PALM OIL FIBER COMPOSITE LEAF SPRING FOR HEAVY VEHICLE

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

This research work investigates the current design of leaf spring suspension for heavy vehicles and the substitute material that can be used. The study involves investigating a suitable substitute material made of oil palm fiber and designing the suitable leaf spring. The static behavior of the spring is also investigated. The model is made according to the simplified current design of leaf spring used for heavy vehicle. The problem identified in this research is that the material used for current design is too expensive to produce and rusts easily. Also, the weight reduction from using composite material can reduce overall fuel consumption of the vehicle. The purpose of this study is to determine the suitable oil palm fiber composite material that can be used and to determine the static behavior of the material. The model is made using ANSYS Static Structural Analysis solver. The data obtained is the stress and strain inside the spring and also the total deformation of the spring. The simulation result will be validated by comparing the obtained result with past research on fiber composite leaf spring. Also, the result is validated by calculating the theoretical stress and deformation of the spring. In a nutshell, the spring can withstand forces up to 70kN; however the deformation is too big for practical use. At 42kN the deformation is small and is suitable to be used. As a conclusion, oil palm fiber composite material can be used as a substitute material in construction of leaf spring for heavy vehicles.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Leaf-spring suspension is a type of suspension system used for heavy vehicles that dated back to the medieval times. It is also known as laminated spring or carriage spring. The leaf-spring suspension is actually a series of metal beams with a little curvature bonded together making an elliptic shape. It has the advantage of the end points of the spring can be guide along a path.

There are two types of leaf-spring suspension system, one is known as monoleaf springs which consist of a single plate that is thick in the middle and become thinner at it ends. These types of springs are usually lighter but don't have high strength. The other type is multileaf spring that is made of many layers of beams. Multileaf springs has a higher strength but a slightly heavier than monoleaf.

There is also an array of shapes for a leaf-spring suspension depending on the configuration of installment used for different purposes. Some of the shapes are full elliptic which is two arched leaf-spring joined at its tips, semi elliptic which is the bottom leaf-spring is joined to a body, and three-quarter elliptic the top leaf-spring is cut in the middle and joined to the body and its end is joined to the bottom leaf-spring.

1.2 Problem Statement

Current design of the leaf-spring suspension utilizes steel as the base material. This material will cause degradation of the suspension which will lead to the disposal of the suspension. Using a composite material as a substitute material for leaf-spring suspension has been studied. Palm oil is available in abundance in Malaysia which makes it the more logical substitute material.

1.3 Objective and Scope of Study

The objective this research is as follows:

1) Study the current design of the leaf-spring suspension system
2) Study how the palm oil fiber can be used to substitute for the suspension
3) Design and model the system in ANSYS.
4) Analyze the model under different load conditions

CHAPTER 2

LITERATURE REVIEW

2.1 Theory

Leaf-spring suspension is usually used for trains and heavy vehicles suspension system. The basic principle of a leaf-spring is similar to a cantilever beam used for diving boards in swimming pools. In practice, a laminated leaf-spring is often used. Imagine two beams with a thickness h, beam 1 have a uniform width while beam 2 has a decreasing width from the base to the tip. Both of these beams are supported at one end. If a mass is placed at the end of each beam, the deflection and bending stress can be calculated as show:

Case 1 (uniform width)

$$\sigma = \frac{6FL}{bh^2} \qquad \text{Eqn 2.1}$$

$$\delta = \frac{4FL^3}{Ebh^3} \qquad \text{Eqn 2.2}$$

Where, F = force at the end of the beam

L = length of beam

E = modulus of elasticity of the material

σ = maximum bending stress of the beam

δ = maximum deflection of beam

Case 2 (non uniform width)

$$\sigma = \frac{6FL}{bh^2} \quad \text{Eqn 2.3}$$

$$\delta = \frac{6FL^3}{Ebh^3} \quad \text{Eqn 2.4}$$

From the equations, the maximum bending of the two beams are equal. However, for the non uniform beam, the maximum deflection is more than the uniform beam. This means that a beam with non uniform width will have a greater resilience. Resilience by definition is the ability to absorb more potential energy during deformation. Case 2 have a larger deflection making it able to store more potential energy than case 1.

For the purpose of conventional leaf-spring suspension, the support condition would be different. The beam is supported at both ends with 1 end is able to move in a selected 1 direction. However, the equations used for cantilever beam is also applicable to calculate the maximum stress and deflection but with a slight modification. The equations are as follows.

Calculations for non uniform beam (lozenge shaped)

$$\sigma = \frac{3FL}{bh^2} \quad \text{Eqn 2.5}$$

$$\delta = \frac{3FL^3}{Ebh^3} \quad \text{Eqn 2.6}$$

As shown in the equations above, the deflections and stress is reduced by half. This is because the support reaction from both ends provides more resistance to bending. In normal application, the centre of the beam is attached to the wheel axle.

Therefore, the force acting on the beam would be upwards while the reaction forces will be pointing downwards.

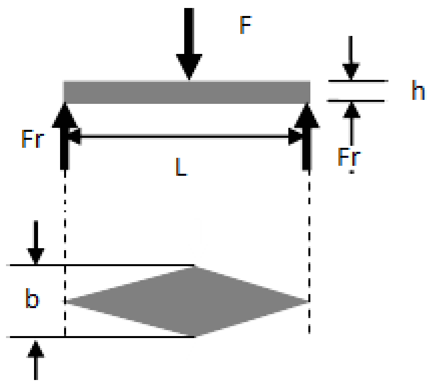


Figure 2.1: Support condition of the beam

Now that understanding of the basic principle of a leaf-spring suspension is achieved, to design a leaf-spring, the thickness, h, plays an important role. The thickness can be calculated as follows:

$$h = \frac{\sigma L^2}{E\delta} \quad \text{.........Eqn 2.7}$$

The maximum stress and deflection can be substituted with design stress and design deflection. These values should be according to the application of the leaf-spring suspension. Therefore, the beam thickness is dependent on the design parameters and also the material properties, which is also a design parameter. The value L is the characteristic length of the beam.

Once the value of h is determined, it can be substituted in to the above equation to evaluate the required thickness b. using the same principle, the value of h and b of any support condition for leaf-spring suspension can be calculated. The downside of using a single beam is that the width of the beam will be too wide for higher design stress. Sometimes it cannot fit into the machinery that it is designed to use.

To circumvent this problem, laminated beams are introduced. The aforementioned lozenge shaped beam is cut in to several segments and aligned as figure bellow.

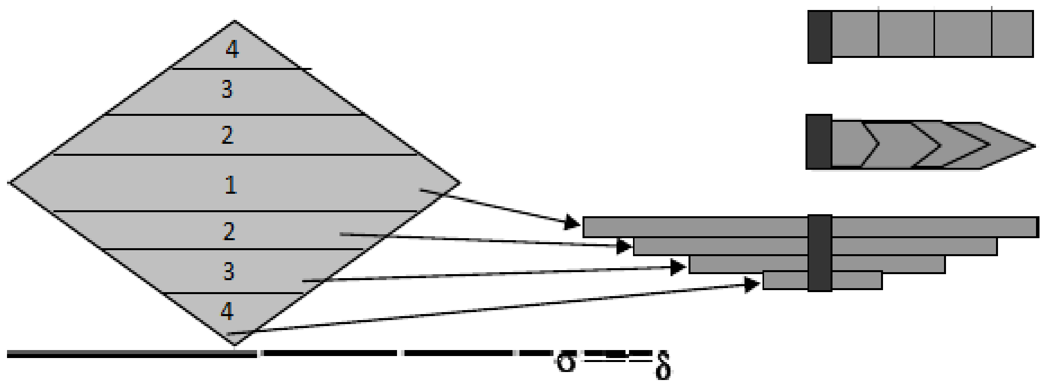


Figure 2.2: Lozenge shaped beam is cut into laminated beam.

The most upper part of the beam is called master leaf. Strip number 2 are put together side by side and is placed under the master leaf and followed by strips number 3 and 4 in the same manner. the width of each strip is given by this equation:

$b_N = \frac{b}{N}$ ……………………………………………………………………………Eqn 2.8

Where;

b_N = width of each strip

b = width of lozenge shaped beam

N = number of strips

In the figure shows that the end of each strip is pointed, in practice this is not done. In fact the ends of the strips are blunt so as to increase the bearing load capacity. This design of leaf-spring also has a weakness. In practice, a slight curve is introduced to the strips so that they are semi-elliptical in shape.

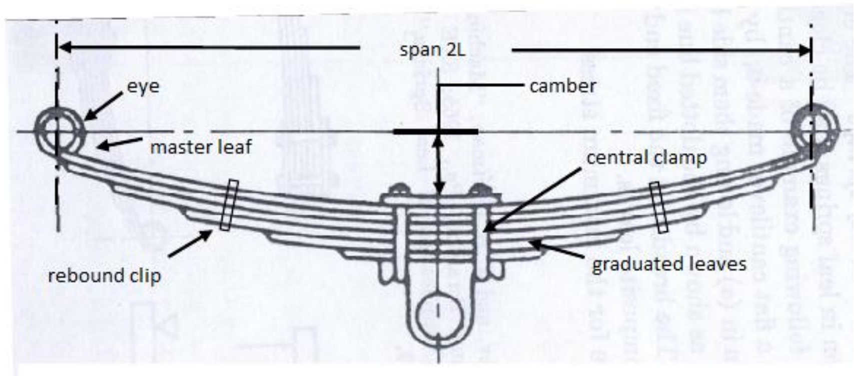


Figure 2.3: Semi-elliptic leaf spring.

From the figure above, the eye on the master leaf is used to attach the leaf-spring to the machine member. The slight bend from the central line to the spring is the camber. The function is to avoid the spring from touching the machine member when operating at full load. All of the strips are held together by the central clamp. However, the bolt used to hold the leaves weaken the spring. The usage of rebound clip is to share a bit of stress from the master leaf to other leaves.

In order to carry more load, a few extra full length strip is placed beneath the master leaf. This modification will not affect the maximum bending stress. However it will affect the deflection of the leaf-spring. Therefore, the deflection correction is given by:

$\delta = \frac{\delta_c q F L^3}{E N b_N h^3}$……………………………………………………………………Eqn 2.9

Where;

q = constant given by support condition

$\delta_c = \frac{1.0-4m+2m(1.5-\ln(m))}{(1.0-m)^3}$…………………………………………………..Eqn 2.10

$m = \frac{N_f}{N}$…………………………………………………………………………Eqn 2.11

N_f = number of full length leaves

N = total number of leaves

2.2 Past Research

A research about leaf spring suspension made out of composite material has already been done by several institutes around the world. One of these researches entitled Design and Analysis of Composite Leaf Spring in Light Vehicle by M. Venkatesan and D. Helmen Devaraj [2] has the objective of designing and analyzing glass fiber/epoxy composite leaf spring without end joints and bonded end joints using hand-layup technique. The composite material they are using is glass fiber/epoxy. The model of the leaf spring is made and analyzed using ANSYS. The leaf spring is modeled to have a constant cross-section with a little camber at the middle. The model is done for every leaf with eight-node 3D brick elements and five-node elements to represent the contact and sliding between adjacent leaves. The test is to measure the stress and shear along the adhesive layer. The result was the composite leaf spring has a lighter weight than conventional leaf spring. It is also feasible to be used in light vehicle and is more economical.

Another research with composite leaf spring entitled Automobile Leaf Spring from Composite Materials done by H. A. Al-Qureshi [3] uses glass fiber reinforce plastic (GFRP) to create a single leaf spring with variable thickness with similar mechanical and geometrical properties as the conventional leaf spring. The leaf spring is fabricated using hand lay-up vacuum bag process. This fabricated prototype leaf spring is tested in the lab and the result is compared with conventional leaf spring. The composite leaf spring was tested with static loading test to determine its load-deflection curve. As result, the composite leaf spring has a higher deflection than the conventional leaf spring. But the composite leaf spring has a substantial weight reduction. The conclusion of this study was a composite single leaf spring with a constant width will have a lower flexure stress but a higher shear stress. Therefore, it is suitable to be used in light vehicles. This spring also have a greater weight saving compared to the conventional leaf spring and also have a better fatigue behavior.

A study made by Mouleeswaran Senthil Kumar and Sabapathy Vijayragan [4] entitled Analytical and Experimental Studies on Fatigue Life Prediction of Steel and Composite Multi-Leaf Spring for Light Passenger Vehicles Using Life Data Analysis. The design of the composite leaf spring is based on existing steel seven-leaf spring. The material e-glass/epoxy is selected as it has the nearest mechanical properties as the steel. The model is designed with ANSYS 7.1. The spring has seven layers with each composite layer have 20 layers. The loading condition for this test is static. The fatigue testing is done by experimentation in the lab using life data analysis. The conclusion is the composite leaf spring has lesser stress values, higher stiffness and higher natural frequency compared to existing steel leaf spring. The composite leaf spring also has a lighter weight and a higher fatigue life.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

To ensure the completion of all of the objectives stated above, a step by step methodology is required.

3.1.1 Data gathering

Since there have been researches about composite leaf-spring suspension system, the data from their study could prove useful to validate the findings of this research. Data and information about leaf-spring suspension particularly about its construction, material production and geometry properties is also important to be used as reference.

3.1.2 Modeling and simulation

Restriction on time and equipment makes using a computerized model analysis a viable choice. The model of the leaf-spring suspension will be created using real values for its material properties and also the design parameters of the spring. The model will be design for a specific load and installment configuration.

3.1.3 Model testing and analysis

The model created will be tested using ANSYS for its dynamic properties. Its natural frequency and deflection will also be investigated. The simulation will also provide the stress concentrated region that will be used to determine the breaking point of the spring. The simulation will also be done in different loading to fully investigate the properties of the spring.

3.1.4 Result validation

The results obtain during model testing will then are compared to current existing leaf-spring suspension and studies about composite leaf-spring. If the data is within acceptable range then the model is complete, if not the model will be remade and retest.

3.2 Flow Chart

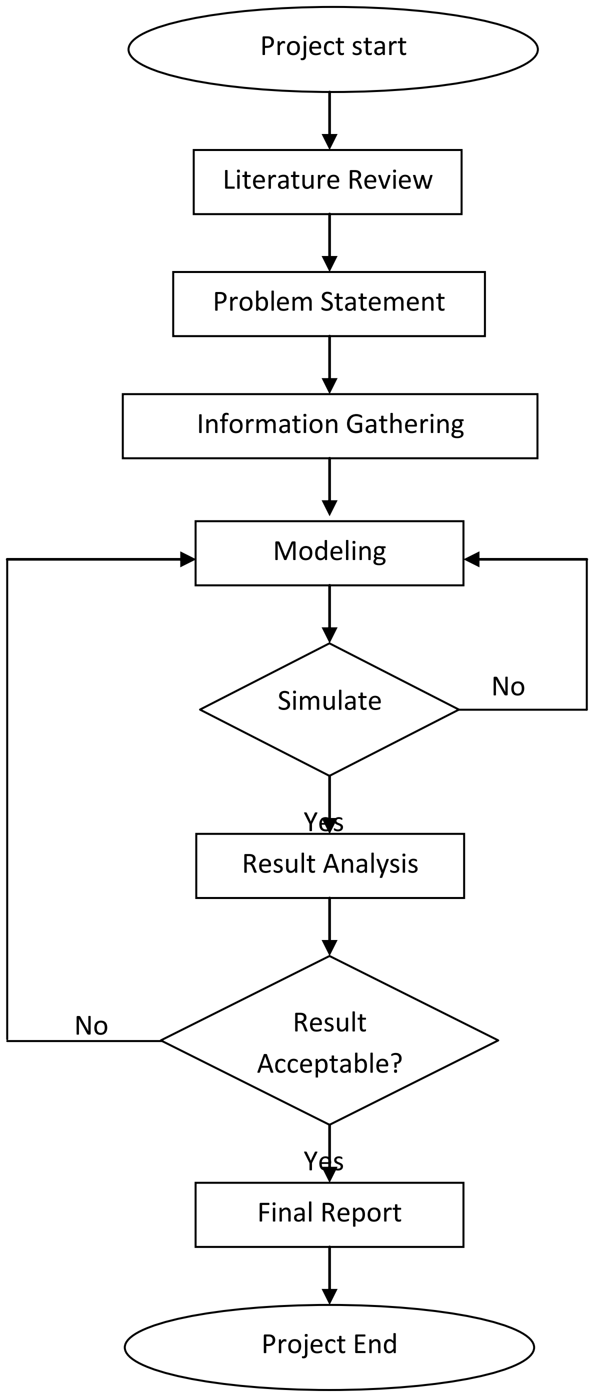
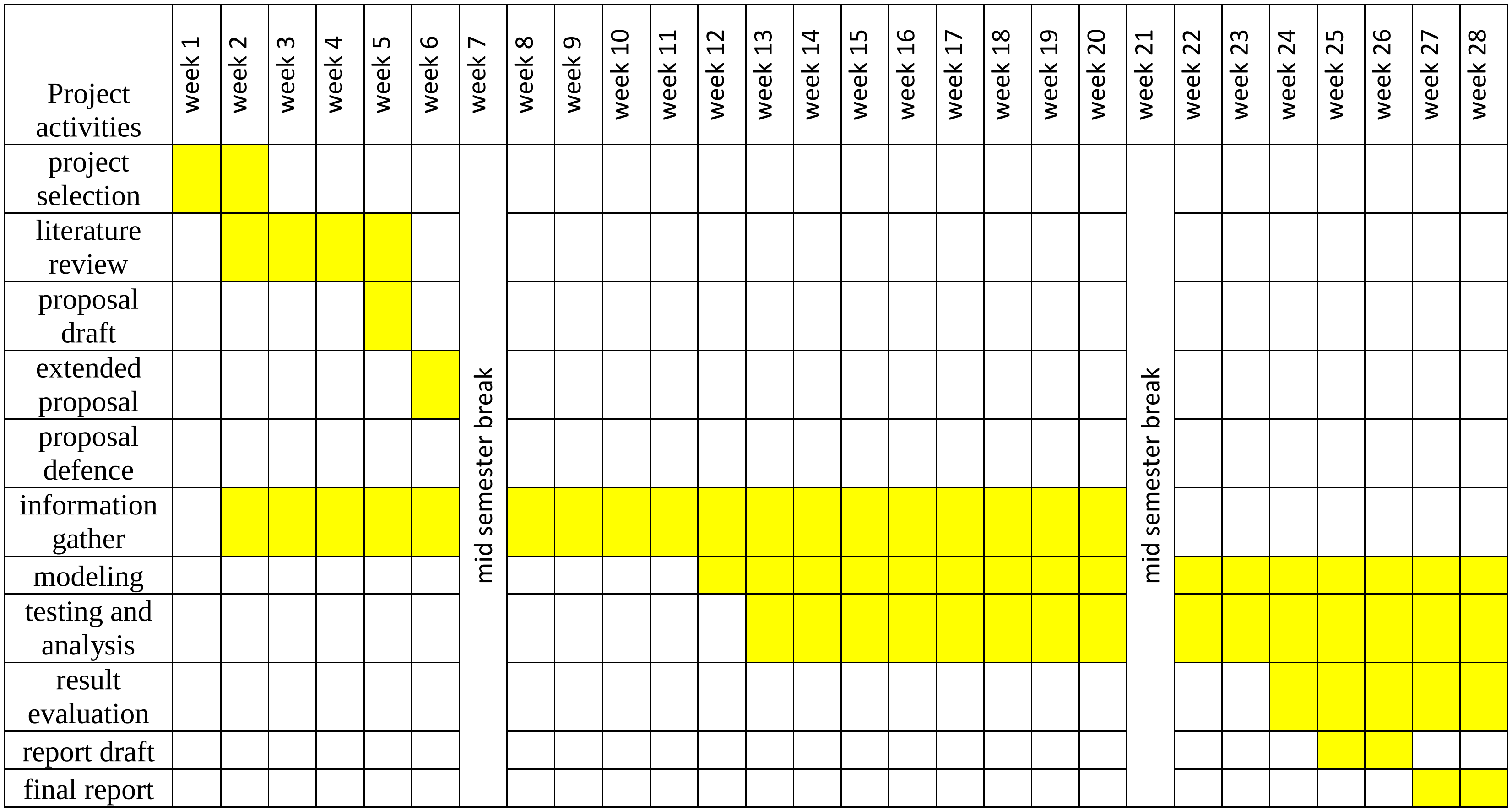


Figure 3.1: Flowchart of the research

3.3 Gantt Chart

Figure 3.2: Gantt Chart of the project



3.4 Modelling and simulation

The model was made with ANSYS Workbench with Static Structural as a solver. The dimension of the model is based on current design of leaf-spring. However, for simplicity the model is a straight beam without camber or eye-pins at the end. The model is a multi-leaf spring with 1 full length leaf and five short leaves. The leaves are modeled as a flexible rigid body so that it can perform as a spring. According to Malaysia's weight restriction order (amendment 2003) the maximum weight of a small lorry is 16 metric tons. Assuming equal weight distribution, the spring must withstand a maximum force of 40kN. For model validation, the stresses inside the spring shall not exceed the material yield point in order for the spring to perform in elastic region. The material used to make the model is a custom material with Young's Modulus 1150 Mpa taken from M.S Sreekala, M.G Kumaran, Seena Joseph and Maya Jacob's [7] research on material properties of oil palm fiber reinforced phenol-formaldehyde composite. It is made of short random fibers with curing temperature of 100^{o}C. The composite has 40%wt of fibers.

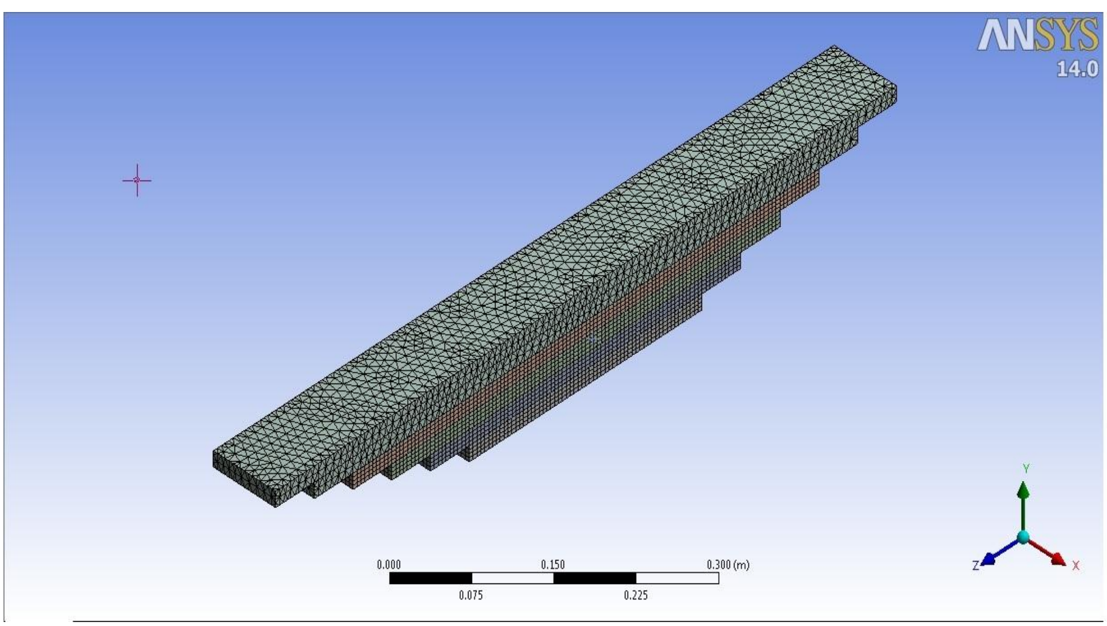


Figure 3.3: Meshing of the model

The mesh of the model is set to fine and the size of the elements is set to 5mm giving it 34802 elements with 137054 nodes. The shape control of the elements is program controlled. For finite element analysis, the more elements and nodes in a model, the better the data taken, therefore these values are considered enough for this model to give a reliable data.

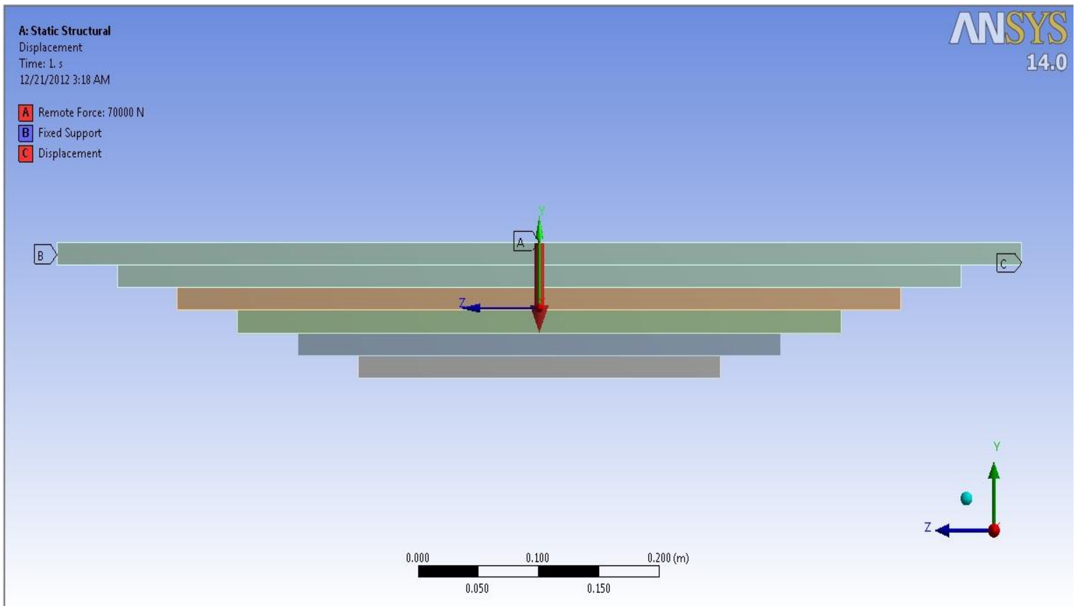


Figure 3.4: load conditions of the leaf spring

From figure 3.2, the model was tested using Static Structural as a solver. The boundary conditions of the model are based on previous research done on FEA for conventional leaf spring. All of the leaves in the model is attached to the adjacent leaves, thus the whole model can be considered as a rigid body. The beam configuration is cantilever beam with a fixed support at one end (point B) and slider support at the other end (point C). The slider support will allow the member to move along the X-direction but it is fixed along Z-direction and Y-direction. The force applied is at the middle of the beam where the wheel axle of the vehicle will be situated.

CHAPTER 4

RESULT AND DISCUSSION

During the simulation, the total deformation, maximum stress and maximum strain is measured. The simulation is also run several times with varying load on the beam with increments of 7000N. The aim of the simulation is to see the behavior of the beam under increased stress. Table 1 shows the increasing force and the deformation and stress.

Table 4.1: stress and deformation of beam

Load(N)	Stress(Mpa)	Deformation(mm)
7000	24.5	7.0
14000	49.0	13.7
21000	73.6	20.0
28000	98.1	27.0
35000	123.0	34.0
42000	**147.0**	**41.0**
49000	171.0	48.0
56000	196.0	55.0
63000	220.0	60.0
70000	245.0	68.0

From the table above, the spring can withstand force up to 70kN. At this point, the stresses inside the beam are really close to its yield point. However, since the spring is designed for small trucks, the maximum load for a small truck is 16tons; the maximum force for the spring to withstand is only 40kN.

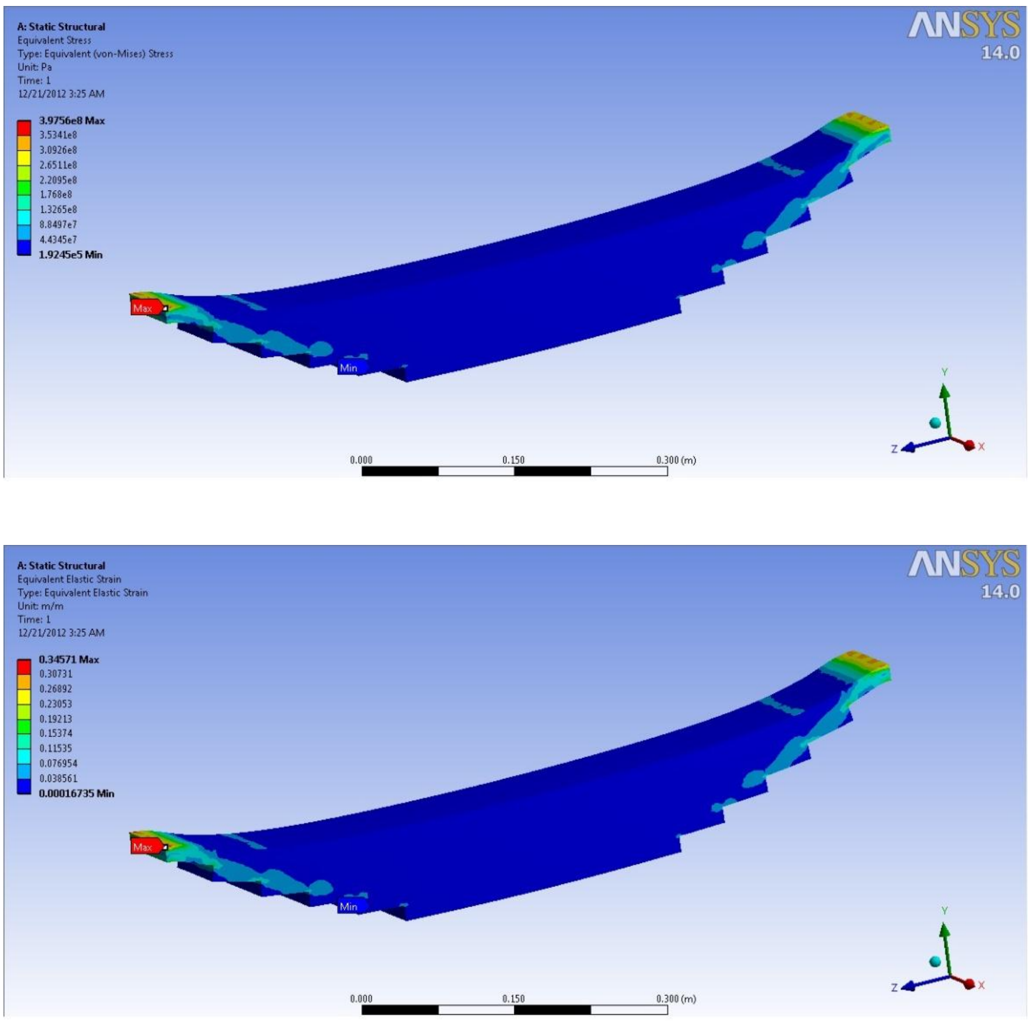


Figure 4.1: Von-Mises stress distribution and strain distribution

In figure 4.1 it shows the stress distribution on the leaf spring at 70kN load. From the figure, the stress is more concentrated at the fixed end of the beam with high stresses at the opposite end and low stress values at the corner of each leaves. When the beam is under load, it will bend. Since the end of the beam is fixed, it will elongate creating a high stress region in that area. Also, since the ends of each leaves are sharp edges, they are stress concentrators. That is the reason why the stress is more on that area. This effect can be reduced by introducing chamfer at every edge. The strain distribution of the beam is equal to the stress distribution. Normally, the region with the highest stress concentration must have the longest elongation.

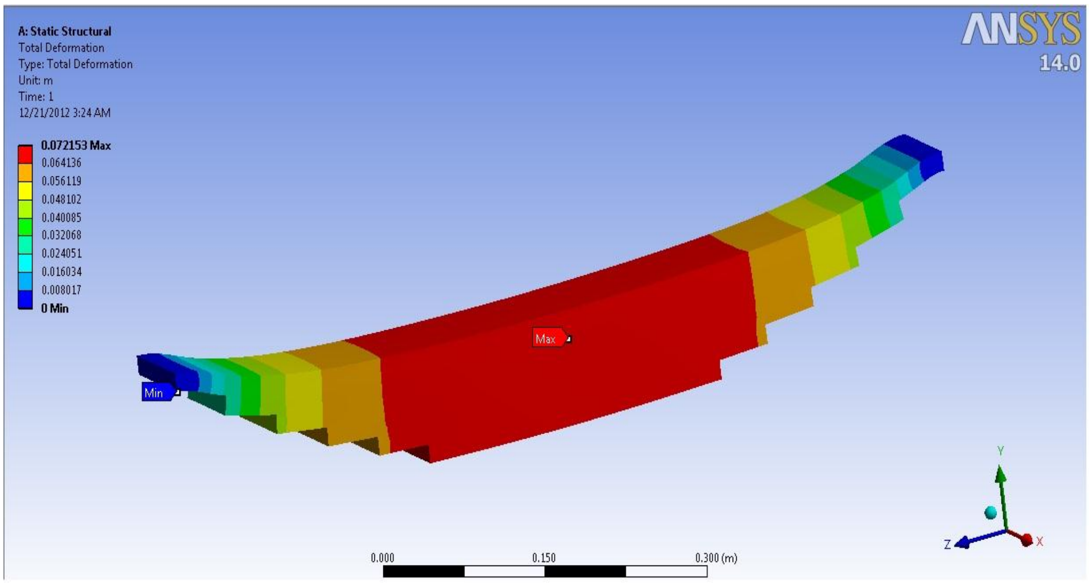


Figure 4.2: Total deformation of beam

Figure 4.2 shows the deformation of the beam under 70kN of force. The force acts on the middle of the beam, thus giving it the deformation as in figure 4.2. The beam deforms equally from the right side to the left side because the configuration of the beam is cantilever. The region that is nearest to the point of applied force has the largest deformation and it gradually decreases further away to both sides with no deformation at the fixed ends.

To validate these results, the data taken from the simulation will be compared to the data taken from past research on GFRP leaf-spring entitled Design and Analysis of Composite Leaf Spring in Light Vehicle by M. Venkatesan and D. Helmen Devaraj. Also, these results will be compared to the results obtain from calculation method using the same load conditions and parameters.

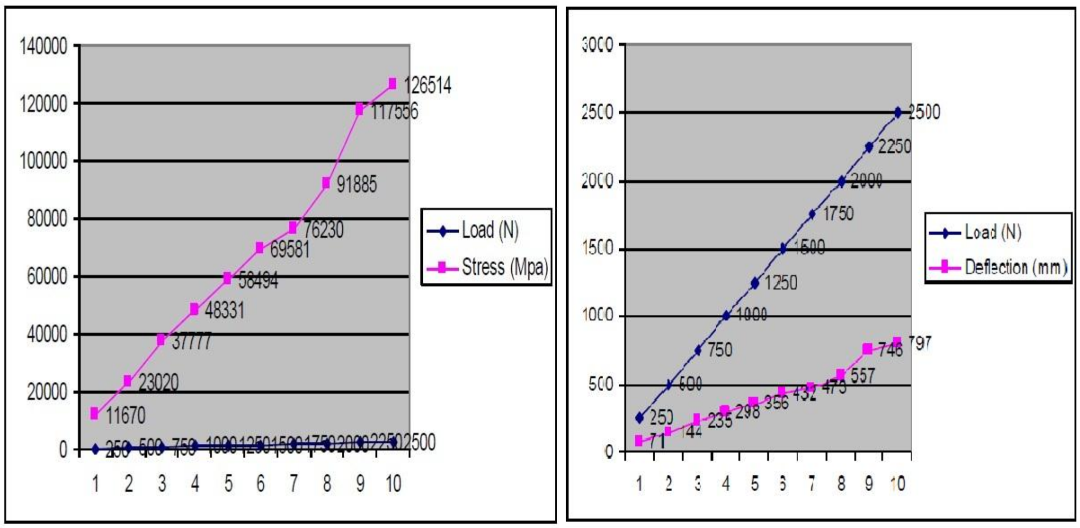


Figure 4.3: stress and deformation data of past research

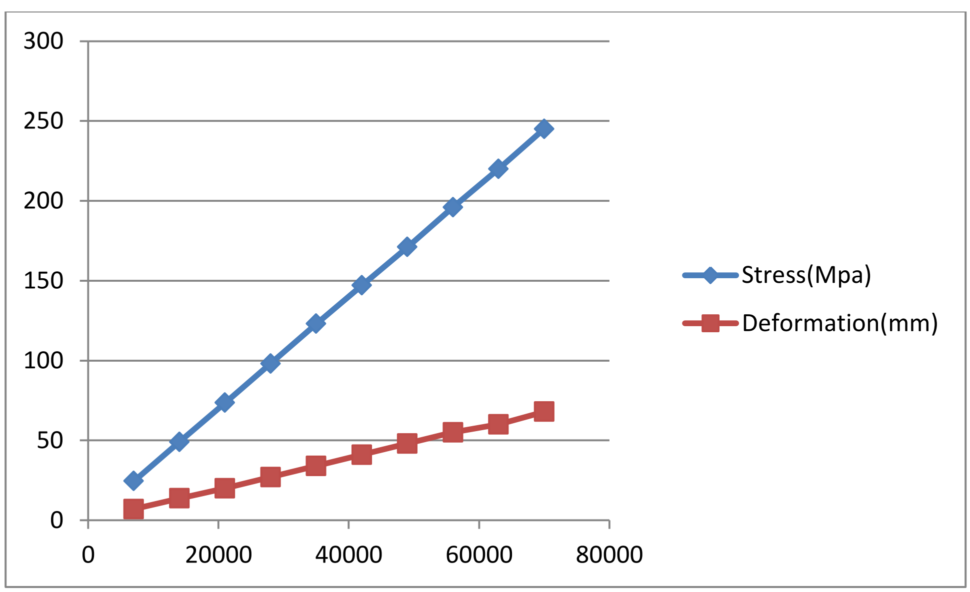


Figure 4.4: Stress and deformation data

Figure 4.3 is the data taken from past research on GFRP leaf spring for light vehicles. The stress inside the spring is higher when compared to the result from the simulation. This is due to a number of reasons. The past research is done for light vehicles, therefore the dimension of the spring is smaller and the number of leaves is 4. However, both results show a similar linear pattern for both the stress and deformation.

To further validate the results of this simulation, the model is solved using beam deflection equation with the same boundary conditions and material properties. The boundary condition is cantilever beam with the same dimension as the model. The equations used are:

$$\sigma = \frac{6FL}{bh^2}$$

…………………………………………………………………….………………… Eqn 4.1

$$\delta = \frac{6FL^3}{Ebh^3}$$

………………………………………………………….……………………Eqn 4.2

The results are then tabulated and compared to the results obtained from the simulation.

Table 4.2: Stress and deformation results from simulation and calculation

Load(N)	Stress(Mpa)	Calc Stress(Mpa)	Deformation(mm)	Calc Deformation (mm)
7000	24.5	34.18	7	9.91
14000	49	68.36	13.7	19.81
21000	73.6	102.54	20	29.72
28000	98.1	136.72	27	39.63
35000	123	170.90	34	49.54
42000	147	205.08	41	59.44
49000	171	239.26	48	69.35
56000	196	273.44	55	79.26
63000	220	307.62	60	89.16
70000	245	341.80	68	99.07

The percentage difference for the stress and deformation is then calculated. For stress, there is 28.3% difference between the calculated model and simulated model while for deformation the average difference is 31.2%. The differences occur because of the model used for simulation is the simplified model. If the model is made to be more complex with the eye and camber, the result would be more accurate. Also, the calculated result is only the theoretical result. For a better result, an experiment using the same model and material is to be done.

CHAPTER 5

CONCULSION AND RECOMMENDATION

5.1 Conclusion

As for conclusion, when 42kN of force acting on the beam, the stress inside the spring is 147Mpa and the deflection of the beam is 41mm. the young's modulus for the material is 1150Mpa. Therefore the spring can withstand the stresses at 42kN force. The small deflection is also acceptable so that the spring will not hit the body of the vehicle during full load condition. However, at 70kN, while the stress of the spring is still below the yield point, the deformation of the spring is high and it will risk hitting the body of the vehicle. Thus it is not acceptable. Therefore, the material oil palm phenol formaldehyde composite can be used in construction of leaf spring for heavy vehicles.

5.2 Recommendations

1) The matrix for the composite can be change with other materials to improve the performance of the spring, however more extensive research must be made for the new materials. The length of the fiber can also be increased to increase the material properties of the composite

2) for this particular materials and spring dimension, an experiment must be done to give a more conclusive result for using oil palm fiber composite in construction of leaf spring

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