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Design and Analysis of Composite Leaf Spring with Different Arrangements

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Abstract
The main aim of this paper is to obtain the optimum design model of composite leaf spring with different arrangements to improve the weight to strength ratio and to reduce cost. The multi-leaf spring contains seven leaves considered for design and analysis purposes. Five sets of design models with different materials for the leaves are designed and modeled using CREO software. The basalt fiber material is selected as an alternate material for conventional steel plates. All design models are designed for a factor of safety 4 and analysis is carried out by using ANSYS software. Stress and deformation results obtained using software compared with analytical results. Results that composite leaf spring has maximum deformation and strain energy compared to conventional steel leaf spring. Fully basalt fiber leaf spring has minimum stress which is closer to steel leaf spring compared to other models.

Keywords:*Leaf spring, Composite leaf spring, Composite material, Finite element analysis, Ansys,*

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I. INTRODUCTION

The automobile industries are showing an increased interest in the use of composite leaf springs in the place of conventional steel leaf springs due to their high strength-to-weight ratio. The introduction of composite materials has made it possible to reduce the weight of the leaf spring without any reduction in load carrying capacity and stiffness. Strength and toughness rise due to the fibers of micro-particles. Despite composites materials having many advantages over conventional steel, it cannot eliminate as it gives strong and rigid support [1].

In a vehicle, the leaf spring is located between the axle housing and the vehicle chassis. When the vehicle comes across a projection on the road surface, the wheel moves up, this leads to deflecting the spring. This changes the length between the spring eyes. The leaf spring should absorb the vertical vibrations and impacts due to road irregularities through vibrations in the spring deflection so that the potential energy is stored in springs as strain energy and then released slowly [2].

The finite element method is a numerical technique which is commercially used for the finding of an approximate solution of partial differential equation as well as an integral equation. In some solving partial differential equations, the first problem is to create an equation that approximates the equation which is to be studied. It means that during calculations the error should not accumulate, thereby causing the output to be meaningless.

ANSYS is a finite element analysis (FEA) software package. It uses a pre-processor software engine to create geometry. Then it uses a solution routinely to apply loads to the meshed geometry. Finally, it outputs desired results in post-processing. FEA is used throughout almost all engineering designs including mechanical systems and civil engineering structures.

II. ANALYTICAL DESIGN OF LEAF SPRING

The leaf spring parameters like span, thickness, maximum bending stress, the factor of safety, and equivalent young's modulus for different models of composite material with different arrangements are calculated by analytical method

Table 1 provides materials properties of steel and composite material which is used for this analysis process with different arrangements

Table 1: MATERIAL PROPERTIES

S.No	Property	Steel	Basalt fiber
1	Density (kg/m^3)	7850	2750
2	Young's Modulus (MPa)	200000	89000
3	Poisson Ratio	0.3	0.26
4	Ultimate strength (MPa)	400	1000

2.1 Analytical design

Number of leaf springs in vehicle = 4
Number of leaves in leaf spring, N = 7
Number of full-length leaves,N_f= 2
Number of graduated leaves, N_g = 5
Overall span of the spring, 2L = 1270mm
Width of leaves, b = 120mm
Thickness of the leaves, t = 12mm
Center load = 2P = 10 tones = 10000kg = 98000N

$2P = \frac{\text{Total load}}{\text{No.of springs}}$ = 98000/4 = 24500N

P = 12250N
Maximum bending stress = $\frac{3*P*L}{2*N*b*t^2}$ = 96.46 MPa
Maximum ultimate strength = 400 MPa
Factor of Safety = 400/96.46 = 4.15

Table 2 represents the lengths of leaves and different arrangements of material

Table 2: Different arrangement of leaves

<table>
<tr><th rowspan="2">Leaf</th><th rowspan="2">Length (mm)</th><th colspan="5">Material</th></tr>
<tr><th>Model 1</th><th>Model 2</th><th>Model 3</th><th>Model 4</th><th>Model 5</th></tr>
<tr><td>Master leaf</td><td>1320</td><td rowspan="7">Steel</td><td>Steel</td><td>Steel</td><td>Steel</td><td rowspan="7">Basalt fiber</td></tr>
<tr><td>Full length leaf</td><td>1270</td><td>Basalt fiber</td><td>Steel</td><td>Steel</td></tr>
<tr><td>Graduated leaf 1</td><td>1060</td><td>Steel</td><td>Basalt fiber</td><td>Basalt fiber</td></tr>
<tr><td>Graduated leaf 2</td><td>850</td><td>Basalt fiber</td><td>Basalt fiber</td><td>Basalt fiber</td></tr>
<tr><td>Graduated leaf 3</td><td>635</td><td>Steel</td><td>Basalt fiber</td><td>Basalt fiber</td></tr>
<tr><td>Graduated leaf 4</td><td>430</td><td>Basalt fiber</td><td>Basalt fiber</td><td>Steel</td></tr>
<tr><td>Graduated leaf 5</td><td>220</td><td>Steel</td><td>Basalt fiber</td><td>Steel</td></tr>
</table>

2.2 Young's Modulus for different models

In a finite element analysis, combining different materials becomes transparent within the stiffness matrix of the solution. Typically, the elastic modulus of a leaf spring system will be constant. To understand material combinations, the following discussion looks at general cases: equivalent Modulus However, for designs with dissimilar elastic properties, an equivalent elastic modulus can be derived. This equivalent modulus can be used to approximate the displacement and load of a design. Therefore, when the width remains constant then the equivalent modulus becomes,

$$E_{eq} = \frac{\sum E_n}{\sum n}$$

For model 1:

$E_{eq} = 7E_S/7$ = 200Gpa

For model 2:

$E_{eq} = (4E_S+3E_B)/7$ = 152.43Gpa

For model 3:

$E_{eq} = (2E_S+5E_B)/7$ = 120.71Gpa

Formodel 4:

$E_{eq} = (4E_S+3E_B)/7$ = 152.43Gpa

For model 5:

$E_{eq} = 7E_B/7$ = 89GPa

III. DESIGN AND FEA ANALYSIS

The leaf spring design model is created and modeled by using modeling software CREO and imported into analysis software ANSYS. All models are designed with the factor of safety 4. Finite Element Analysis (FEA) is a computer-based mathematical tool that converts geometry into several elements with series of equations to solve simultaneously and predict the behaviors of the system. FEA tool is useful to solve a complicated problem with complicated material properties, geometry, and loading conditions where an accurate and exact analytical solution is difficult to find.

3.1 Meshing

Discretizing geometry into small elements calledmeshing. Tetrahedron mesh element is used for this analysis

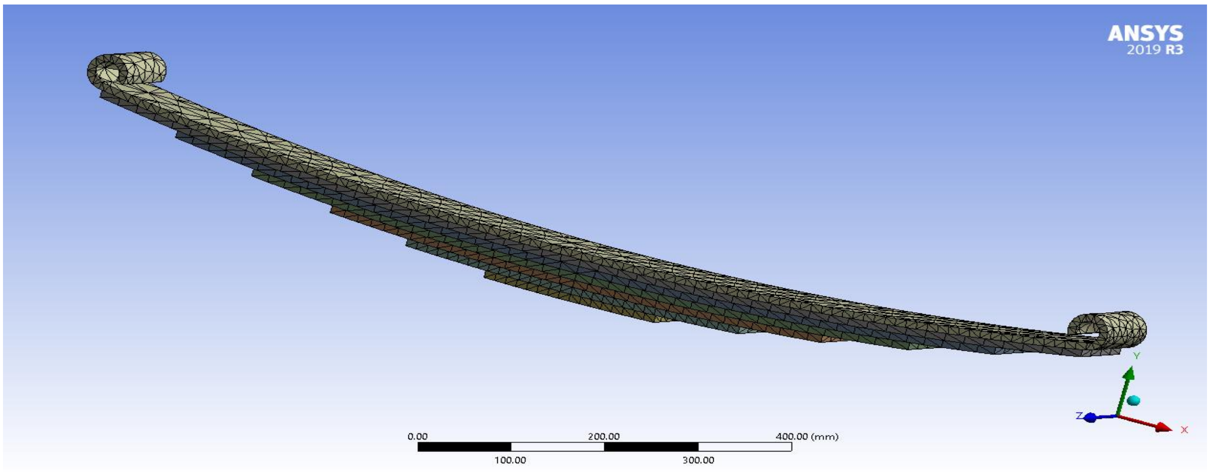

Figure 1: Meshed model of leaf spring

Figure 1 shows that meshed model of leaf spring with 5mm of element size which has been considered for the concept of grid-independent to select best mesh quality

3.2 Boundary conditions and Loading

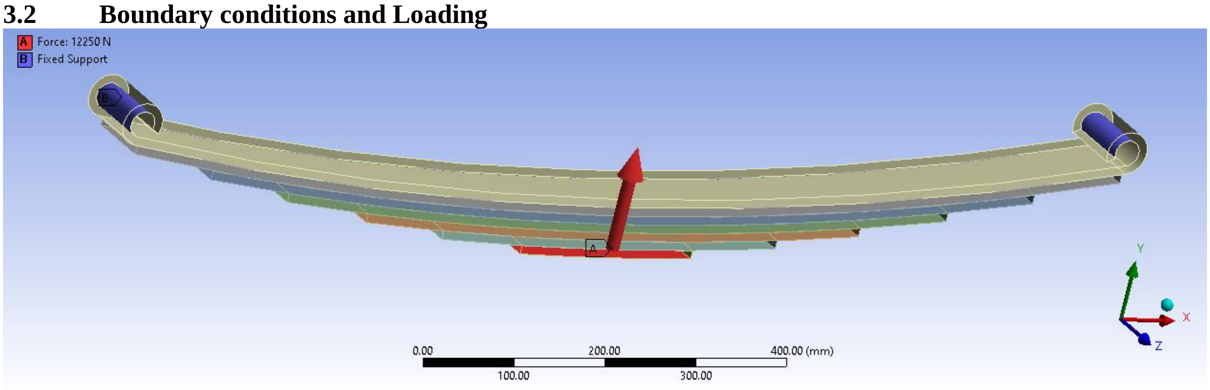

Figure 2: Boundary conditions of leaf spring

In the leaf spring analysis process, the system is considered as a simply supported beam where both eyes of the leaf spring are fixed. Fixed support restricts to move in the X and Y axis as well as rotation about the axes at a fixed point. Therefore, the degree of freedom at the fixed point is zero. A central load of 12250N is applied to the leaf spring model. Boundary conditions and load acts on leaf spring shown in figure 2.

IV. RESULT AND DISCUSSION

The results of the analysis process are obtained and discussed below

4.1 Total Deformation

4.1.1 Model 1

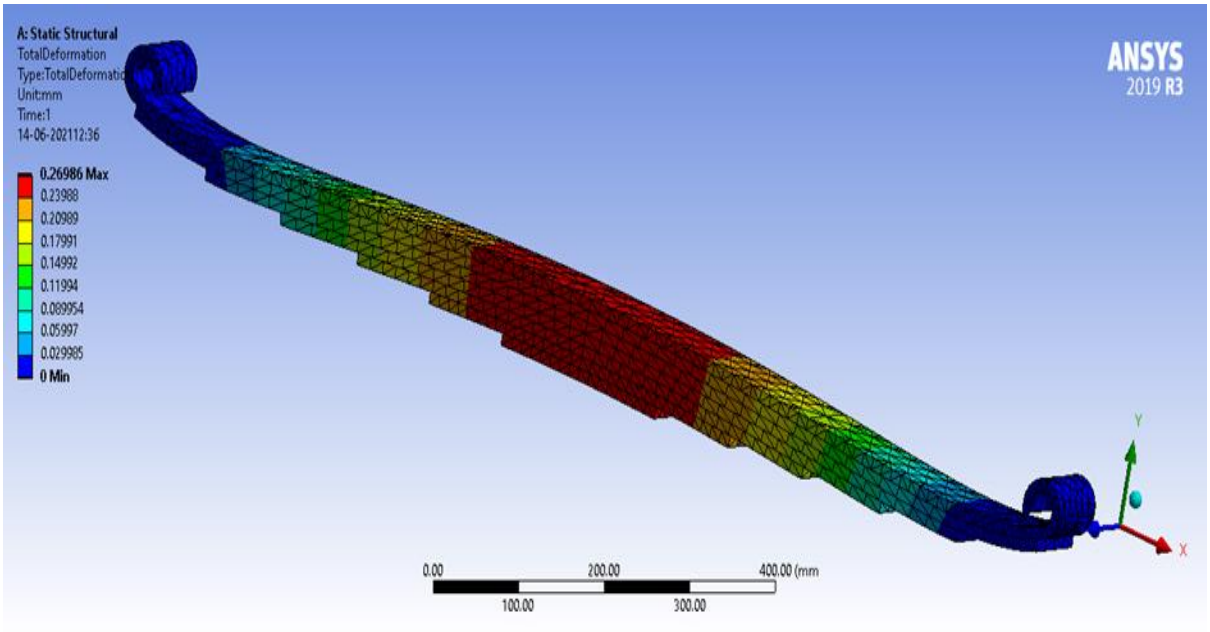

Figure 3: Total Deformation for model 1

Figure 3 shows the total deformation of model 1 where all leaves are conventional steel materials. Leaf spring is loaded under the center load of 12250N. The red zone at the center indicates maximum deformation of 0.27mm and the blue zone indicates minimum deformation.

4.1.2 Model 2

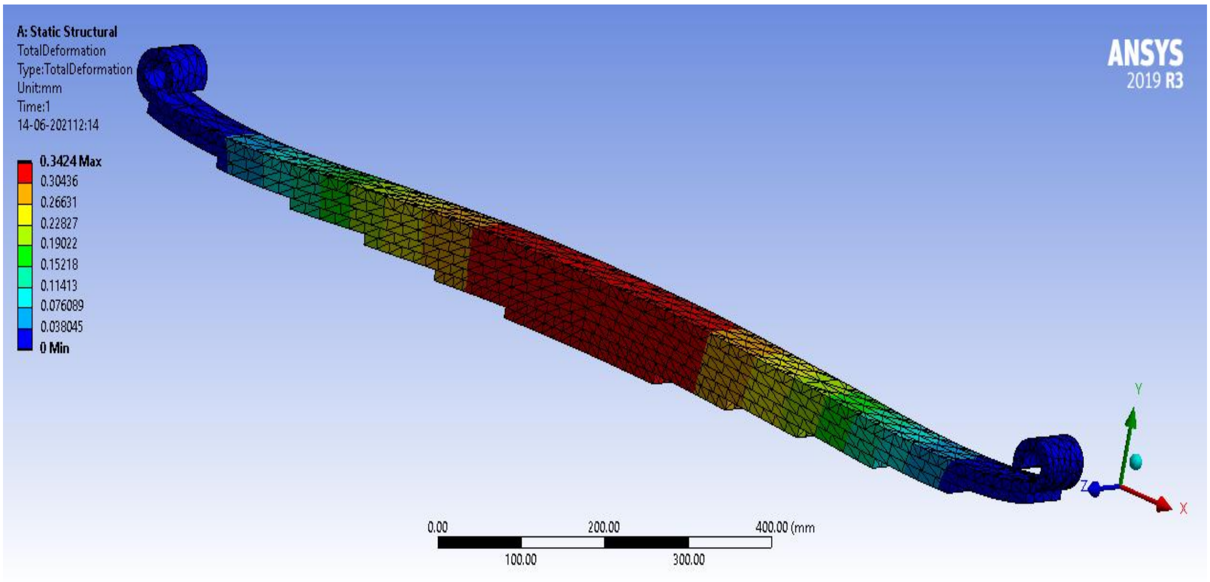

Figure 4: Total Deformation for model 2

Figure 4 shows that the maximum deformation is 0.34mm at the center of the leaf spring under the load of 12250N

4.1.3 Model 3

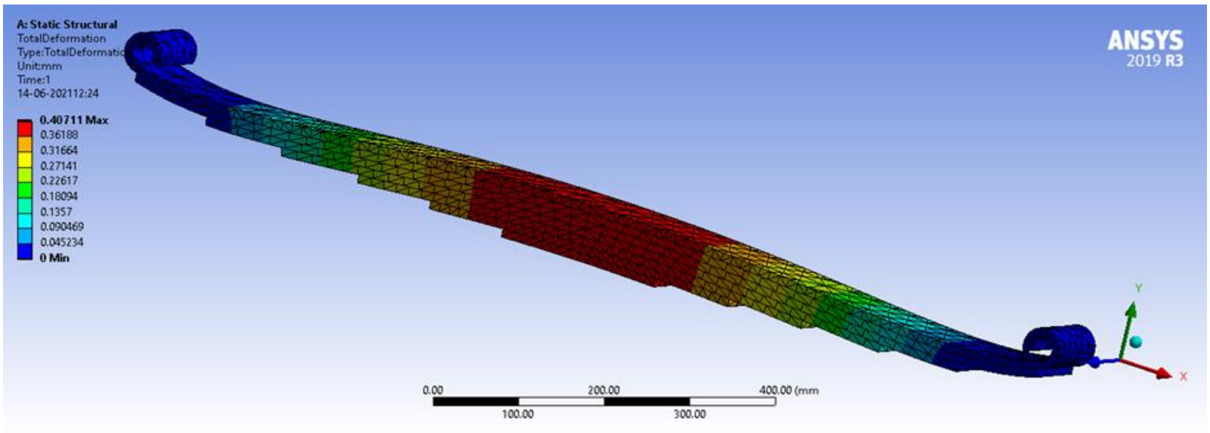

Figure 5: Total Deformation for model 3

Figure 5 shows that the maximum deformation is 0.41mm at the center of the leaf spring under the load of 12250N

4.1.4 Model 4

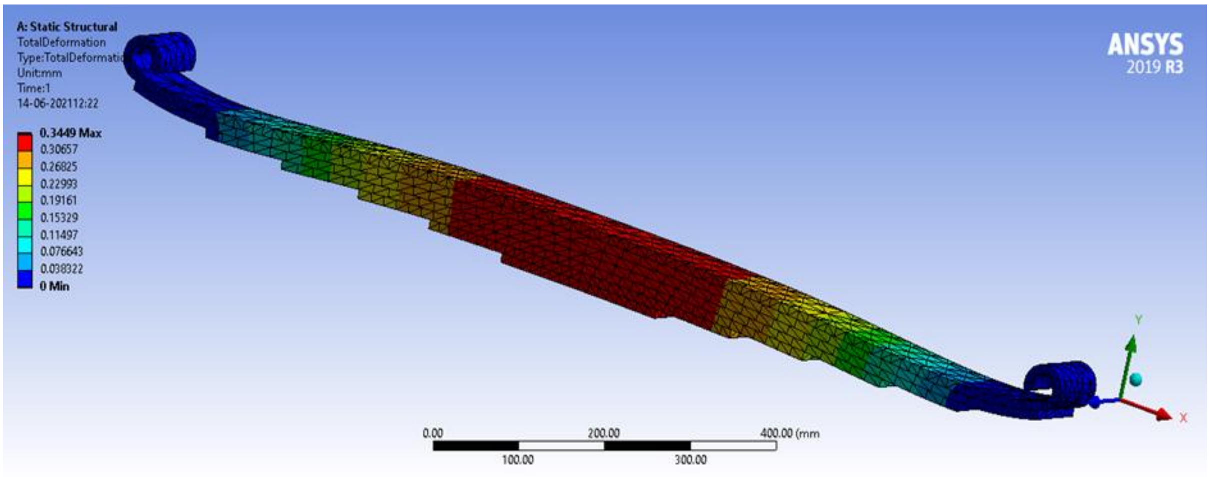

Figure 6: Total Deformation for model 4

Figure 6 shows that the maximum deformation is 0.35mm at the center of the leaf spring under the load of 12250N

4.1.5 Model 5

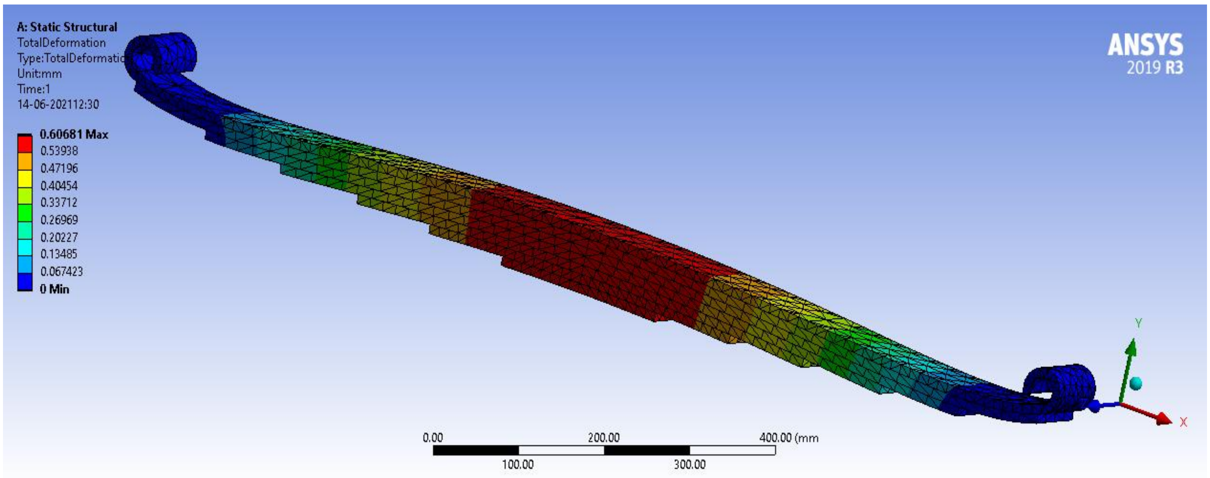

Figure 7: Total Deformation for model 5

Figure 7 shows that the maximum deformation is 0.61mm at the center of the leaf spring under the load of 12250N

4.2 Stress

4.2.1 Model 1

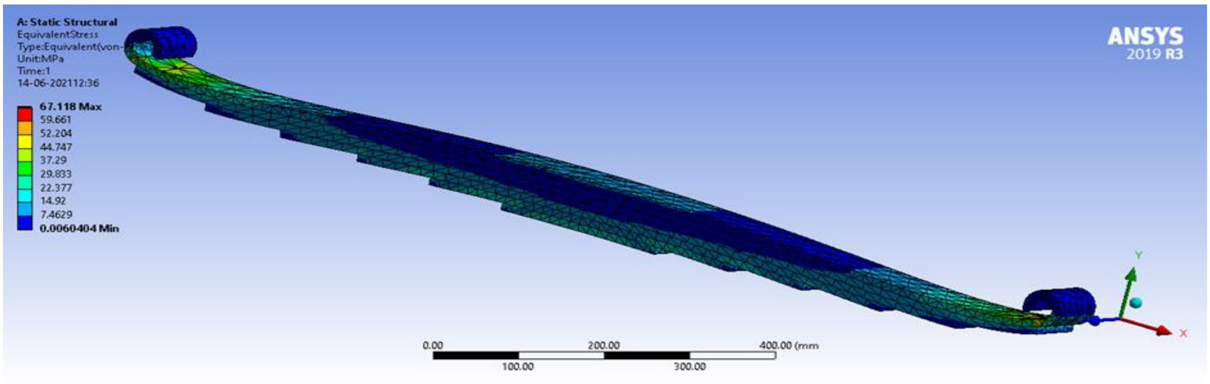

Figure 8: Von-mises stress for model 1

Figure 8 shows the equivalent von-mises stress induced in leaf spring under the load of 12250N. Maximum stress value of 67.12MPa induced near foxed ends of leaf spring. Whereas analytical stress for lead spring design is 96.46MPa. Maximum ultimate stress for steel is 400MPa. The factor of safety for this design is 5.96. The red zone indicates the maximum stress area and the blue zone indicates the minimum stress area

4.2.2 Model 2

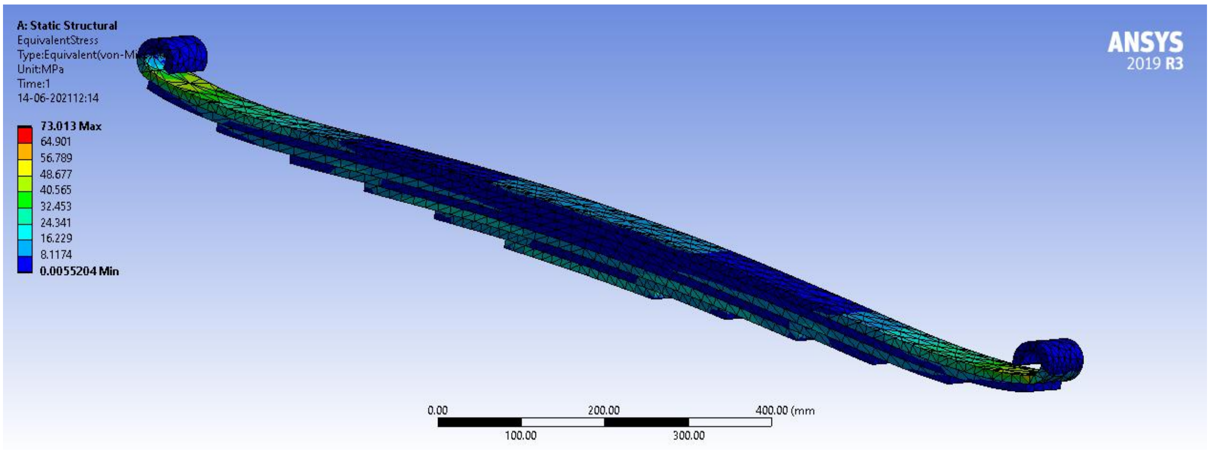

Figure 9: Von-mises stress for model 2

Figure 9 shows the equivalent von-mises stress induced in leaf spring under the load of 12250N. Maximum stress value of 73.01MPa induced near foxed ends of leaf spring. Whereas analytical stress for lead spring design is 96.46MPa. Maximum ultimate stress for steel is 400MPa. The factor of safety for this design is 5.48

4.2.3 Model 3

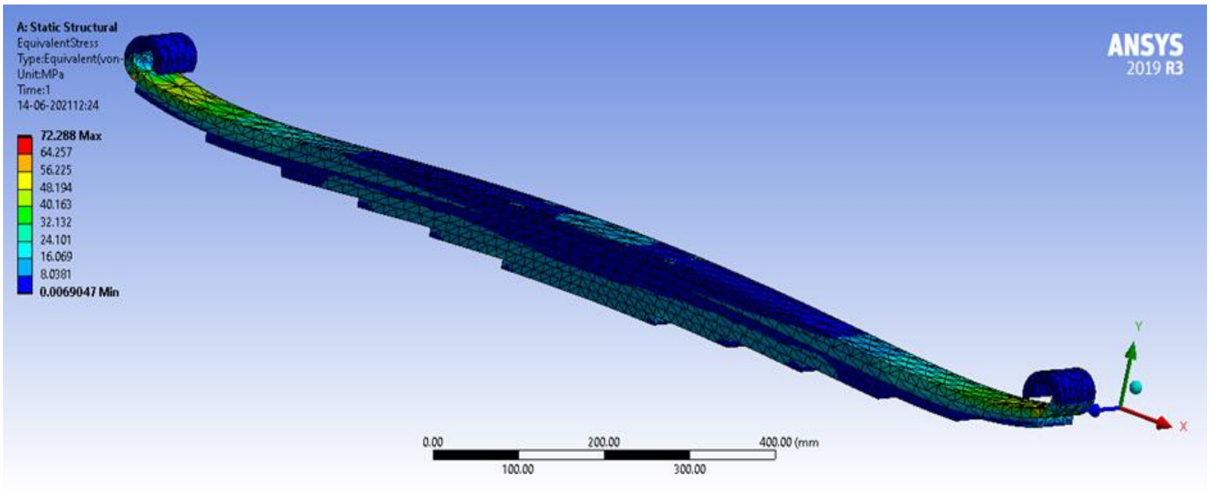

Figure 10: Von-mises stress for model 3

Figure 10 shows the equivalent von-mises stress induced in leaf spring under the load of 12250N. Maximum stress value of 72.29MPa induced near foxed ends of leaf spring. Whereas analytical stress for lead spring design is 96.46MPa. Maximum ultimate stress for steel is 400MPa. The factor of safety for this design is 5.53

4.2.4 Model 4

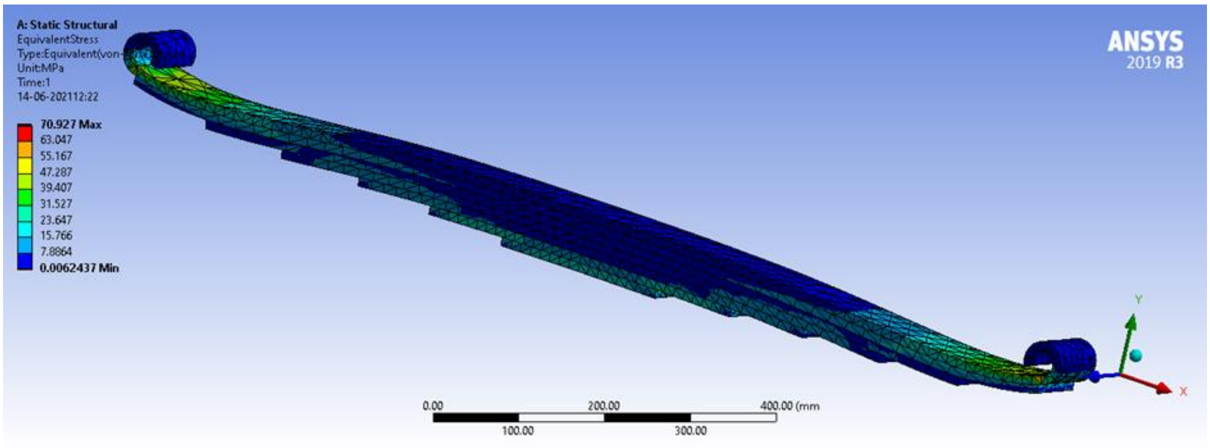

Figure 11: Von-mises stress for model 4

Figure 11 shows the equivalent von-mises stress induced in leaf spring under the load of 12250N. Maximum stress value of 70.93MPa induced near foxed ends of leaf spring. Whereas analytical stress for lead spring design is 96.46MPa. Maximum ultimate stress for steel is 400MPa. The factor of safety for this design is 5.64

4.2.5 Model 5

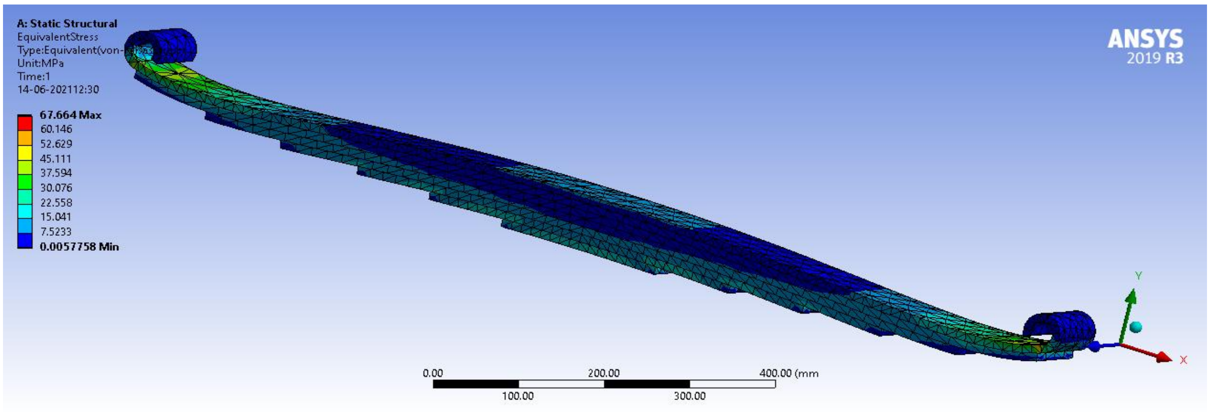

Figure 12: Von-mises stress for model 5

Figure 12 shows the equivalent von-mises stress induced in leaf spring under the load of 12250N. Maximum stress value of 67.66MPa induced near foxed ends of leaf spring. Whereas analytical stress for lead spring design is 96.46MPa. Maximum ultimate stress for steel is 400MPa. The factor of safety for this design is 5.91

Table 3 represents the comparison of results obtained by finite element analysis

Table 3: Comparison of results

Results	Model 1	Model 2	Model 3	Model 4	Model 5
Equivalent stress (MPa)	67.12	73.01	72.29	70.93	67.66
Maximum Deformation (mm)	0.27	0.34	0.41	0.35	0.61
Strain Energy (mJ)	7.13	9.37	8.86	8.55	16.1
Factor of safety	5.96	5.48	5.53	5.64	5.91

V. CONCLUSION

The design model of leaf spring is created and analyzed for different arrangements of basalt fiber leaves with steel leaves. Comparison has been done for five models for deformation, stress, strain energy, and factor of safety. All models are created for factor of safety 4 and calculated that the analytical factor of safety is 4.15. From the analysis process, model 5 showing that the factor of safety 5.91 which is close to the factor of safety of steel (model 1) i.e., FOS 5.96.Model 5 provides strain energy of 16.1mJ whereas the steel model (model 1) provides minimum strain energy compared to other models. Basalt fiber model (model 5) provides maximum deformation of 0.61mm whereas the steel model (model 1) provides minimum deformation compared to other models. Equivalent von-mises stress of basalt fiber leaf spring is 67.66MPa which is close to steel model i.e., 67.12MPa

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