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Analysis and Comparision of Different Composites on Truck Leaf Spring

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ABSTRACT

The suspension leaf spring is one of the potential items for weight reduction in automobile. This helps in achieving the vehicle with improved riding qualities. It is well known that springs, are designed to absorb and store energy and then release it. In every sector designers were looking forward to reduce the weight of component simultaneously to increase the efficiency of the material. The weight reduction is mostly possible with composite materials. Present the automobile industry has shown interest in the replacement of steel spring with composite leaf spring since the composite material has high strength to weight ratio and good corrosion resistance properties. The report describes static analysis of EN45 steel spring and composite materials. Here the comparison made between the three composite materials along with EN 45 steel spring on stress, deformation and weight. Modeling of leaf spring done with CATIA V5. The static analysis of model of leaf spring is performed using ANYSIS.

The composite materials here used are Polycarbonate with 30 % Glass, Polycarbonate with 40 % Glass, and Thermo Plastic Polymide. The comparison was done at different loading conditions i.e., at 100%,120%,140%,160%,180%,200% for EN45 steel spring and three composite materials. The comparison made to ascertain the efficient composite leaf spring.

1. INTRODUCTION

In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturer in the present scenario.

Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for ten to twenty percent of the unstrung weight. This helps in achieving the vehicle with improved riding qualities. It is well known that springs, are designed to absorb and store energy and then release it. Hence, the strain energy of the material becomes a major factor in designing the springs. The introduction of composite materials was made it possible to reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness.

Since; the composite materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to those of steel.

1.1 Why we use composites?

The biggest advantage of modern composite materials is that they are light as well as strong. By choosing an appropriate combination of matrix and reinforcement material, a new material can be made that exactly meets the requirements of a particular application. Composites

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also provide design flexibility because many of them can be moulded into complex shapes. The downside is often the cost. Although the resulting product is more efficient, the raw materials are often expensive.

A composite material is made by combining two or more materials – often ones that have very different properties. The two materials work together to give the composite unique properties.

However, within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other.

1.3 Springs

1.3.1 Definition for spring:

Springs are elastic bodies (generally metal) that canbe twisted, pulled, or stretched by some force. They canreturn to their original shape when the force is released. In other words it is also termed as a resilient member.

A spring is defined.as an elastic body, whose function is to distort when loaded and to recoveritsoriginal shape when the load is removed.

1.3.2 CLASSIFICATION OF SPRINGS:

Based on the shape behavior obtained by some applied force, springs are classified into the following ways:

1.3.4 TYPES OF SPRINGS

1) Helical springs
2) Conical and volute springs
3) Torsion springs
4) Disc or Belleville springs
5) Special purpose springs
6) Laminated or leaf springs

1.4 Definition of Leaf spring

A leaf spring is a simple form of spring commonly used for the suspension in wheeled vehicles. Originally called a laminated or carriage spring, and sometimes referred to as a semi-elliptical spring or cart spring.

2. LITERATURE REVIEW

2.1 Design, Analysis and Optimization of Composite Leaf spring for Light Vehicle Application

ErolSancaktaret. al. (1999) [1], in his work described the design and manufacture of a functional composite leaf spring for solar powered light vehicle. The main objective of this work was to provide and understanding of the manufacture, use and capabilities of composite leaf spring. The material selected for the fabrication of the initial design leaves consisted of a full thickness of unidirectional E-glass fibers with two layers of bi-directional fabric on the outer layers embedded in a vinyl ester resin matrix. The bi-directional fabric used to prevent leaf deformation and subsequent failure in bending about its longitudinal axis it was selected due to overall weight reduction of the vehicle primarily considered. The reasons discussed in this paper were sort out by giving the alternative designs by modification of the initial leaf spring. The design offered many advantages over the initial design. By tapering the leaves in the thickness direction as well as in the width direction towards the ends, an even distribution of stresses was achieved providing efficient material usage. The low stress region at the tips of the hole, as well as the holes themselves, present in the initial design is now eliminated. Also, the fibers have a more uniform orientation resulting in a spring, which was easier to model analytically and manufacture. In the alternative design the material selected as E-glass due to their high extensibility, toughness and low cost. In order to facilitate the wetting of the fibers, epoxy resin with 2 h pot life was selected. When the comparison was done, it was found that the redesign of the solar car's front suspension leaf springs was successful as it met all design targets and requirements.

2.2 Analysis and Optimization of a Composite Leaf Spring

Mahmood M. Shokriehet. al. (2003) [2], in their work they focused on the objective of shape optimization of the spring to give the minimum weight for the objective of a light commercial vehicle. For the purpose, they considered a LCV (Light commercial vehicle) and

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analyzed a conventional leaf spring used in the rear suspension system using ANSYS V5.4 software and the results were verified with analytical and experimental solutions. The experimental results were not sufficient to design the leaf spring. So, a stress analysis was performed using finite element method. In this approach every leaf was modeled with eight-node 3D brick elements (SOLID 45) and then five node 3D contact elements (CONTACT 49) were used to represent contact and sliding between adjacent surfaces of leaves. Considering several types of vehicles that have leaf springs and different loading on them, various kinds of composite leaf spring have been developed. But in this study the simplified assumptions were removed and the spring was designed using a more realistic situation. The main criterion was considered for selecting the composite material as the storable energy in the leaf spring. The amount of elastic energy that can be stored by a leaf spring volume unit is given by the equation [2]. This paper provided a graph which clearly shows the specific strain energies of the spring materials. The given figure was specify the percentage of strain energies for static loading and hatched region shows for dynamic loading when the fatigue strength is used.

2.3 Mono Composite Leaf Spring for Light Weight Vehicle – Design, End Joint Analysis and Testing

GulurSiddaramanna Shiva Shankar et. al. (2006) [3], aim of their paper was to present a low cost fabrication of complete mono composite leaf spring and mono leaf spring with bonded end joints and also general study was done on the analysis and design. In this work a single leaf designed and fabricated by hand lay-up technique and tested. The single leaf of leaf spring variable in thickness and width and material used for the fabrication as unidirectional glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multi leaf spring. In this work computer algorithm using C-language was used for the design of constant cross-section leaf spring. For this work design constraints were stresses (Tsai-Wu failure criterion) and displacement, a stress analysis was performed using the finite element method done using ANSYS software. Modeling was done for every leaf with eight-node 3D brick element (solid 45) and five-node 3D contact element (contact 49) used to represent contact and sliding between adjacent surfaces of leaves. Also, analysis carried out for composite leaf spring with bonded end joints for Glass/Epoxy, Graphite/Epoxy and Carbon/Epoxy composite materials and the results were compared with steel leaf spring with eye end. It was concluded that there is no objection from strength point of view also, in the process of replacing the conventional leaf spring by composite leaf spring. It was observed that the major disadvantage of composite leaf spring is chipping resistance. The matrix material is likely to chip off when it is subjected to poor road environments which may break some fibers in the lower portion of the spring. This may result in a loss of capability to share flexural stiffness. But this depends on the condition of the road. In normal road condition, this type of problem will not be there. It was concluded that the weight of the composite leaf spring 85% lesser than the conventional leaf spring.

4. METHODOLOGY

4.1 Leaf spring

A spring is defined as an elastic body, whose function is to distort when loaded and to recover its original shape when the load is removed. Springs are elastic bodies that can be twisted, pulled or stretched by some force. They can return to their original shape when the force is released

A leaf spring is a simple form of spring commonly used for the suspension in wheel vehicles. Originally called a laminated or carriage spring, and sometimes referred to as a semi-elliptical spring or cart spring.

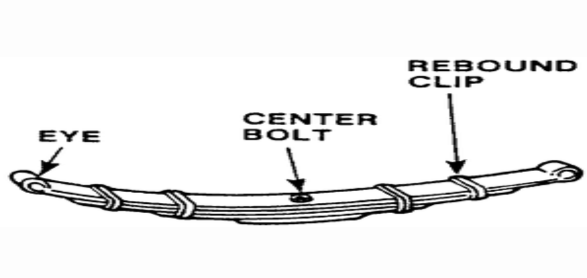

Figure 4.1 Leaf spring

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4.1.3 MATERIAL FOR LEAF SPRING

The material used for leaf springs is usually a plain carbon steel having 0.90 to 1.0% carbon. The leaves are heat treated after the forming process. The heat treatment of spring steel produces greater strength and therefore greater load capacity, greater range of deflection and better fatigue properties.

Materials constitute nearly 60%-70% of the vehicle cost and contribute to the quality and the Performance of the vehicle. Even a small amount in weight reduction of the vehicle, may have a wider economic impact. Composite materials are proved as suitable substitutes for steel in connection with weight reduction of the vehicle. Hence, the composite materials have been selected for leaf spring design.

The material of the spring should have high fatigue strength, high ductility, high resilience and it should be creep resistant. It largely depends upon the service for which they are used i.e. severe service, average service or light service. Severe service means rapid continuous loading where the ratio of minimum to maximum load (or stress) is one-half or less, as in automotive valve springs. Average service includes the same stress range as in severe service but with only intermittent operation, as in engine governor springs and automobile suspension springs. Light service includes springs subjected to loads that are static or very infrequently varied, as in safety valve springs.

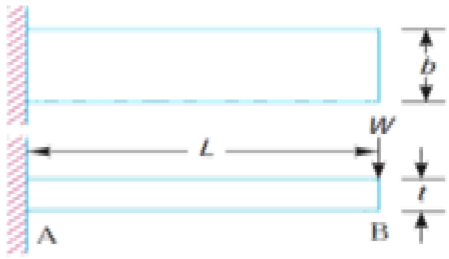
According to Indian Standards the Recommended Materials are:
For Automobiles: 50 Cr 1 , 50 Cr 1 V 23 , 55 Si 2 Mn 90 , used in Hardened and Tempered state.
For Rail Road Springs: C 55(water-Hardened ,C 75-Oil hardened) , 40 SI 2 Mn 90 (Water Hardened) and 55 Si 2 Mn 90 (Oil hardened)

THEORTICAL DESIGN CALCULATION OF LEAF SPRING

Conventional design methods of leaf springs are largely based on the application of empirical and semi-empirical rules along with the use of available information in the existing literature.
The functions of springs are absorbing energy and release this energy according to the desired functions to be performed. So leaf springs design depends on load carrying capacity and deflection.

LEAF SPRING DESIGN

Leaf spring (also known as flat springs) is made out of flat plate. The advantage in leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition the energy absorbing device. Thus the leaf springs may carry lateral loads, brake torque, driving torque etc., in addition to shocks. Single plate fixed at one end and loaded at the other end as shown in figure 1.1. This plate may be used as a flat spring.



The bending stress & deflection of this flat plate is calculated using following equation.
Bending stress spring:

$$\Sigma_b = \frac{6 * W * L}{b * t^2}$$

Deflection of spring:

$$Y = \frac{4 * W * L^3}{E * b * t^3}$$

W = Load on leaf spring
L = Length of the spring
E = Modulus of elasticity
b = Width of the leaf spring
t = thickness of the leaf

If the spring is consider as simply supported beam the length is 2L and load 2W as shown in figure 1.3. The bending stress & deflection of this at plate is calculated using following equation.

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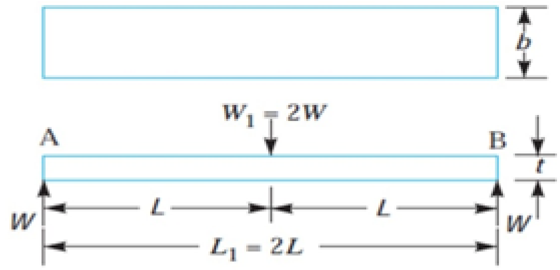


Flat Spring Simple Supported Beam Type

Bending stress in spring:

$$\sigma_b = \frac{6 * W * L}{b * t^2}$$

Deflection of spring:

$$Y = \frac{4*W*L^3}{E*b*t^3}$$

Design calculations of EN45 steel spring

Existing steel leaf spring specifications is consider for design

Parameters	values
Length of spring (eye to eye)	750mm
No. of leaves in full length (with master leaf)	02
No. of graduated leaves	06
Thickness of leaf (t)	10mm
Width of leaf spring (b)	150mm
Camber	213mm
Length of ineffective length of spring	285mm

Parameters	Specification
Material	EN 45
Tensile Ultimate Strength	615.4Mpa
Tensile Yield Strength	375.8Mpa
Density	7860 kg/m3
Poisson's Ratio	0.290
Young's Modulus	204 x 103Mpa

Properties of En 45 leaf spring

Load acting on the leaf spring assembly =

W = 3.56E3K N

L= 350 mm; N= 8; E = 2.04e5 MPA; b=150 mm; t=10mm;

Deflection generated in the assembly of leaf spring is as under:

$$Y = \frac{4*W*L^3}{N*E*b*t^3}$$

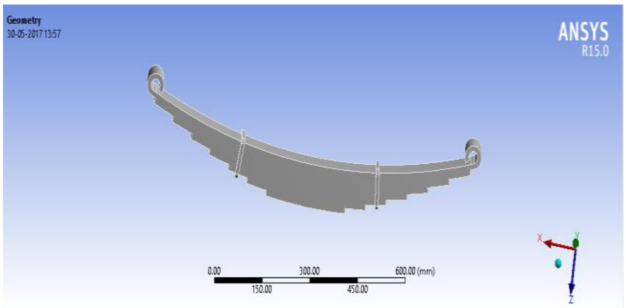
Y= 0.0249 mm

$$\sigma_b = \frac{E * \delta l}{l}$$

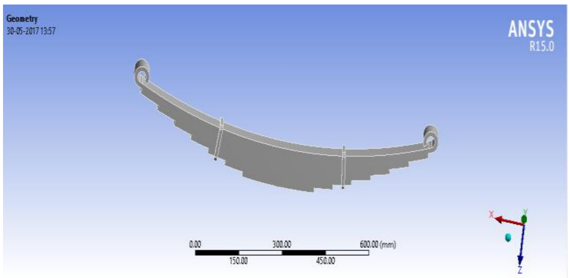
=7.269MPA

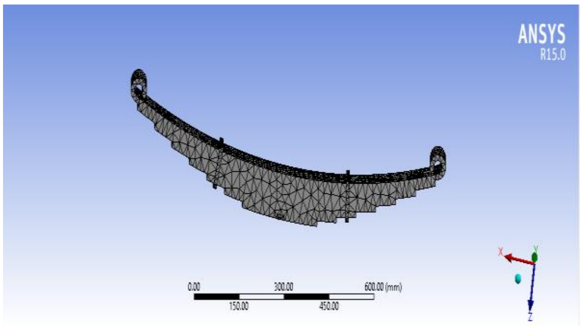
MODELING OF LEAF SPRING

Modelling of leaf spring is performed in CATIA V5 R21.



Analysis of leaf spring





Meshed model of leaf spring

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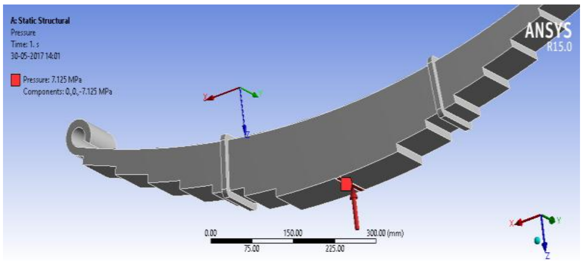


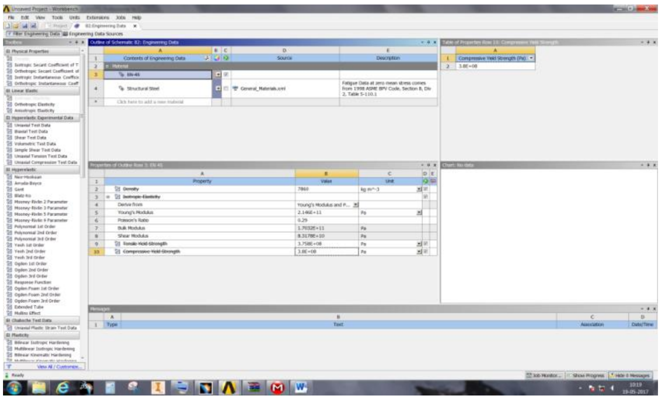
define the pressure

RESULTS

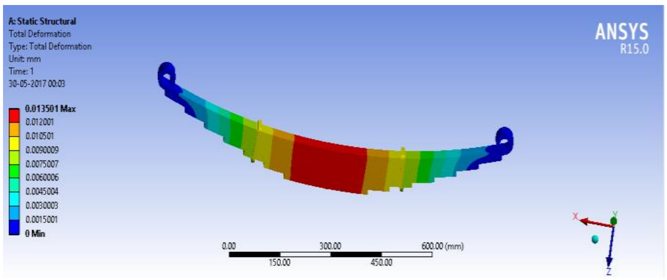
The analysis results for von-mises stress and deflection on EN45 steel spring, Polycarbonate with 30% glass fiber, Polycarbonate with 40% glass fiber, Thermo Plastic Polyamide with 30% glass fiber at pressure of 100%, 120%, 140%, 160%, 180%, 200%.

The weight of the springs is 54 kg for EN45 material, 9.8kg for Polycarbonate with 30% glass fiber material and 10.45 kg for Polycarbonate with 40% glass fiber material, 10.59 Kg for Thermo Plastic Polyamide material.

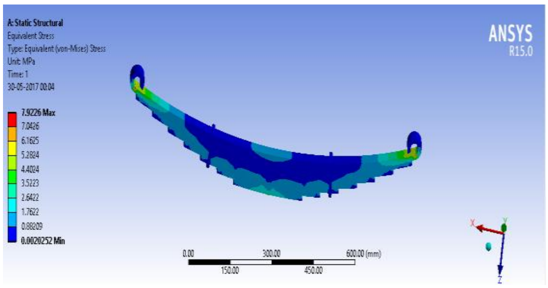
At pressure of 100% i.e., 3652500 Pa



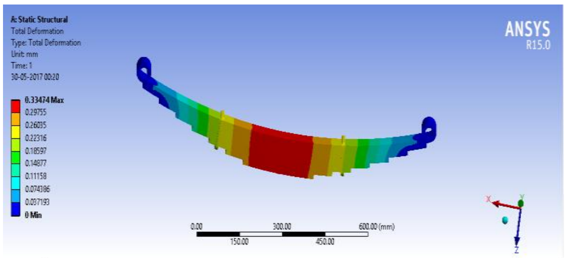
properties of EN materials



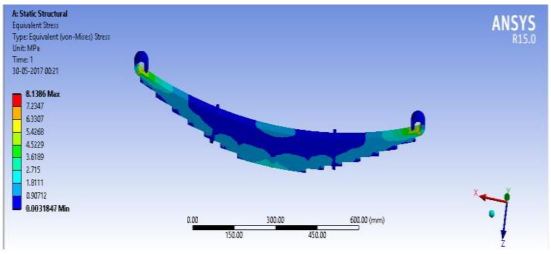
n of EN 45 steel at 3652500Pa



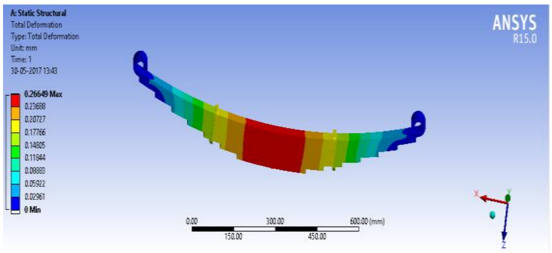
Equivalent (von-misies) Stress for EN45 Steel at 3562500 Pa



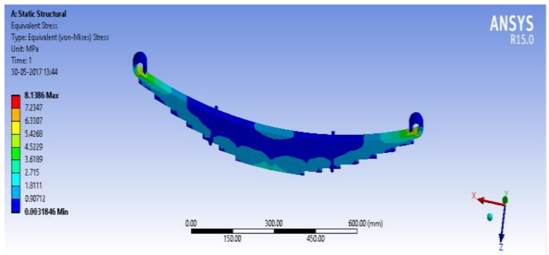
Total Deflection of Polycarbonate with 30% glass fiber at 3652500Pa



Equivalent (von-misies) Stress of Polycarbonate with 30% glass fiber at 3652500Pa



Total Deflection of Polycarbonate with 40% glass fiber at 3652500Pa



Equivalent (von-misies) Stress of Polycarbonate with 40% glass fiber at 3652500Pa

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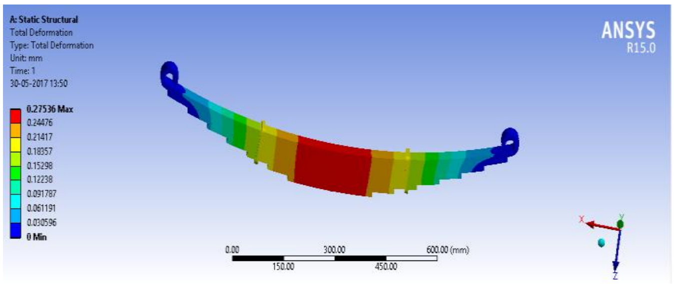
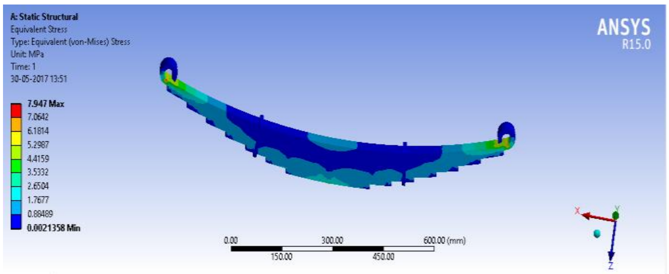


Total Deflection of Thermo Plastic Polyamide with 30% glass fiber at 3652500Pa



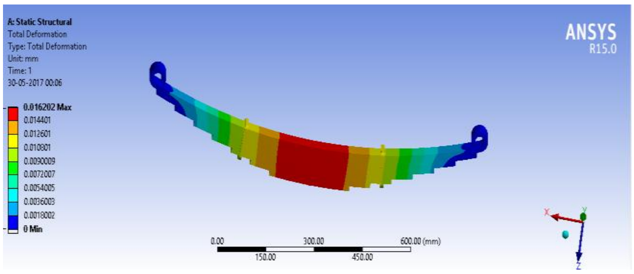
Equivalent (von-misies) Stress of Thermo Plastic Polyamide with 30% glass fiber at 3652500Pa

PRESSURE AT 100% i.e. 3562500 Pa

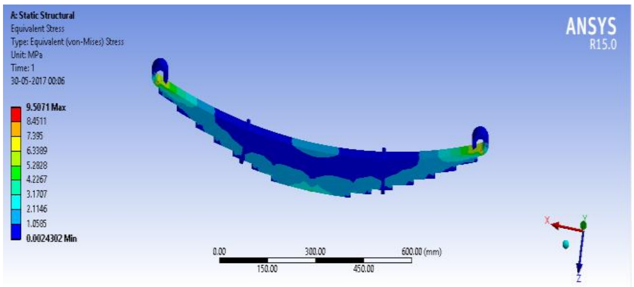
MATERIAL	DEFORMATION (MM	VON-MISES STRESS (MPa)
EN45 STEEL	0.0135	7.922
POLYCARBONATE + 30 % GLASS	0.334	8.138
POLYCARBONATE + 40 % GLASS	0.25	8.138
THERMO PLASTIC POLYMIDE	0.275	7.947

Comparison of Deformation and Equivalent stress at 3562500Pa

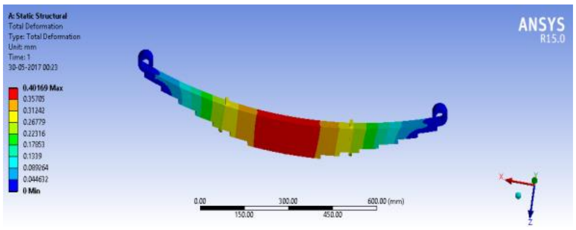
At pressure of 120% i.e., 4275000 Pa



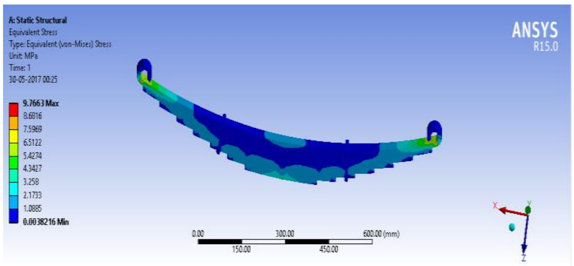
Total Deflection of EN 45 steel at 4275000Pa



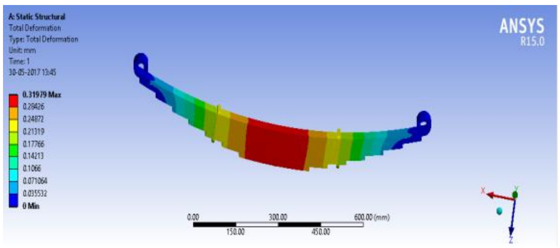
Equivalent (von-misies) Stress of EN 45 steel at 4275000Pa



Total Deflection of Polycarbonate with 30% glass fiber at 4275000Pa



Equivalent (von-misies) Stress of Polycarbonate with 30% glass fiber at 4275000Pa



Total Deflection of Polycarbonate with 40% glass fiber at 4275000Pa

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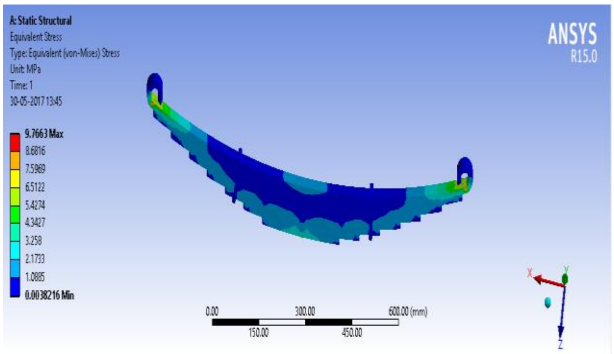
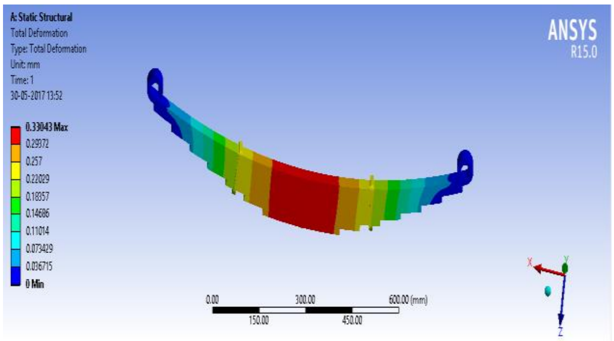
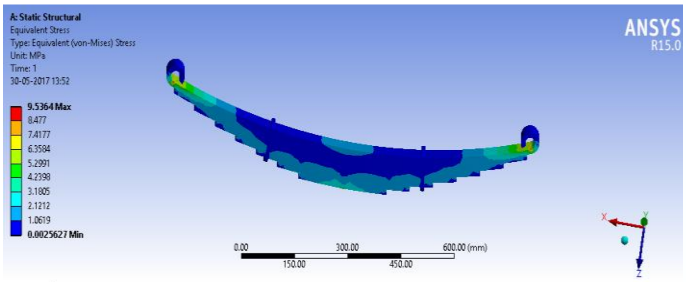


Equivalent (von-misies) Stress of Polycarbonate with 40% glass fiber at 4275000Pa



Total Deflection of Thermo Plastic Polyamide with 30% glass fiber at 4275000Pa



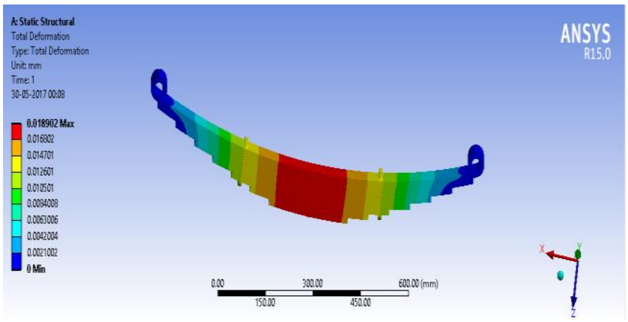
Equivalent (von-misies) Stress of Thermo Plastic Polyamide with 30% glass fiber at 4275000Pa

PRESSURE AT 120% i.e. 4275000Pa

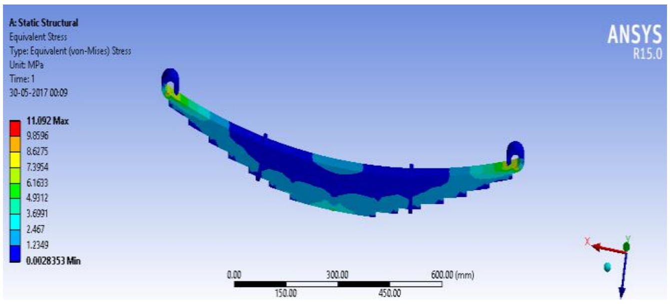
MATERIAL	DEFORMATION (MM)	VON-MISES STRESS (MPa)
EN45 STEEL	0.0162	9.507
POLYCARBONATE + 30% GLASS	0.401	9.766
POLYCARBONATE + 40% GLASS	0.319	9.766
THERMO PLASTIC POLYMIDE	0.33	9.536

Comparison of Deformation and Equivalent stress at 4275000Pa

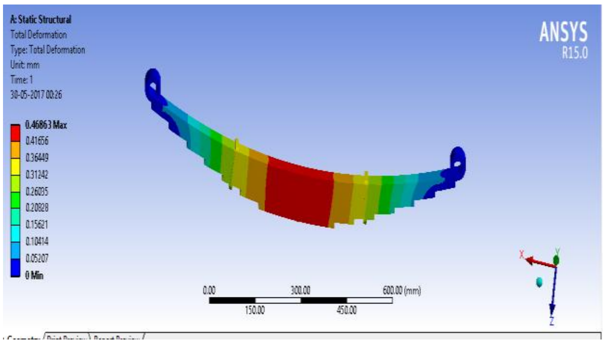
Pressure 140% i.e., 4987500 Pa



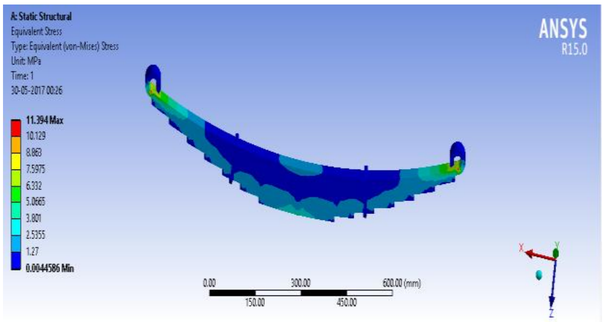
Total Deflection of EN 45 at 4987500Pa



Equivalent (von-misies) Stress of EN 45 at 4987500Pa



Total Deflection of Polycarbonate with 30% glass fiber at 4987500Pa



Equivalent (von-misies) Stress of Polycarbonate with 30% glass fiber at 4987500Pa

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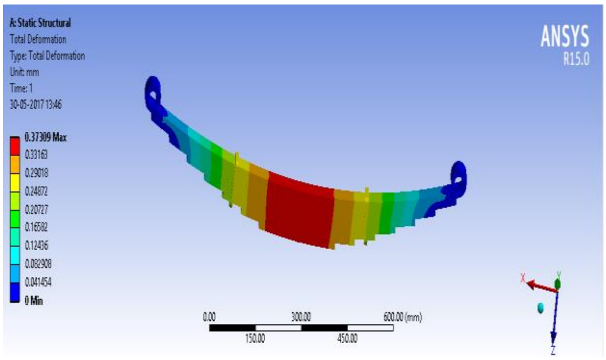
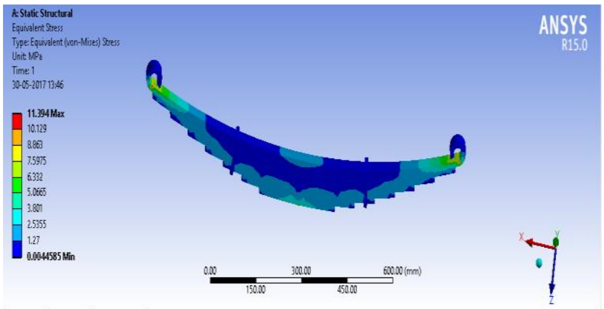
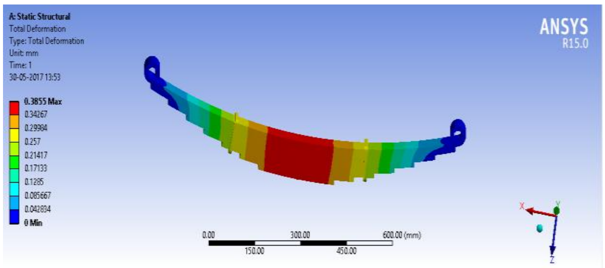


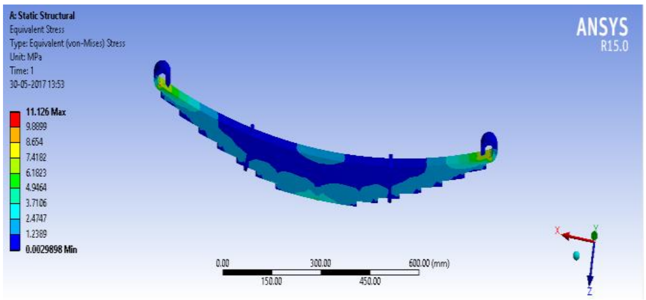
Total Deflection of Polycarbonate with 40% glass fiber at 4987500Pa



Equivalent (von-misies) Stress of Polycarbonate with 40% glass fiber at 4987500Pa



Total Deflection of Thermo Plastic Polyamide with 30% glass fiber at 4987500Pa



Equivalent (von-misies) Stress of Thermo Plastic Polyamide with 30% glass fiber at 4987500Pa

PRESSURE AT 140% i.e. 4987500Pa

MATERIAL	DEFORMATION (MM)	VON-MISES STRESS (MPa)
EN45 STEEL	0.0189	11.092
POLYCARBONATE + 30% GLASS	0.468	11.394
POLYCARBONATE + 40% GLASS	0.373	11.394
THERMO PLASTIC POLYMIDE	0.385	11.126

Comparison of Deformation and Equivalent stress at 4987500Pa

Deformation at various load conditions

EN 45 STEEL								
S.NO.	LOADING CONDITION	PRESSURE(MAP)	AREA	LOAD(KN)	DEFORMATION(MM) FEM	DEFORMATION(MM) ANALYTICAL	STRESS(N/mm2)FEM	STRESS(N/mm2)ANALYTICAL
1	100%	3.56E+06	1.00E+03	3.56E+06	0.0135	0.0249	7.922	7.268
2	120%	4.28E+06	1.00E+03	4.28E+06	0.0162	0.0299	9.507	8.728
3	140%	4.99E+06	1.00E+03	4.99E+06	0.0189	0.0349	11.092	10.183
4	160%	5.70E+06	1.00E+03	5.70E+06	0.0216	0.0399	12.676	11.638
5	180%	6.41E+06	1.00E+03	6.41E+06	0.0243	0.0449	14.261	13.092
6	200%	7.13E+06	1.00E+03	7.13E+06	0.027	0.0499	15.845	14.547

POLYCARBORATE + 30%GLASS								
S.NO.	LOADING CONDITION	PRESSURE(MAP)	AREA	LOAD(KN)	DEFORMATION(MM) FEM	DEFORMATION(MM) ANALYTICAL	STRESS(N/mm2)FEM	STRESS(N/mm2)ANALYTICAL
1	100%	3.56E+06	1.00E+03	3.56E+06	0.334	0.6205	8.138	7.268
2	120%	4.28E+06	1.00E+03	4.28E+06	0.401	0.7451	9.766	8.728
3	140%	4.99E+06	1.00E+03	4.99E+06	0.468	0.8693	11.394	10.183
4	160%	5.70E+06	1.00E+03	5.70E+06	0.535	0.9934	13.022	11.638
5	180%	6.41E+06	1.00E+03	6.41E+06	0.602	1.1176	14.65	13.092
6	200%	7.13E+06	1.00E+03	7.13E+06	0.669	1.2418	16.277	14.547

POLYCARBORATE + 40%GLASS								
S.NO.	LOADING CONDITION	PRESSURE(MAP)	AREA	LOAD(KN)	DEFORMATION(MM) FEM	DEFORMATION(MM) ANALYTICAL	STRESS(N/mm2)FEM	STRESS(N/mm2)ANALYTICAL
1	100%	3.56E+06	1.00E+03	3.56E+06	0.266	0.4940	8.138	7.268
2	120%	4.28E+06	1.00E+03	4.28E+06	0.319	0.5932	9.766	8.728
3	140%	4.99E+06	1.00E+03	4.99E+06	0.373	0.6920	11.394	10.183
4	160%	5.70E+06	1.00E+03	5.70E+06	0.426	0.7909	13.022	11.638
5	180%	6.41E+06	1.00E+03	6.41E+06	0.479	0.8898	14.65	13.092
6	200%	7.13E+06	1.00E+03	7.13E+06	0.532	0.9886	16.277	14.547

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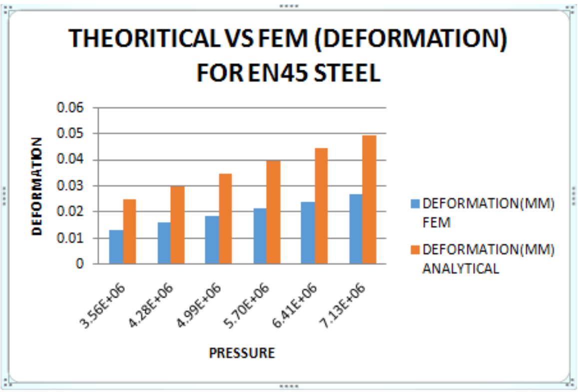
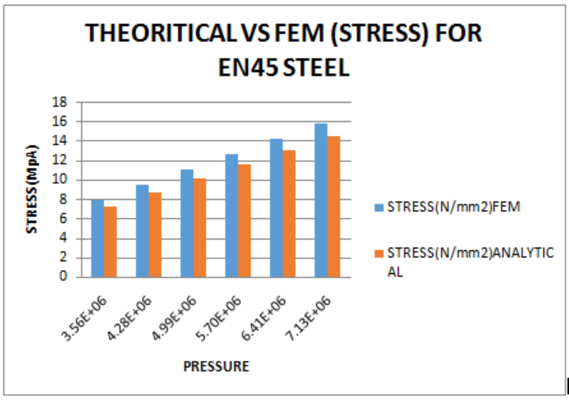
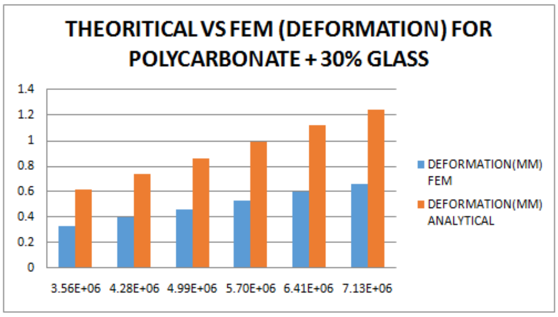
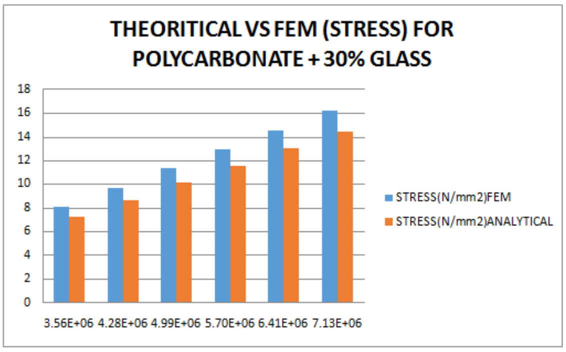
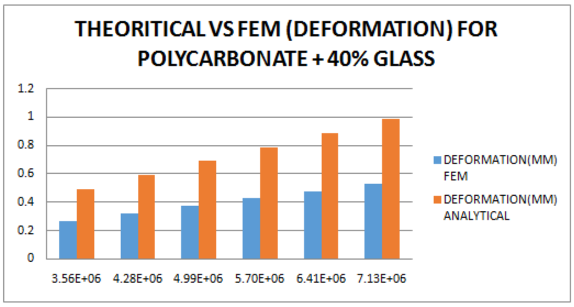
S. NO.	LOADING CONDITION		AREA	LOAD(KN)	DEFORMATION(MM) FEM	DEFORMATION(MM) ANALYTICAL	STRESS(N/mm2)FEM	STRESS(N/mm2)ANALYTICAL
THERMO PLASTIC POLYMIDE								
1	100%	3.56 E+06	1.0 0E+ 03	3.56 E+06	0.275	0.5088	7.947	7.268
2	120%	4.28 E+06	1.0 0E+ 03	4.28 E+06	0.33	0.6110	9.536	8.728
3	140%	4.99 E+06	1.0 0E+ 03	4.99 E+06	0.385	0.7128	11.126	10.183
4	160%	5.70 E+06	1.0 0E+ 03	5.70 E+06	0.44	0.8146	12.715	11.638
5	180%	6.41 E+06	1.0 0E+ 03	6.41 E+06	0.495	0.9165	14.305	13.092
6	200%	7.13 E+06	1.0 0E+ 03	7.13 E+06	0.55	1.0183	15.894	14.547

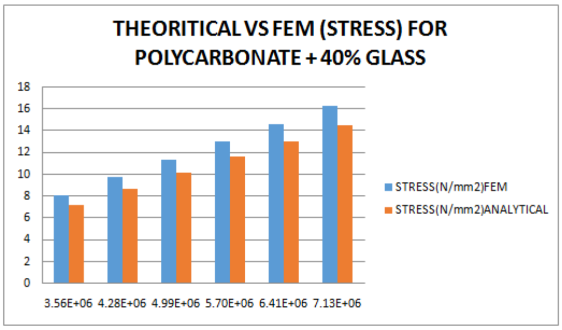












Overall comparision of deformation and equivalent stress for all materials

LOAD CONDITIONS	PRESSURE (Pa)	SOLUTION	EN 45 STEEL	POLYCARBORATE + 30%GLASS	POLYCARBORATE + 40%GLASS	THERMO PLASTIC POLYMIDE
100%	3560000	DEFORMATION (MM)	0.0135	0.334	0.266	0.275
		VON-MISES STRESS (MPa)	7.922	8.138	8.138	7.947
120%	4275000	DEFORMATION (MM)	0.0162	0.401	0.319	0.33
		VON-MISES STRESS (MPa)	9.507	9.766	9.766	9.536
140%	4987500	DEFORMATION (MM)	0.0189	0.468	0.373	0.385
		VON-MISES STRESS (MPa)	11.092	11.394	11.394	11.126
160%	5700000	DEFORMATION (MM)	0.0216	0.535	0.426	0.44
		VON-MISES STRESS (MPa)	12.676	13.022	13.022	12.715
180%	6412500	DEFORMATION (MM)	0.0243	0.602	0.479	0.495
		VON-MISES STRESS (MPa)	14.261	14.65	14.65	14.305
200%	7125000	DEFORMATION (MM)	0.027	0.669	0.532	0.55
		VON-MISES STRESS (MPa)	15.845	16.277	16.277	15.894

CONCLUSION

1. Comparsion made between EN 45 steel leaf spring and other composite leaf springs (poly carbonate with 30% glass fiber, polycarbonate with 40% glass fiber and thermo plastic polymide with 30% glass fiber)
2. Comparatively the weight of the polycarbonate with 30% glass fiber leaf spring has less weight but the deformation is more when comparing with polycarbonate with 40% glass fiber leaf spring
3. Thermo plastic polyamide with 30% glass fiber leaf spring has got the better results by comparing with the EN 45 steel leaf spring
4. Among all the polycarbonate with 40% glass fiber is the best suitable composite material which is suitable for leaf spring in truck at varying load conditions.

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