Design and static structural analysis of hybrid leaf spring using fea

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***Abstract*: Leaf spring is one of the oldest suspension components and they are still frequently used in commercial vehicles. Weight reduction is most effective way of improving fuel economy without losing the performance of vehicles. So the Automobile Industry has shown interest in overall weight reduction of vehicle by the replacement of steel leaf spring with composite leaf spring since the composite material has a high strength to weight ratio, good corrosion resistance, more elastic strain energy storage capacity. The main objectives of this work is to compare the stress, deflection, stiffness and weight savings of composite leaf spring with that of steel leaf spring and an attempt to design a hybrid leaf spring in order to obtain qualitative spring at affordable mid- range of cost. In this research work standard existing multi leaf spring is modeled in CATIAV5 and analysis is carried out by using ANSYS (Workbench 16.0) software. A comparative study has been made between different composite (E-Glass/Epoxy, Carbon Epoxy, Graphite Epoxy, etc.) multi-leaf spring, steel multi-leaf spring and mono composite leaf spring with respect to stress, deformation and weight to find out the best material that have minimum weight and stress for same load carrying capacity.Theoretical and software based results are presented and compared for validation. Finally referring to the results obtained in these research studies, the present work proposes a new idea regarding the construction of hybrid leaf spring which is the combination of steel and composite material leaves based on practical applications and cost analysis.**

***Keywords*: leaf spring, composite material, hybrid leaf spring, static analysis, CatiaV5, Ansys etc.**

I. INTRODUCTION

Suspension system of any vehicles contains leaf spring to absorb shock and vibration. The vehicles must have a good suspension system that can deliver a good ride and good human comfort. It is observed that the failure of steel leaf springs is usually catastrophic. According to studies made for leaf spring the material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material. In order to reduce the accidents, arising out of such failures conventional steel leaf spring can be replaced with gradually failing composite leaf springs. By doing this, the weight of the vehicle may also be reduced while maintaining the strength of the leaf spring. A suspension system of vehicle is also an area where these innovations are carried out regularly. More efforts are taken in order to increase the comfort of user. Appropriate balance of comfort riding qualities and economy in manufacturing of leaf spring becomes an obvious necessity. To improve the suspension system, many modifications have taken place over the time. The suspension leaf spring is one of the potential items for weight reduction in automobiles as it accounts for 10% - 20% of the un-sprung weight. This achieves the vehicle with more fuel efficiency and improved riding qualities. Weight reduction is an effective measure for energy conservation. It reduces overall fuel consumption of the vehicle. The strain energy of the material becomes a major factor in designing the springs. The material having lower modulus and density will have a greater specific strain energy capacity. It helps in achieving the vehicle with improved riding qualities. This paper is mainly focused on the implementation of composite materials by replacing steel in conventional leaf springs of a suspension system to reduce product development cost, weight, improving the safety, comfort and durability. The composite materials having more elastic strain energy storage capacity due to low young's modulus and low density than steel.

In this present work, a six-leaf steel spring used in Tata sumo vehicle is replaced with a composite multi leaf spring made of E-carbons/epoxy composites. The dimensions and the number of leaves for both steel leaf spring and composite leaf springs are considered to be the same. The introduction of composite materials was made it possible to reduce the weight of the leaf spring without any reduction of load carrying capacity. The primary objective is to compare their load carrying capacity, stiffness and weight savings of composite leaf spring and focused on study of design and analysis of hybrid leaf spring which is the combination of steel and composite material in order to obtain qualitative spring at affordable mid-range of cost.

LEAF SPRING-

Leaf spring was 1st used in 1804 by Obadiah Elliot for suspending the horse drawn cart. It was than incorporated in early designs of motor vehicles. A spring is an elastic machine element which undergoes deflection for the application of any load and intends to regain its original shape depending upon the magnitude of applied load. Major application of spring may include its use as a shock and vibration absorber and storing potential energy by its deflection during the application of load. Leaf spring is used in almost all the trucks and light vehicles. It improves the suspension quality and can support heavy load. Advantages of leaf spring over the helical spring are that the ends of the spring are guided along a definite path and it is act as structural member.

A leaf spring is a simple type of suspension commonly used in vehicles. The leaf spring can be arranged in two different ways based on the vehicles. First type is simple supported type of leaf spring in which both the ends of the leaf spring are fixed to the chassis of the vehicle and the second one is cantilever type of leaf spring in which one end is fixed to the chassis of the vehicle and other end is left free for displacement. The Leaf spring is generally made of Steel. A leaf spring takes the form of a slender arc-shaped of spring steel of rectangular cross section. In the most common configuration the Centre of arc provides location for the axle while loop formed at either end provide for attaching to vehicle chassis.

Leaf spring is an important component of automobile act as a linkage for holding axle in a position. Multi leaf spring carries lateral load, break torque, driving torque in addition to shock absorbing. In its construction the leaf spring consists of a series of flat plates or leaves, usually of semi-elliptic shape, which are held together with the help of U-bolts and Centre clip. Generally two types of leaves may be observed in a multi-leaf spring i.e. some graduated -length leaves and a few extra full-length leaves. The length of the leaves gradually decreases from top to bottom. The longest leaf in the top is known as master leaf which is bent at both the ends to form spring eyes. The extra full-length leaves are inserted between the master leaf and the graduated-length leaves to support the transverse shear force. In order to maintain proper alignment and to restrict the lateral shifting of leaves, rebound clips are used. In practice, these springs rest on the axle of an automobile. Its front end is connected with the frame by means of a simple pin joint and the rear end is connected with the frame through a flexible link (known as shackle).

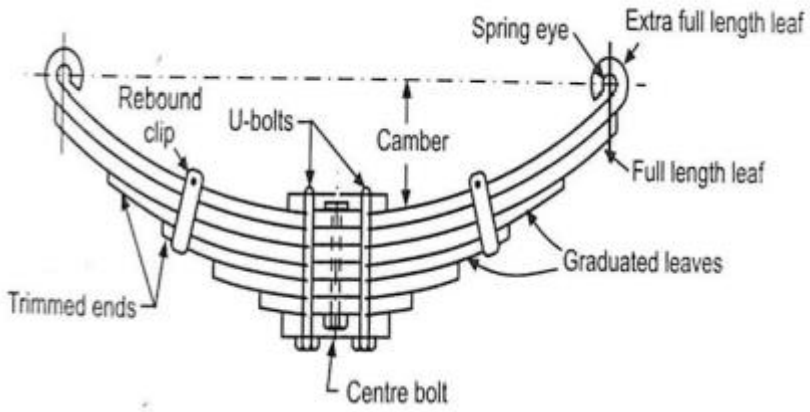

Fig. leaf spring

II. AIM AND SCOPE OF THE WORK

The objective of the present work is to design and analysis of composite leaf spring for automobile suspension system. In the present work finite element analysis is carried out using ANSYS 16.0 to determine the stress and deformation in conventional steel multi-leaf spring and various composite multi-leaf springs to determine the best one. This is done to achieve the following objectives-

- To develop 3D CAD model of leaf spring and study the behavior of different material of leaf spring under static analysis.
- To calculate the total deformation and stress developed in steel multi-leaf spring, composite multi-leaf spring, composite mono leaf spring and hybrid multi leaf spring under same loading conditions.
- To compare the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring and conclude a best metal.
- To reduce product development cost, weight, improving the safety, comfort and durability and reducing fuel consumption of vehicle.
- To achieve substantial weight reduction in the suspension system by replacing steel leaf spring with composite leaf spring.

III. LITERATURE REVIEW

[1] Rohit Ghosh, Sushovan Ghosh and Shirish Ghimire

Average cost of E-Glass that can be used to manufacture the springs, ranges from 40-55 USD per square foot. Whereas steel ranges from 16-20 USD per square foot, hence, if the entire spring is made of composite material then it would not be cost effective at all. He further concluded that, stresses in extra full-length leaves were almost 50% more (1.5 times) than that of the graduated-length leaves. Finally, the present work offers an exclusive idea regarding the construction of multi-leaf spring through its proposal for manufacturing the extra full-length leaves with composites, while using steels for the rest of the leaves, to minimize the cost..

[2] Manjunath H.N,

In this paper a comparative study has been made between different composite (E-Glass/Epoxy, Graphite/Epoxy, Boron/Aluminum, Carbon/Epoxy, Kevlar/Epoxy) materials and steel in respect of stiffness, deflection and stress. It is found that all the composite leaf spring has good performance characteristics as compared to conventional steel spring with similar design specifications. Boron/Aluminum has minimum deflection and stress, and posses high stiffness as compared to other composites.

[3] **Pinaknath Dewanji**
This paper deals with the Design and analysis of composite leaf spring. The conventional multi leaf spring weights about 10.27kg whereas the E-glass/Epoxy multi leaf spring weighs only 3.26 kg. Thus, the weight reduction of 67.88% is achieved. By the reduction of weight and the less stresses, the fatigue life of composite leaf spring is to be higher than that of steel leaf spring. Totally it is found that the composite leaf spring is the better that of steel leaf spring.

[4] Vamsi Krishna dommeti, Raghavendra rao
This paper deal with FEA analysis of leaf spring by composite glass fiber epoxy reinforced with natural fibre material. Static analysis has been conducted to predict the displacement and stress at different location. A comparative study has been made between Steel, GFRP and GFRP reinforced with natural fiber's springs with respect to weight, riding quality, cost and strength. From the study it is seen that Banana fiber reinforced composite material spring is lighter 72% compared to conventional steel leaf spring and stress is reduced 4.15% from steel for similar performance.

[5] Dara Ashok, M.V. Mallikarjun, and Venkata Ramesh Mamilla
The objective of this paper is to compare the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring. Leaf spring consist two full length leaves and five graduated leaves. The material of the conventional leaf spring was 65Si7 and the material of the composite material was E-Glass/Epoxy. Dimensions of the composite leaf spring are to be taken as the same dimensions of the conventional leaf spring for modeling. It is concluded that composite multi leaf spring is an effective replacement for the existing steel leaf spring in vehicles.

[6] Mouleeswaran Senthil kumar, Sabapathy Vijayarangan
This paper describes static and fatigue analysis of steel leaf spring and composite multi leaf spring made up of glass fiber reinforced polymer using life data analysis. Compared to steel spring, the composite leaf spring is found to have 17.35 % lesser stress and weight reduction of 68.15 % is achieved. It is found that the life of composite leaf spring is much higher than that of steel leaf spring.

[7] N. Vijiya Rami Reddy, B Rajnaveen
In this paper the leaf spring has been modeled using solid tetrahedron 4-node element. By performing static analysis it is concluded that the maximum safe load is 4000 N and the stresses in the mono composite leaf spring are much lower than that of conventional steel leaf spring. Result shows that the composite spring can design to strength and stiffness much closer to steel spring by varying the layer configuration and fiber orientation angles. The strength to weight ratio is higher for composite leaf spring than conventional leaf spring with similar design.

[8] Dev Dutt Dwevedi, V.K. Jain
This paper deal with the design and analysis of automobile leaf spring using Ansys. Results demonstrate that composite leaf spring for a particular load is less compared to conventional leaf spring. Stress generated in E-glass/Epoxy is lower than steel leaf spring. Composite has lower directional deformation compared to steel leaf spring.

[9] D.Lydiamahanthi In this paper design and analysis of composite of leaf spring is done for light weight vehicles. As automobile world demands research of reducing weight and increasing strength of products, composite material should be up to the mark of satisfying these demands. As leaf spring contributes considerable amount of weight to the vehicle and needs to be strong enough, we introducing Kevlar material which is least in weight and bears more load with less deformation when compared to other materials. The results of static analysis of both steel and composite leaf springs like EN47, KEVLAR, S-Glass Epoxy & E-Glass shows that Kevlar material is better than conventional steel, E-Glass/Epoxy, S-Glass Epoxy and the other composite materials.

IV. COMPOSITE MATERIALS

Composite materials (or composites for short) are engineered materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure. It is any substance employed in making some useful thing or artifact. The metals and ceramics are materials used in industries as good conductors and refractory materials respectively. Generally, a composite material is composed of reinforcement (fibers, particles, flakes, and/or fillers) embedded in a matrix (polymers, metals, or ceramics).The main difference between an alloy and composites are constituent materials which are insoluble in each other and the individual constituents retain those properties in case of composites, where as in alloys, constituents are soluble in each other and forms a new materials which has different properties from their composites. The advanced composites materials such as Graphite, Carbon, Kevlar, Glass, with suitable resin are widely used because of their high specific strength (strength/density) and high specific modulus (modulus /density). But complex mechanical characterization, high fabrication cost and difficulty in their rework and repair are some of the limitations of composite materials.

The specific properties of composites are listed below.

- Low density
- High specific strength
- High specific modulus
- High thermal conductivity

- Good fatigue modulus
- Control of thermal expansion
- High abrasion and wear resistance

V. METHOD AND MATERIALS

A model is created with the help of computer aided drafting software, CATIA V5. The CATIA model is saved in IGES format and imported in ANSYS Workbench 16.0 for pre-processing and then static structural analysis is carried out. The Analysis involves the discretization called meshing, boundary conditions and loading. Materials taken for analysis are 50Cr1V23 steel, E-Glass/Epoxy, Carbon Epoxy, Graphite Epoxy and Kevlar Epoxy etc.

5.1 Specifications of Leaf Spring: Dimensions of Tata Sumo standard leaf spring has been taken [11], which are as follows:

Span of leaf spring (eye to eye) = 1250mm
No. of full length leaves = 2
No. of graduated leaves = 4
Thickness of leaves = 7mm
Width of leaves = 60mm
Ineffective length of spring = 110mm
Free Camber at no load conditions = 190mm
Total load = 2850kg

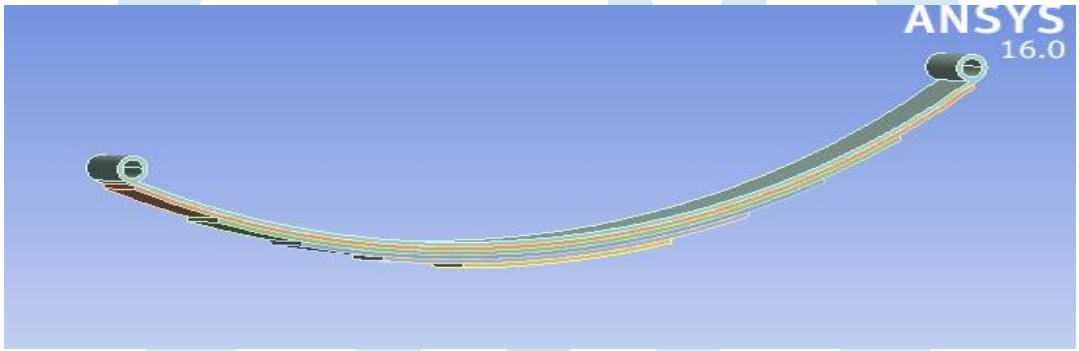

Fig: 1 – 3D CATIA model of multi-leaf spring

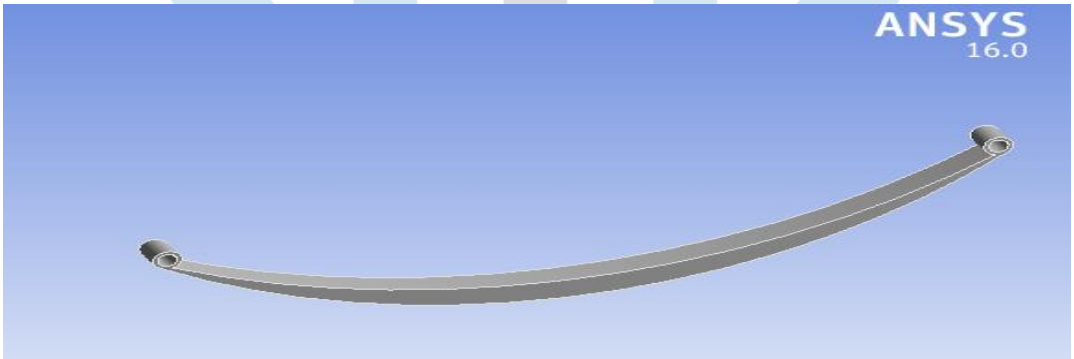

Fig: 2 - 3D CATIA model of mono leaf spring

5.2 Properties of steel leaf spring: Material selected - 50Cr1V23 [9]
Composition – 0.45% C, 0.1%-0.3% Si, 0.6%-0.9% Mn, 0.9-1.2% Cr

Parameter	Value
Young modulus	200000 Mpa
Poison ratio	0.3
BHN	534-601
Tensile strength ultimate	2000 Mpa
Tensile strength yield	1800 Mpa
density	7850 kg/m^3

Table1. Properties of steel material

Materials / Properties	E-Glass/Epoxy	Carbon Epoxy	Graphite Epoxy

Tensile modulus (E_x), Mpa	43000	177000	294000
Tensile modulus (E_y), Mpa	6500	10600	6400
Tensile modulus (E_z), Mpa	6500	10600	6400
Poisson's Ratio (V_{xy})	0.27	0.27	0.23
Poisson's Ratio (V_{yz})	0.06	0.02	0.01
Poisson's Ratio (V_{zx})	0.06	0.02	0.01
Shear Modulus (G_{xy}), Mpa	4500	7600	4900
Shear Modulus (G_{yz}), Mpa	2500	2500	3000
Shear Modulus (G_{zx}), Mpa	2500	2500	3000
Density, kg/mm^3	0.000002	0.0000016	0.0000015

Table2. Properties of composite material [10]

VI. ANALYTICAL CALCULATIONS:

Maximum capacity = 2850 kg = 28500N
Tata sumo is equipped with 4 no. of leaf spring.
So load acting on each leaf spring 2W = 28500/4 = 7125N
Thickness of leaves = 7mm
Width of leaves = 60mm
Span length = 1250mm
Bending stress generated in leaf spring, $\sigma_{max} = 6WL/nbt^2 = (6*3562.5*625)/(6*60*7^2)$

$\sigma_{max} = 757.334$ N/mm^2

Maximum deflection of leaf spring, $y_{max} = 6WL^3/nEbt^3 = (6*3562.5/625^3)/(6*200000*60*7^3)$

$y_{max} = 181.12$ mm

From theoretical analysis we got maximum stress is 757.334Mpa which is lower than allowable design (1800Mpa) stress so our design is safe.

VII. ANALYSIS Of LEAF SPRING

1) Material – Steel 50Cr1V23

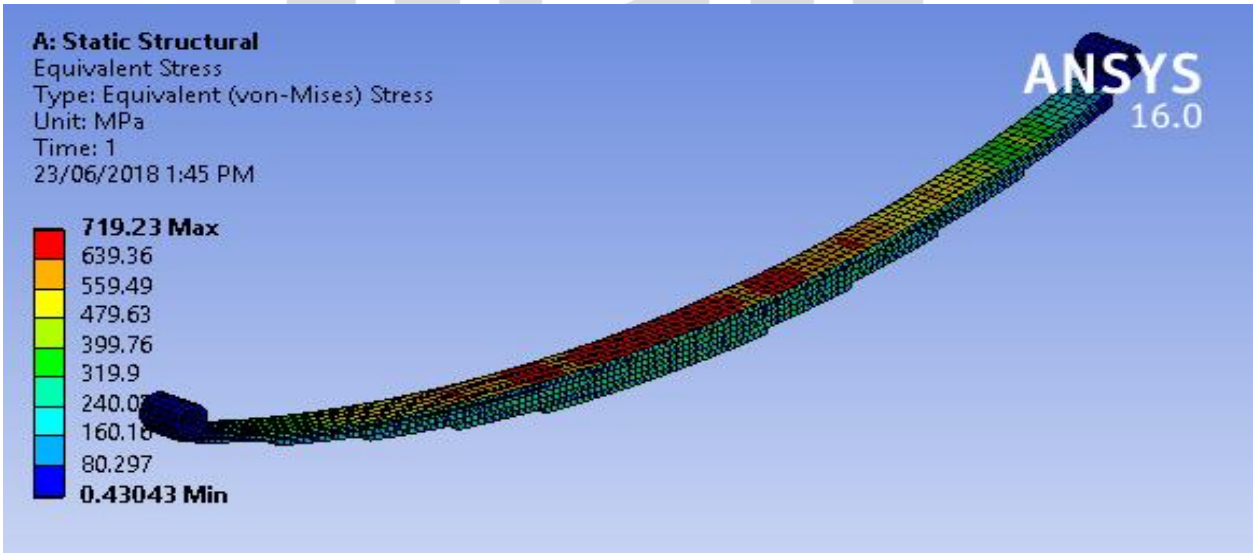

Fig.3 - Equivalent stress in steel multi-leaf spring at maximum load of 7125N

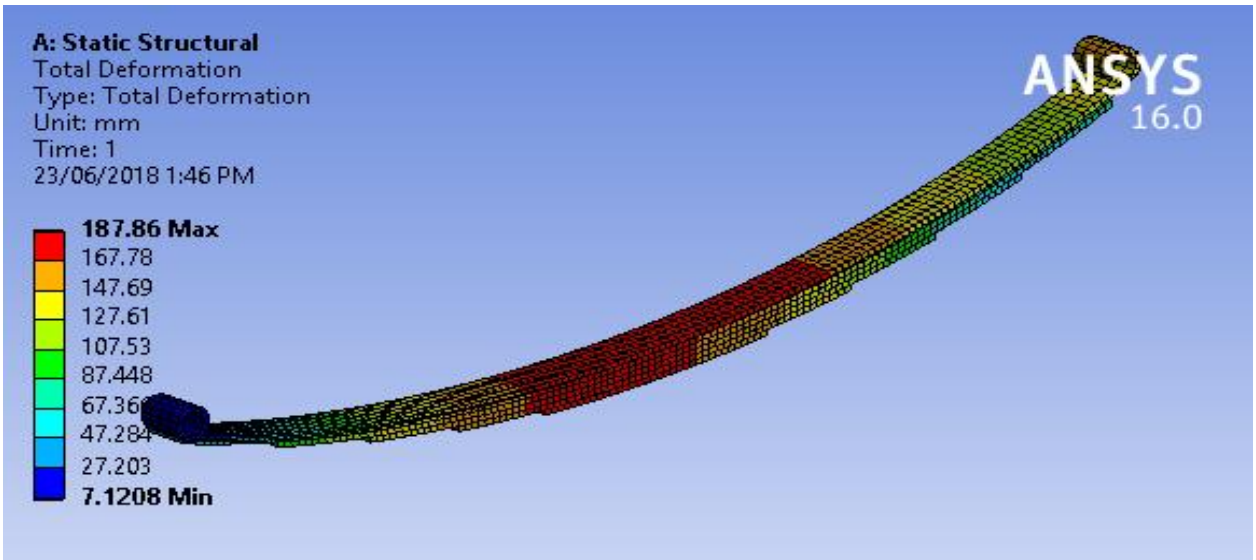

Fig. 4- Total deformation of steel multi-leaf spring at maximum load of 7125N

Result table for analytical and ANSYS based results for steel leaf spring –

Parameter	Analytical results	Static analysis results	Percentage variation
Maximum stress (Mpa)	757.334	719.23	5.03%
Maximum deflection (mm)	181.12	187.86	3.72%

Table3. Comparison of analytical and ANSYS based results for steel leaf spring

From above table we can see that percentage variations in analytical and software based results for steel leaf spring are negligible hence our model is validated.
Now we will do analysis of composite multi-leaf spring and composite mono leaf spring (42mm thick at centre and 7mm thick at eye end) under same applied load.

2) Material – E-Glass/Epoxy

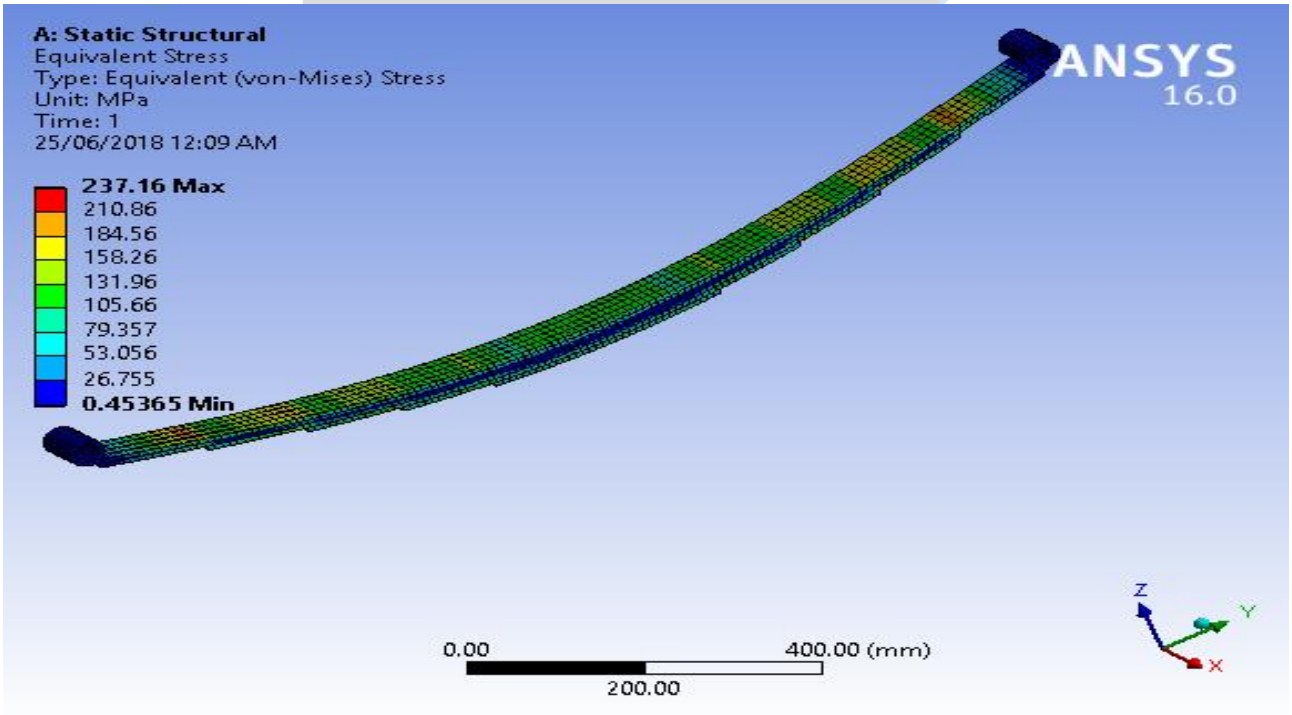

Fig.5 – Equivalent stress in E-Glass/Epoxy multi-leaf spring at maximum load of 7125 N

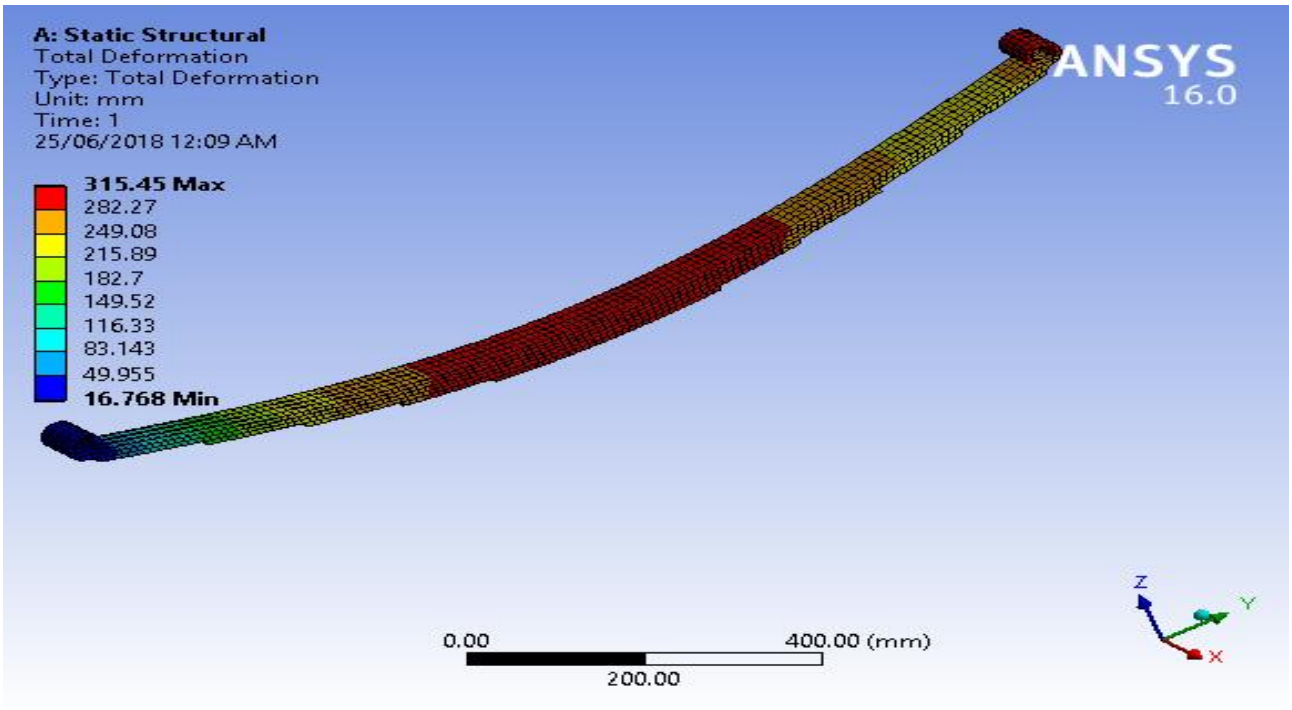

Fig.6 – Total deformation of E-Glass/Epoxy multi-leaf spring at maximum load of 7125N

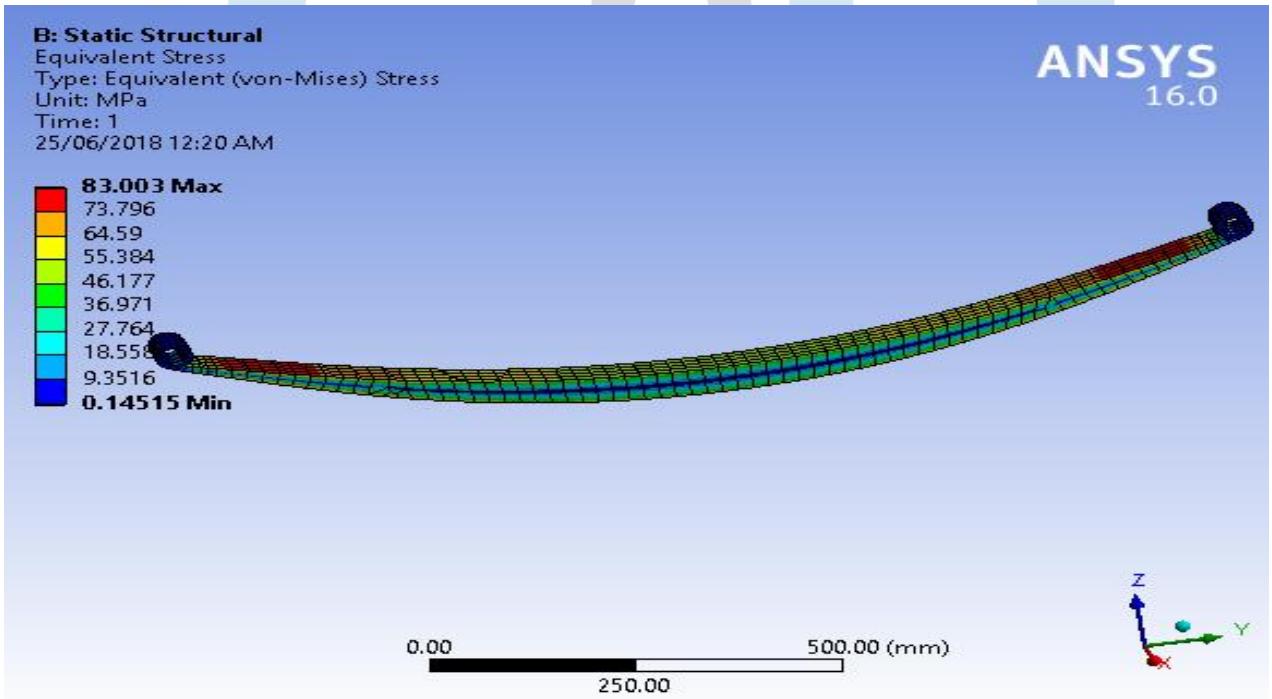

Fig.7 – Equivalent stress in E-Glass/Epoxy mono leaf spring at maximum load of 7125 N

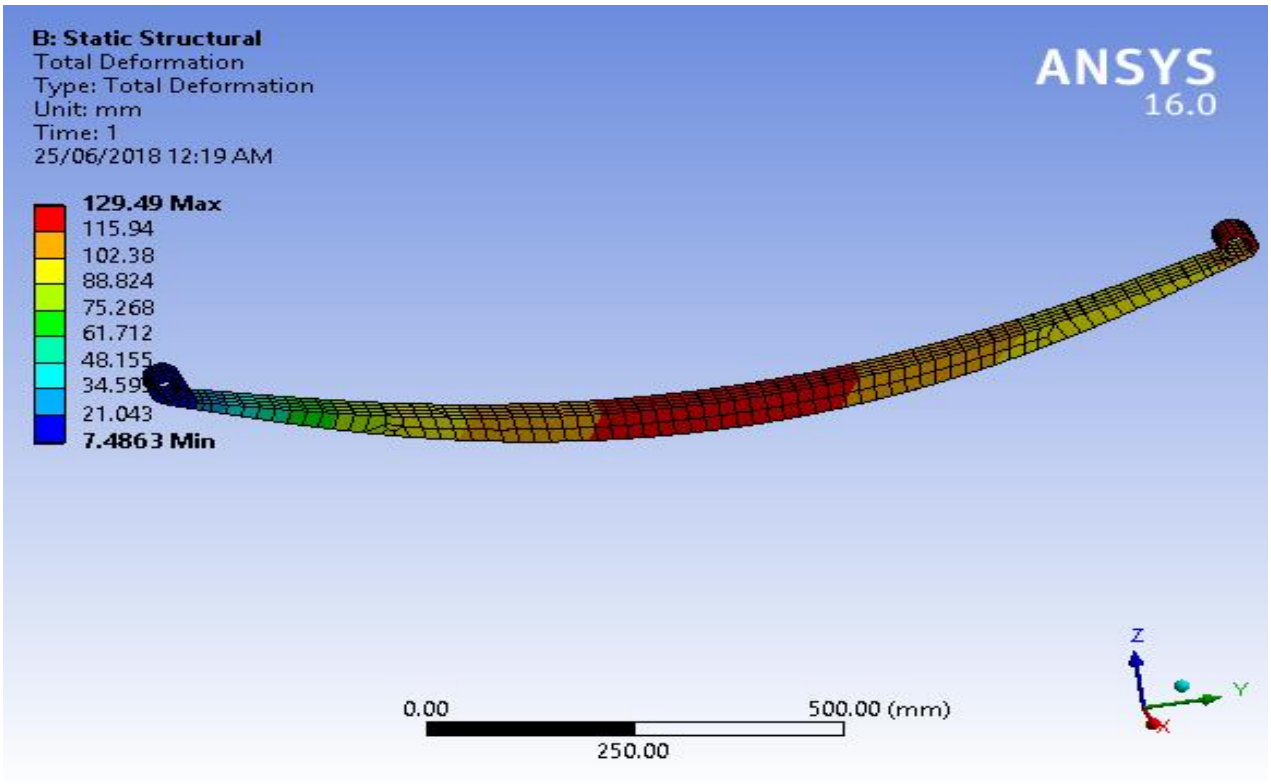

Fig.8 – Total deformation of E-Glass/Epoxy mono leaf spring at maximum load of 7125N

3) Material – Carbon Epoxy

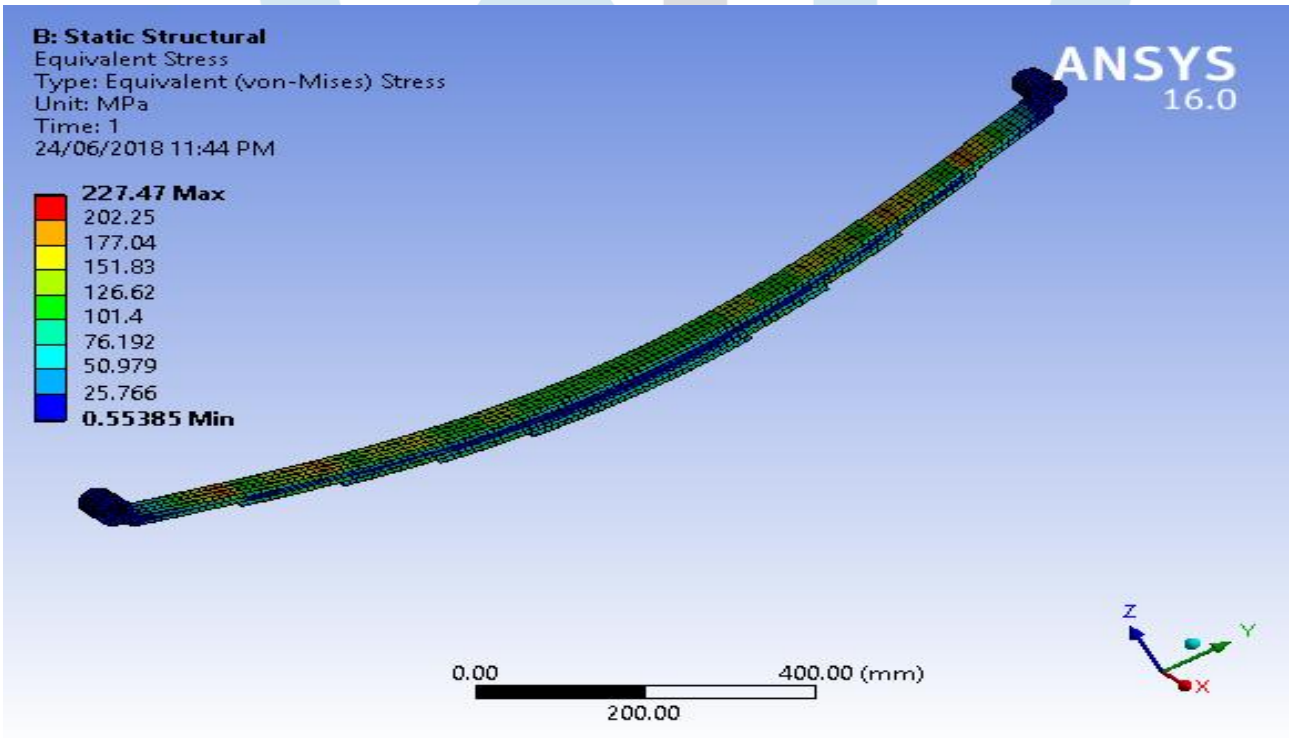

Fig.9 – Equivalent stress in Carbon Epoxy multi-leaf spring at maximum load of 7125 N

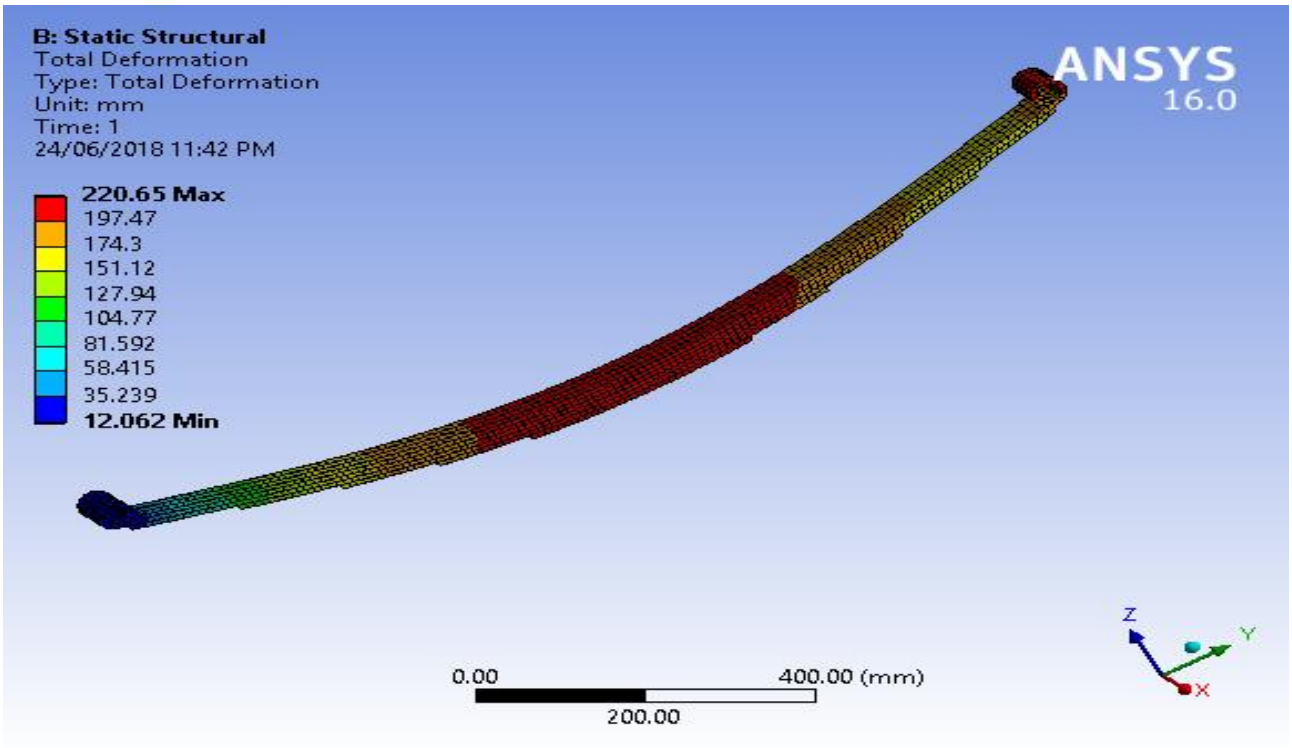

Fig.10 – Total deformation of Carbon Epoxy multi-leaf spring at maximum load of 7125N

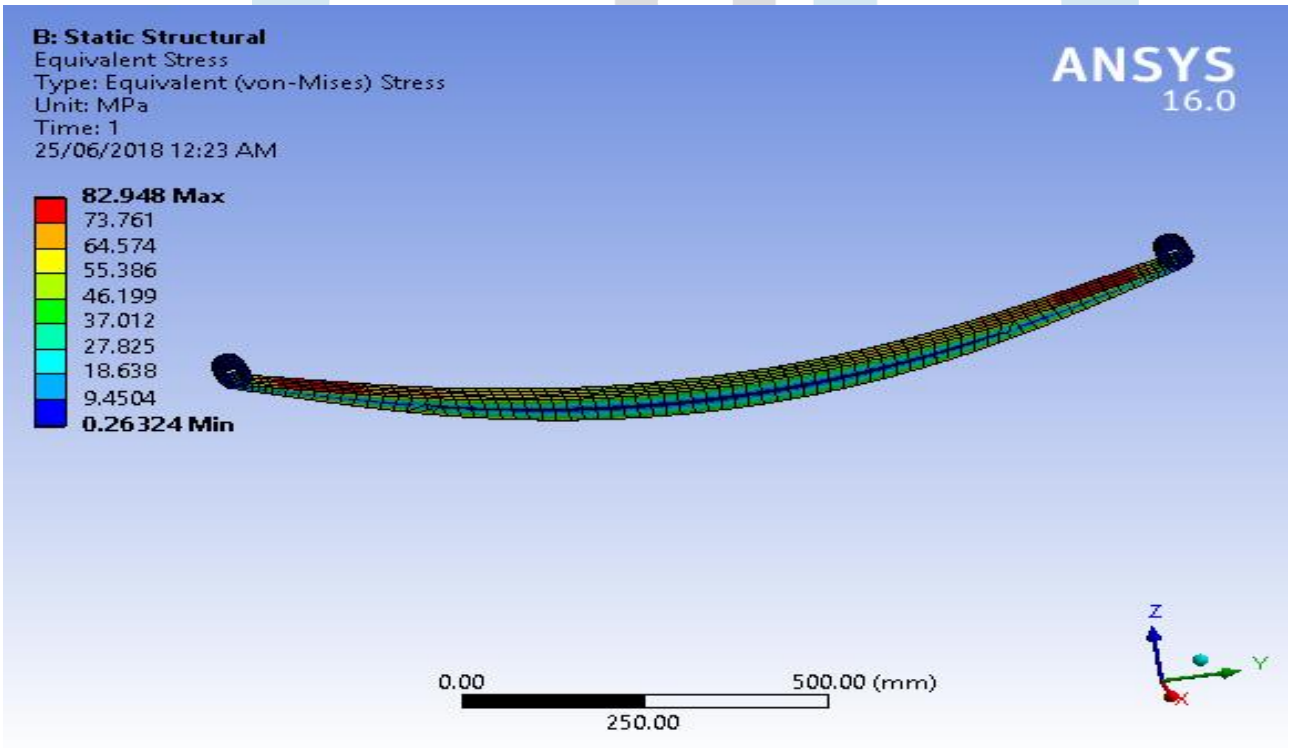

Fig.11 – Equivalent stress in Carbon Epoxy mono leaf spring at maximum load of 7125 N

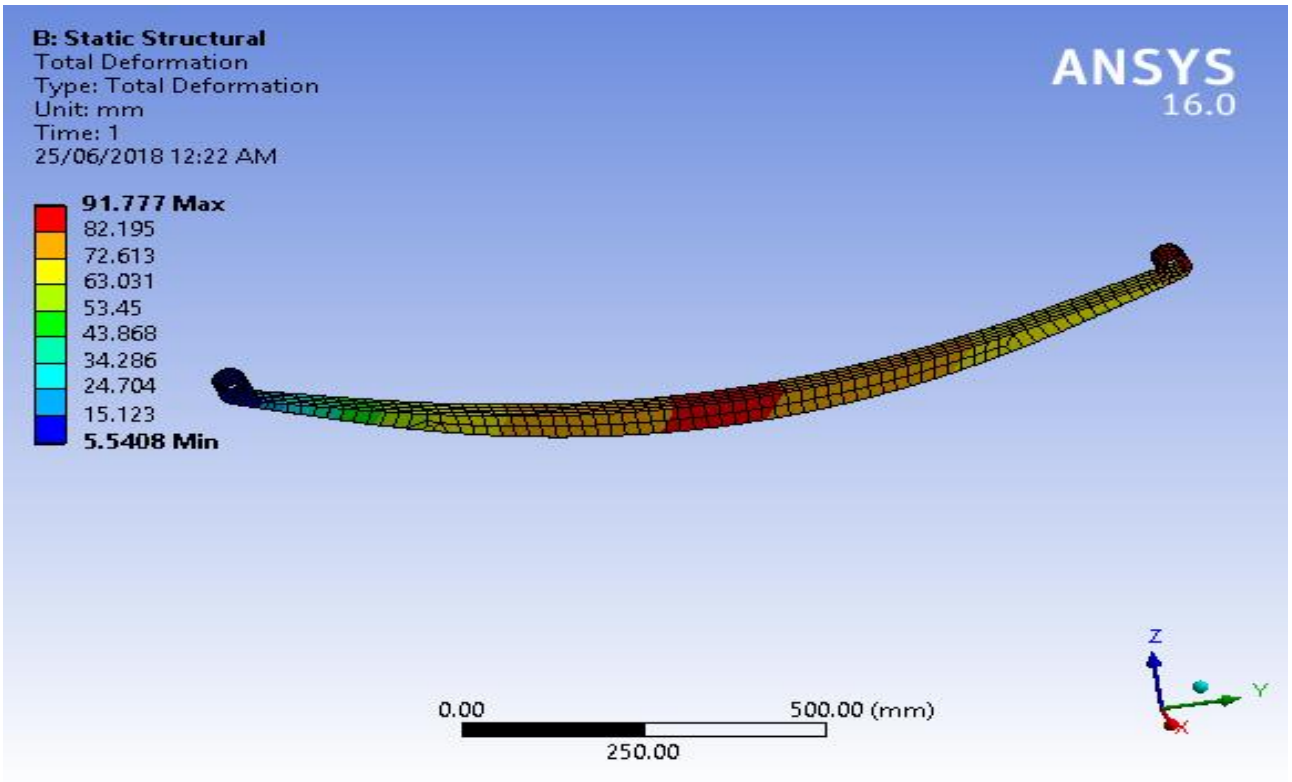

Fig.12 – Total deformation of Carbon Epoxy mono leaf spring at maximum load of 7125N

4) Material – Graphite epoxy

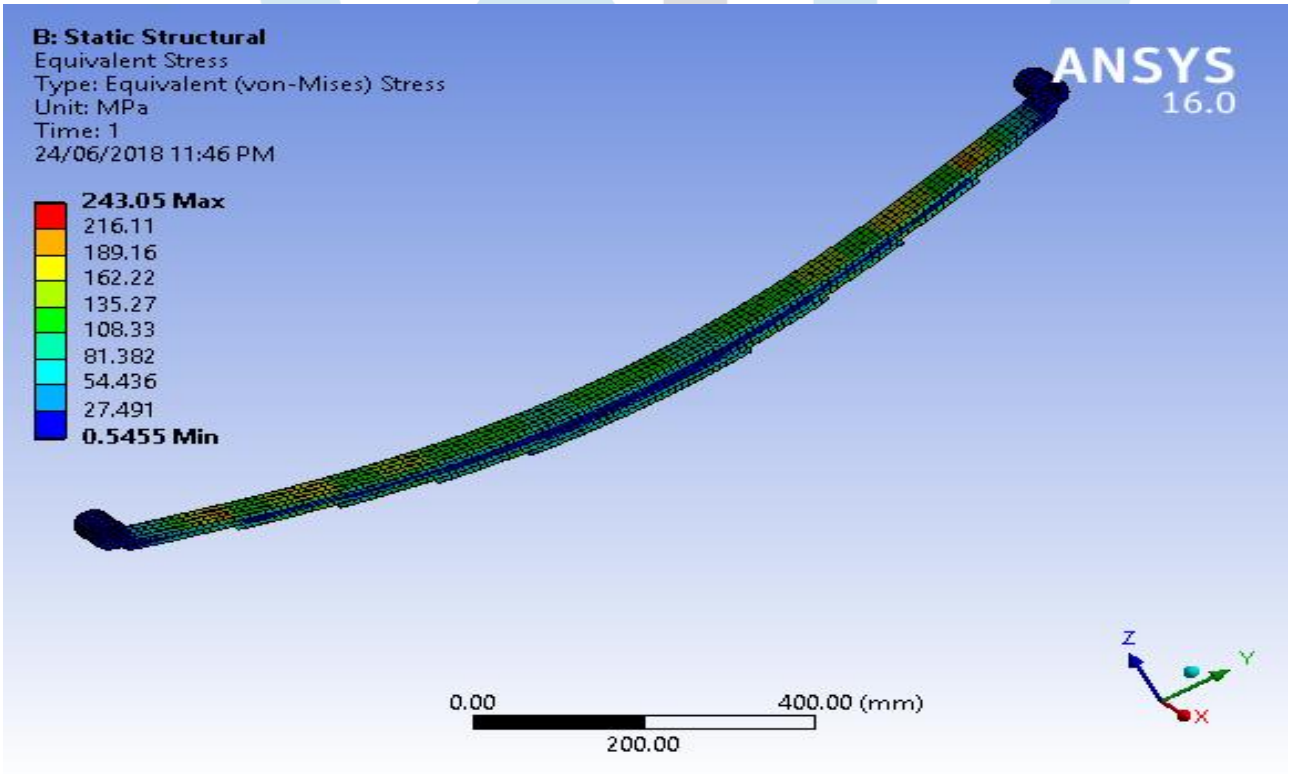

Fig.13 – Equivalent stress in Graphite Epoxy multi-leaf spring at maximum load of 7125 N

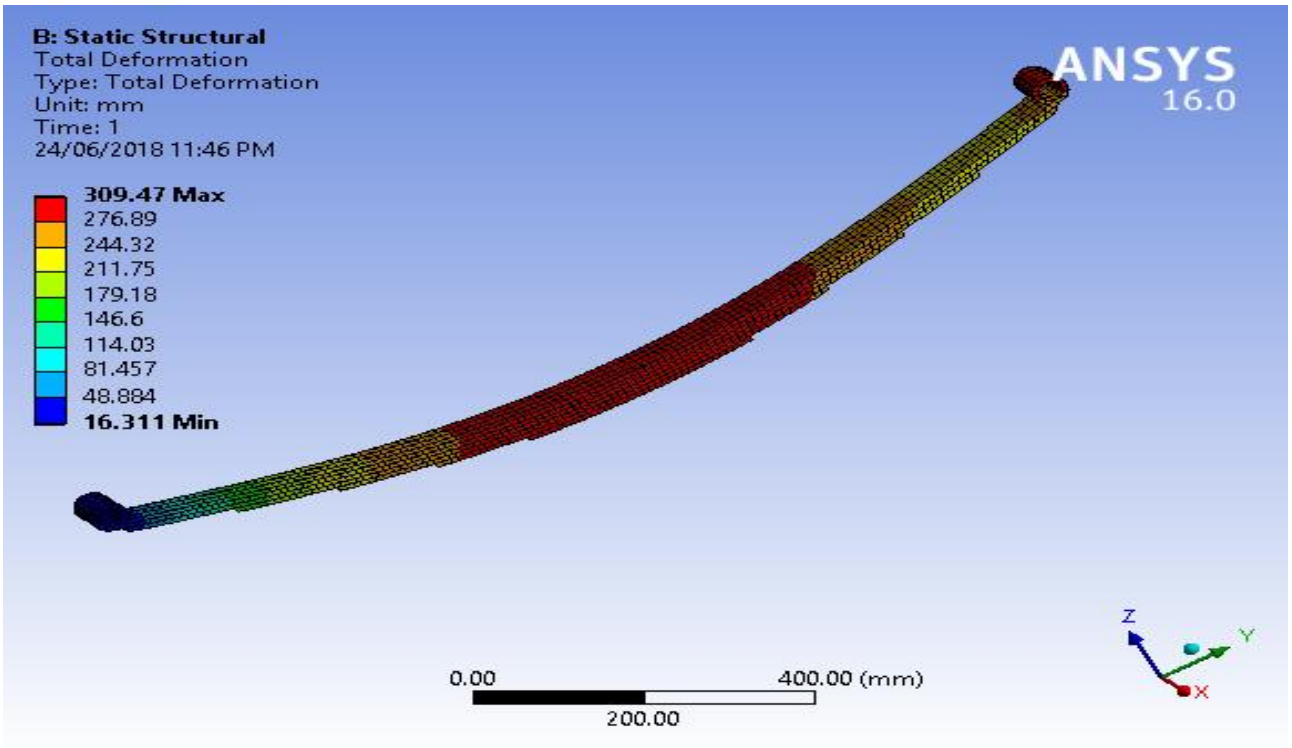

Fig.14 – Total deformation of Graphite Epoxy multi-leaf spring at maximum load of 7125 N

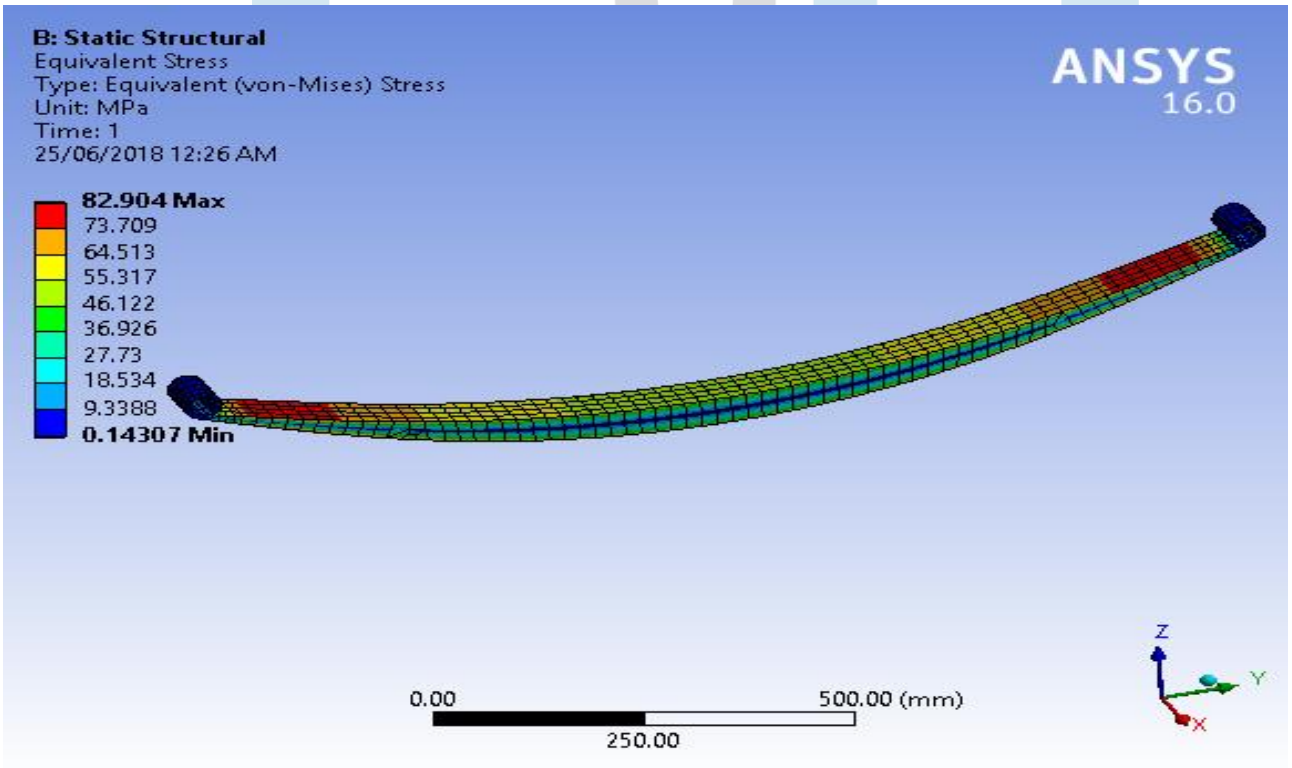

Fig.15 – Equivalent stress in Graphite Epoxy mono leaf spring at maximum load of 7125 N

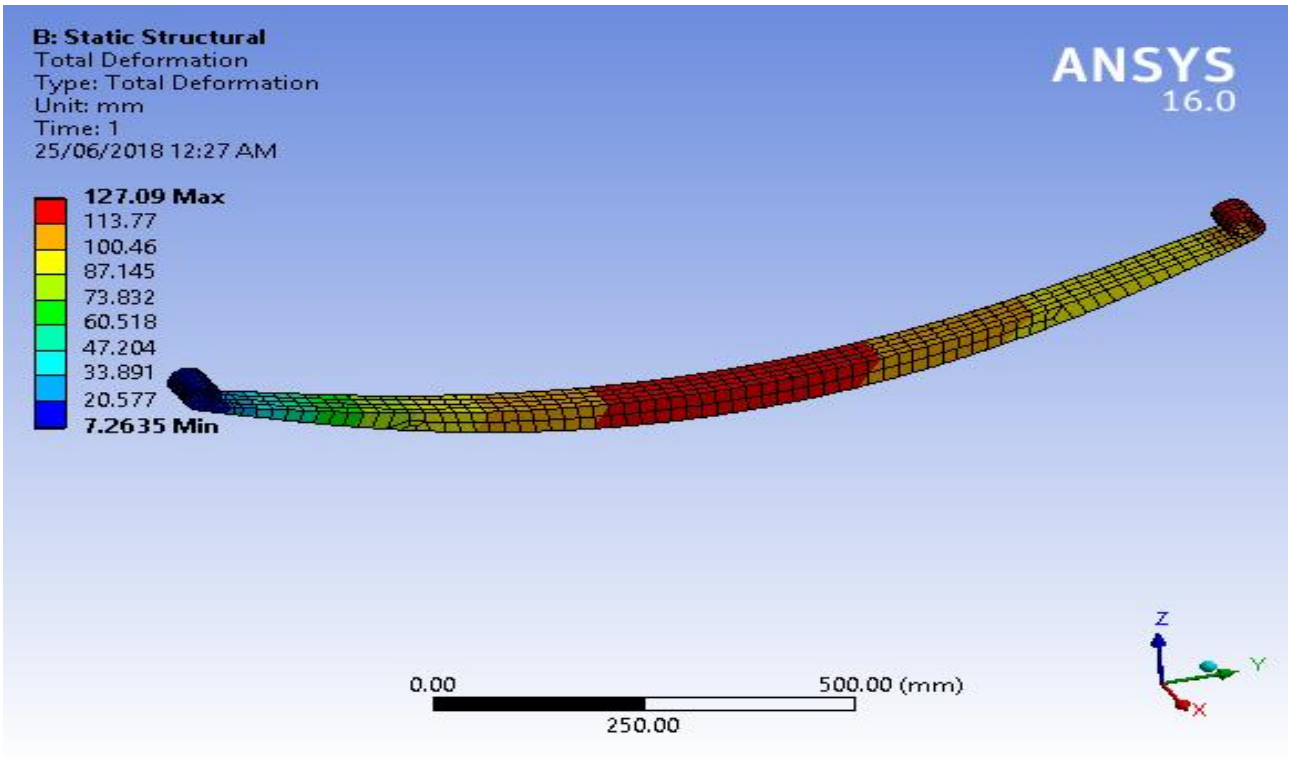

Fig.16 – Total deformation of Graphite Epoxy mono leaf spring at maximum load of 7125 N

5) **Hybrid leaf spring** (master leaf 1 &2 – carbon epoxy, leaf 3,4,5 & 6 – steel 50Cr1V23)

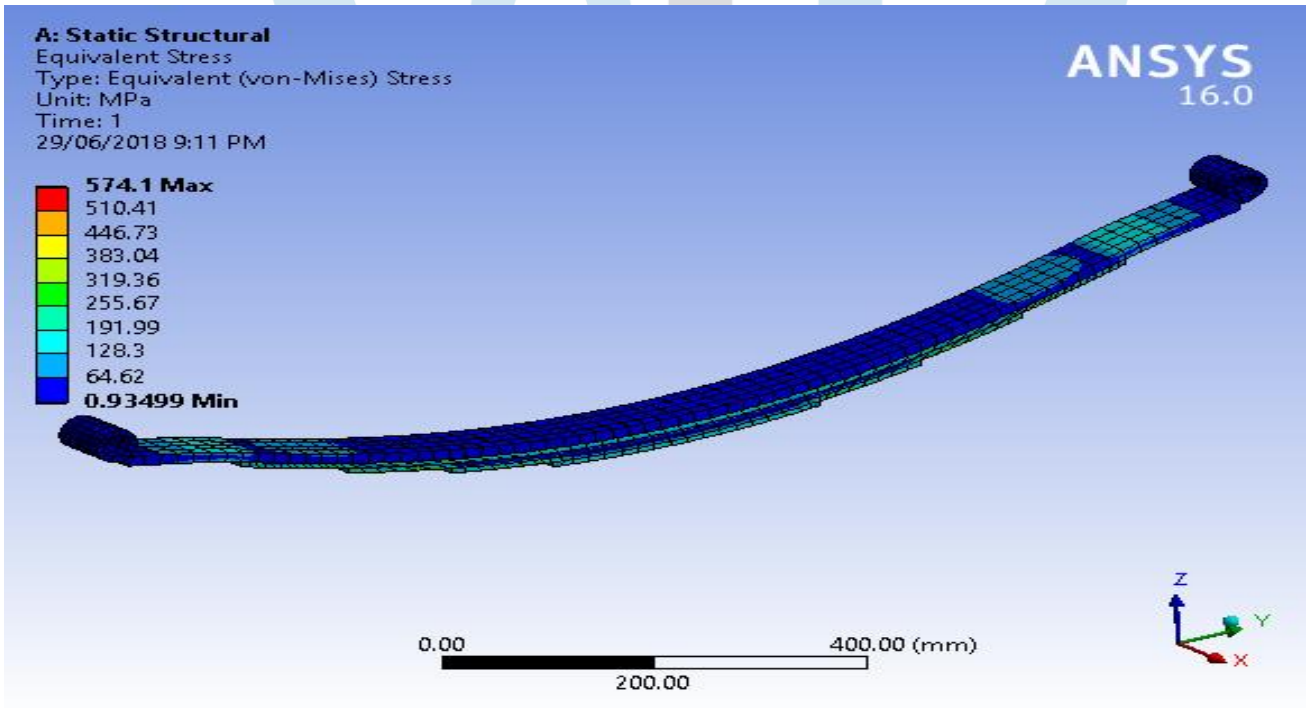

Fig. 17 - Equivalent stress in hybrid leaf spring at maximum load of 7125 N

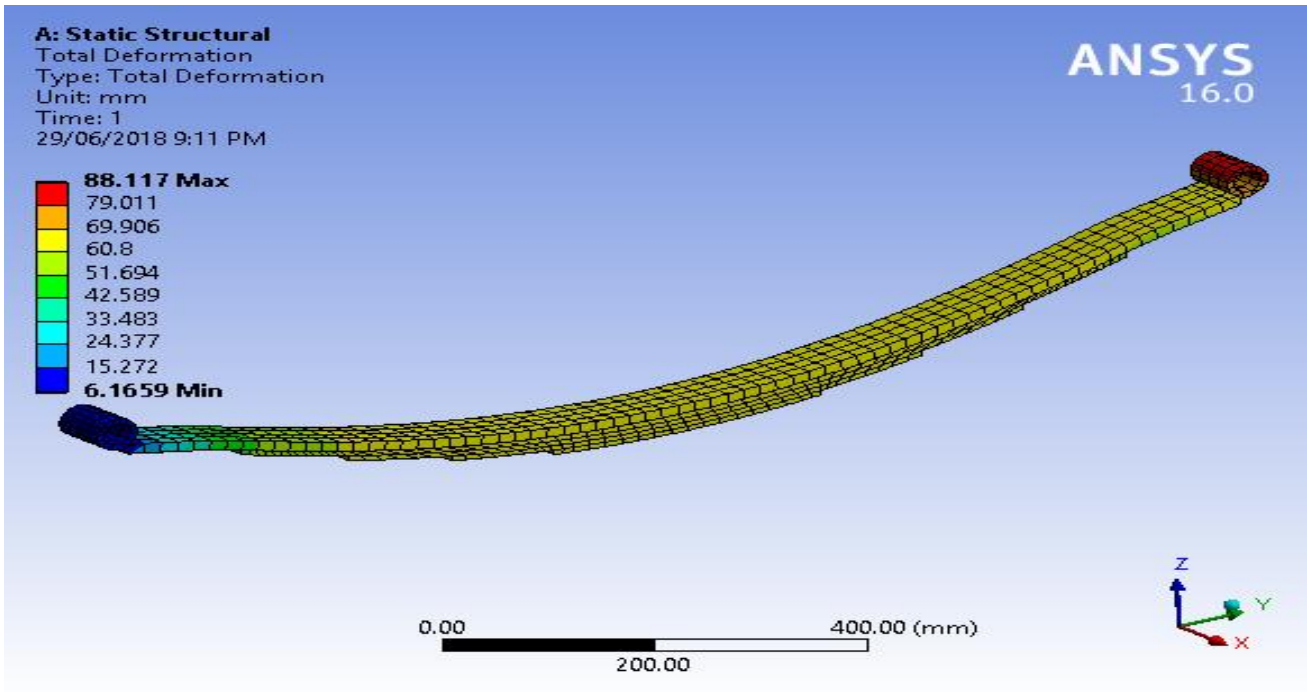

Fig. 18 – Total Deformation in hybrid leaf spring at maximum load of 7125 N

VIII. RESULTS:

8.1 Static Structural analysis

Parameters / Metal	Equivalent stress (Mpa)	Total deformation (mm)	Weight (Kg)	Percentage weight saving
Steel 50Cr1V23 (multi-leaf)	719.23	187.86	18.331	-
E-Glass/Epoxy (multi-leaf)	237.16	315.45	4.6703	74.52%
Carbon Epoxy (multi-leaf)	227.47	220.65	3.7363	79.61%
Graphite Epoxy (multi-leaf)	243.05	309.47	3.5027	80.89%
E-Glass/Epoxy (mono leaf)	83.003	129.49	5.3871	70.61%
Carbon Epoxy (mono leaf)	82.948	91.777	4.3097	76.48%
Graphite Epoxy (mono leaf)	82.904	127.09	4.0403	77.95%
Carbon epoxy + steel (Hybrid leaf spring)	574.1	88.117	10.819	40.97%

IX. CONCLUSION

A lot of research work has been carried out in the context of leaf spring considering its material and a significant progress has been observed in the field of weight reduction, improvement of load carrying capacity when we replace the material of the spring by any advanced material like composites as E-glass/epoxy, carbon/epoxy etc. From the static analysis results it is found that all the

composite material shows better result as compared to conventional steel leaf spring, although when we use multi-leaf spring of composite material, deflection is found to be quite high as compared to steel leaf spring. But when we use mono leaf spring of composite material, stresses and deflections are found to be very low as compared to steel leaf spring and weight saving of around 75% is achieved. Overall Carbon epoxy mono leaf spring is found to have best results among all the leaf springs with respect to strength, deflection and weight saving. Hence we can conclude that composite materials are better replacement for conventional steel leaf spring. A new combination of steel and composite leaf springs (hybrid leaf springs) are used and given the same static loading and From the static analysis results it is found that it have values of stresses and weight in between that of steel and composite leaf springs while the value of deflection in hybrid leaf is lower in comparison of conventional steel leaf spring and composite leaf spring .As we know that composite material are costly in comparison to convention steel, so hybrid leaf spring can be suggested to use from economic point of view which utilizes combination of both conventional steel and composites material leaves.

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