leaf springs using the shot peening method, which is a procedure of improving the spring's fatigue strength by imparting residual stresses. Also, suitable and efficient circumstances for the shot peening procedure may be applied [7]. In addition, residual stresses are carefully managed to improve the fatigue performance of the leaf spring. Furthermore, fretting occurs across leaf surfaces due to inter-leaf contact in multi-leaf springs, resulting in microscopic fractures due to stress concentration. However, fretting weariness can be alleviated by refining the surface of the leaves [9]. Another way is material optimisation, in which

experimentally validated materials are utilised for leaf spring design for a specific loading. Optimisation methods are also employed in order to attain optimal geometry. The geometry of the spring was first modelled and analysed numerically. The tensions at various locations in the design were calculated and optimised to provide the best design [8].

II. NUMERICAL MODELING AND FE ANALYSIS

This chapter investigates the numerical modelling and FEA of a composite-based mono leaf springs. The finite element approach is briefly defined, the micromechanical behaviour of composites structure are quickly discusses, and modelling procedure of a composite leaf springs is thoroughly introduce [9].

2.1 Finite Element Method

Analytical solutions to processes or problems are not always available or are too time-consuming. Yet, numerically procedures using a computer may be employed to obtain a solution to a problems or the behaviour of a structure more quickly. The Finite Element Method is a numerical approach for estimating the solution to a structures or issue. The method does not give proper solutions for many scenarios due to their intricate boundaries and loading circumstances [10].

2.1.1 Finite Element (FE)

FE, which can have various geometrics forms, are subdomain of the overall framework. They are formed by discretizing the structures, and their characteristics behaviour is utilised to derive the structure solutions following the assembly of full pieces. There are different features of Abaqus that may be used to tackle various problems. Each constituent is distinct and has its own name. Its broad element capability makes this

application valuable, particularly for composite modelling, which requires more attention[11].

2.1.2 Element Formulation

Typically, the Eulerian or Lagrangian formulation is employed as a function to explain the behaviour of elements in the finite element technique. In solid mechanics problems, the Lagrangian formulation is often utilised. Throughout the analysis, the material in the element borders remains stable in this procedure. Alternative formulations, such as Eulerian, are commonly utilised in material flows and fluid mechanics problems when components are stable in the given space. While calculating the composite leaf spring behaviour is a topic of solid mechanics and quasi-static issue, the elements employed in this work use the Lagrangian formulation[12].

1) 2.1.3 Element Integration

Integration points are essential parameters in analysis because they impact the accuracy and overall duration of the solution that Abaqus produces using numerical methods such as Gaussian. In Abaqus, fully integrated or reduced integrated elements are offered; nevertheless, the issue should be carefully analyzed to determine the appropriates elements type in term of problems correctne. Fully integrated elements with integration point totally integrate the polynomial terms using the relevant Gauss points[13].

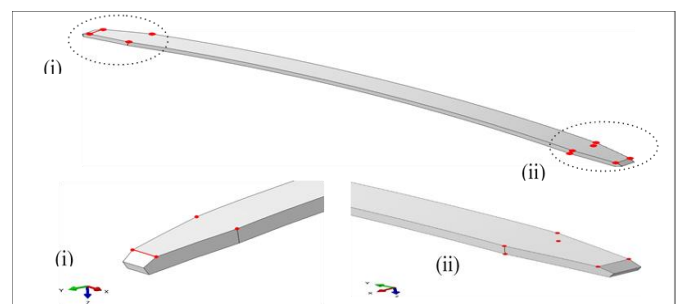
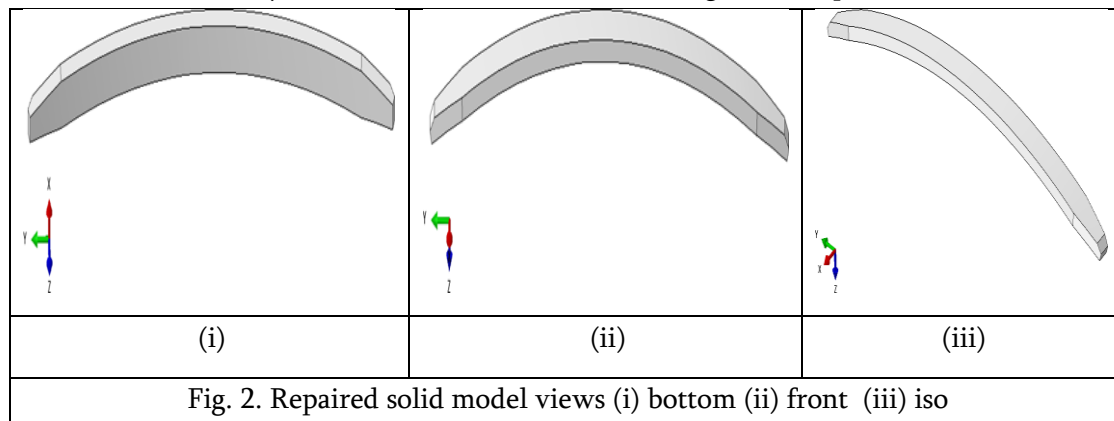


Fig. 1. Geometry import process



As the conversion technique, the Tighten Gaps approach was used. The holes have been filled, and the portion now has correct geometry and topology. Fig. 2 depicts the component acquired following the import and repair processes in various viewpoints. It is critical in the partition process to create datum plane on the models in order to correctly separate the face. On the model, four datum planes have been generated.

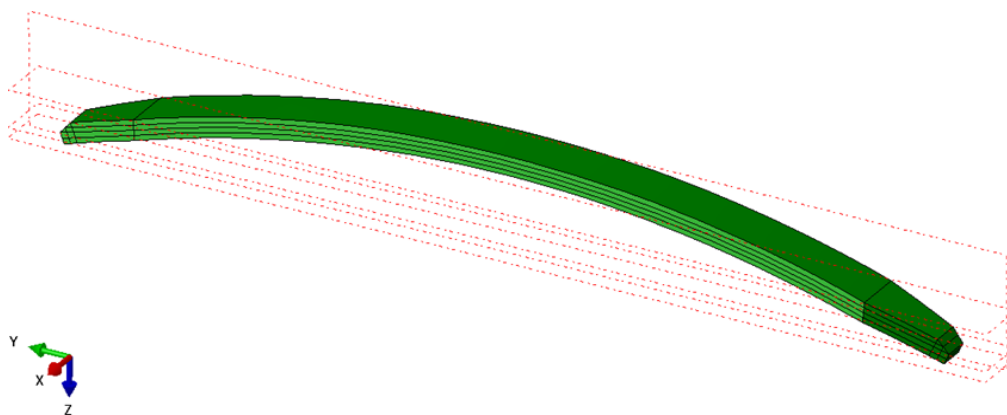


Fig. 3. Datum planes

Following this stage, the cell partition and face partition operations were carried out. On the portion, eleven faces and sixteen cells were partitioned. Face partition was created using sketches, shortest routes between two places, and stretched faces. The partition face is then separate from one another using the extrude/sweep edges tool sets.

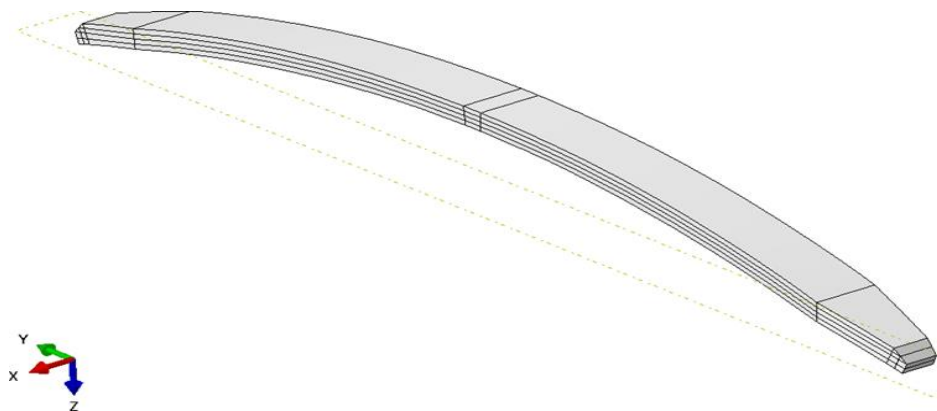


Fig. 4. Partitioned solid part

Despite Abaqus/composite CAE's modelling capacity due to its better attribute of composites lay-up construction, producing mesh employing hex components in curve composites part are a significant challenge for programme user. As a result, curve portion on the part's edge were removed, yielding final shape displayed in Fig. 5.

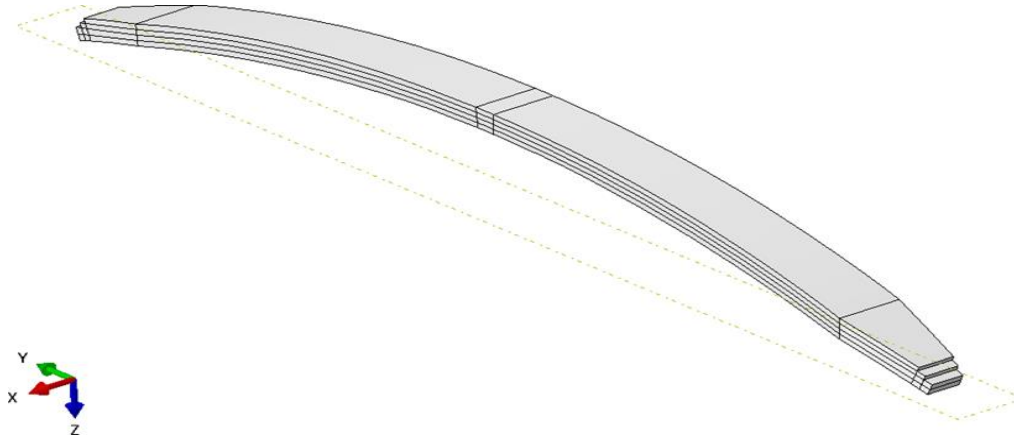


Fig. 5. The final geometry of the part

2.3.2 Composite Modeling

Abaqus has a plethora of approaches for composite modelling. They are divided into two categories: macro-modeling and micro-modeling. Abaqus, on the other hand, supports mixed modelling, submodeling, and discrete reinforcement modelling. Composites Modeler micro-modeling technique opens up new possibilities in ply modelling by transferring accurate ply thicknesses and fibre angles to the component. Some modelling approaches give a ply table to describe ply parameters for creating a composite layup. This table contains the name, coordinate system, material, region, thickness. The material parameters of E-glass / epoxy plies are shown in Table 4.1. After everything is finished, the part's composite modelling is complete, as illustrated in Fig. 6 [4][14][15].

Table 4.1. Unidirectional E-glass/epoxy plies material characteristics

G_{12}	G_{13}	G_{23}	E_1	$E_2 = E_3$	d	$\nu_{12} = \nu_{13}$	ν_{23}
3490.00 MPa	3770.00 MPa	3460.00 MPa	37000.00 MPa	9500.00 MPa	2600.00 kg/m ³	0.262	0.350

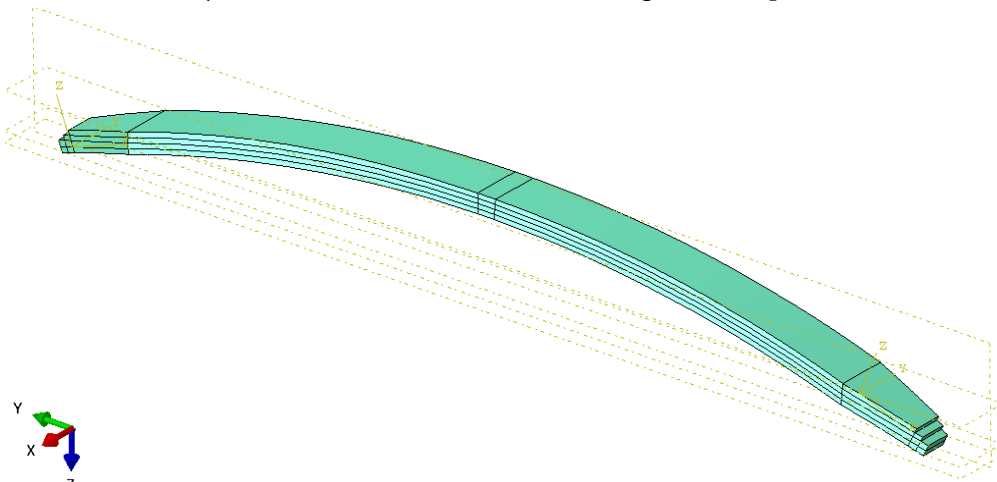


Fig. 6. Composite mono leaf spring model

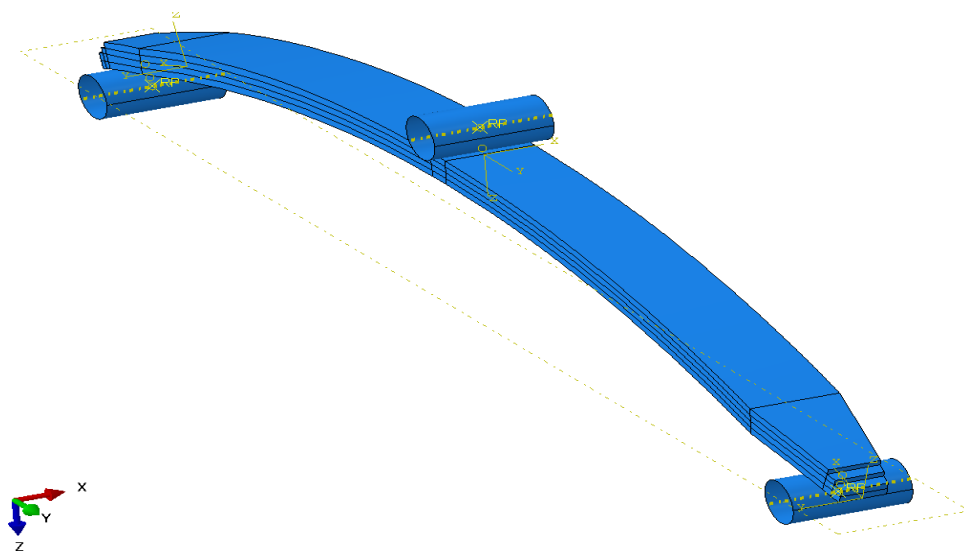


Fig. 7. Assembly of the composites mono leaf springs model

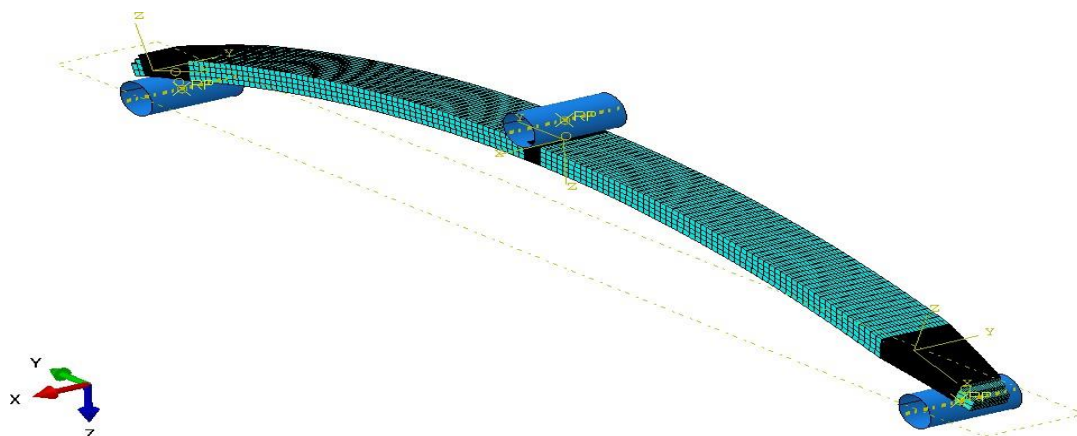


Fig. 8. Composite leaf spring mesh model

III. RESULTS AND DISCUSSIONS

This chapter describes the validation investigation, controls of the boundary condition and stresses analysis of the developed composite-based leaf spring. In addition, natural frequency studies of the structure are offered.

3.1 Finite Element Model Validation

To verify the FEM of the composite leaf springs made inside this study using Abaqus/CAE, an existing composite mono leaf spring was utilized as a model structure. The modelling techniques were carried out in accordance with the procedure given in details in the preceding chapter. Modelling work was conducted by considering the given loading condition and test rig boundary condition. Sensitivity of modelling factors such as contact definition, the mesh, constraints, and element type and the aforementioned processes with reference to the FEM of the composite mono leaf spring were ultimately obtained. A composite leaf spring is normally tested in two basic processes. The composite leaf spring is initially fitted with strain gauges designed for composite-based materials.

3.2 Boundary Conditions Control and Stress Analysis of the Composite Leaf Springs

Within the scope of the paper study, composite leaf spring behaviour was explored using the commercial FEM Abaqus and a three-dimensional finite element model. Maximum stress and deflection values, which occur on the FEM with the specified boundary and loading circumstances, were calculated in this respect. Various material configurations were researched, as well as the best configuration in the ideal composite construction.

3.2.1 Design Composite-based Leaf Spring

Three distinct composite-based leaf spring model with varying materials configuration were developed in order to determine the mechanical characteristics and behaviour under loading circumstances and specified boundary. The material parameters of the Carbon / Epoxy plies are shown in Table 5.1.

Design 3 consists of carbon and glass plies and represents the ideal configuration in the optimum composites structures, as well as meeting the spring rate criteria. Table 5.2 shows the model list that was created.

Table 5.1. Unidirectional carbon / epoxy plies materials properties

G_{12}	G_{13}	G_{23}	E_1	$E_2 = E_3$	d	$\nu_{12} = \nu_{13}$	ν_{23}
4500 MPa	4500 MPa	3000 MPa	105000 MPa	8200 MPa	1580 kg/m ³	0.3	0.4

Table 5.2. Configurations for leaf spring systems based on composite were developed.

Design	Material	Plies	Orientation
1	Carbon	60	[0°] ₆₀
2	Glass	60	[0°] ₆₀
3	Glass and Carbon	60	[0°6G/0°2C/0°22G] _s

3.2.2 Mechanical Properties and Behavior of the Designed Springs

The comparison of the necessary the simulation results and spring rate of the glass fiber/epoxy composite based leaf springs model is shown in Fig. 9. (1st-Design). Because we tested in an elastics zone and did not establish any damage criterion, displacements grows linearly as loads increase. According to this Fig., this design offers 169.50 N/mm spring rate, whereas the needed theoretical springs rates is 177.75 N/mm. Fig. 5.10 to 5.20 show the stress results in the key locations. These numbers are thoroughly explored as follows. According to these results, the largest stress values occur in the centre of the structures on both lower surface and top surface in term of normal stress. The results also show that compressive stresses on the structure are more dominant than tensile stress. As a result of the loading situation, this might be displayed. Nevertheless, this material combination does not completely satisfy the requisite spring rate criterion. As a result, the material configuration has to be altered in order to boost system stiffness based on stress findings obtained under boundary's circumstances. As a consequence, 2nd-Design was constructed, which consisted of 60 plie of carbon/epoxy with a 0° orientations.

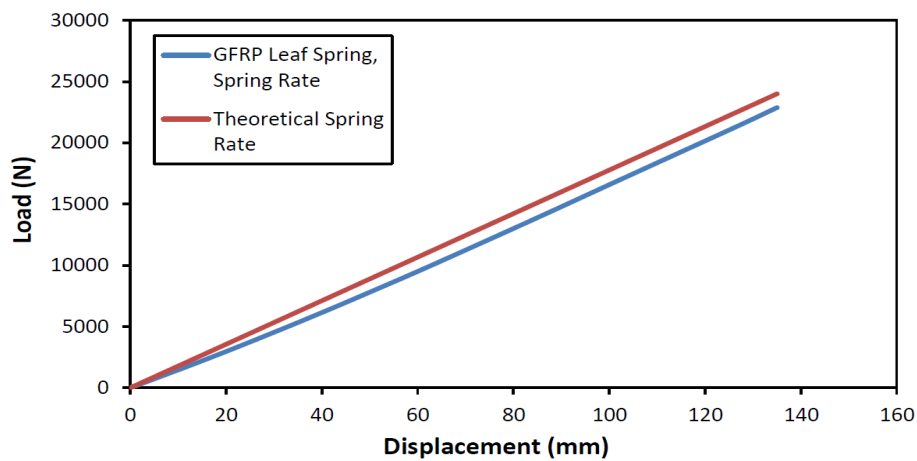


Fig. 9. The load v/s displacement curves

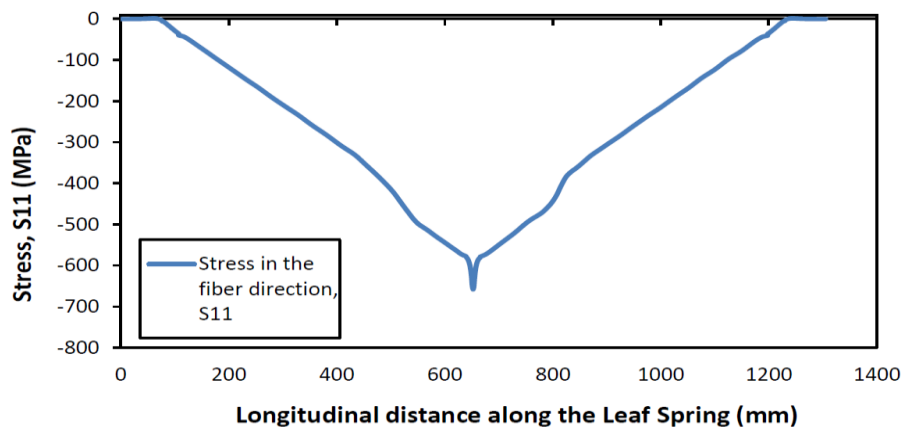


Fig. 10. S11Stress distribution v/s longitudinal distance along the leaf spring upper surface

Normal stresses value in the increasing towards the loading zone and fibre directions are negatives on the top surface of the structures, as illustrated in Fig. 5.10. Also, few positives stress value is obtained along the edges up to the supports zone. Transverse stresses are positive up to the loading zone, as shown in Fig. 5.11. Compressive stresses are seen as predicted in that location, and the stress distributions then proceed symmetrically.

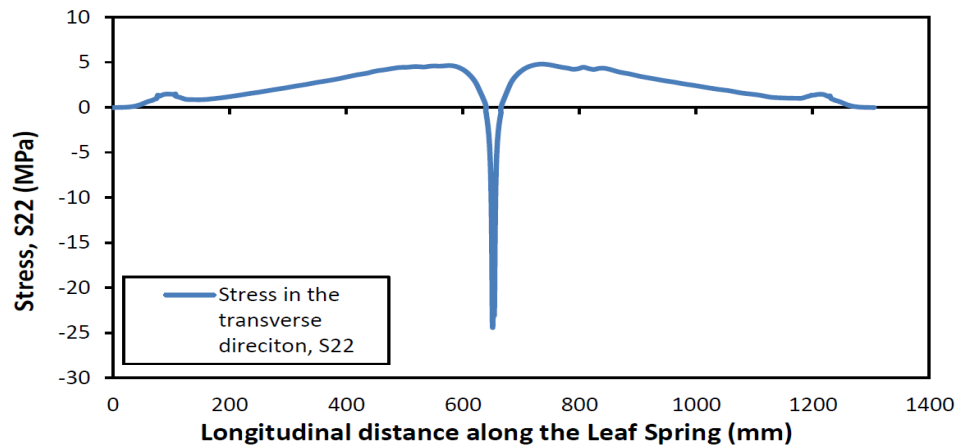


Fig. 11. S22 Stress distribution v/s longitudinal distance along the leaf springs upper surface

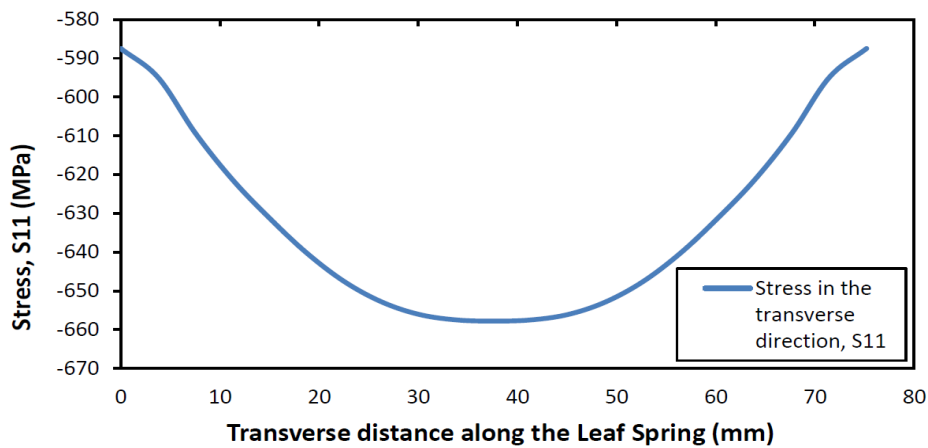


Fig. 12. S11 Stress distribution v/s Transverse distance along the leaf springs upper surface

Compressive pressures in the fiber direction increase by 10.81% from the margins to the center over the transverse span, as shown in Fig. 5.12. As expected, tensile stresses are achieved on the lower surface as opposed to the upper surface. Conversely, some compressive stresses that are related to the supports are depicted in Fig. 5.13.

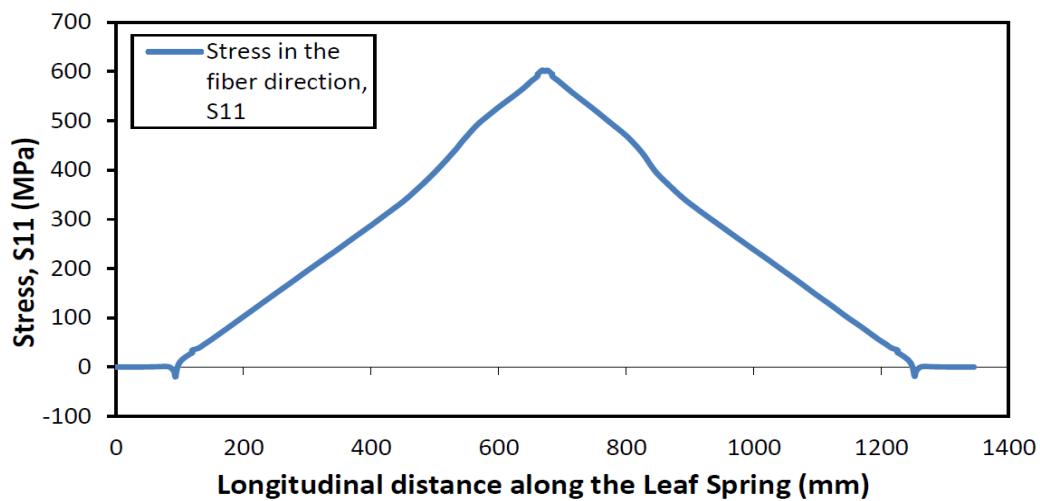


Fig. 13. S11 Stress distribution v/s longitudinal distance along the leaf spring bottom surface

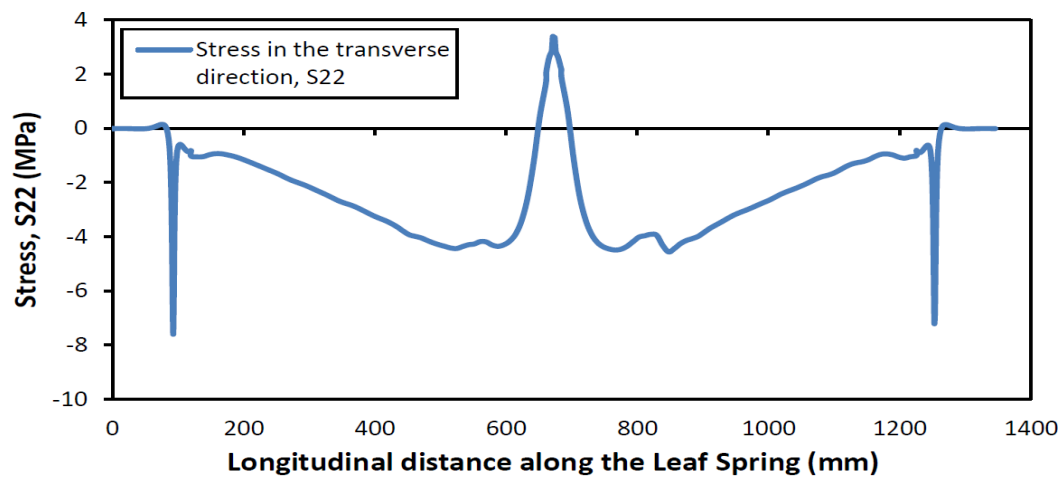


Fig. 14. S22 Stress distribution v/s longitudinal distance along the leaf spring bottom surface

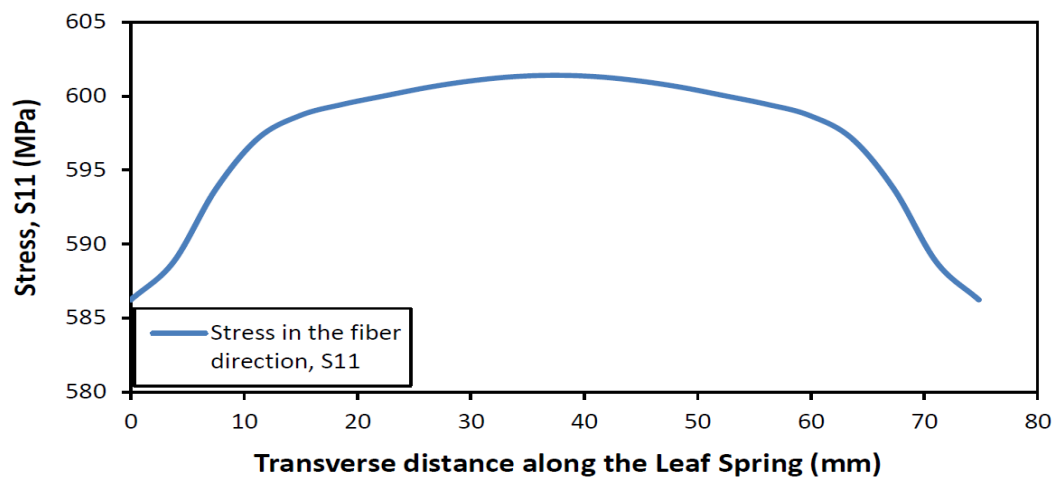


Fig. 15. S11 Stress distribution v/s Transverse distance along the leaf spring bottom surface

Compressive pressures in the transverse directions are found in the supports sections, as illustrated in Fig. 5.14. The regions correspond the loading points influences this tendency. Tensile stresses on the bottoms surfaces of the transvers increases by roughly 2.45 percent from the margins to the centre. When the findings are compared to the results on the upper surfaces, it is clear that the structure's dominant stress state is compressive.

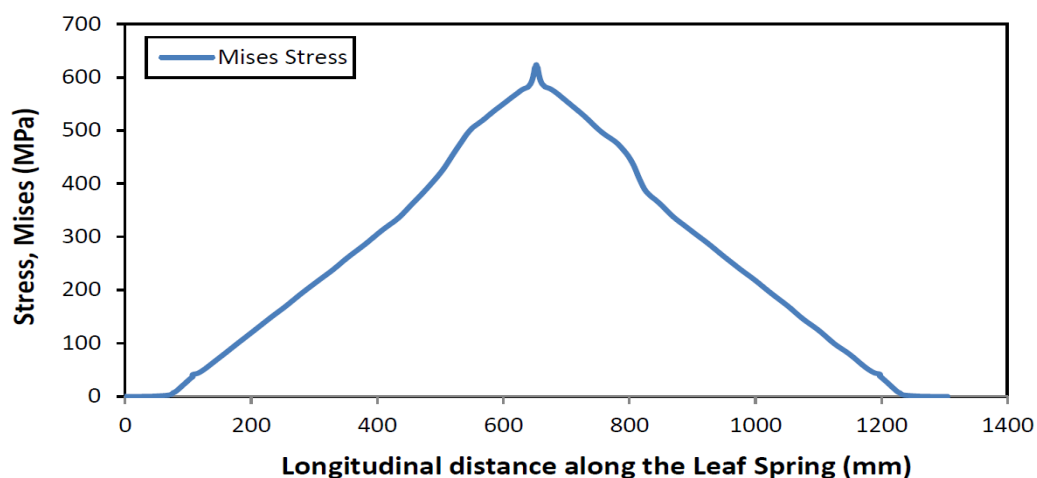


Fig. 16. Mises stress distribution v/s longitudinal distance along the leaf spring upper surface

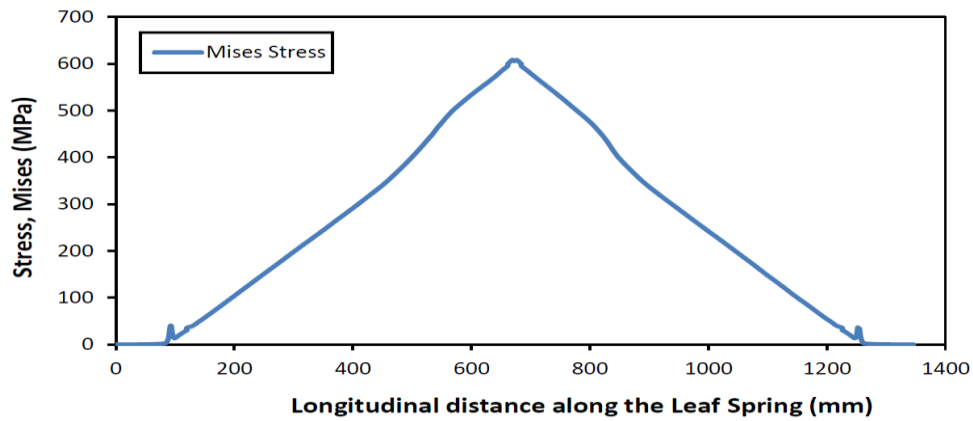


Fig. 17. Mises stress distribution v/s longitudinal distances along the leaf spring bottom surface

Fig. 5.16 to 5.20 highlight the shear stresses and Mises stresses that are essential in the midsection of the structures due to the nature of the flexural loading circumstances. The Fig. show that Mises stresses on lower and upper surfaces follow a similar pattern to normal stresses graphs shown above.

Fig.s 5.19 to 5.20 show the shear stress findings of the planned model. As predicted, the greatest stress values are achieved in ply 30, which is in the structure's midsection. According to these findings, the achieved shear strength parameters of the glass fiber/epoxy composite ply are safer. Color bars are solely utilised to indicate results ranges on the structures in this case.

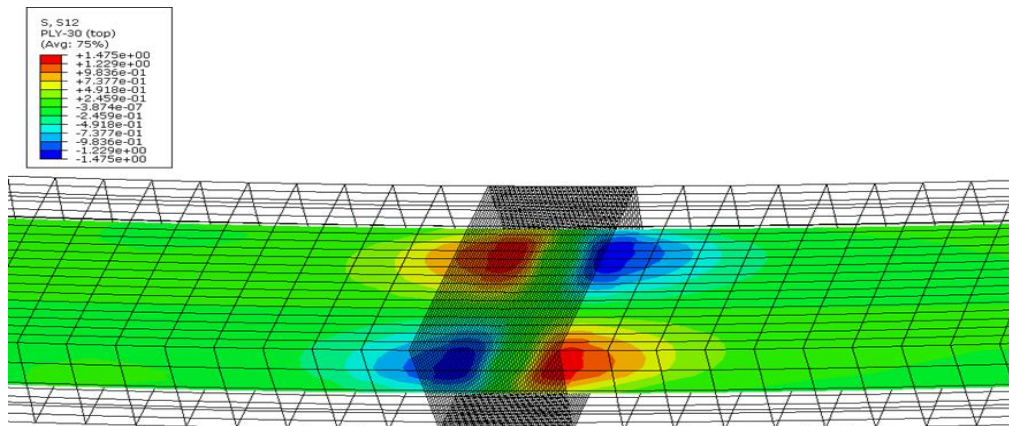


Fig. 18. S12 Midsection in-plane shear stress contour

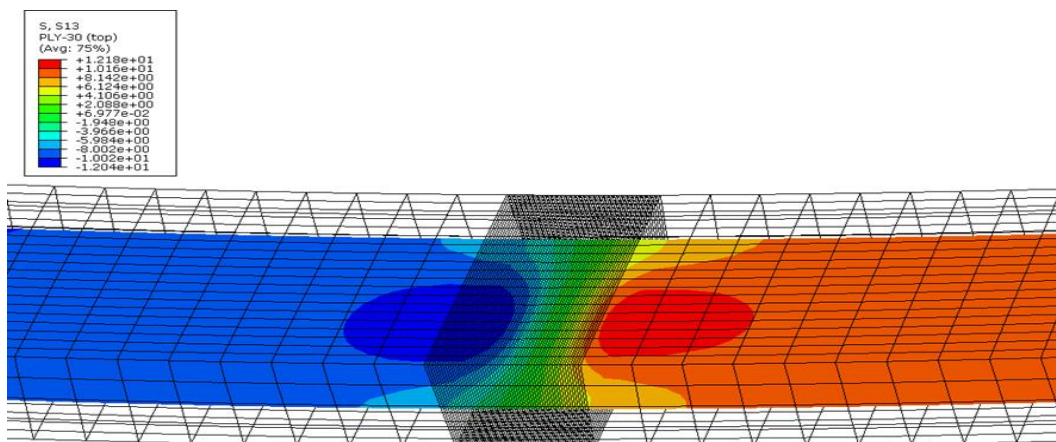


Fig. 19. S13 Through the midsection's thickness shear stress shape

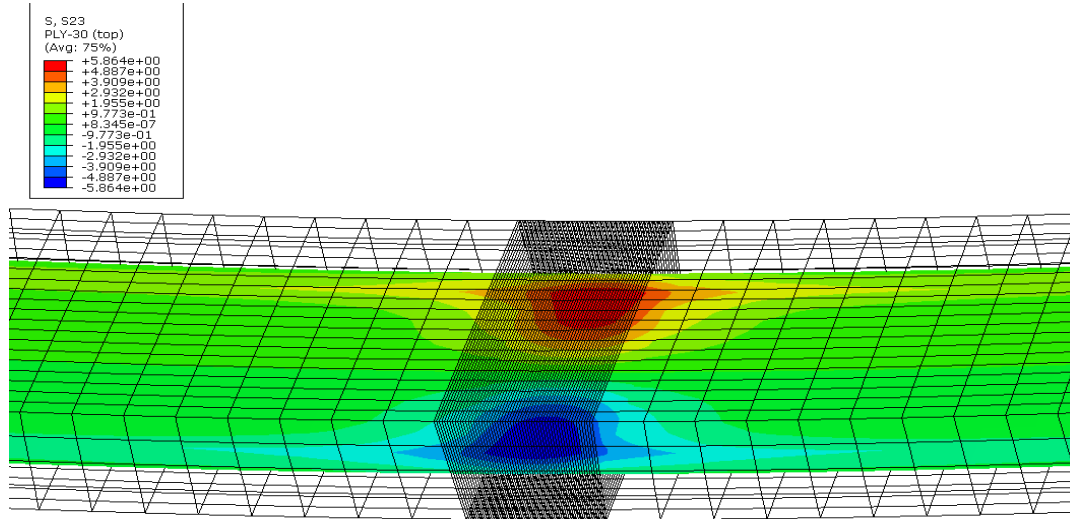


Fig. 20. S23 Through the midsection's thickness shear stress shape

Carbon fiber/epoxy composites leaf springs models was examined in the second design. Because of the mechanical properties of carbon fibres, this design was chosen to improve the rigidity of the structure. Figs 5.21 to 5.32 depict mechanical characteristics and the behaviour of the structures in term of stress based on the analysis finding.

Fig. 5.21 depicts a comparison between simulation results and the required spring rate of carbon fiber/epoxy composites leaf springs model. Because we researched in an elastic zone, displacement rises linearly as the load increases, as seen in the picture. Based on the this number, it was discovered that this design gives a spring rates of 473.77 N/mm, which is significantly more than necessary value. Stiffer structure of the carbon fibres is to blame for this predicament. Figs 5.22 to 5.32 show the stress results in the key locations for this design. When strengths of carbon/fiber epoxy composites plies is evaluated, the max stressess values are again authorized, and the stress distributions follow a similar pattern to 1st design. As a result, the materials configurations was altered several times in order to get the right configuration. Ultimately, design 3 was devised, which included the carbon and glass plies and provided the requisite springs rates.

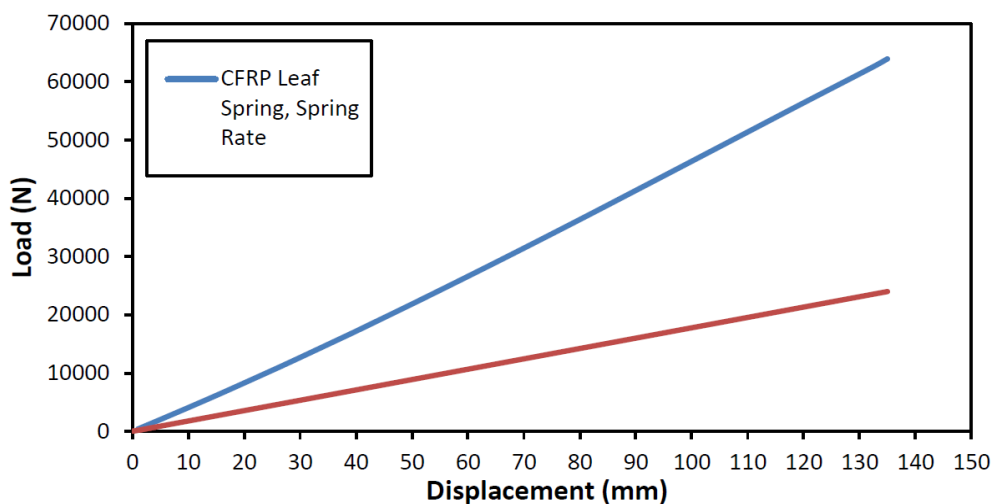


Fig. 21. The load vs. deflection curve under flexural loading

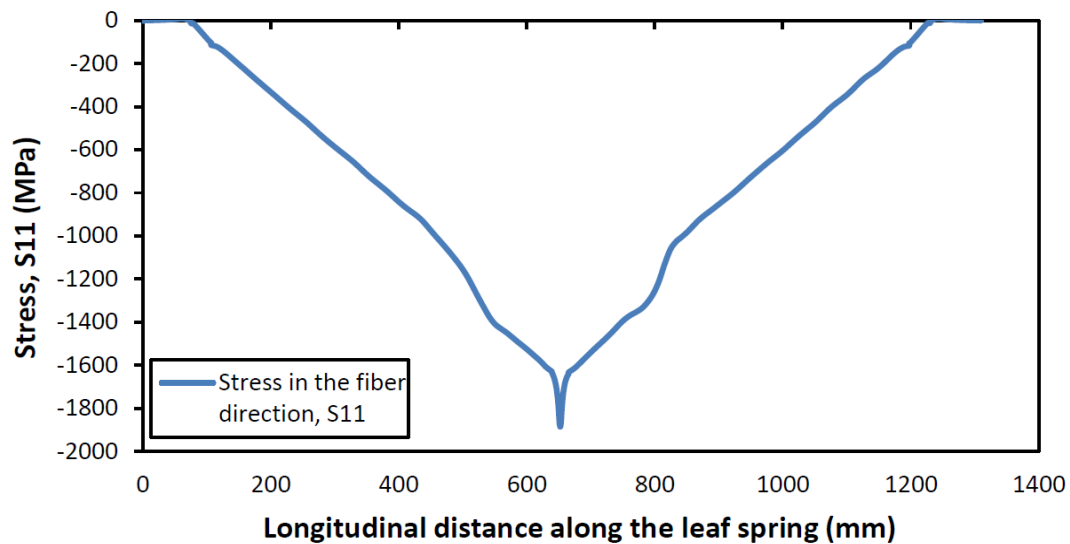


Fig. 22. S11 Stress distribution v/s longitudinal distance along the leaf spring upper surface

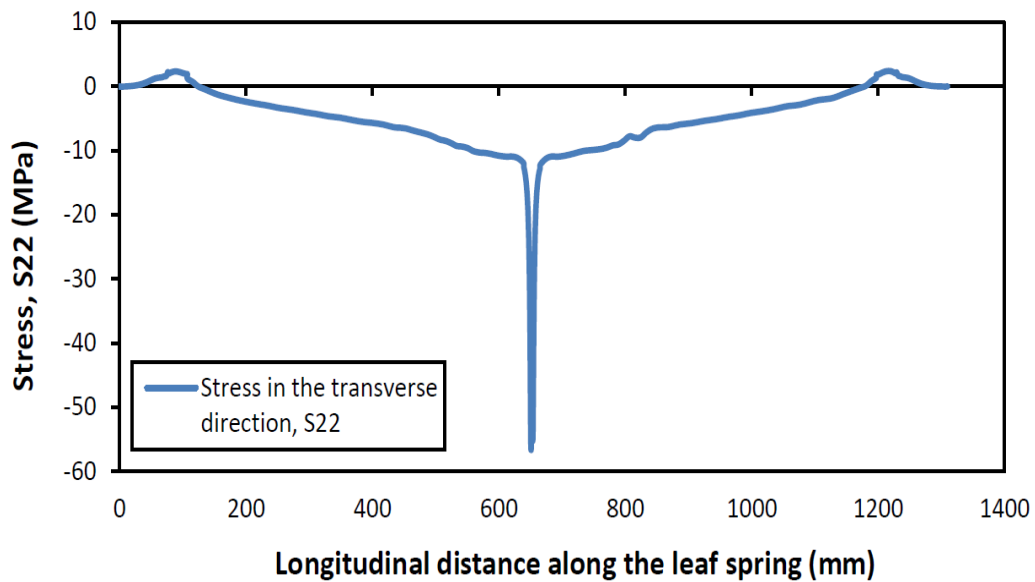


Fig. 23. S22 Stress distribution v/s longitudinal distance along the leaf spring upper surface

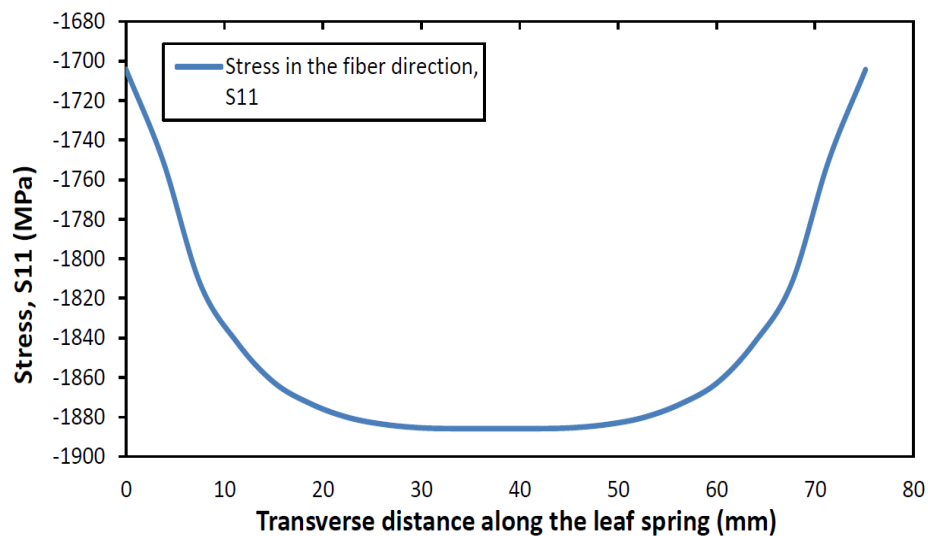


Fig. 24. S11 Stress distribution v/s transverse distance along the leaf spring upper surface

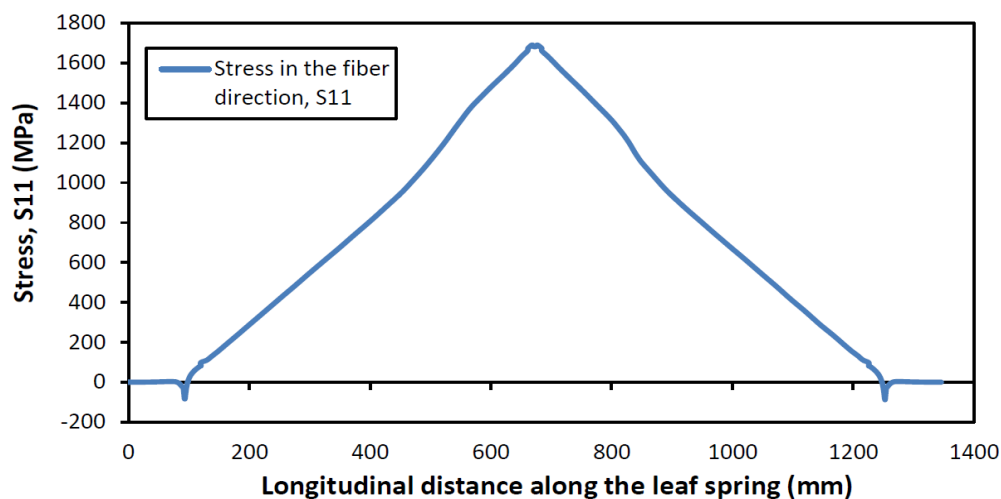


Fig. 25. S11 Stress distribution v/s longitudinal distance along the leaf spring bottom surface

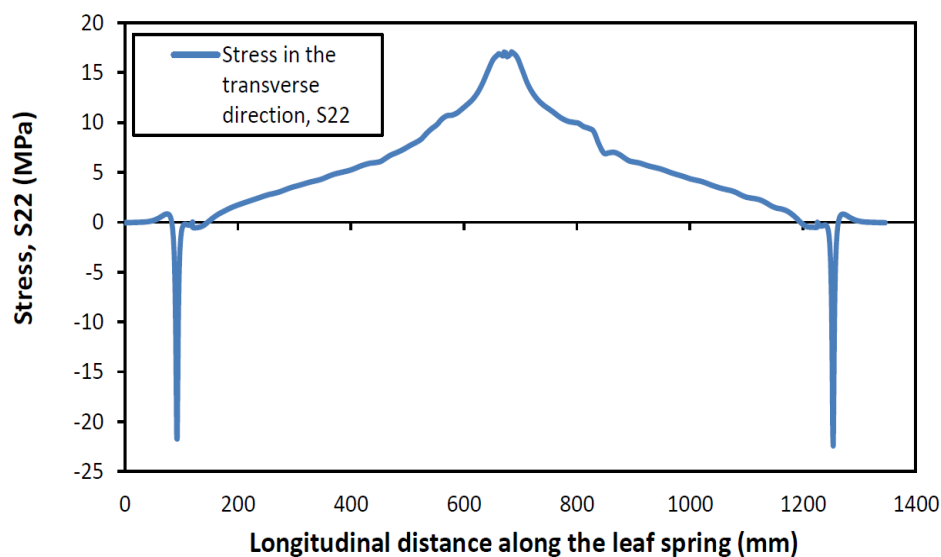


Fig. 26. S22 Stress distribution v/s longitudinal distance along the leaf spring bottom surface

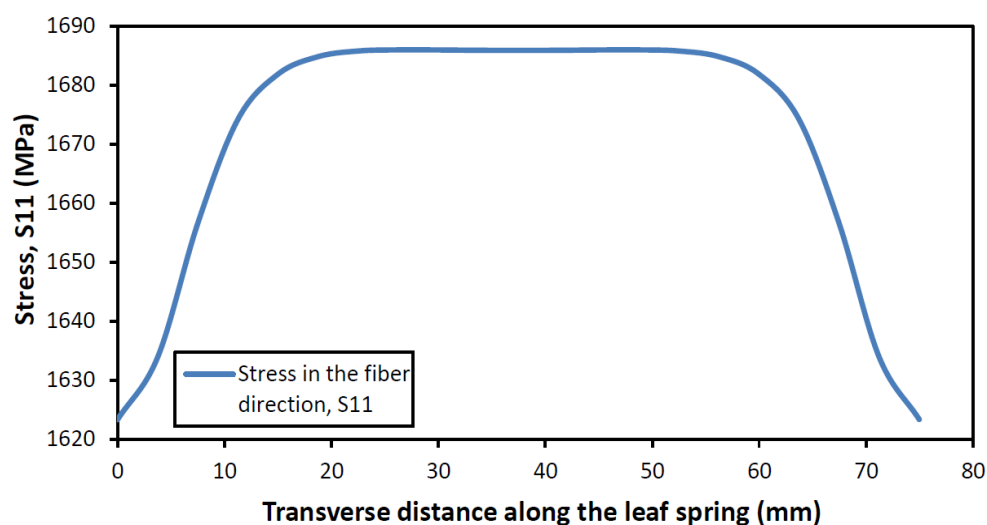


Fig. 27. S11 Stress v/s transverse distance along the leaf spring bottom surface

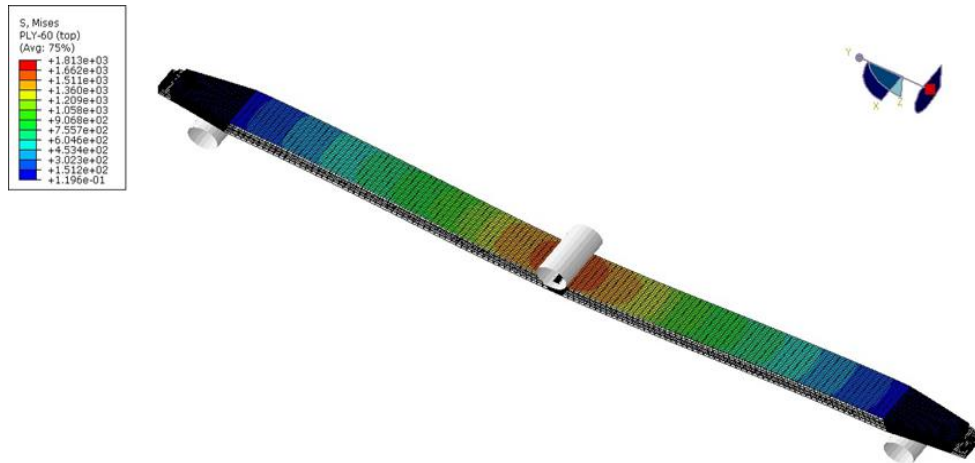


Fig. 28. Comparable stress contour of Mises on the upper surface

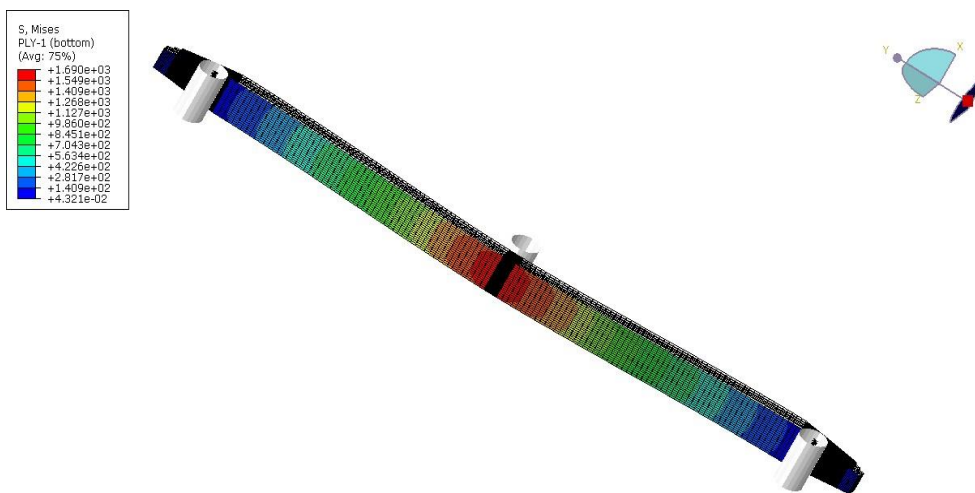


Fig. 29. Mises equivalent stress profile at the base

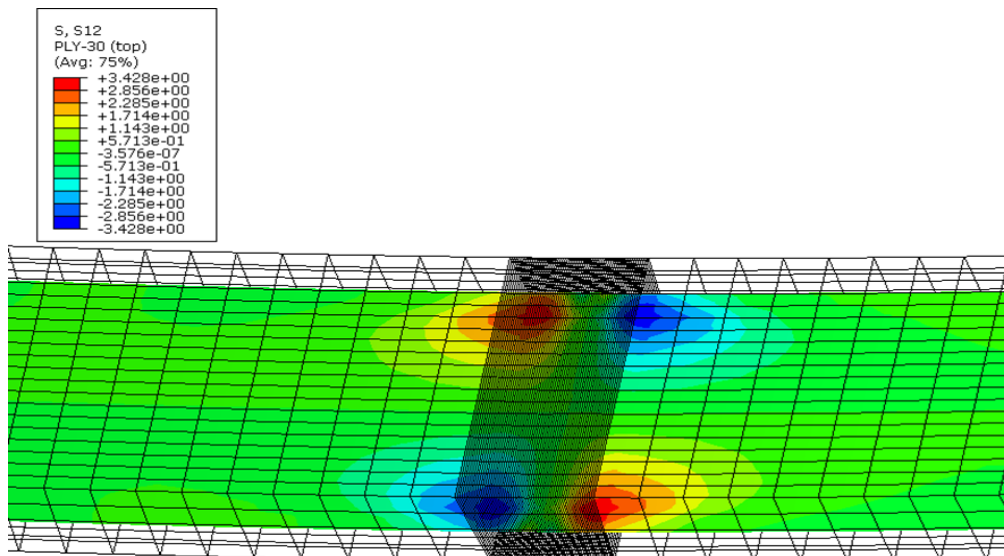


Fig. 30. S12 Midsection In-plane shear stress contour

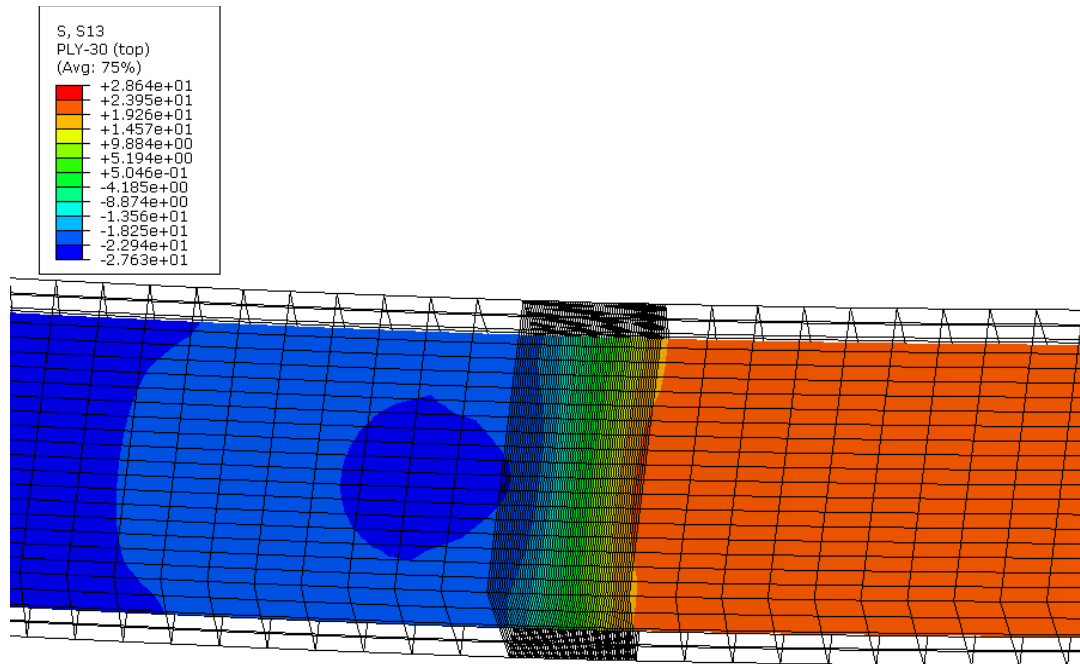


Fig. 31. S13 Through the midsection's thickness shear stress shape

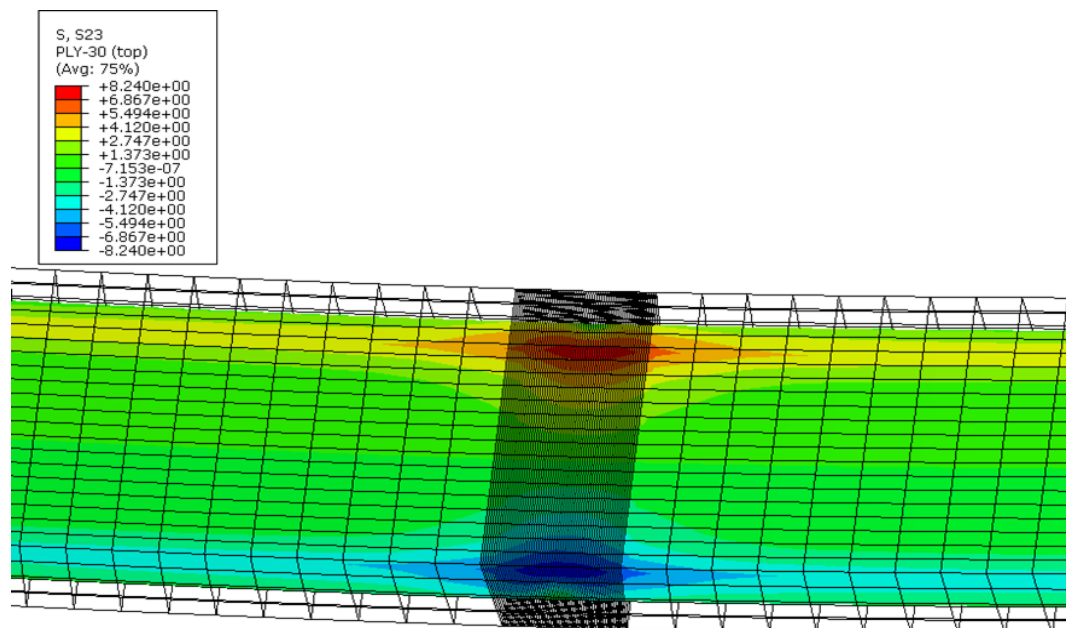


Fig. 32. S23 Through the midsection's thickness shear stress shape

Finally, the aforementioned ideal arrangement in the leaf springs was investigated, and the findings shown below indicate the structure's behaviour and mechanical qualities in terms of stresses. Fig. 5.33 depicts a comparisons of the loads and displacements curves for Design 3 are needed. As shown in the picture, the numericals findings accord with the experimentals data with a 0.514% variance using C3D8R element.

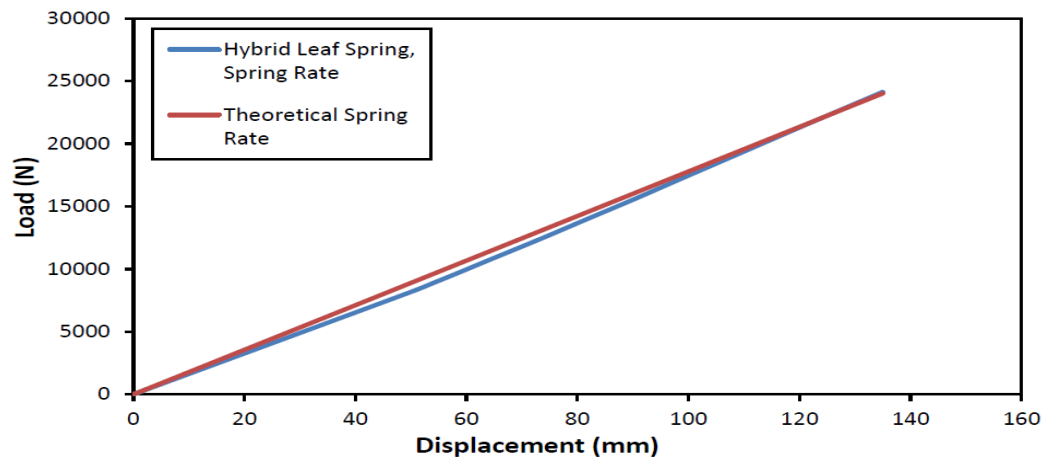


Fig. 33. Load vs. displacement curve under flexural loading

As illustrated in Fig. 5.34, the normal stresses value in the fibres direction rise by 8.101 MPa on the upper surfaces of the structures depending on the materials qualities of the additional carbon fibres.

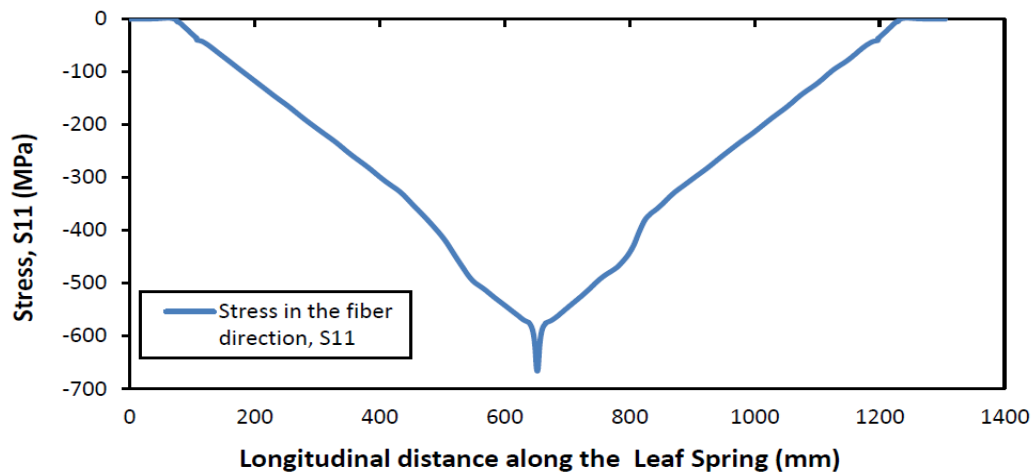


Fig. 34. S11 Stress distribution v/s longitudinal distance along the leaf spring upper surface

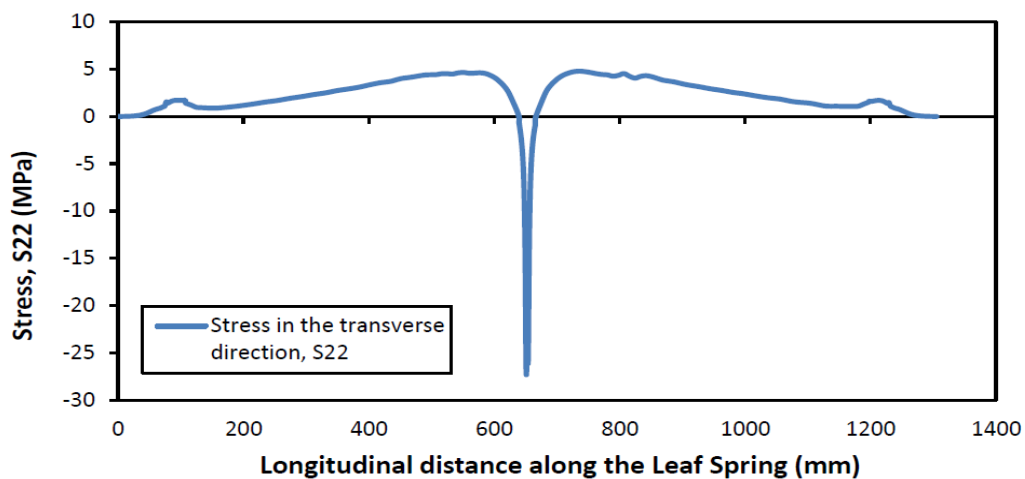


Fig. 35. S22 Stress distribution v/s longitudinal distance along the leaf spring upper surface

The highest stress in the transverse direction, as shown in Fig. 5.35, is -27.29 MPa, which is within the range of values found in the first two designs. Again, the added carbon fiber plies are to blame for this behavior.

According to Fig. 5.36, from the edges to the center of the final design, the compressive stresses in the fiber direction climb by around 11.50% along the transverse extent.

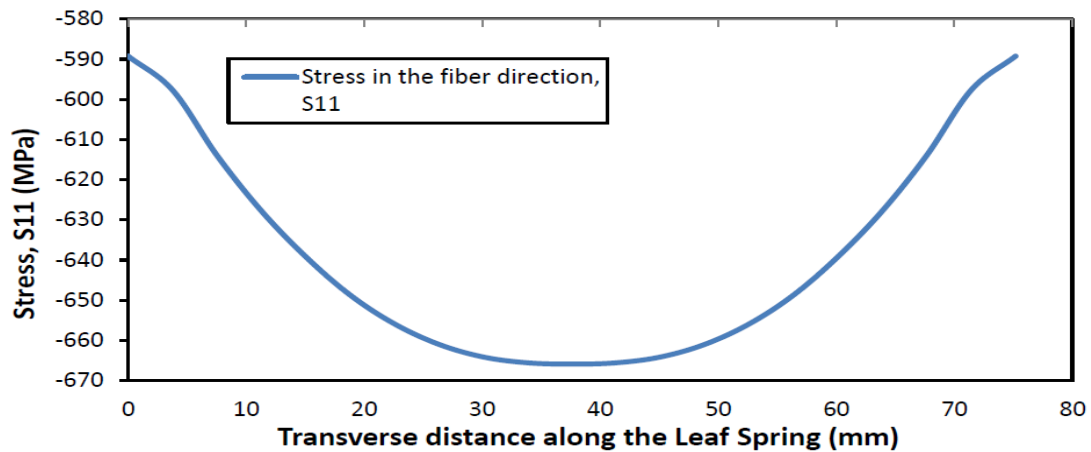


Fig. 36. S11Stress distribution v/s transvers distance along the leaf spring upper surface

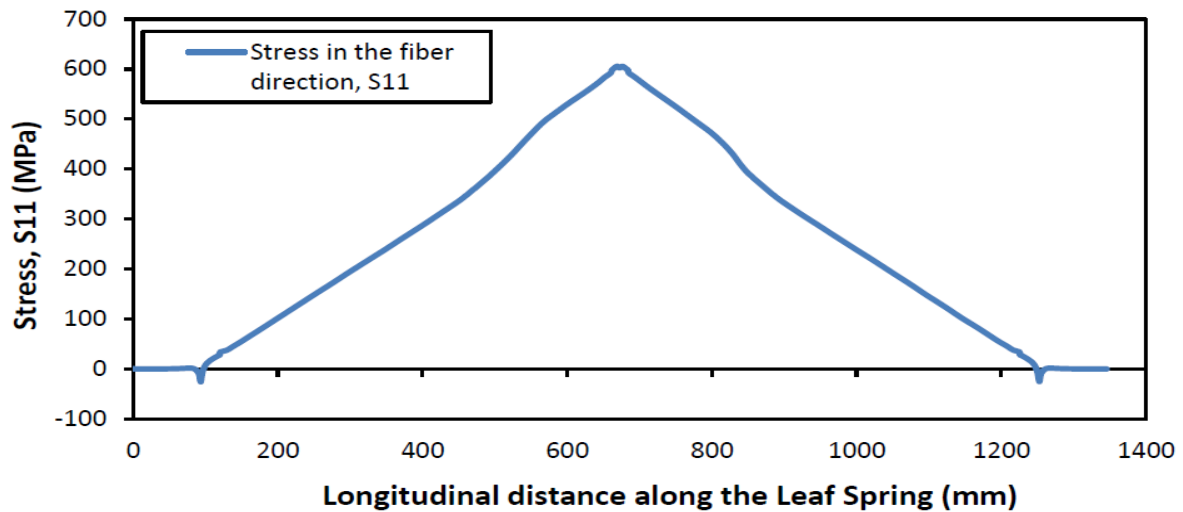


Fig. 37. S11Stress distribution v/s longitudinal distance along the leaf spring bottom surface

In contrast to Design 1, the maximum tensile stress on Design 3's bottom surface demonstrates an increase of 2.67 MPa. As in the previous designs, Fig. 5.37 demonstrates that compressive stresses in the transverse direction are noted in the supports sections. Additionally, the support zones' maximum stress values have risen by 20.14%. However, in terms of the plies' strength qualities, this tendency translates to a 1.5 MPa rise, which is negligible and, once again, permitted.

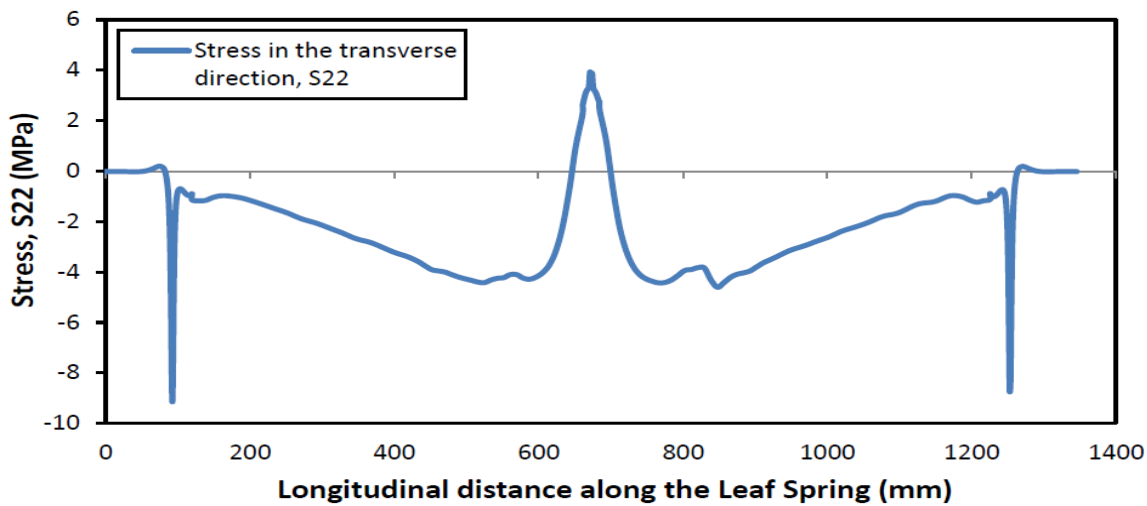


Fig. 38. S22 Stress distribution v/s longitudinal distance along the leaf spring bottom surface

According to Fig. 5.39, compressive stresses on the bottom surface along the transverse extent climb by approximately 4.08% from the margins to the center in the fiber direction. This tendency is safer when looking at strength traits.

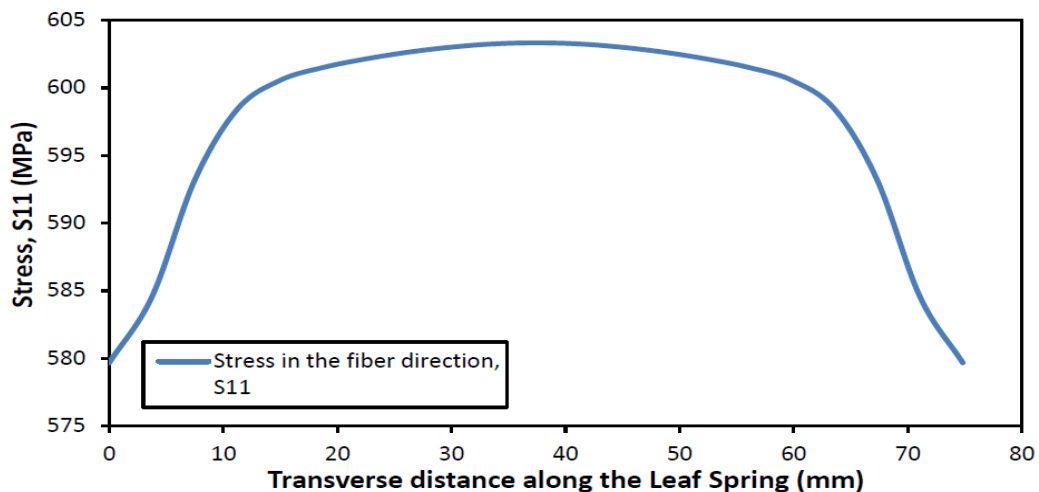


Fig. 39. S11 Stress distribution v/s transvers distance along the leaf spring bottom surface

The final design's Mises stress and shear stress contours are shown in Figs. 5.40 to 5.44. The Fig. demonstrates that shear stress values in the center of the structure are permitted and that Mises stresses on the upper and lower surfaces follow a pattern resembling the normal stress findings. In terms of shear stress data, very minor differences are detected when compared to Design1.

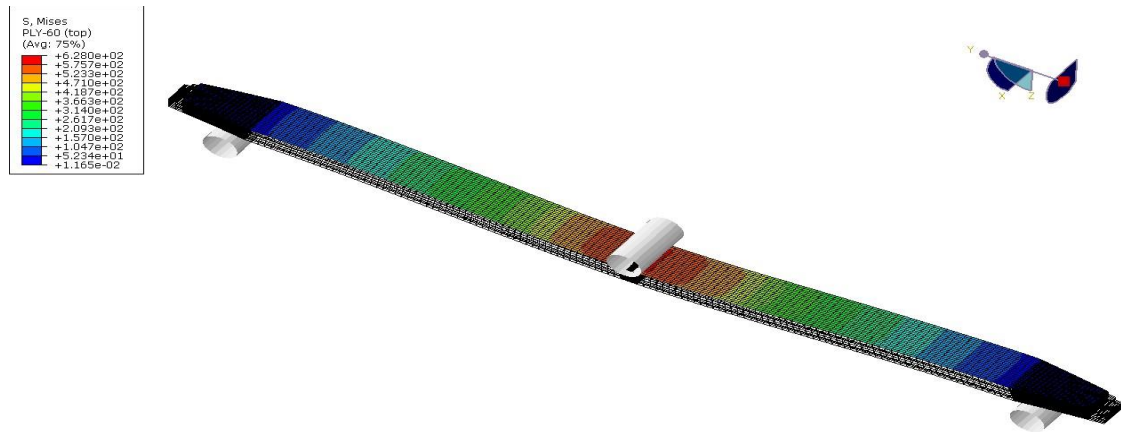


Fig. 40. Mises comparable stress contour on glass and carbon fiber/epoxy leaf spring upper surfaces

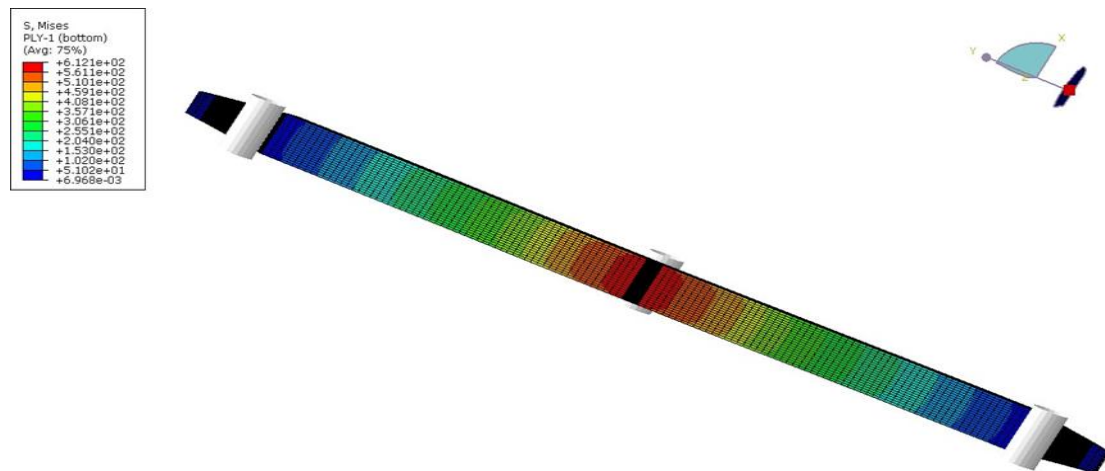


Fig. 41. Mises the corresponding stress contour on the glass and carbon fiber/epoxy leaf spring bottom surfaces.

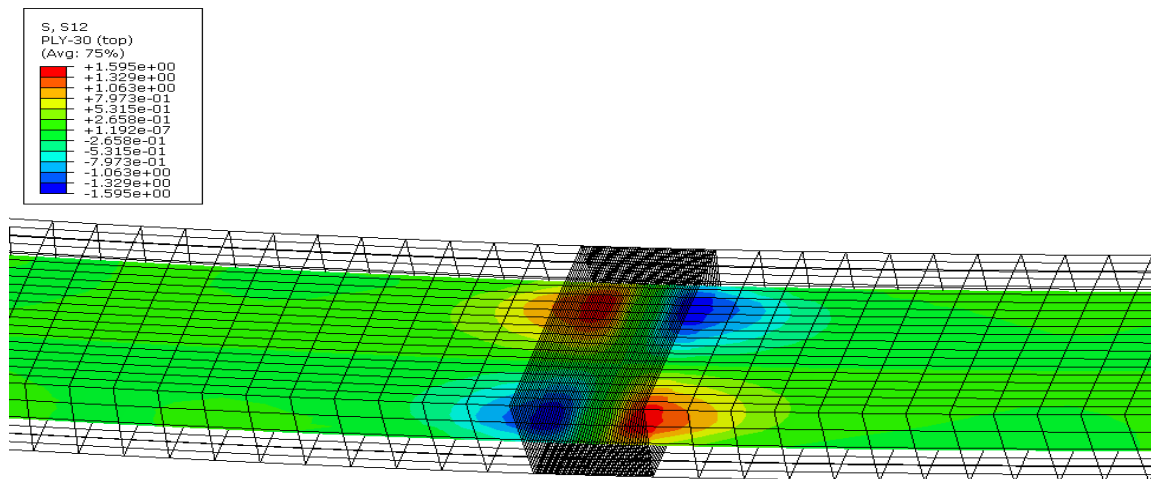


Fig. 42. S12 in the midsection's planar shear stress shape

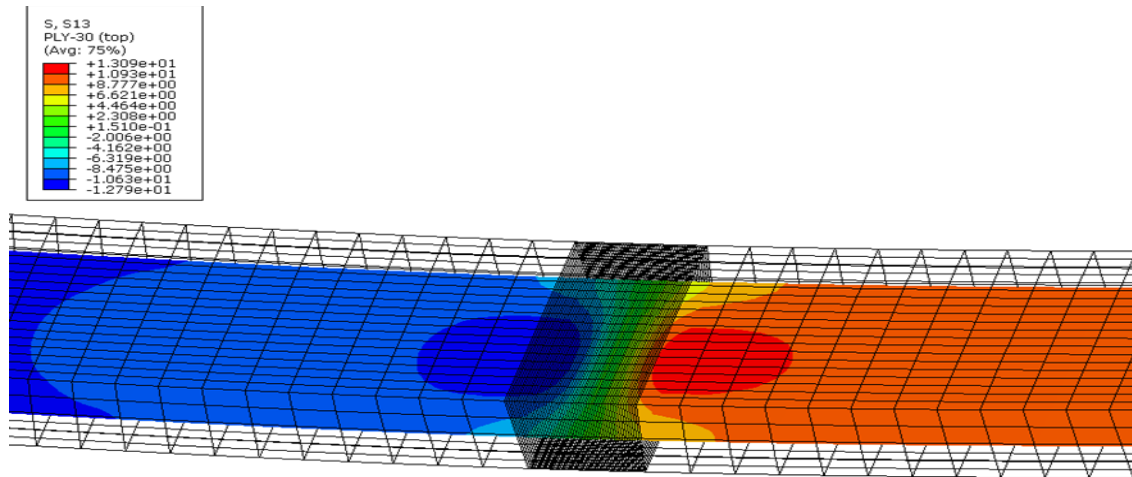


Fig. 43. S13 Through the midsection's thickness shear stress shape

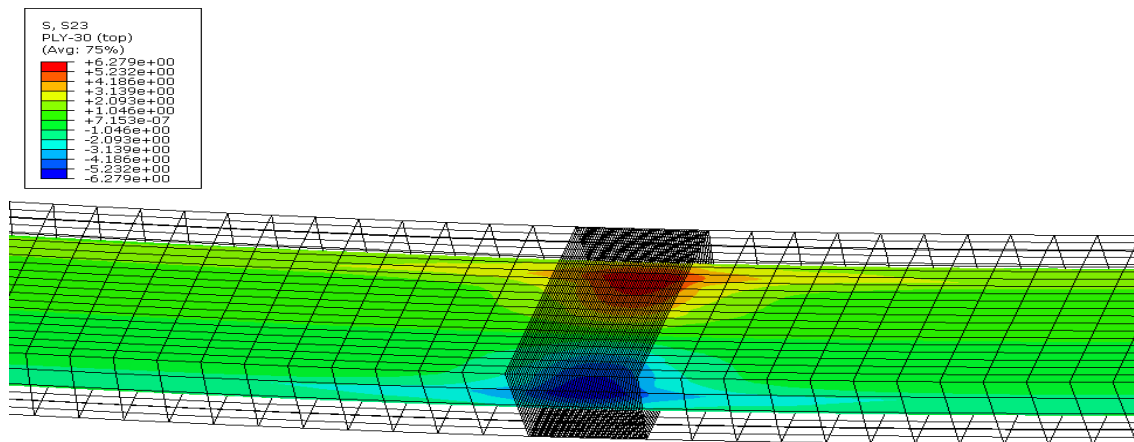


Fig. 44. S23 Through the midsection's thickness shear stress shape

IV. CONCLUSION

This paper built composite leaf springs systems with various material combinations and examined the composite mono leaf spring behaviour using a 3-D finite element model. Throughout the finite element modelling and analysis procedure, Abaqus/CAE 6.12-1 was utilised. In terms of strength and affordability, the E-glass / epoxy combination has been deemed the best material. Because of the loading type, the layup orientation was chosen to be 0° unidirectional. Vertical loading is determined to be the most powerful and critical mechanical force delivered to a leaf spring. The highest limit of the load and the boundary conditions were also calculated by

considering the vehicle weight, road conditions and vehicle dynamics. Boundary condition and Stress analysis control of composites leaf springs systems were performed in this manner. The built systems were modelled using three-dimensional brick pieces. Also, natural frequency evaluations of leaf spring systems were done. The findings have been shown to be more than the maximum frequencies of road imperfections.

To reach a more accurate result, the grid independence of the study was further studied. According to the verification results, C3D8R and the C3D20R element can be used to analyze composites mono leaf springs model. However, researchers' top priority is time, and linear components are less

expensive than second order parts. Therefore, for the investigation of thick composite-based leaf spring systems, C3D8R components were selected. Since all designs have the same boundary and loading conditions, they are all acceptable in terms of normal and shear stress, and the findings show that each design follows a similar trend. However, Design-2 is relatively stiff when compared to the required spring rate. Furthermore, the cost of the carbon/epoxy composite systems is unaffordable. As a result, the other two designs have been considered in terms of manufacture.

We calculated the eigenmodes and eigenfrequencies for undamped systems. Leaf spring structures, on the other hand, involve some form of energy dissipation. Because the damping ratio of the structures may impact the accuracy of the undamped result, the eigenfrequencies and eigenmodes of the damped structure should also be studied. Finally, in this work, the best configuration of the composite mono leaf springs model was manually explored. Employing a computer programme with an optimization strategy may produce a better answer while also saving time.

V. REFERENCES

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