Fabrication and Analysis of Leaf Spring using Hybrid Composite

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Abstract— Leaf spring is one of the commonly used suspension systems in automobiles. Particularly, it is used in heavy trucks and other heavy-duty earthmovers because of its high load bearing capacity. Heavy weight of the leaf spring plates is a disadvantage faced by automobile sectors for more than a decade. This paper deals with the suitability of hybrid composite as the leaf spring material. Hybrid composite composed of Carbon/E-Glass fiber (as reinforcement), Alumina particle (as ceramic filler) and Epoxy (as matrix) is fabricated by hand-lay technique and tested for mechanical properties such as Tensile strength, Impact strength and Flexural strength. With the obtained test result, finite element analysis of leaf spring is carried on the ANSYS 2020 R1. The simulation result reveals that the leaf spring made up of hybrid composite has high strain energy and low stress when compare to leaf spring made up of conventional ASTM5160 carbon steel. And the hybrid composite also accompanies the advantage of less weight compare to its conventional counterpart.

Keywords— *Leaf Spring, Hybrid Composite, Carbon Fiber, Glass Fiber, Alumina Particle, ANSYS.*

I. Introduction

In present day world, rampant technology advancements are superseding the old and conventional products with novel and advantageous ones. In automobile sector this trend is spontaneous. Especially, composites are widely used in this process because of their numerous merits. Composite is a structural element composed of fiber and matrix. It is preferred for various application because it harnesses the properties of components which are present in it. As composite facilitate the amalgamation of myriad of desirable properties, it becomes the first material choice of the engineers.

In automobile industries, reducing the weight of the vehicle is being one of the paramount goals for more than two decades. As the weight and fuel consumption are directly proportional, decrease in weight of the automobile will save fuel. Ultimately it led to increase in the efficiency of the vehicle and plummet the demand on fuel. Further, this objective can be effectively fulfilled by using composites. Usually, every composite has high strength to weight ratio and this feature facilitate to use composite in various arena of automobile. Nowadays, Glass Fiber Reinforced Plastics (GFRP) and Carbon Fiber Reinforced Plastics (CFRP) are the commonly used composites in automobile industries to manufacture chassis, body, wheel rims etc.

Among various automobile systems, suspension system account for considerable amount of automobiles' weight. Leaf spring in heavy trucks hold a significant amount of unsprang weight which decrease the vehicle performance. Unsprang weight includes weight of the wheels, axel and spring. Therefore, decreasing the weight of the leaf spring plates improve the riding condition and efficiency of the vehicle. This can be achieved by using Hybrid composite. The hybrid composite composed of more than one reinforcement agent. In this project Carbon and E-glass fibers as reinforcement and Alumina Particulate matter as ceramic filler and Epoxy as matrix are chosen to attain the objective.

II. Literature Survey

Automobile sectors are showing keen interest in reducing the unsprang weight of the vehicle. Before the advent of composite, advanced manufacturing process are used to reduce the unsprang mass. Mr. Scuracchio et al [1] increased the fatigue strength of conventional leaf spring plate using shot peening process. This facilitates the team to decrease the width of the plate without compromising its mechanical properties. As a result, unsprang weight reduced by small extent. After performing design optimization in leaf springs, the major weight reduction takes place when composite comes into picture. Mr. Harmeet Singh et al [2] conducted an experiment to compare the performance of aluminum alloy laminated leaf spring and steel leaf spring. They concluded that former has better performance with reduced weight. In due course of time, synthetic fibers were begun to use as reinforcement in polymer composite. Mr. Ganesh.R et al [3] fabricated a leaf spring using Glass FIBER Reinforced Polymer composite (GFRP) and compared it with conventional leaf spring in terms of strain energy and weight. They concluded that the spring made up of GFPR has 85% reduced weight and increased strain energy.

Then the trend shifts into use of natural fiber as reinforcement and it happened because of specific properties available in these FIBERs. Mr. Y. Sai Bhargav et al [4] compared the performance of leaf spring made up of jute fiber composite and conventional steel. It was observed that fiber reinforcement accompanied with particulate matter possess high resistant to deformation than its typical counterpart. These particulates include ceramic fillers like Alumina (Al_2O_3), Silicon Oxide (SiO_2), Silicon carbide (SiC), Zirconium Oxide (ZrO_2) etc. Because of their high hardness, refractories and low thermal expansion, they are considered as reinforcement in high performance application composite. Mr. Sandhyarani Biswas et al [5] confirmed this by conducting an experiment in bamboo and glass fiber composite with several particulate matter. The concept of hybrid composite emerged when more than one reinforcement agents are used in single composite because of their unique properties. To integrate properties like better elastic modulus, high hardness, low thermal expansion, better strength to weight ratio, various material is chosen as reinforcing agent. Presently, carbon fiber is widely used as the reinforcement in high end composite. It possesses high tensile strength in reduced weight. Mr. Umanath [6] studied performance of leaf spring composed of bamboo and carbon fiber composite and investigated based upon hardness, toughness, impact strength and compression strength.

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III. MATERIAL SELECTION

Composite typically composed of reinforcement and matrix. The former is a strong material embedded in later which is a relatively weaker material. The function of the matrix is to transfer the load acting on it to the fiber, to give shape to the composite and to prevent fiber from corrosion. As for as the reinforcements are concerned, they are the members which truly determines the properties of the composite. By changing the reinforcement agent in a matrix, wide variety of composites with plethora of mechanical properties can be produced. Furthermore, hybrid composite is the composite which harness the merits of more than two reinforcement simultaneously at single instant. This concept led the engineer to design composite with precise properties needed to accomplish the intended goal. In this work the hybrid composite for leaf spring is composed of carbon/e-glass fiber, alumina filler and Epoxy.

A. Carbon Fiber

Carbon fiber is also called graphite fiber. The typical diameter of the carbon fiber ranges from 5-10 micrometer and it mostly composed of carbon atom. Carbon fiber has numerous advantages including high toughness, high tensile strength, low weight to strength ratio, high temperature tolerance, and chemical resistance. Because of its superior nature, it is used in various sectors including aerospace, military, motorsports, automobiles and civil engineering. On other hand, when comes to carbon fiber the major disadvantage is that it is relatively expensive when compare to glass or plastic fiber.

B. Glass Fiber

Glass fiber is nothing but fine fiber of glass. The fabrication of glass fiber become possible only after the introduction finer machine tooling. The mechanical properties of glass fibers are roughly comparable with carbon fiber but because of its relatively cheap cost it has universal applications. Glass fibers are therefore used to produce low cost, lightweight, strong polymer product called Glass Reinforced Plastic (GRP) or “fiberglass” and this product has its application in various sectors like automobiles, beverage industries, chemical industries and food processing.

C. Alumina (Al_2O_3)

Alumina is the common name given to Aluminium Oxide (Al_20_3). Alumina is produced from bauxite ore by Bayer process. Besides the production of aluminium, alumina is used in variety of application such as refractories, ceramics, polishing and abrasives. Alumina is preferred over other material because of its high strength, high corrosion resistance and high wear resistance.

D. Epoxy Resin

There are many grades of epoxy resin are available and in this work Epoxy (LY556) is considered for composite fabrication. Typically, epoxy is an organic compound mainly composed of carbon with other functional element such as oxygen, hydrogen and nitrogen. Epoxy resin creates a rigid yet highly flexible material upon curing. As the curing is controlled by external agents like heat, air and chemical additives, it increases the control over the fabrication of composite. Nowadays, mostly epoxies are preferred over other polymer because of its significant properties like high strength, low shrinkage, high adhesiveness, chemical and solvent resistance and low cost.

IV. FABRICATION

There are numerous methods to fabricate composite. Among these methods Hand-Layup technique is simplest and highly credible technique to fabricate composites. This paper concern with laminar composite specimens for testing and these specimens are prepared by open molding hand-layup method.

- **Step 1:** First The specimen dimensions (length, width and thickness) are finalized for each of the tests.
- **Step 2:** Based upon the length and width of the specimen, the area of the prepreg required to provide three specimens for a single test is determined and this step is repeated for each one of the tests.
- **Step 3:** Based upon the thickness of the specimen, number of prepreg required to attain the thickness is calculated and this step also repeated for each one of the tests. While calculating the plies required to attain certain

thickness, consolidated thickness of plies is considered rather than considering actual thickness. As consolidated thickness are the thickness of the plies after curing, considering it will increase the precision of specimens' dimension

- **Step 4:** The area of the rectangular ply required to provide three specimens and number of plies needed to provide the thickness of the specimens is determined for each of the test separately. After finalization, the required number of plies are cut out in required dimension.
- **Step 5:** After cutting out the plies, a glass or polythene surface is cleaned up for fabrication process. It is kept free of dust and any irregularities.
- **Step 6:** Release agent is applied on the fabrication surface to facilitate smooth removal of end composite product.
- **Step 7:** Then matrix is prepared. With Epoxy resin Alumina powder and hardener is added. The proportion in terms of weight is - 10 parts Epoxy:3 parts Alumina: 1 part hardener.
- **Step 8:** After preparing the resin, stacking of prepregs are done in an alternative manner. Required amount of resin is added in between each layer of reinforcements during the stacking and the whole process is kept free of forming air bubbles.
- **Step 9:** After allowing the composite plates to cure for required amount of time (24hrs) they are removed from the surface and specimens are cut down from the acquired rectangular composite plates using a jig-saw machine.

V MATERIAL TESTING

A. *Tensile Test*

Among various available tests Tensile Test is one of the most preferred tests to determine the important mechanical properties. Tensile test typically conducted in a Universal Testing Machine (UTM) where the specimen is pulled in opposite directions [fig1]. The result reveals the entire profile of the tensile behaviour of the material. The result is normally depicted in stress strain curve and from the curve important values are derived and manipulated for further calculation. Ultimate tensile strength, Elastic Modulus or young's Modulus and Poisson ratio are the most general properties derived from the curve. Ultimate tensile strength denotes the maximum stress that the material can withstand without breaking. While, Young's modulus denotes the slope of the straight line present in the elastic region in stress strain curve. During the initial loading, almost all material has the capability to regain its shape after the removal of load and this property diminishes when the applied load crosses certain limit. Hence, the path followed by the material while possessing the elasticity is straight line and the slope of the straight line is the Modulus of Elasticity. On the other hand, Poisson ratio is a dimension less quantity which entirely depends on the strain occurring in the material during the loading. It is the ratio of Lateral strain (strain taking place in a direction perpendicular to the direction of applied load) to the Longitudinal strain (strain taking place in the same direction of the applied load). The test result shows that the hybrid composite has UTS of 291MPa, Young's Modulus of 1.25 x10^5MPa and Poisson ratio of 2.64.

B. *Charpy Impact Test*

Charpy test is one of the impact tests carried to find out the toughness of the material. Toughness is the measure of the energy observed by the material during plastic deformation. In the test, a pivoting arm is raised to particular height and then dropped against the simply supported specimen on the anvil [fig2]. Once the pendulum hits the specimen, the energy observed by the specimen is indicated by the needle. Usually, the result is indicated in joules and the energy observed by the hybrid composite is 94.67 Joules.

C. *Flexural Test*

Materials are subjected to flexural bend test to find out the flexural strength. In this test the specimen is simply supported and a load is applied in the middle of the specimen. The loading continuous until the failure of the specimen takes place [fig3]. The stress at the outermost fiber of the material on either compression or tension side accounts for Flexural strength. The properties obtained from the flexural test is not a fundamental property. As the specimen undergoes tensile, compressive and shear stresses during the loading, the properties obtained as a result of the test is the combined effect these stresses and the geometry of the specimen. The flexural strength of the hybrid composite is 140Mpa.

TABLE 1.TEST RESULT

	Carbon\Glass Epoxy composite with Alumina Filler	**Unit**
Density	1759	Kg/m^3
Poisson's Ratio	0.263	
Young' Modulus	1.29x10^5	N/mm^2
Ultimate Tensile strength	291	MPa
Flexural Strength	140	MPa
Impact strength	94.67	Joules

Fig 1. Tensile Test Specimens

Fig 2. Charpy Test Specimen

Fig 3. Flexural Test Specimens

VI MODELLING

In order to simulate the actual working condition of leaf spring, a fully assembled leaf spring is designed in SolidWorks. To alienate the discrepancy in result caused by design optimization, readymade dimensions of a leaf spring is considered in designing i.e. specification of "JEEP WILLYS" [TABLE 2] leaf spring is taken in to account.

TABLE 2. JEEP WILLYS LEAF SPRING SPECIFICTION

DESCRIPTION	**THEORITICAL WEIGHT (Kg)**	**DIMENSIONS (mm)**	
JEEP WILLYS	12.67	Width x Thickness	Length
1.LEAVE	2.32	45 x 6	460-460
2.LEAVE	2.39	45 x 6	565-565
3.LEAVE	1.86	45 x 6	440-440
4.LEAVE	1.63	45 x 6	385-385
5.LEAVE	1.39	45 x 6	330-330
6.LEAVE	1.18	45 x 6	280-280
7.LEAVE	0.97	45 x 6	230-230
8.LEAVE	0.76	45 x 6	180-180
9.LEAVE	0.55	45 x 6	130-130

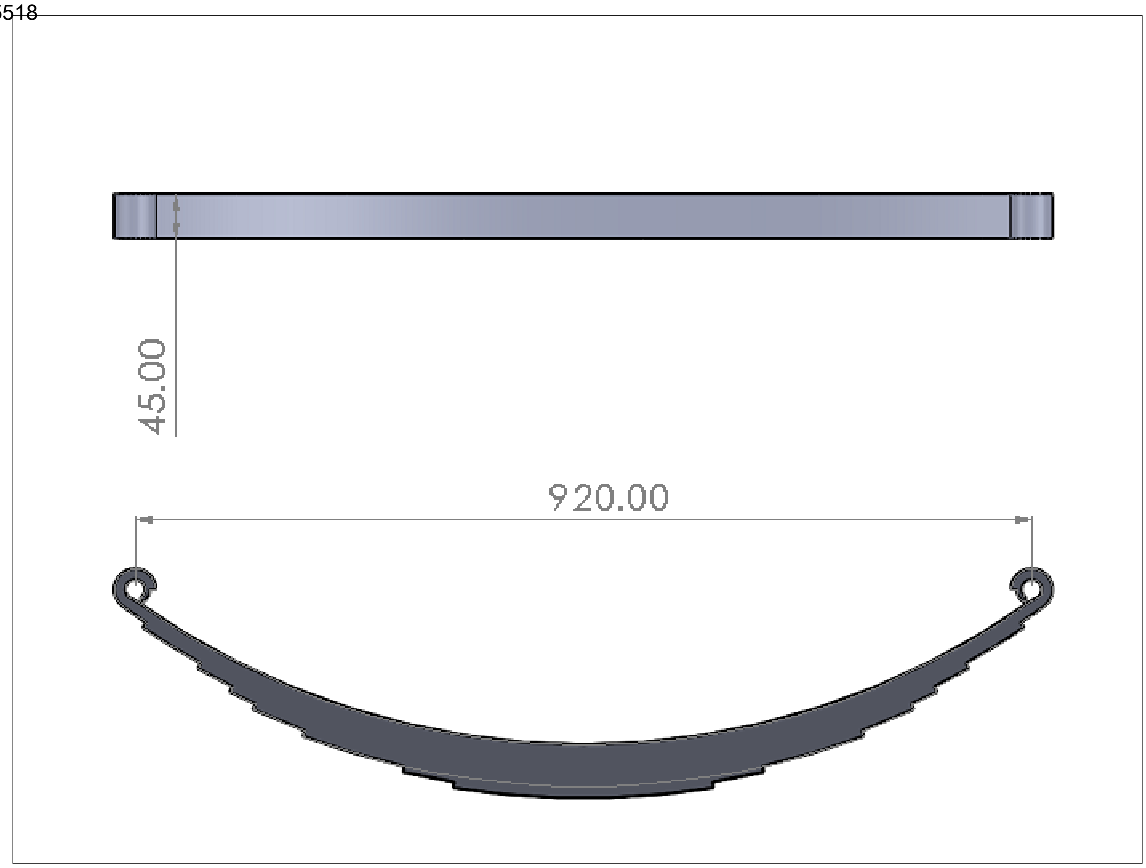

Fig 4. Front and Top View of Leaf Spring Design

Fig 5. Isometric View of the Leaf Spring Design

VII SIMULATION

The static analysis of the leaf spring is carried on Ansys2020R1. In Ansys, the leaf spring made up of ASTM5160carbon steel and Hybrid Composite is analysed based upon Stress, Total Deformation and Strain energy. In ANSYS Workbench, Static Structural frame work is used to carry on the static structural analysis. In the engineering Data segment, values of the required mechanical properties (for ASTM5160 carbon steel values obtained from datasheet is used and for hybrid composite test result values are used) are uploaded. Next, in Geometry segment, the model designed in SoildWorks is imported. The rest process is accomplished in the Model segment. In this segment, first the properties are assigned to the designed leaf spring. Then constrains are applied to each eyes of the leaf spring, among six degree of freedom, the left eye of the leaf spring is made to have only the rotation along Z axis [fig6]. On the other hand, the right eye is made to have two degree of freedom i.e., translation along X axis and rotation along Z axis [fig7]. Then the load is applied to the bottom of leaf spring in Y direction [fig8]. Finite element analysis is carried out with a load magnitude of 25000N and contour plot for Stress, Strain energy and Total Deformation is obtained.

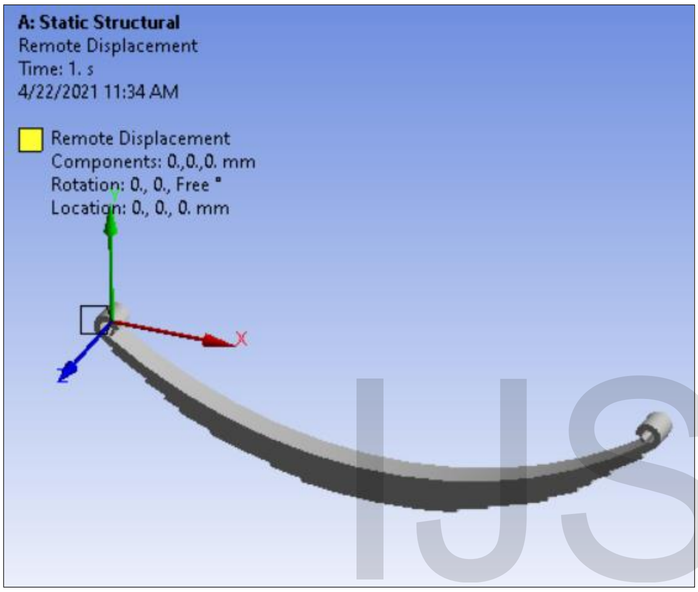

Fig 6. Constraints on the Left Eye of the Leaf spring

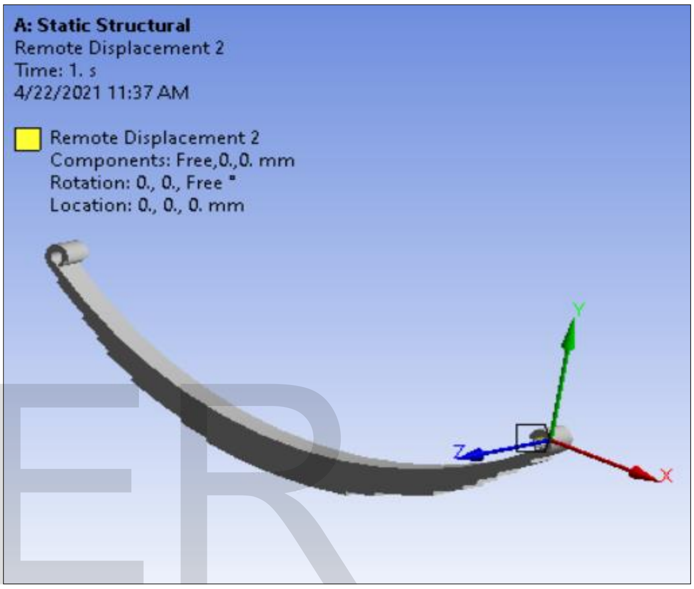

Fig 7. Constraints on Right Eye of the Leaf spring

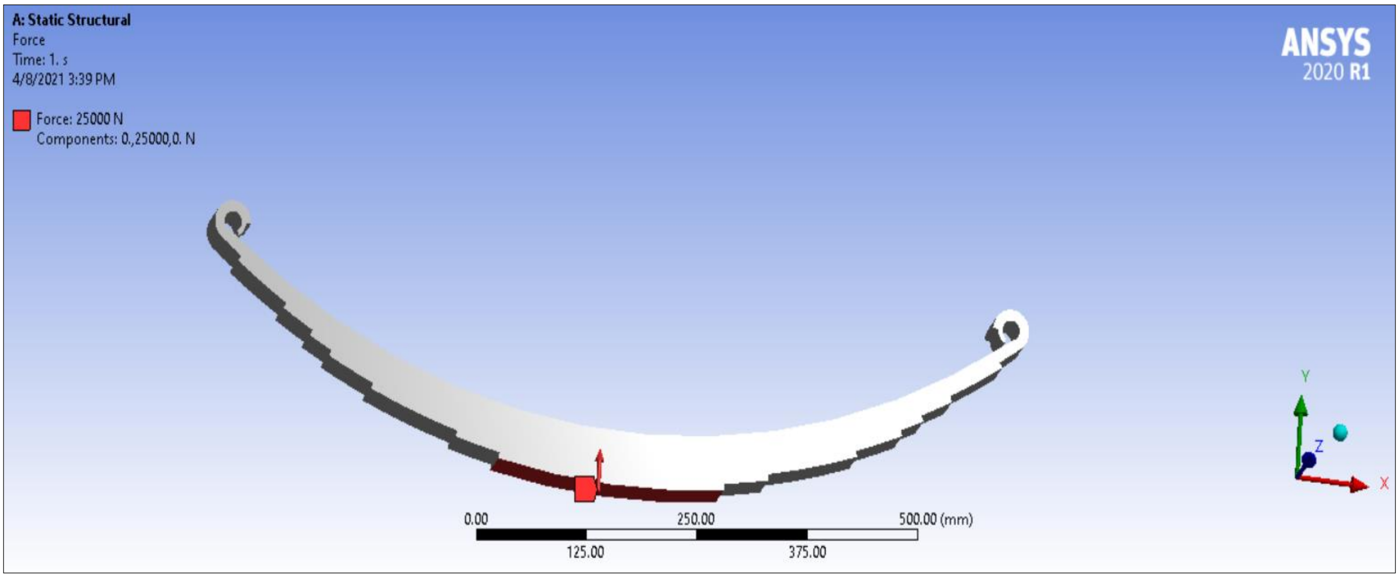

Fig 8. Force acting on the Leaf Spring

VIII SIMULATION RESULT

Contour plots are best way to examine the effects of load in the system. In this work, contour plots are obtained on each analysis for two different leaf springs (spring made up of ASTM5160 Carbon Steel and Hybrid Composite) to determine the performance of each leaf spring and to compare the efficiency of leaf spring. Furthermore, the maximum and minimum values of stress, strain energy and total deformation are sorted in Table 3.

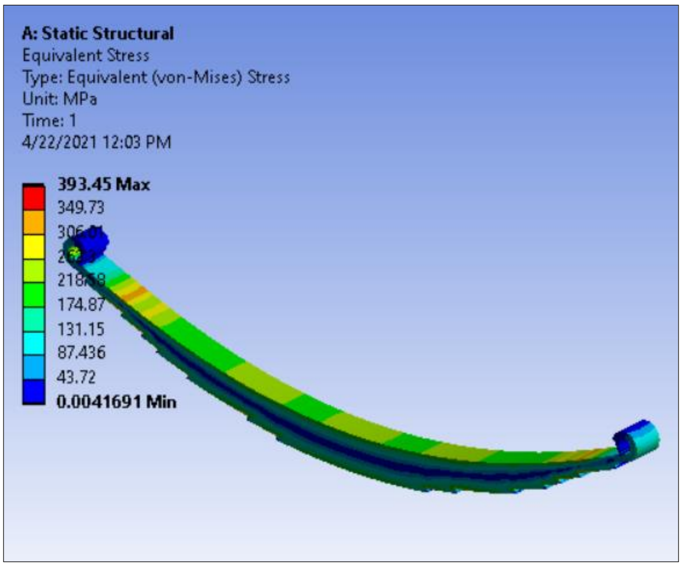

Fig 9. Stress Analysis – Hybrid Composite

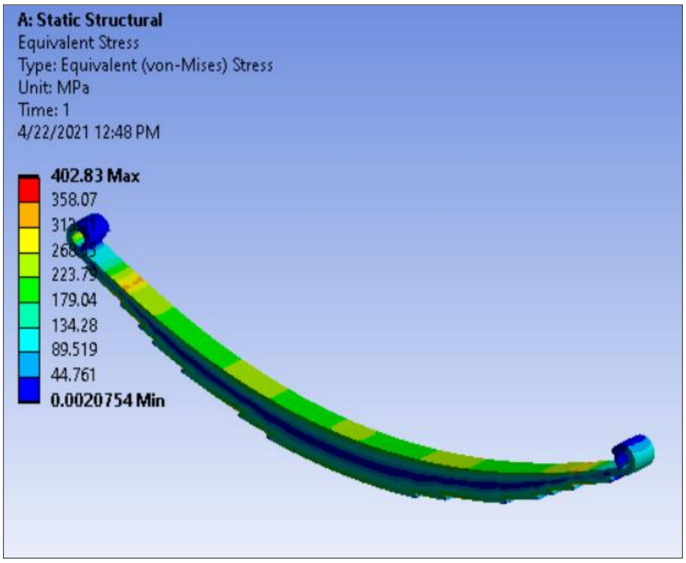

Fig 10. Stress Analysis – ASTM5160 Carbon Steel

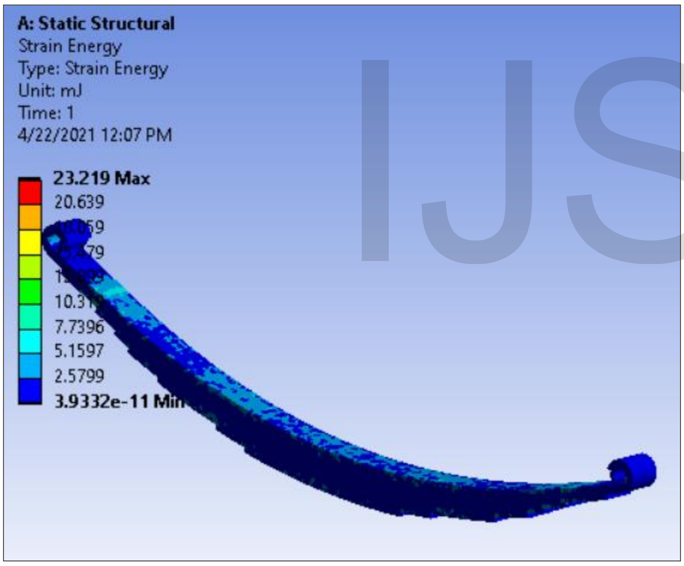

Fig 11. Strain Energy Analysis – Hybrid Composite

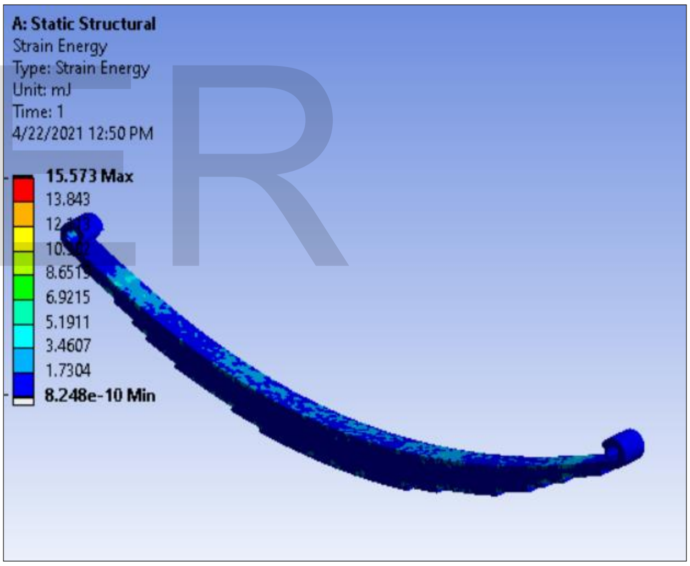

Fig 12. Strain Energy Analysis – ASTM5160 Carbon Steel

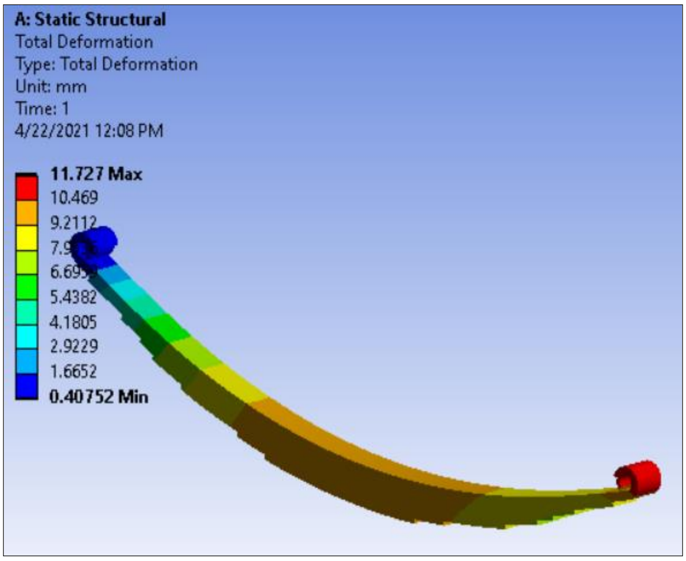

Fig 13. Total Deformation Analysis - Hybrid Composite

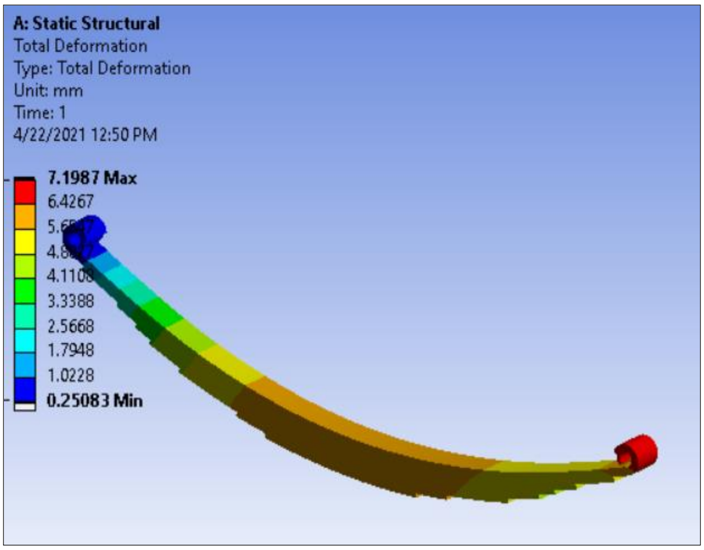

Fig 14. Total Deformation Analysis – ASTM5160 Carbon Steel

TABLE 3. SIMULATION RESULT

Material	Stress (MPa)		Strain energy (MJ)		Total Deformation (mm)	
	Max	Min	Max	Min	Max	Min
ASTM5160 Carbon Steel	402.83	0.00207	15.573	8.24e-10	7.19	0.28
Hybrid Composite	393.45	0.0041	23.219	3.9e-11	11.727	0.407

IX CONCLUSION

- From the result it is evident that the leaf spring composed of hybrid composite has lesser stress and high strain energy when compared to leaf spring composed of ASTM5160 steel. Therefore, it can be inferred that in a given condition, the leaf spring made up of hybrid composite has better performance than its steel counterpart.
- In terms of weight, Hybrid composite has upper hand over ASTM5160 steel. The former weighs about 2.84958 Kg whereas the latter weighs about 12.6846kg. Hence, implication of Hybrid composite in manufacturing of leaf spring reduces the weight of the leaf spring by 77%.
- As for as deformation is concerned, hybrid composite produces slightly higher displacement when compared to the ASTM5160 steel. However, the difference between the values of maximum deformation of two material is relatively small. Therefore, the deformation in composite can be reduced by adding two or three leaf plates to the system. Nevertheless, the total weight remains to be significantly small than other.
- Hence, it can be concluded that this hybrid composite can be used as a material for leaf spring manufacturing

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