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# Analysis of multi leaf spring based on contact mechanics – a novel approach

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**Abstract.** A leaf spring, especially the longitudinal type is liable and persistent element in automotive suspension system. In the present scenario the composite materials are widely used in the automobile industries has shown a great interest in the replacement of steel spring due to high strength by weight ratio. Previous investigations focused on stresses and displacement analysis of single leaf spring for different materials. The present work aims to design and analysis of leaf spring for two different cases by considering the Young's modulus to yield strength ratio. In the first case the analysis deals with the design and analysis of a single cantilever solid triangle beam which is an equivalent beam of a spring with three leaves having uniform strength. In the second case a 3- beams of rectangular cross section has been considered which is equivalent to a spring with three leaves. The analysis was carried out based on contact mechanics approach. The results were compared, that the fiberglass composite leaf spring is suitable for high loading capacity, reliability and efficiency.

**Keywords:** contact analysis; composite material; leaf spring; Young's modulus; yield strength

## 1. Introduction

A leaf spring is a simple form of spring commonly used in the suspension vehicles. It is also called as semi-elliptical spring, as it takes the form of a slender arc shaped of an ellipse for the

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given length of spring steel of rectangular cross section. Suspension is the term given to the system of springs, shock absorbers and linkages that connects a vehicle to its wheel. Suspension systems serve several purposes contributing the vehicles in terms of road handling, braking for good active safety and driving pleasure, keeping vehicle occupants well isolated from road noise, bumps, and vibrations etc. When acceleration comes into force and force translates into raw energy and this energy travels through the frame of the vehicle without coils and springs to absorb this the vertical energy that would cause the vehicle to jump up off the road reducing tyre friction and control which would result in a heavy bounce back downwards by the vehicle with even greater force which could be very dangerous. Coil spring and leaf springs absorb all forces and keep the tyres firmly planted to the ground so that the tyre always remains in contact with the ground. The suspension also protects the vehicle itself and any cargo or luggage from damage and wear. In this phase of work it is focused to analyze the leaf spring suspension for heavy vehicles.

## 2. Literature review

In recent years, researches in the area of automobile components have been receiving considerable attention focused on reduction in the weight of vehicles. The introduction of composite materials like FRP made this possible to reduce the weight of the leaf spring without any reduction in load carrying capacity and stiffness. Hence the strain energy of the material becomes a major factor in designing the springs. Mahmood *et al.* (2003) expressed the relationship of the specific strain energy as

$$U = \frac{1}{2}\left(\frac{\sigma^2}{\rho \mathrm{E}}\right) \tag{1}$$

Where, $\sigma$ is the strength, $\rho$ is the density and $E$ is young's modulus of the spring material.
Investigation of composite leaf spring in the early 60's failed to yield the production facility because of inconsistent fatigue performance and absence of strong need for mass production. But the fatigue strength can be increased by incorporating carbon woven fibers and E-glass continuous fibers to reinforce the polymer matrix. The E-glass fiber is a high quality glass, which is used as a standard reinforcement fiber for all the present systems well complying with the mechanical property requirements. As well carbon fiber is a material consisting of extremely thin fibers about 0.005–0.010 mm in diameter and composed of carbon atoms. The carbon atoms are bonded together in microscopic crystals that are aligned parallel to the long axis of the fiber. The crystal alignment becomes an important parameter to decide the load carrying capacity with respect to the fiber direction. X-ray and electron diffraction studies have shown that in high modulus type fibers, the crystals are arranged around the longitudinal axis of the fiber with planes of layer highly oriented as parallel to the axis.

Papers with more emphasis on composite leaf spring were reviewed for this work. Mahdi *et al.* (2006) concluded that it is essential for the composites to control the failure by utilizing their strength in principal direction instead of shear during the suspension. In due consideration of flexural rigidity as an important parameter in the leaf spring design Rajendran *et al.* (2001) have proposed that amongst different possibilities constant cross section design can be selected to accommodate continuous reinforcement of fibers and also for mass production too. Abdul Rahim *et al.* (2010) experimented modal analysis of composite based elliptic spring in structural mechanics to determine the natural shapes and frequencies of an object or structure modes and it has an alternative to solving the full set of equations for '*n*' unknown displacements. Erol Sancaktar and Mathieu Gratton (1999) designed a new model to reduce the strain on outer fibers by a total of four leaves, two on each side of the strut. Tapered leaves in the thickness direction as well as in the width direction towards the ends provides even distribution of stresses and also efficient material usage. Beardmore (1986) investigated the utilization of glass reinforced epoxy resin for composite leaf spring application.

Subramanian *et al.* (2010) reported the influence of reinforced fiber length on the performance of injection moulded thermoplastic leaf spring joint and also notch sensitivity characteristics. Gulur siddaramanna and Shivashankar (2006) explained the stress induced in composite spring has much lower, the natural frequency is higher and the spring weight is nearly 85% lower with bonded end joint and with complete eye unit. The leaf spring model was considered to be a parabolically tapered, constant width beam carrying a concentrated load and assumed to be symmetrical with different cord lengths for the two limbs of the spring by Al-Qureshi (2001) to enhance fatigue behaviour by hybridization. A longitudinal type double tapered GRP leaf spring was designed and investigated for different loading conditions by Yu and Kim (1988) in which GFRP leaf springs possesses superior endurance and fail safe characteristics. Peijs and DeKok (1993) studied the hybrid effects of carbon-high-performance polyethylene/epoxy hybrid composites in monotonic tensile testing. Hou and Cherrualt (2007) studied various eye end attachment for composite leaf springs related to its de-lamination characteristics. In their design, the curvature of spring and fiber misalignment in the width and thickness direction is neglected. A general discussion on analysis and design of constant width, variable thickness composite leaf spring was presented. Daugherty (1981) studied the application of composite structures for automobiles and reported the performance. In the present work the design and finite element contact analysis of unidirectional leaf spring without end joints and composite leaf spring using bonded end joints by hand-layup technique is attempted.

## 3. Materials and methods

In this work the leaf spring has been considered as a single cantilever solid triangle which is an equivalent beam of uniform strength having three leaf springs and a spring with three leaves of rectangular cross section is considered. The analysis is carried out in contact mechanics approach. The analysis is carried out for a maximum load of 2000 N (Equivalent for an experimental work). The different materials has been considered for analysis. The E/Y ratio of materials are listed in the Table 1.

Table 1 Materials E/Y ratio

| S. No | Materials | E/Y ratio |
|---|---|---|
| 1 | GFRP - D | 34.1 |
| 2 | GFRP - A | 46 |
| 3 | GFRP - C | 53 |
| 4 | GFRP - E | 84 |
| 5 | Titanium | 138 |
| 6 | C45 steel | 552 |
| 7 | 304 Austentic steel | 975 |

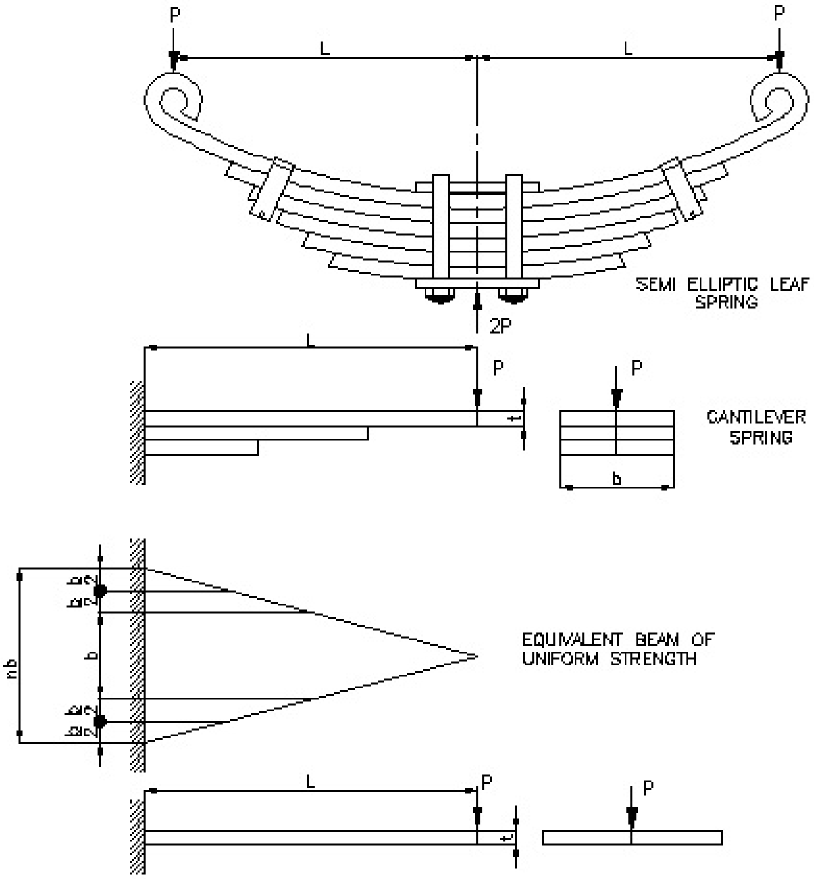


Fig. 1 Design parameters of cantilever solid triangle beam

### 3.1 Design of cantilever solid triangle beam

The following specification of the leaf spring was considered for the design and analysis. The master leaf which is of 520 mm and rest is graduated leaf of considerable length with respect to the width ‘b’.

Fig. 1 shows the design parameters of cantilever solid triangle beam of equivalent beam of uniform strength of three leaf spring having three leaves. The bending stress and deflection of beam are calculated from the following Eqs. (2) - (3).

Bending stress, $$\sigma_b = \frac{6PL}{nbt^3} \quad (2)$$

Deflection, $$y = \frac{6PL^3}{Enbt^3} \quad (3)$$

where,

Width of the spring, $b$ = 50 mm

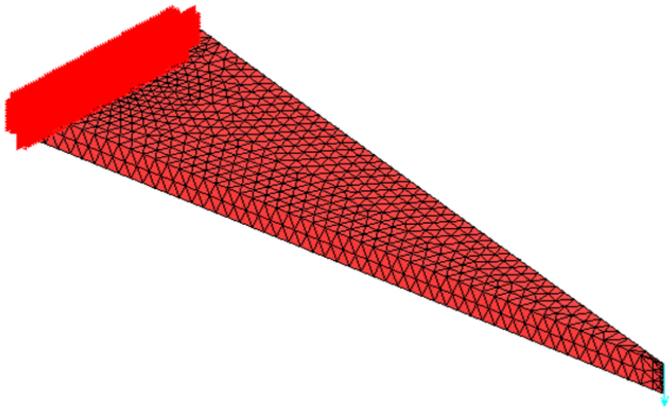

Fig. 2 FEA model of cantilever solid triangular beam

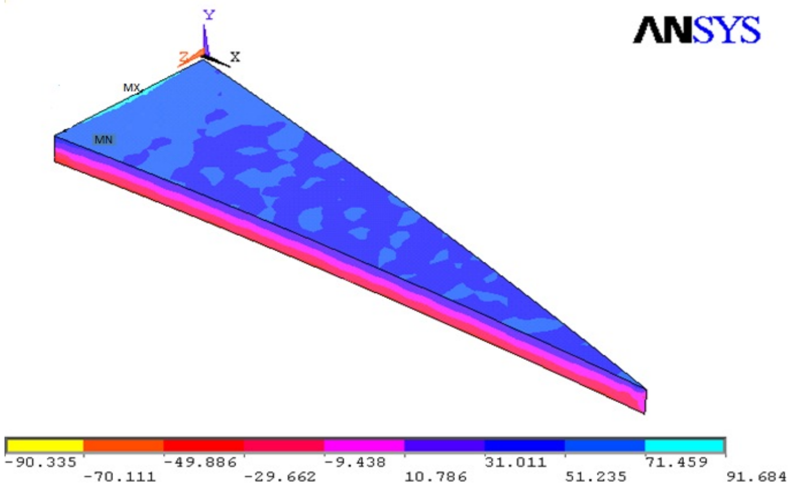


Fig. 3 Bending stress - cantilever solid triangular beam (N/ $mm^2$)

Thickness of the spring, $t$ = 25 mm
Length of the cantilever beam (spring), $L$ = 520 mm
Number of leaves in the spring, $n$ = 3
Load, $P$ = 2000 N

### *3.2 Analysis of cantilever solid triangle beam*

The modeling of cantilever solid triangle beam is equivalent to spring with three leaves is carried out in Ansys V10 software by designing the co-ordinates. The element type selected is solid 45. The finite element model of cantilever solid triangle beam is shown in Fig. 2. In this model the master leaf is converged to a single node and the load step options are carried out at the free end of the spring. The boundary conditions are all the DOF at left end of the beam are fixed and the beam is permitted to move in the vertical direction only. The load is applied at the converged point in the right side node.

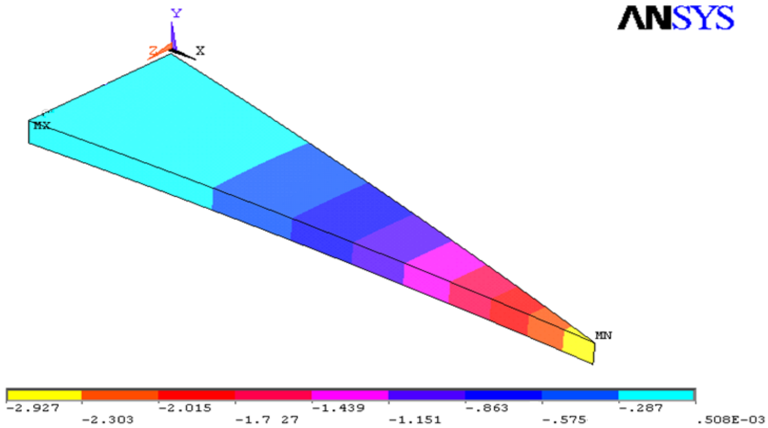


Fig. 4 Deflection - cantilever solid triangular beam (mm)

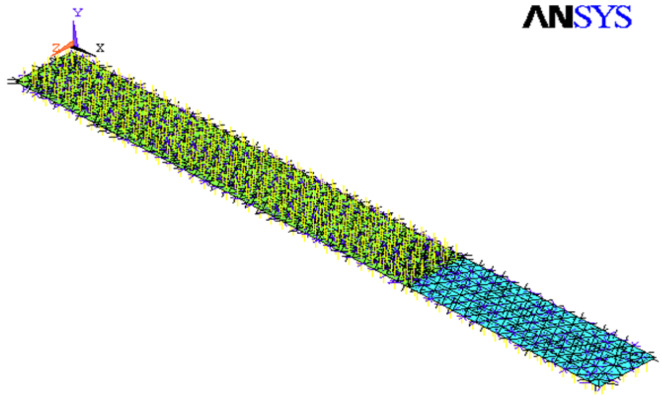


Fig. 5 Contact creation between the master and first graduated leaf

### 3.2.1 Stress analysis

The stress analysis is carried out within the elastic limit. The base end of the triangle is fully constrained and the load of 2000N is applied at the single node. The bending stress induced in the cantilever solid triangle beam of C45 material in X-direction is shown in Fig. 3. The magnitude of the same at the free end is 51.235 N/mm$^2$. The maximum bending stress is developed at the fixed end of the beam.

### 3.2.2 Deflection analysis

The deflection analysis is also carried out within the elastic limit. The base end of the triangle is fully constrained and the load of 2000N is applied at the single node. The displacement occurs in Y-direction. The magnitude of the displacement at free is 2.927 mm. The deflection of cantilever solid triangle beam for C45 steel is shown in Fig. 4.

### 3.3 Contact analysis of 3-beam rectangular cross sectional leaf spring

The 3-beam which shows the similar characteristics of springs with three leaves. In this design

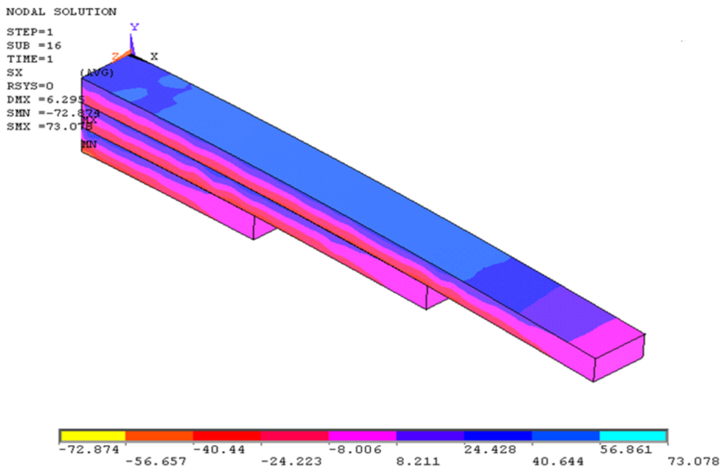


Fig. 6 Plot for Stress developed in GFRP - E material (N/ mm$^2$)

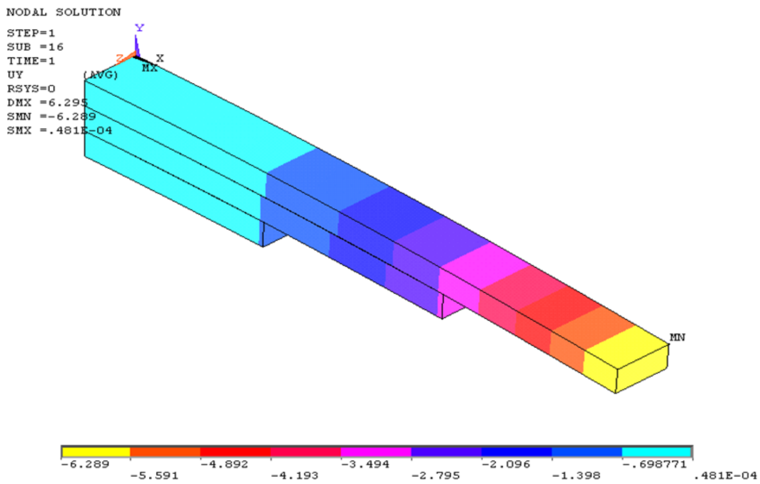


Fig. 7 Plot for displacement of GFRP - E material (mm)

and modeling the length of master leaf is alone considered and graduated leaf length is considered in the ratio of b/2. The contact area is created between two sliding surfaces. The contact area is created between the master leaf (Blue region) and the first graduated leaf (Green region). Fig. 5 shows the contact creation between the master and first graduated leaf.

### *3.3.1 Analysis of contact stress for 3-beam model*

The Finite element contact analysis has been performed for 3-beam of load 2000 N. The load is applied at the free end of the beam; the stress occurs between the two contact regions in the X - direction. Fig. 6 shows the stress developed in the contact regions for the material GFRP - E. The maximum stress developed is 73.078 N/mm$^2$.

### *3.3.2 Analysis of displacement for 3-beam model*

The displacement analysis is performed in the 3-beam equivalent having three leaves. The

Table 2 Stress for cantilever solid triangle beam

| S. No | Material | Analytical – Stress* (N/mm$^2$) | FEA – Stress (N/mm$^2$) |
|---|---|---|---|
| 1 | GFRP - D | 66.56 | 62.118 |
| 2 | GFRP - A | 66.56 | 61.019 |
| 3 | GFRP - C | 66.56 | 67.325 |
| 4 | GFRP - E | 66.56 | 62.188 |
| 5 | Titanium | 66.56 | 59.561 |
| 6 | C45 Steel | 66.56 | 51.235 |
| 7 | 304 Austentic steel (Aust) | 66.56 | 59.249 |

*calculated using Eq. (2)

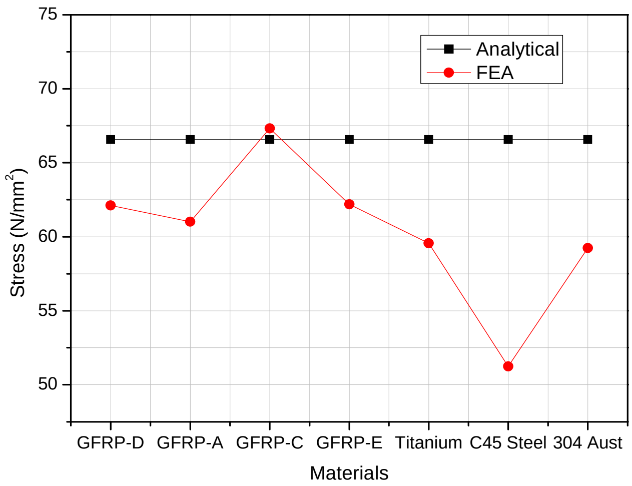


Fig. 8 Materials Vs stress for cantilever solid triangle beam

displacement occurs in the Y-direction. The maximum displacement is taken place at the free end of the beam. Fig. 7 shows the displacement plot of the spring with three leaves for material GFRP - E.

## 4. Results and discussion

The Multi leaf spring has been analysed for the following two cases.

(a) By considering spring with three leaves as a cantilever solid triangular beam.

(b) By considering spring with three leaves as a 3-beam uniform rectangular cross sectional.

The following are the results have been obtained from this analysis.

Table 2 shows, the stress value for different materials in analytical and finite element analysis. The analytical values are calculated without considering the material properties. So that the values are same for all the materials. But in the finite element analysis the material properties are considered.

Table 3 Displacement for cantilever solid triangle beam

| S. No | Material | Analytical Displacement* (mm) | FEA Displacement (mm) |
|---|---|---|---|
| 1 | GFRP - D | 13.92 | 10.897 |
| 2 | GFRP - A | 10.44 | 8.106 |
| 3 | GFRP - C | 10.44 | 7.966 |
| 4 | GFRP - E | 9.94 | 7.702 |
| 5 | Titanium | 6.315 | 4.906 |
| 6 | C45 Steel | 3.42 | 2.591 |
| 7 | 304 Austentic steel (Aust) | 3.599 | 2.605 |

* calculated using Eq. (3)

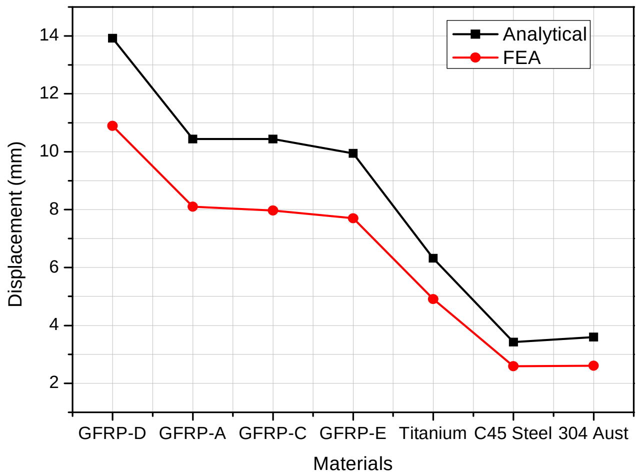


Fig. 9 Materials Vs displacement for cantilever solid triangle beam

Fig. 8 shows the relation between material and stress induced in the spring. It clearly shows that, the maximum stress is developed in the GFRP materials in the FE analysis for the same load of 2000 N.

Table 3 shows, the displacement value for different materials in analytical and finite element analysis. The analytical values are calculated without considering the yield strength of the material. So the values are of same magnitude for all the materials. But in the finite element analysis the yield strength is considered.

Fig. 9 shows the relation between material and displacement. It is shown that, the maximum displacement is developed in the GFRP materials in the FE analysis for the same load of 2000 N.

Table 4 shows, the Stress and displacement value for different materials in finite element analysis. The material GFRP - D gives a maximum stress and displacement compared with rest of materials.

Fig. 10 shows the relationship between material and stress, displacement for linear analysis in simulation. It is shown that, the maximum stress and displacement is developed in the GFRP - D materials in the FE analysis for the load of 2000 N.

Table 4 Stress and displacement for 3-beam model

| S. No | Material | FEA – Stress ($N/mm^2$) | FEA –Displacement (mm) |
|---|---|---|---|
| 1 | GFRP - D | 73.102 | 8.89 |
| 2 | GFRP - A | 56.47 | 6.614 |
| 3 | GFRP - C | 57.48 | 7.902 |
| 4 | GFRP - E | 73.078 | 6.289 |
| 5 | Titanium | 55.981 | 4.004 |
| 6 | C45 Steel | 60.425 | 2.131 |
| 7 | 304 Austentic steel (Aust) | 64.035 | 2.157 |

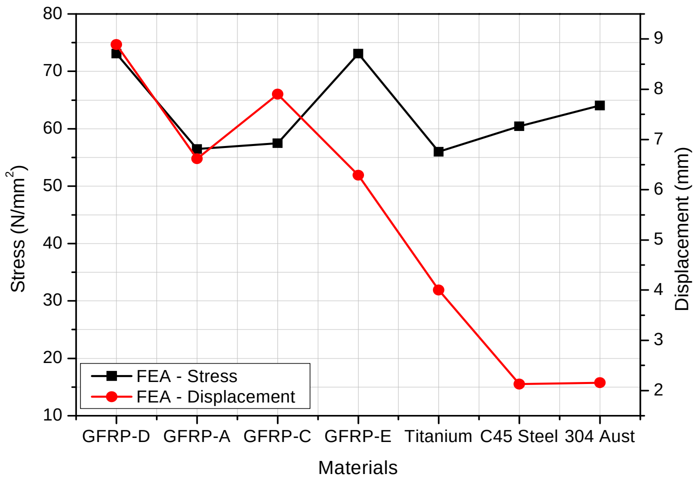


Fig. 10 Materials Vs stress and deformation for 3 - beam model

Fig. 11 Experimental setup

### *4.1 Experimental work*

In an experimental work, special attachment was made with tensile testing machine as shown in Fig. 11.

Table 5 Stress and deformation in FEM and experimental analysis

| Analysis | Stress at free end (N/mm$^2$) | Deflection at free end (mm) |
|---|---|---|
| FEM analysis (Cantilever solid triangular beam) | 51.235 | 2.927 |
| Experimental analysis | 54.5 | 3.00 |

The load is applied at the eye piece by lifting bottom jaw with suitable arrangement. The material C45 is chosen for an experimental work. The applied force is measured by load dial gauge and deflection is measured for different loads at maximum of 2000 N. Maximum stress obtained by using FEM is validated by experimental analysis and is given in Table 5.

## 5. Conclusions

The analysis has been carried out by considered the material properties for cantilever triangle beam and spring with three leaves models. The stress and deflection are computed for both the models analytically and using finite element simulation. The experimental work has been carried out for single leaf spring equivalent to cantilever triangle model. The results are verified with the simulation model. The results show that, the composite material GFRP gives a maximum stress and deflection in both the models. It is concluded that, the composite material is suitable for high loading capacity compared with the rest of materials considered for this analysis.

## References

Al-Qureshi, H.A. (2001), "Automobile leaf springs from composite materials", *Journal of Material Processing Technology,* **118**, 58-61.

Beardmore, P. (1986), "Composite structures for automobiles", *Composite structures,* **5**,163-76.

Daugherty, R.L. (1981), "Composite leaf springs in heavy truck applications", *Composite Materials, Proceedings of Japan - US Conference,* Tokyo.

Hou, J.P., Cherruault, J.Y., Nairne, I., Jeronimidis, G. and Mayer, R.M. (2007), "Evaluation of the eye-end design of a composite leaf spring for heavy axle loads", *Composite Structures*, **78**, 351-358.

Mahdi, E. (2006), "Light composite elliptic springs for vehicle suspension", *Composite Structures,* **75**, 24-28.

Peijs, A.A.J.M. and De Kok, J.M.M. (1993), "Hybrid composites based on polyethylene and carbon fibers, 6. Tensile and fatigue behaviour ", *Composites*, **24**(1), 19-32.

Rajendran, I. and Vijayarangan, S. (2001), "Optimal design of composite leaf spring using genetic algorithms", *Computers and Structures*, **79**, 1121-1129.

Sancaktar, E. and Gratton, M. (1999), "Design, analysis, and optimization of composite leaf springs for light vehicle applications", *Composite Structures,* **44,** 195-204.

Shiva Shankar, G.S. and Vijayarangan, S. (2006), "Mono composite leaf spring for light weight vehicle-design, end joint analysis and testing", *Materials Science (Medziagotyra)*, **12**(3), 220-225.

Shokrieh, M.M. and Rezaei, D. (2003), "Analysis and optimization of a composite leaf spring", *Composite Structures,* **60**, 317-325.

Subramanian, C. and Senthilvelan, S. (2010), "Effect of reinforced fiber length on the joint performance of thermoplastic leaf spring", *Materials and Design,* **31**, 3733-3741.

Talib, A.R.A., Ali, A., Goudah, G., Lah, N.A.C. and Golestaneh, A.F. (2010), "Developing a composite

based elliptic spring for automotive applications", *Materials and Design*, **31**, 475-484.
Yu, W.J. and Kim, H.C. (1988), "Double tapered FRP beam for automotive–suspension leaf spring", *Composite Structures,* **9**, 279-300.

## Nomenclature

| | | |
|---|---|---|
| b | Width of the leaf spring | mm |
| t | Thickness of the leaf | mm |
| L | Length of the cantilever beam (Spring) | mm |
| n | Number of leaves in the spring | - |
| $\sigma_b$ | Bending stress | N/mm$^2$ |
| y | Deflection of spring | mm |
| P | Load applied | N |
| Y | Yield Strength | N/mm$^2$ |
| E | Young's modulus | N/mm$^2$ |
| E/Y | Young's modulus to Yield strength ratio | - |