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Design and Static Structural Analysis of Leaf Spring using FEA

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Abstract: A spring is an elastic machine element which deforms under the application of load and tends to regain its original shape upon removal of load. In modern scenario Automobile Industry has shown a lot of interest in reducing weight of the vehicle. The suspension leaf spring is one of the potential items for the weight reduction in Automobiles. Introduction of composite materials made it possible to reduce the weight of leaf spring without losing load carrying capacity since they have high strength to weight ratio.In this research work standard existing multi-leaf spring is modeled in CatiaV5 and analysis is carried out by using ANSYS16.0. The theoretical and software based results are presented and compared for validation. 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.
Keyword: Leaf spring, Static analysis, Composite, Ansys, Catia.

I. INTRODUCTION

A 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. Nearly 20% of un-sprung mass of the vehicle is usually leaf spring assembly which makes it attractive option for weight reduction study for the design improvements. 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.

Reducing weight while increasing or maintaining strength of products is getting to be highly important research issue in this modern world. Composite materials are one of the material families which are attracting researchers and being solutions of such issue.

The leaf spring should absorb the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection so that the potential energy is stored in spring as strain energy and then released slowly. So, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system. According to the studies made a material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring. Fortunately, composites have these characteristics and have high strength to weight ratio.

II. LITERATURE REVIEW

A. 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.

B. MouleeswaranSenthilkumar, SabapathyVijayarangan

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.

C. RohitGhosh, SushovanGhosh and ShirishGhimire

Average cost of E-Glass that can be used to manufacture the springs very high as compared to steel leaf spring, hence, ifthe 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.

D. PinaknathDewanji

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.

E. P Sai Krishna

In this paper design and analysis of leaf spring is done. Modeling of leaf spring is done in solidworks 2016 design software. First 4mm thickness leaf spring then 5 and 6mm are modeled. The models are saved as igs files to import in ansys. By analysis It is concluded that already 6mm thickness is existing by we reduced it to 5mm and 4mm by varying the thickness reduction in weight occurred from the analysis carbon steel material for 5mm thickness is showing less stress compared to 4mm thickness leaf spring. Leaf spring containing 4mm thickness undergone maximum stress though the weight reduction is maximum but stability to oppose the load is low but 5mm thickness leaf spring got the values nearer to 6mm and it has low weight compared to 6mm leaf spring. Author has concluded that the leaf spring containing 5mm thickness applied with carbon steel material is showing best results.

III. SCOPE OF PRESENT WORK

In thepresent 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 spring to determine the best one.

The objectives of this study are:

A. To develop 3D CAD model of Leaf Spring.
B. To study the behavior of different material of leaf spring under static analysis.
C. To calculate the total deformation and stressdeveloped in steel multi-leaf spring, composite multi-leaf spring, composite mono leaf spring and hybrid multi leaf spring under same loading conditions.
D. To compare all the results and conclude a best material.

IV. 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.

A. Specifications of Leaf Spring: Dimensions of Tata Sumo standard leaf spring has been taken [7], 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

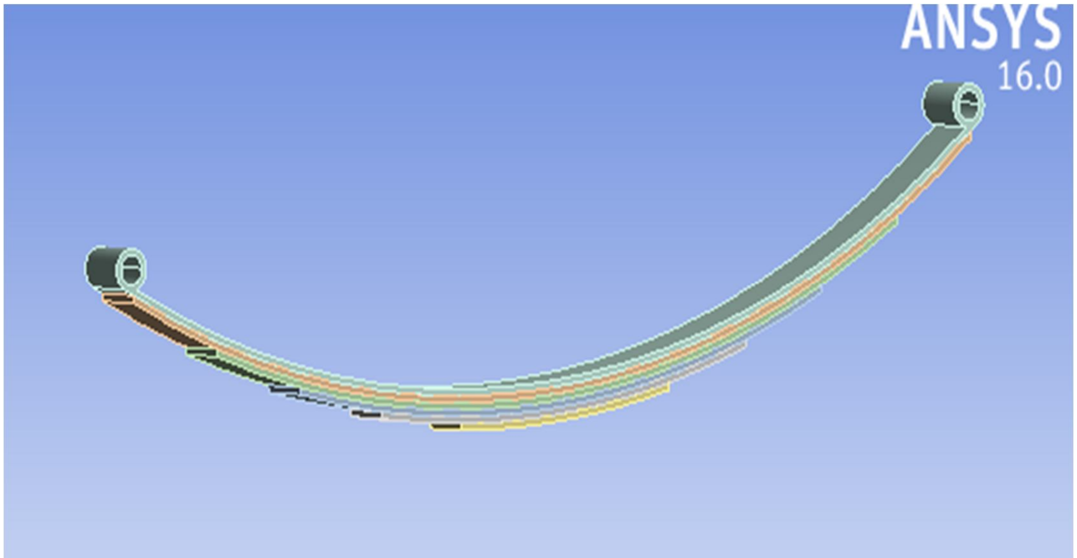

Fig: 1 – 3D CATIA model of multi-leaf spring

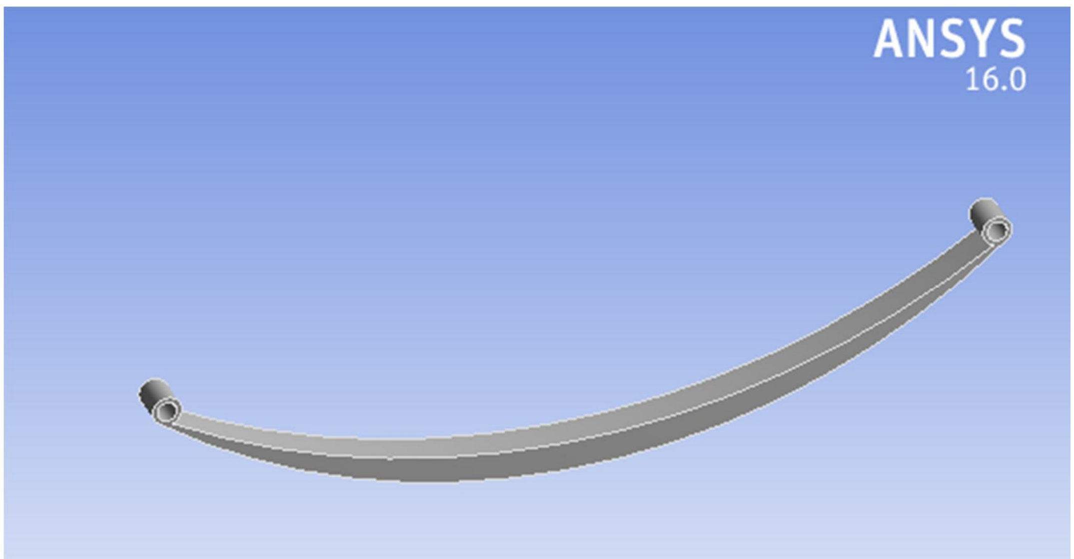

Fig: 2 - 3D CATIA model of mono leaf spring

B. Properties of Steel Leaf Spring: Material selected - 50Cr1V23 [5]

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 [6]

V. 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, $y_{max} = 12WL^3/ [Ebt^3 (2n_g+3n_f)] = (12*3562.5/625^3) / (200000*60*7^{3*}*14)$
$y_{max} = 181.12$ mm
From theoretical analysis we got maximum stress is 712.91Mpa which is lower than allowable design (1800Mpa) stress so our design is safe.

VI. ANALYSIS OF LEAF SPRING

A. Material – Steel 50Cr1V23

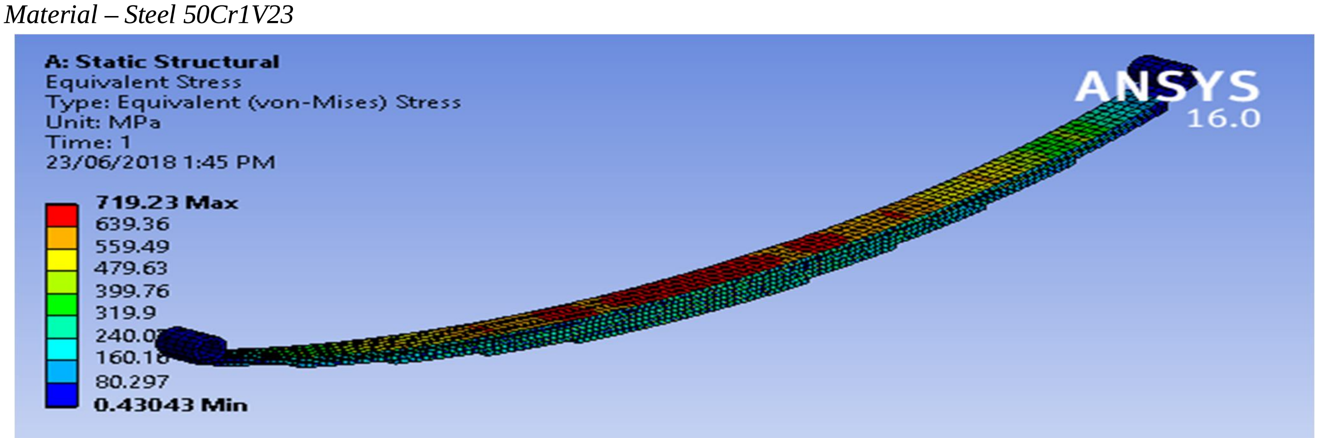

Fig.3 - Equivalent stress in steel multi-leaf spring at maximum load of 7125N

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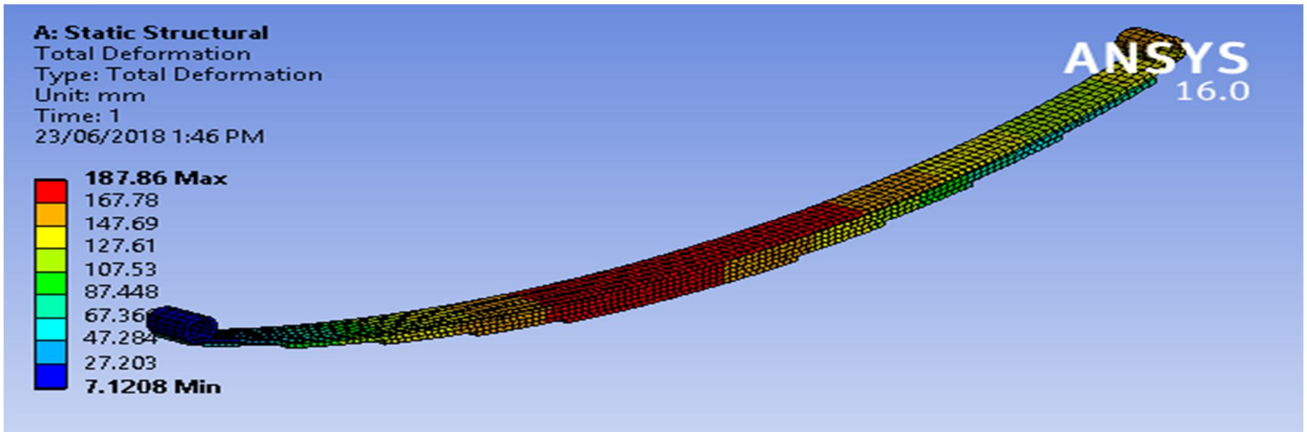

Fig. 4- Total deformation of steel multi-leaf spring at maximum load of 7125N

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.

B. Material – E-Glass/Epoxy

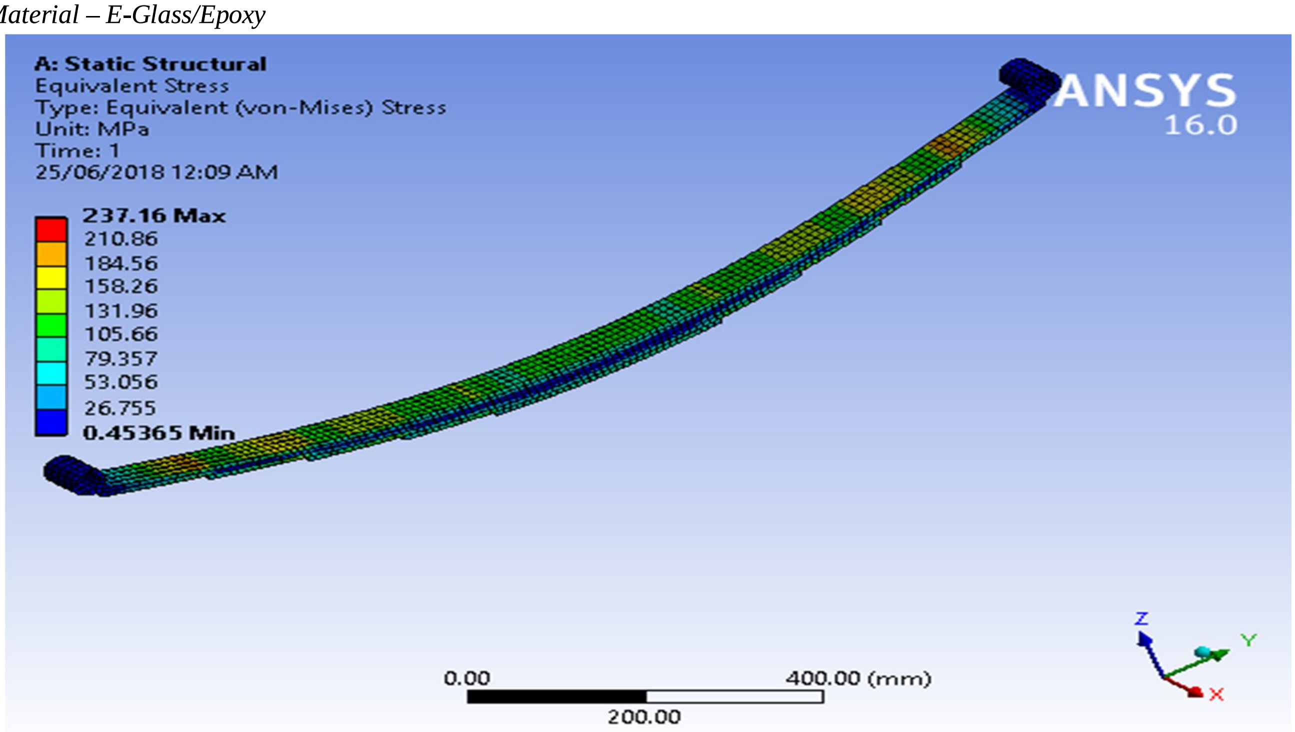

Fig.5 –Equivalent stress in E-Glass/Epoxy multi-leaf spring at maximum load of 7125 N

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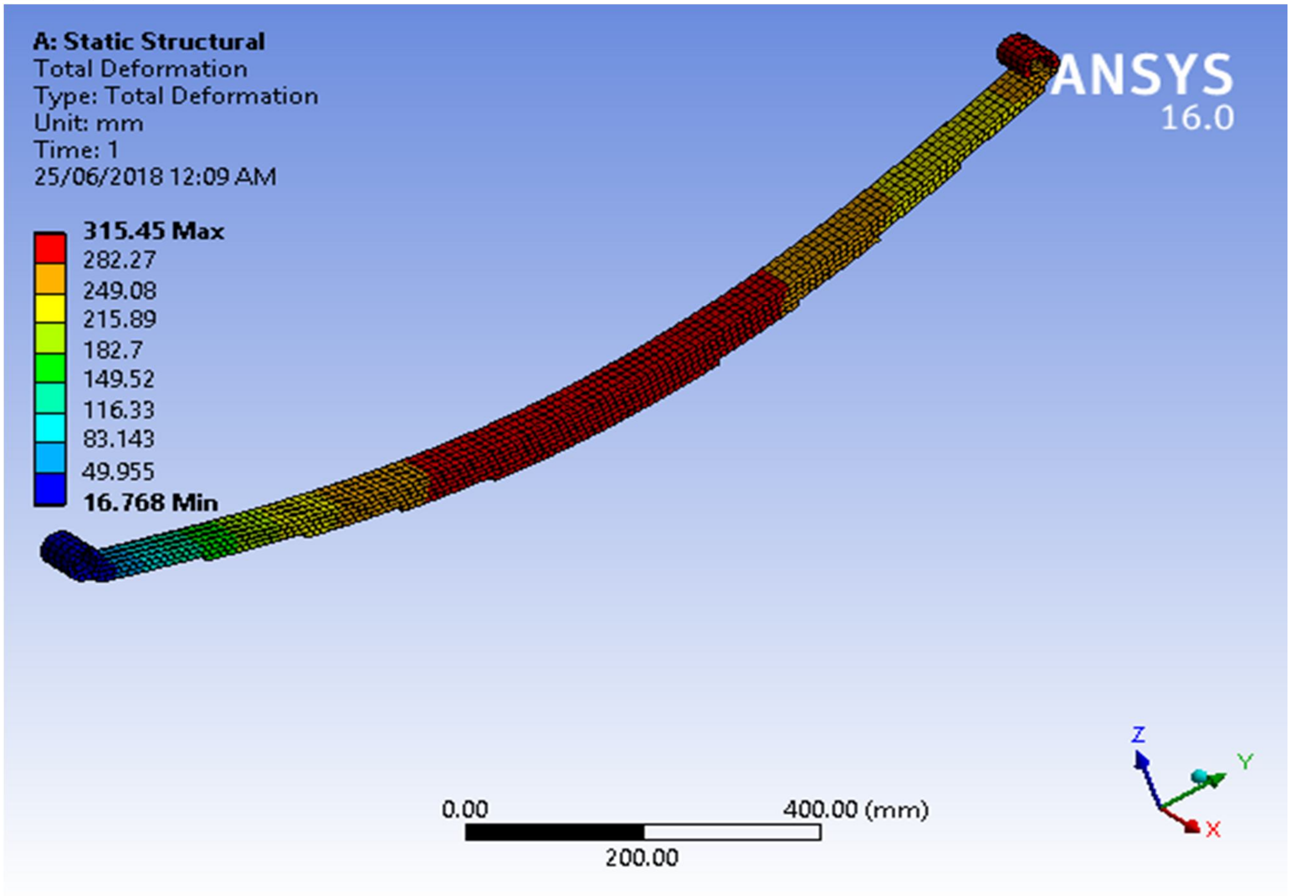

Fig.6 – Total deformation of E-Glass/Epoxy multi-leaf spring at maximum load of 7125N

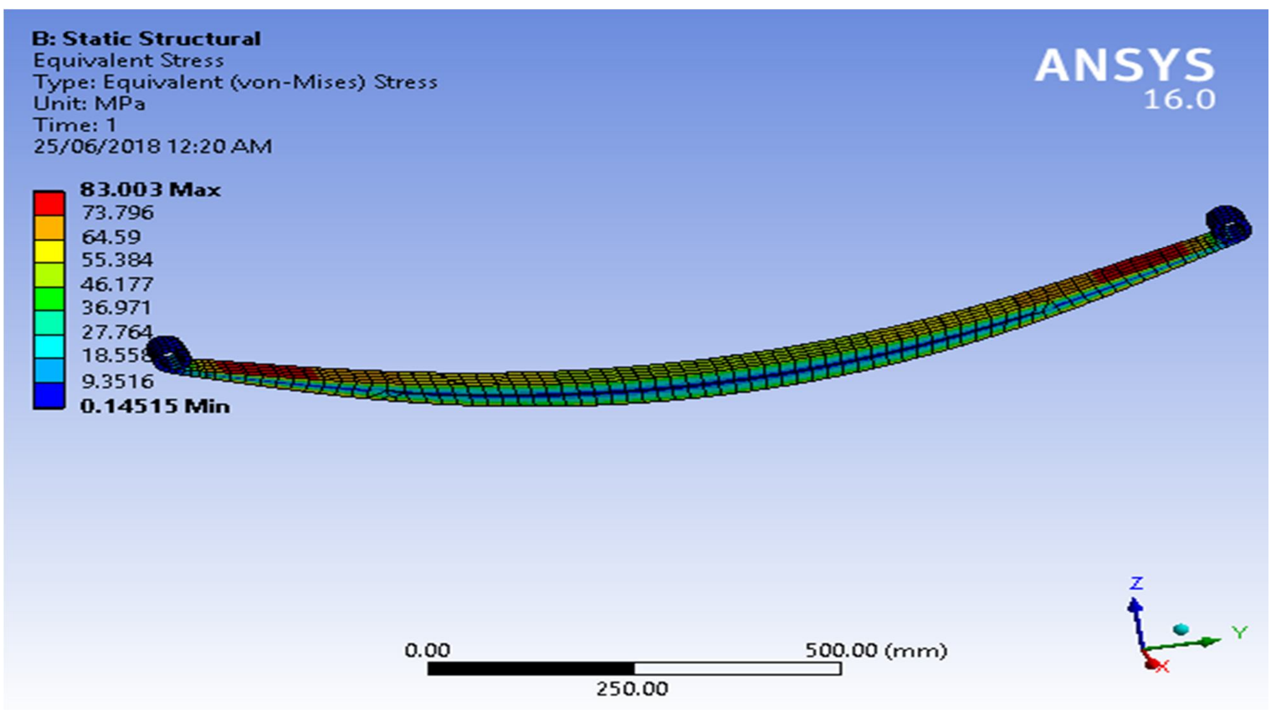

Fig.7 –

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

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Volume 6 Issue VI, June 2018- Available at www.ijraset.com

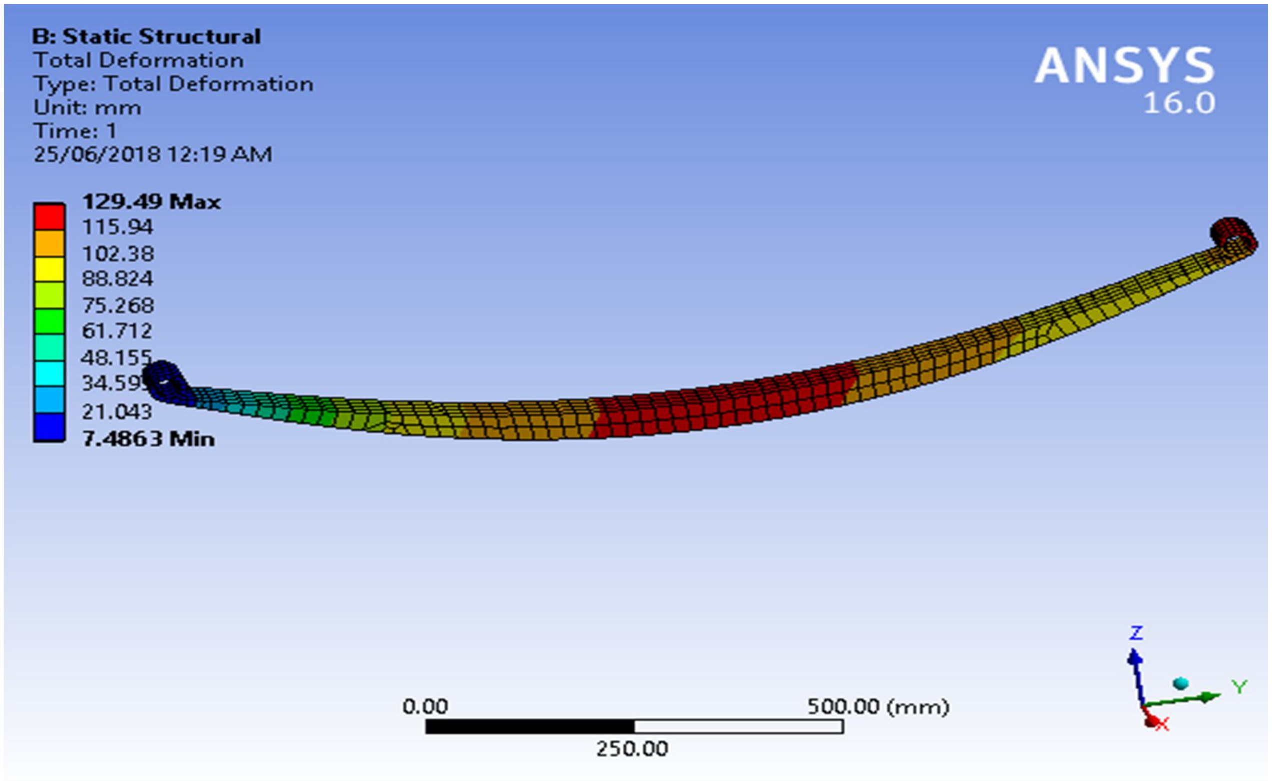

Fig.8 – Total deformation of E-Glass/Epoxy mono leaf spring at maximum load of 7125N

C. Material – Carbon Epoxy

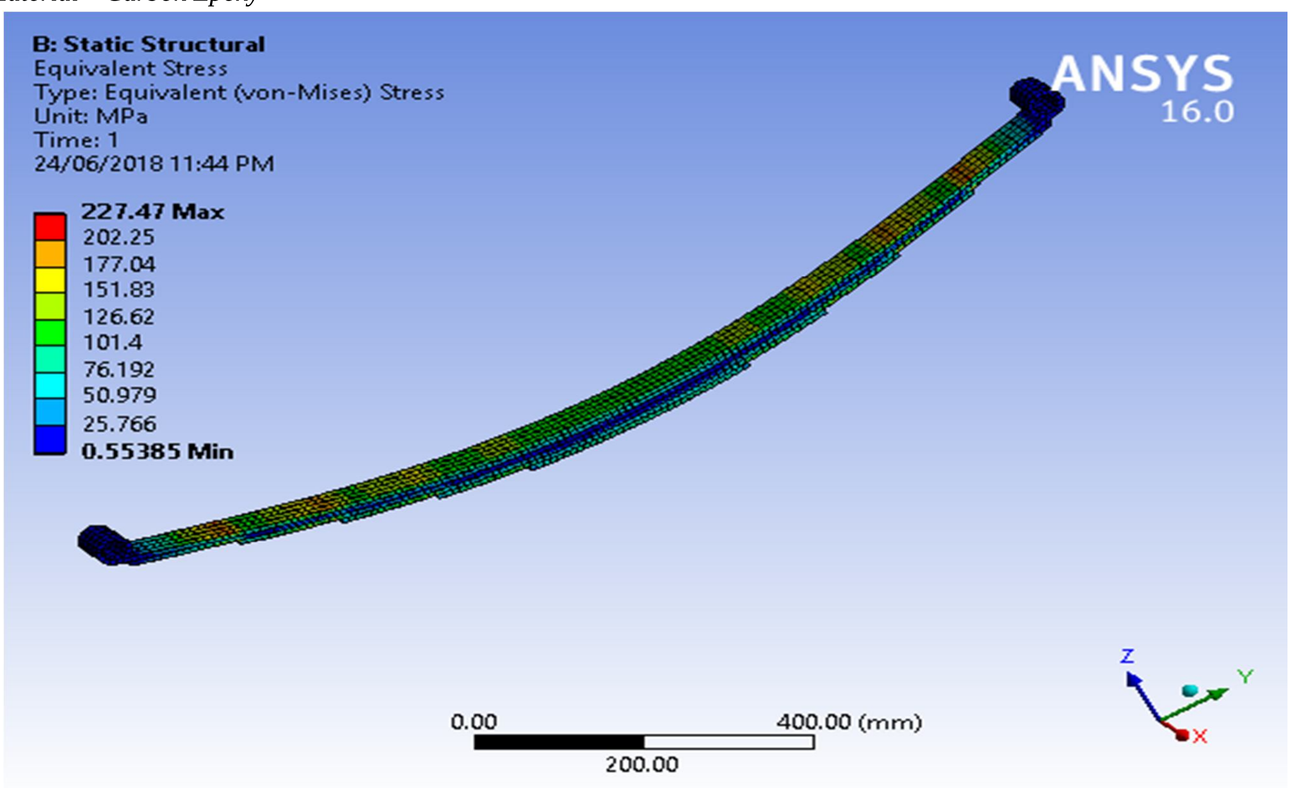

Fig.9 – Equivalent stress in Carbon Epoxy multi-leaf spring at maximum load of 7125 N

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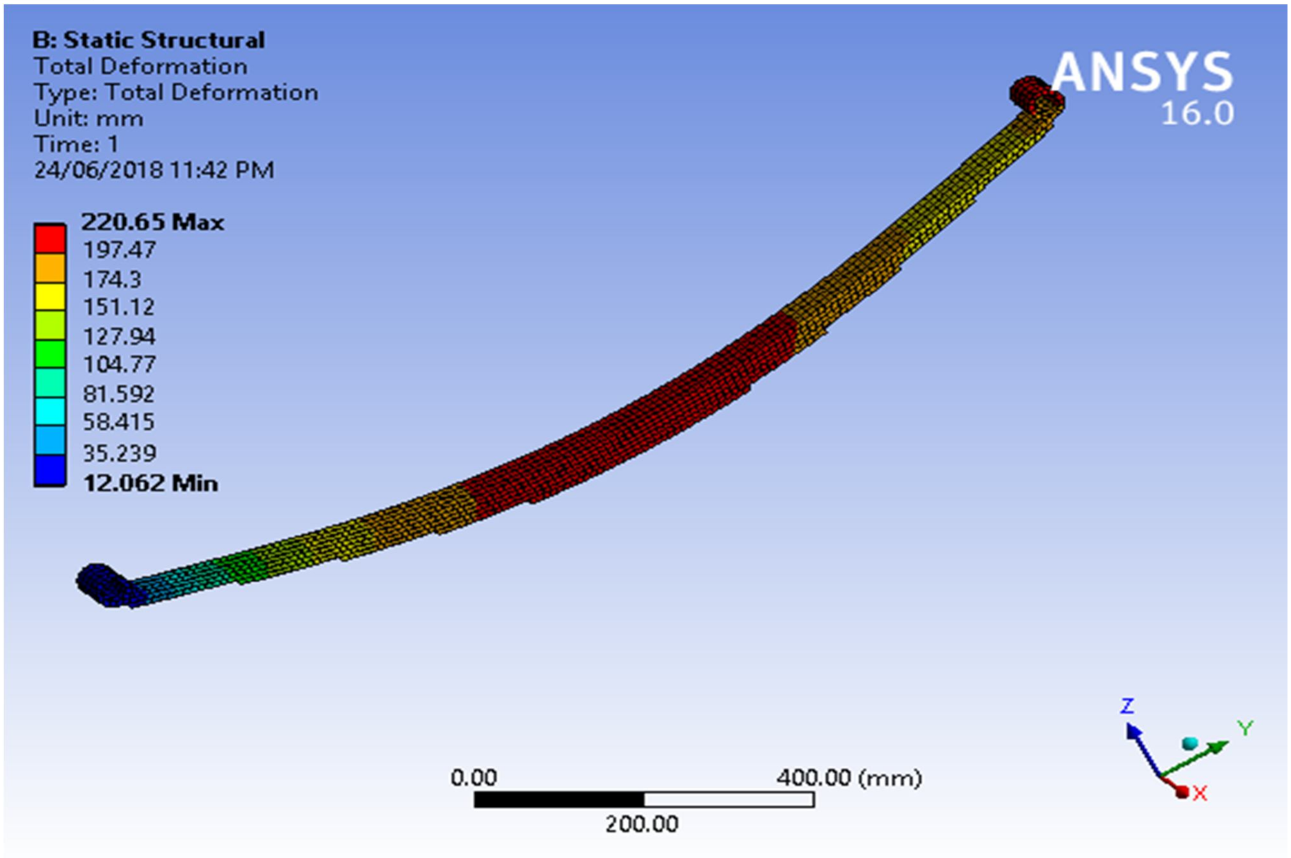

Fig.10 – Total deformation of Carbon Epoxy multi-leaf spring at maximum load of 7125N

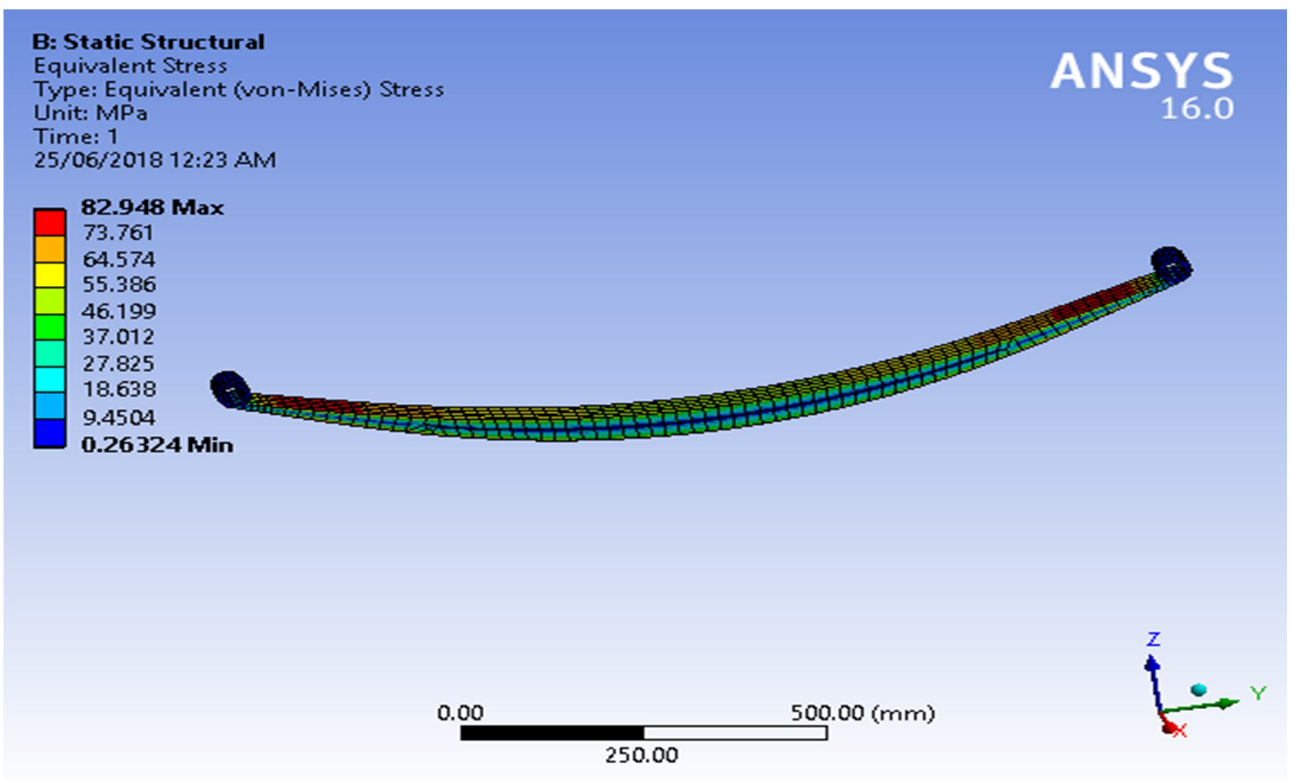

Fig.11 – Equivalent stress in Carbon Epoxy mono leaf spring at maximum load of 7125 N

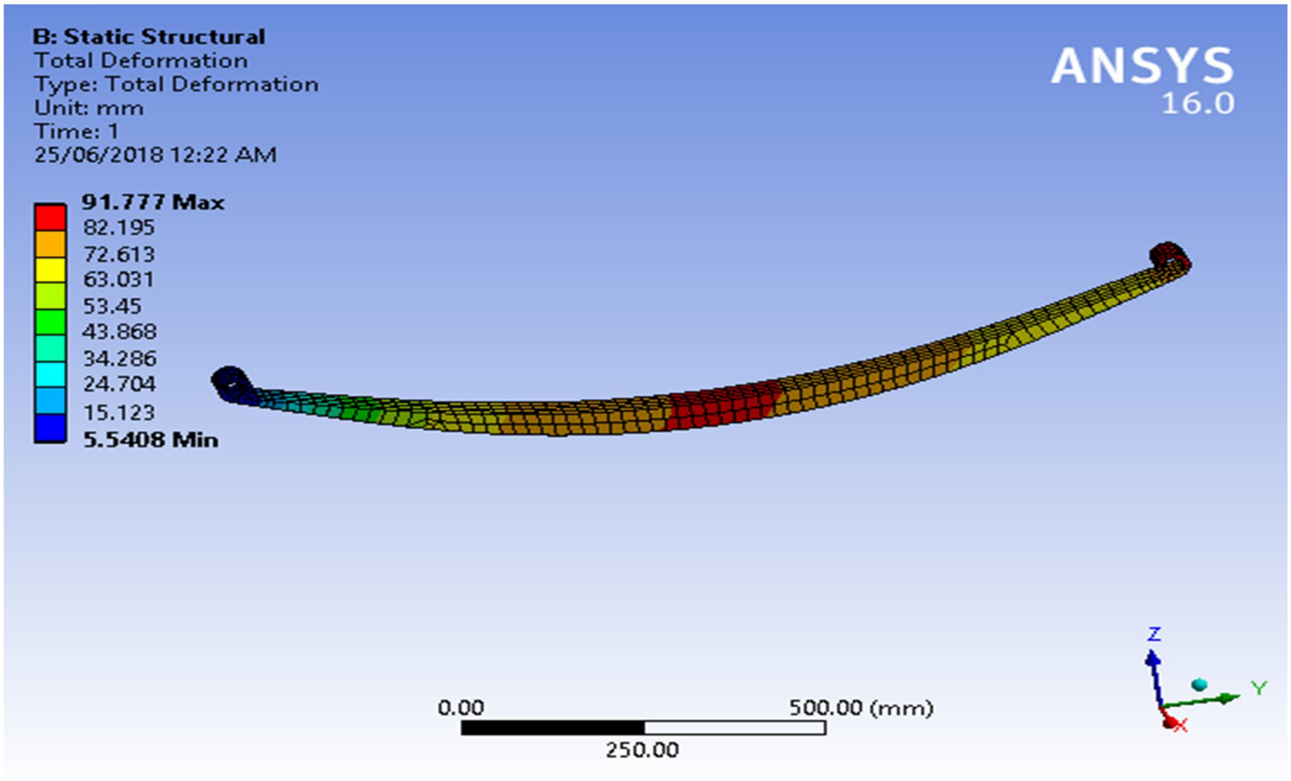

Fig.12 – Total deformation of Carbon Epoxy mono leaf spring at maximum load of 7125N

D. Material – Graphite epoxy

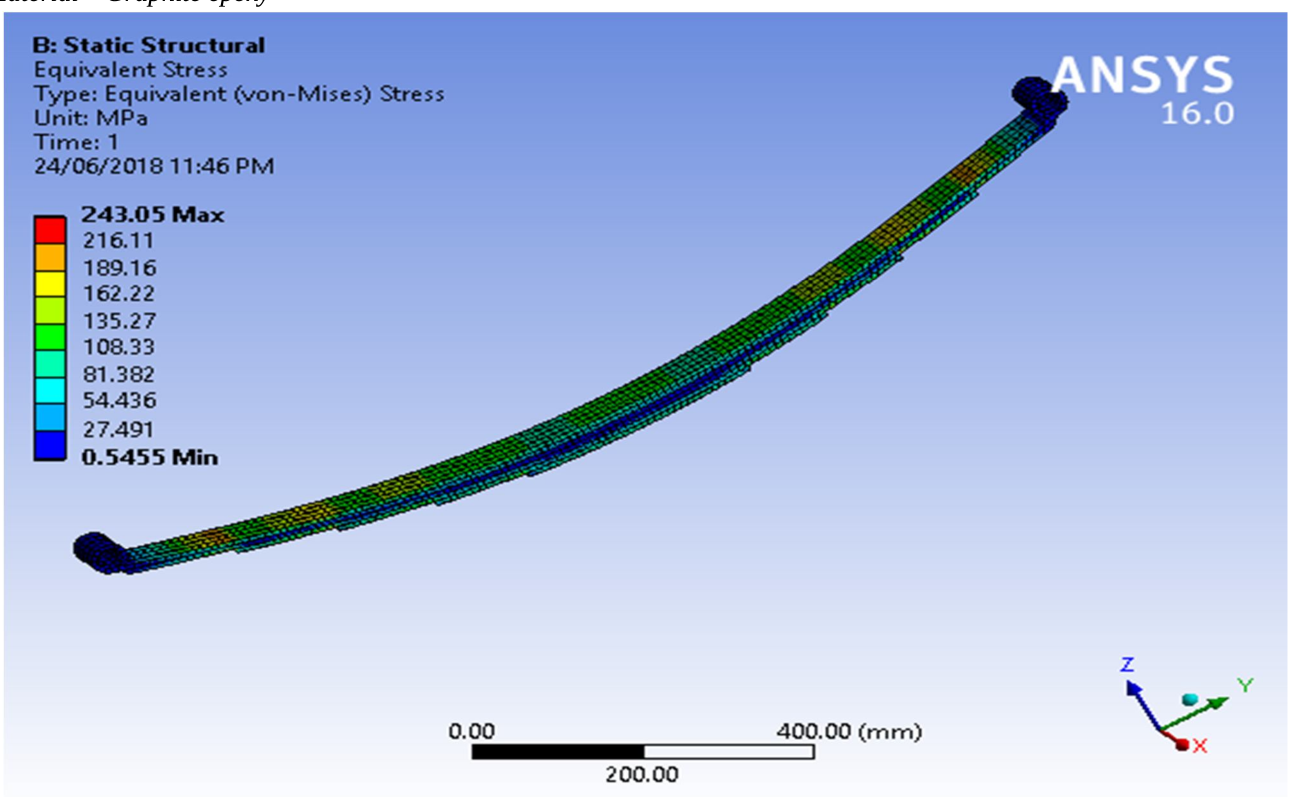

Fig.13 – Equivalent stress in Graphite Epoxy multi-leaf spring at maximum load of 7125 N

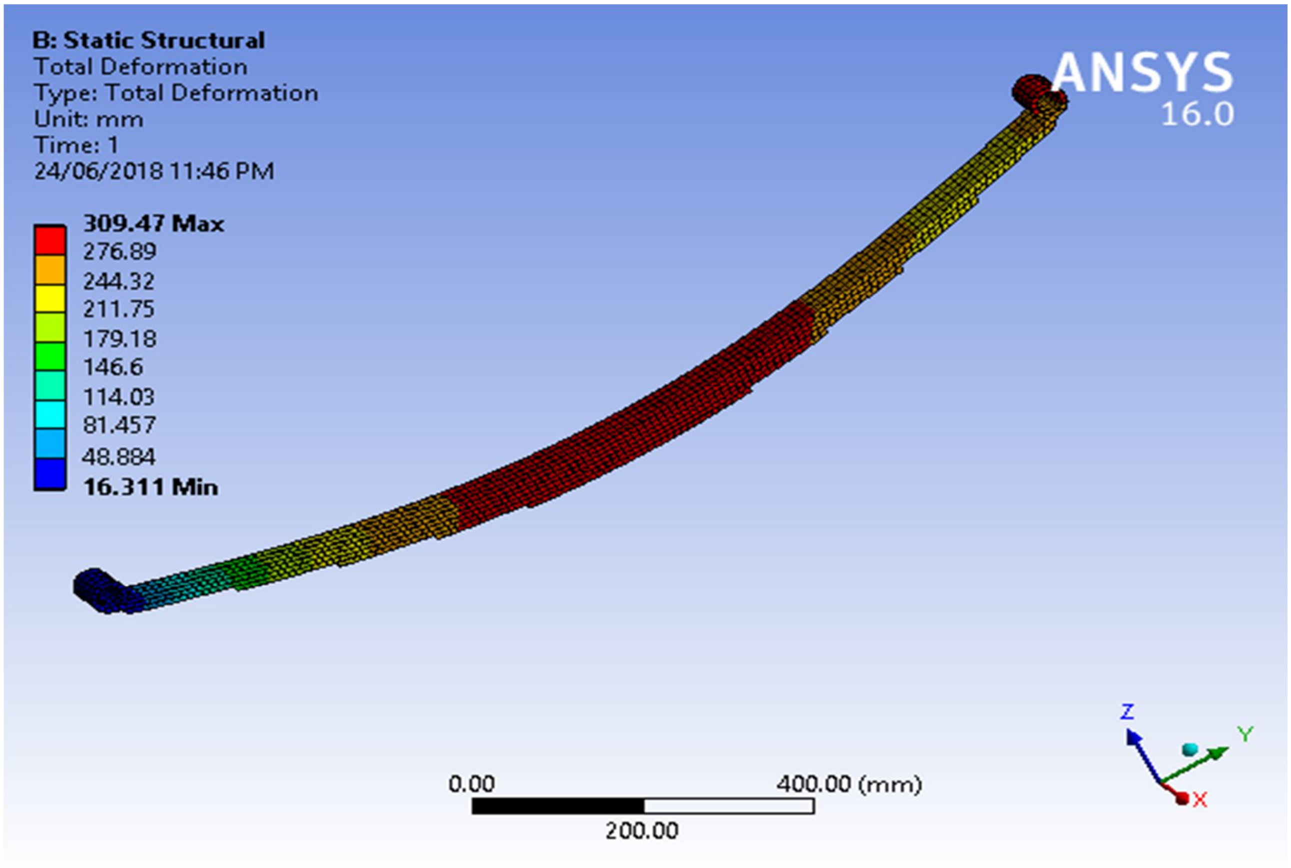

Fig.14 – Total deformation of Graphite Epoxy multi-leaf spring at maximum load of 7125 N

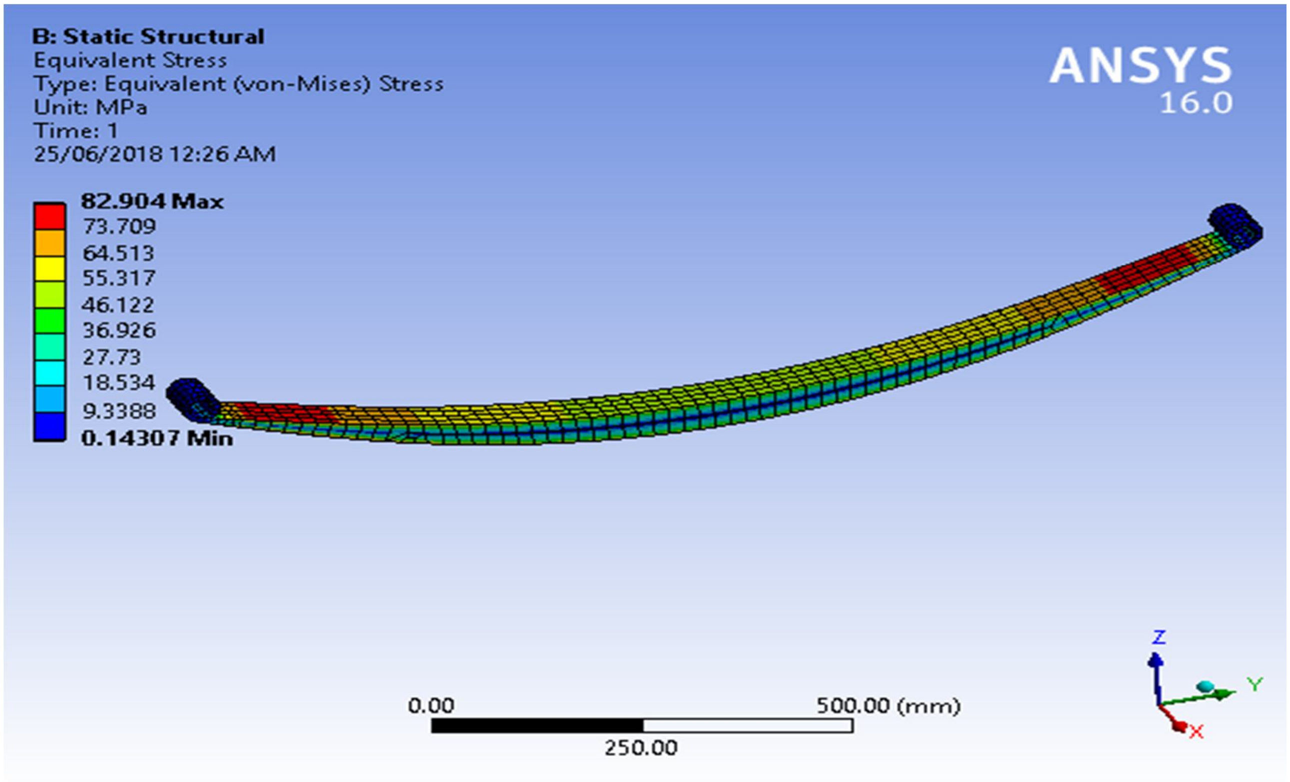

Fig.15 – Equivalent stress in Graphite Epoxy mono leaf spring at maximum load of 7125 N

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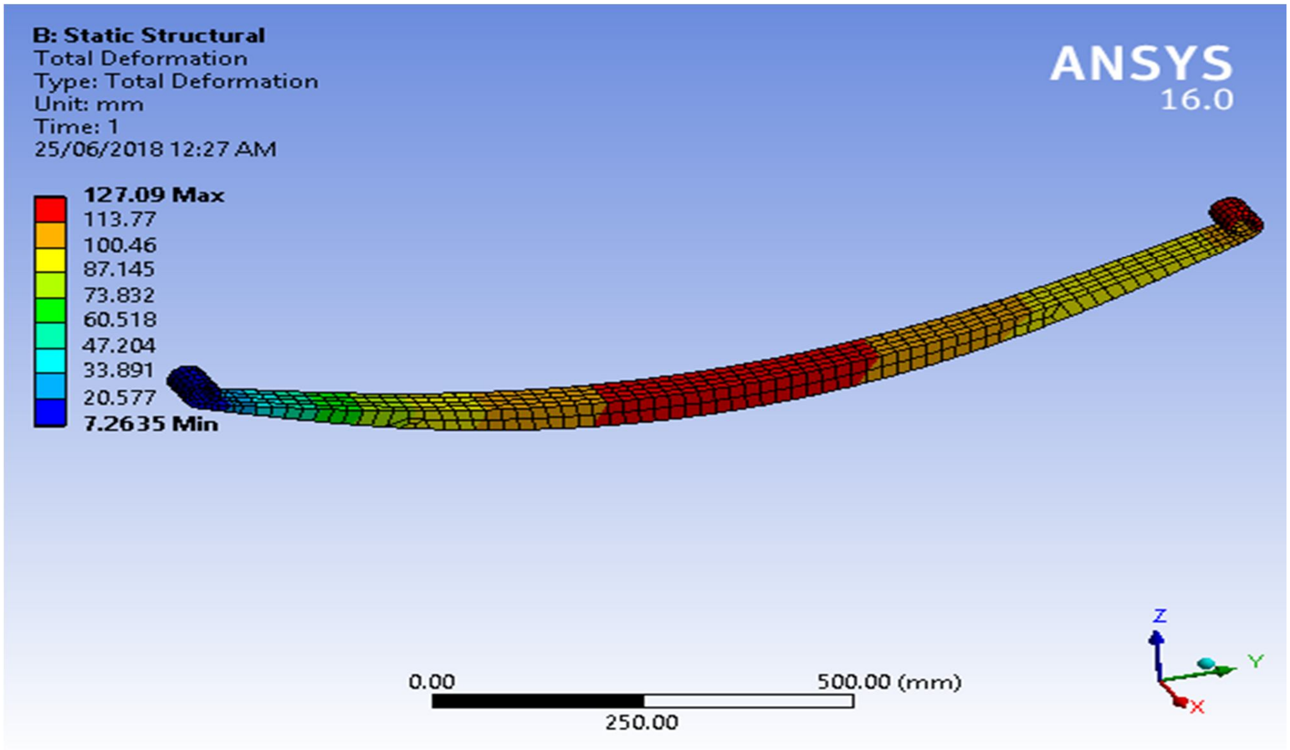
Volume 6 Issue VI, June 2018- Available at www.ijraset.com

Fig.16 – Total deformation of Graphite Epoxy mon



leaf spring at maximum load of 7125 N

VII. RESULTS

A. 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%

VIII. CONCLUSION

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.

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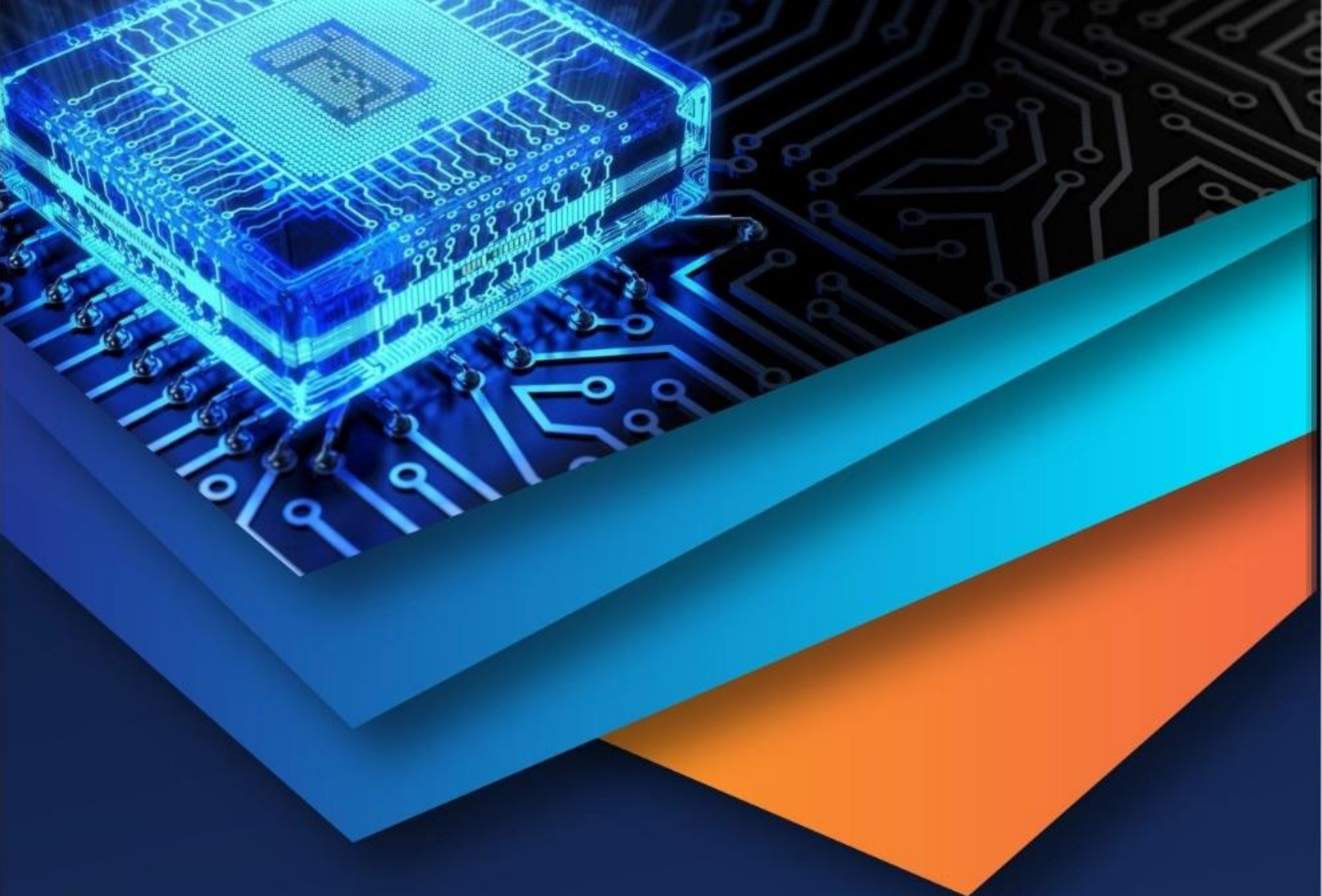

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