Comparison of Static, Dynamic & Shock Analysis for Two & Five Layered Composite Leaf Spring

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Abstract
Leaf springs are used in suspension systems. The past literature survey shows that leaf springs are designed as generalized force elements where the position, velocity and orientation of the axle mounting gives the reaction forces in the chassis attachment positions. The automobile industry has shown increased interest in the replacement of steel spring with composite leaf spring due to high strength to weight ratio. Therefore, analysis of the composite material becomes equally important to study the behaviour.The leaf springs are modeled with Unigraphics software NX7.5 and the analysis is carried out using ANSYS 11.0 FEA software to predict the behavior. Then comparison of static, dynamic & shock analysis for two & five layered composite leaf spring are done.

Keywords: *Leaf spring,E-Glass/Epoxy & FEA.*

1. INTRODUCTION:

A leaf spring is a simple form of spring, commonly used for the suspension in wheeledvehicles. It is also one of the oldest forms of springing, dating back to medieval times. An advantage of a leaf spring over a helical spring is that the end of the leaf spring may be guided along a definite path.

A leaf spring can either be attached directly to the frame at both ends or attached directly at one end, usually the front, with the other end attached through a shackle, a short swinging arm. The shackle takes up the tendency of the leaf spring to elongate when compressed and thus makes for softer springiness. Some springs terminated in a concave end, called a spoon end (seldom used now), to carry a swivelling member. A leaf spring is a long, flat, thin, and flexible piece of spring steel or composite material that resists bending. The basic principles of leaf spring design and assembly are relatively simple, and leafs have been used in various capacities since medieval times.

Increasing competition and innovations in automobile sector tends to modify the existing products or replacing old products by new and advanced material products. To improve the suspension system many modification have taken place over the time. Inventions of parabolic leaf spring, use of composite materials for these springs are some of these latest modifications in suspension systems. This paper is mainly focused on two & five layered composite leaf spring. Automobile-sector is showing an increased interest in the area of composite material-leaf springs due to their high strength to weight ratio. Therefore static, dynamic & shock analysis of two & five layered composite material leaf springs is essential in showing the comparative results.

2. METHODOLOGY:

Finite Element Analysis:

The Basic concept in FEA is that the body or structure may be divided into smaller elements of finite dimensions called "Finite Elements". The original body or the structure is then considered as an assemblage of these elements connected at a finite number of joints called "Nodes" or "Nodal Points". Simple functions are chosen to approximate the displacements over each finite element. Such assumed functions are called "shape functions". This will represent the displacement within the element in terms of the displacement at the nodes of the element.

Mathematically, the structure to be analyzed is subdivided into a mesh of finite sized elements of simple shape. Within each element, the variation of displacement is assumed to be determined by simple polynomial shape functions and nodal displacements. Equations for the strains and stresses are developed in terms of the unknown nodal displacements. From this, the equations of equilibrium are assembled in a matrix form which can be easily be programmed and solved on a computer. After applying the appropriate boundary conditions, the nodal displacements are found by solving the matrix stiffness equation. Once the nodal displacements are known, element stresses and strains can be calculated.

Basic Steps in FEA are:

1. Discretization of the domain.
2. Application of Boundary conditions.

3. Assembling the system equations.
4. Solution for system equations.
5. Post processing the results.

3.MATERIALS FOR LEAF SPRING:

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 unsprung 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 relationship of the specific strain energy can be expressed as

$$U = \frac{\sigma^2}{\rho E}$$

Where, σ is the strength, ρ the density and E the Young's modulus of the spring material. It can be easily observed that material having lower modulus and density will have a greater specific strain energy capacity. 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.

3.1 FRP Composites:

FRP composites are defined as the materials that consist of fibers embedded in a resin matrix. The aim of combining fibers and resins that are different in nature is to take advantage of the distinctive material features of either component to result in an engineered material with desired overall composite action for specific applications. Continuous fiber reinforced composites contain reinforcements having lengths much greater than their cross sectional dimensions. Such a composite is considered to be a discontinuous fiber or short fiber composite if its properties vary with fiber length.

Engineering properties of FRP composites for structural applications, in most cases, are dominated by fiber reinforcements. More fibers usually give rise to higher strength and stiffness. Excessively high fiber/matrix ratios may, however, lead to strength reduction or premature failure due to internal fracture. Fiber lengths and orientation also affect the properties considerably.

3.2 E-Glass:

Epoxy resins are relatively low molecular weight pre-polymers capable of being processed under a variety of conditions. Two important advantages of these resins are over unsaturated polyester resins are: first, they can be partially cured and stored in that state, and second they exhibit low shrinkage during cure. Approximately 45% of the total amount of epoxy resins produced is used in protective coatings while the remaining is used in structural applications such as laminates and composites, tooling, moulding, casting, construction, adhesives, etc.Commonly used matrix materials are described below:

Table - 3.1 Mechanical Properties of E-Glass/Epoxy

Properties	E-Glass/Epoxy
Young's modulus in fiber direction, E_1 (GPa)	53.8
Young's modulus in transverse direction, E_2 (GPa)	17.9
Shear modulus, G_{12} (GPa)	8.96
Major Poisson's ratio, υ_{12}	0.25
Minor Poisson's ration, υ_{21}	0.08
Strength in the fiber direction, X_L (MPa)	1.03×10^3
Strength in the transverse direction, X_T (MPa)	27.58
Shear strength, S (MPa)	41.37

3.3 Soild46:

SOLID46 is a layered version of the 8-node structural solid designed to model layered thick shells or solids. The element allows up to 250 different material layers. If more than 250 layers are required, a user-input constitutive matrix option is available. The element may also be stacked as an alternative approach. The element has three degrees of freedom at each node: translations in the nodal x, y, and z directions.The element is defined by eight nodes, layer thicknesses, layer material direction angles, and orthotropic material properties.

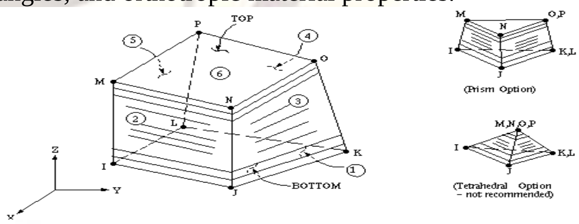


Fig 3.1 Solid46 geometry

4. RESULTS AND DISCUSSION:

The structural analysis of leaf spring is done by first creating a 3D model of it in Unigraphics as shown in the figure 4.1 below.Then structural analysis is carried out in Ansys by importing the 3D model from Unigraphics. In the structural analysis Solid46 is taken as the element type.

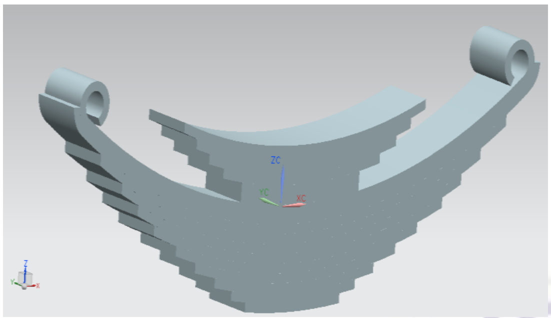


Fig 4.1 3D model of the leaf spring

Table 4.1 Specifications of leaf spring

Description	Upper spring, mm	Lower spring, mm
Number of leaves {n}	6	11
Width of leaves {b}	70	70
Thickness of leaves {t}	10	10
Effective length	410	750
Youngs modulus {e}	$2.04*10^5$ N/mm^2	

4.1. Material Properties:

Young's modulus (EX) must be defined for a structural analysis. If we need to apply inertia loads (such as gravity), we define mass properties such as density (DENS). As we are not applying thermal loads we need not define coefficient of thermal expansion (ALPX). Young's modulus &poisson ratio defined are given in the table. Density is defined as 2e-9 (t/m3)

Table 4.2 Material properties

DIRECTION	Young's modulus in Mpa	Poisson ratio
X – Direction	5e4	0.25
Y – Direction	12e3	0.25
Z – Direction	12e3	0.3

4.2 Loading & Boundary Conditions:

The various boundary conditions set on the leaf spring are

1. The left eye is constraint in ALL DOF.
2. The right eye is constraint only in X & Y direction.

The leaf spring has to withstand a load of 1000kg. So 1000kg load is applied at the centre.

4.3 Finite Element Modelling:

Figure 4.2 shows the finite element model of the composite leaf spring where in it was meshed by taking edge length as 6mm as a result of which a total of 31068 elements and 36881 nodes were created.

No of Elements formed : 31068
No of Nodes created : 36881
Degrees of freedom:Translation in UX UY &UZ directions.

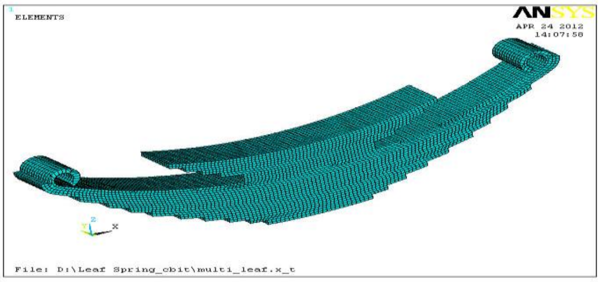


Fig 4.2 Finite element model

4.3 Layers & its Orientation:

Figure 4.3 shows the orientation of two layers. Initially solid46 is divided into 2 layers. As the leaf thickness is 10mm the resultant layer thickness is 5mm. The orientation of the layers is in the range of -90 degree to +90 degree. The layers 1 and 2 are given an orientation of -90 and 90 degrees respectively.

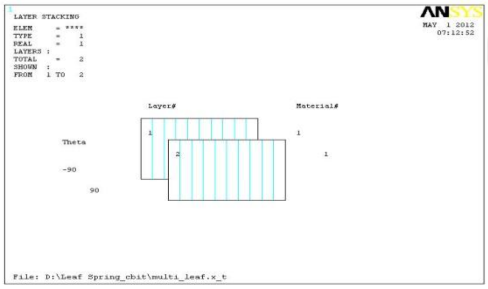


Fig 4.3 Orientation of two layers

Table 4.3 Two layers data of FRP Leaf Spring

Layer Number	1	2
Lay up angle	-90	90
Lay up thickness in mm	5	5

Figure 4.4 shows the orientation of five layers. Then the element solid46 is divided into 5 layers. As the leaf thickness is 10mm the resultant layer thickness is 2mm. The orientation of the layers is in the range of -90 degree to +90 degree. The layers 1,2,3,4 and 5 are given an orientation of -90, -45, 0, 45 and 90 degrees respectively.

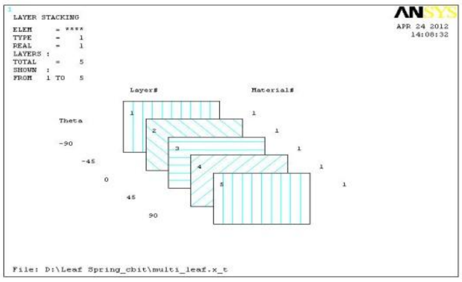


Fig 4.4

Orientation of five layers

Table 4.4 Five layers data of FRP Leaf Spring

Layer Number	1	2	3	4	5
Lay up angle	-90	-45	0	45	90
Lay up thickness mm	2	2	2	2	2

4.4 Static Analysis:

A load of 1000kg is applied along the z direction and all degrees of freedom are constrained in one of the eye and x and y directions are constrained on the other eye.

Figure 4.5 & 4.6 shows total deflection for two & five layered with maximum deflection being 101.5mm for two layer mode and 83.23mm for five layer mode. Figure 4.7 & 4.8 shows Von mises stress for two & five layered with maximum deflection being 795.4Mpa for two layer mode and 948Mpa for five layer mode.

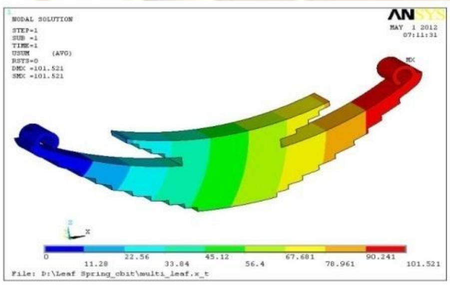


Fig 4.5

Total Displacement for Two layered

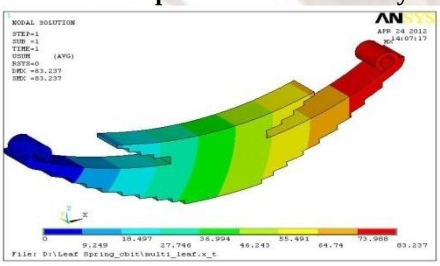


Fig 4.6

Total Displacement for Five layered

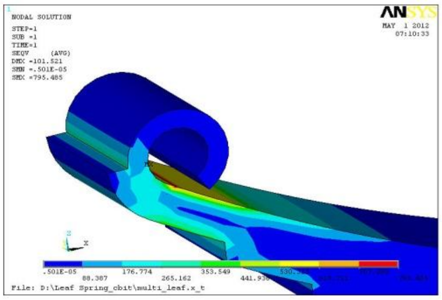


Fig 4.7

Von mises for two layered

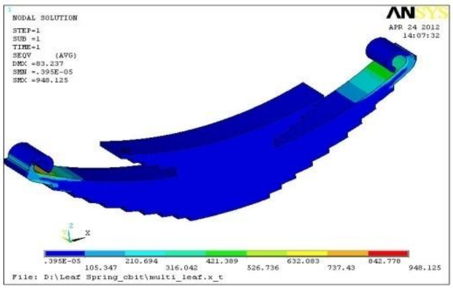


Fig 4.8

Von mises for five layered

Table 4.5 Static analysis parameters comparison

Parameter	Two layer mode	Five layer mode
Maximum displacement along x direction	1.269 mm	1.182 mm
Maximum displacement along y direction	0.03 mm	0.023 mm
Maximum displacement along z direction	0.32 mm	0.25 mm
Toatal displacement	101.5 mm	83.23 mm
Von mises stress	795.4 Mpa	948 Mpa

Figure 4.9& 4.10 shows stress along thickness graph for two layer mode and five layer mode. The graph is plotted by taking stress along y axis and thickness along x axis

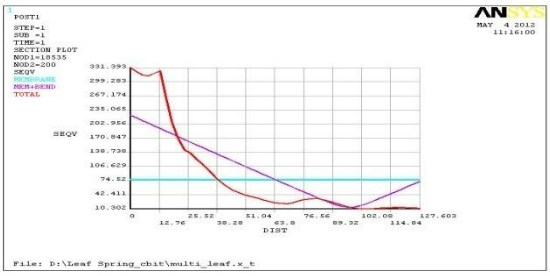


Fig 4.9 Stress Vs Thickness two layered

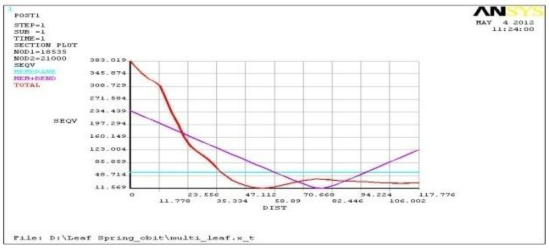


Fig 4.10 Stress Vs Thickness five layered

4.5 Modal Analysis:

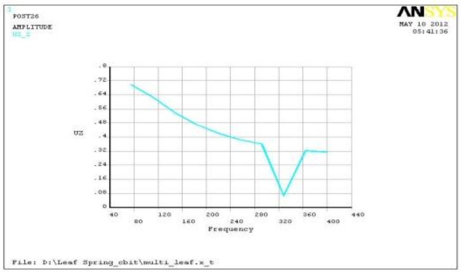
In modal analysis only boundary conditions are applied and no load is acted on the leaf spring. On the left eye all degrees of freedom are constrained and on the right eye only X & Y-directions are constrained.

Table 4.6 Modal analysis frequency table

Node number	Frequency value in hz	
	Two layers	**Five layers**
1	19.2	21.2
2	135	144
3	327	366
4	347	395
5	530	593
6	751	852
7	1200	1367
8	1272	1428
9	1377	1593
10	1433	1612

4.6 Harmonic Analysis:

For Harmonic Analysis the model is considered & then the boundary conditions are applied followed by the loading conditions. On the left eye all degrees of freedom are constrained and on the right eye X & Y-directions are constrained and load is applied at the centre



. **Fig 4.11 Amplitude Vs Frequency for two layered**.

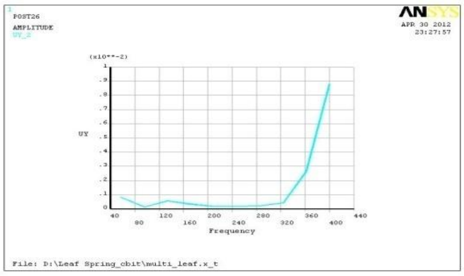


Fig 4.12 Amplitude Vs Frequency for five layered.

Figure 4.11 & 4.12 shows amplitude vs frequency graph for two layer mode and five layer mode. The graph is plotted by taking frequency on the Y axis and amplitude on the X axis.

4.7 Shock Analysis:

In shock analysis load is applied for very small duration along with the boundary conditions. A load of 1000kg is applied on the leaf spring for a time period of 6 micro second.

Table 4.7 Shock analysis parameters comparison

Parameter	Two layer mode	Five layer mode
Maximum displacement along x direction	0.325mm	0.0203mm
Maximum displacement along y direction	0.581E-03mm	0.720E-03mm
Maximum displacement along z direction	0.0105mm	0.003mm
Toatal displacement	0.1318mm	0.1198mm
Von mises stress	15.167Mpa	20.923Mpa

Figure 4.13 & 4.14 shows that as time increases, the displacement initially increases, reaches a maximum and then decreases for a two layermode. The figure also shows the deflection v/s time for five layer mode where the displacement initially decreases, reaches a minimum and then increases as the time progresses.

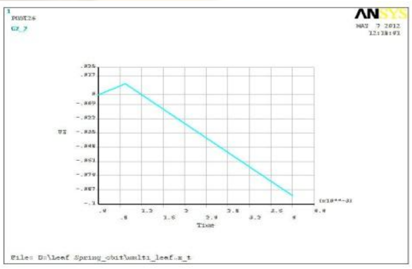


Fig 4.13 DisplacementVs Time for two layered.

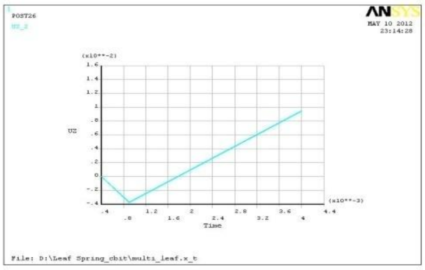


Fig 4.14 DisplacementVs Time for five layered

5. CONCLUSIONS:

In this paper we compared static, dynamic & shock analysis for two & five layered composite leaf spring. The composite material used is E-Glass Epoxy. These are the following conclusions made by comparing the two & five layered.

- In static analysis the maximum displacement is observed in two layered i.e 101.5mm compared to 83.23mm in five layered.
- Also during the static analysis Von-mises stress for the five layered is more than two layered i.e 948Mpa for five layered compared to 795.4Mpa for two layered.
- For modal analysis various nodes are obtained and a comparative table is drawn for various nodes. The range of frequencies for two layers is 19.2 Hz to 1433 Hz and for five layers is 21.2 Hz to 1612 Hz.
- In Hormonic anlaysis amplitude vs frequency graph for two layered and five layered are considered. For two layered amplitude decreases to a minimum and then increases & remains constant. For five layered, amplitude remains constant initially but increases rapidly in the end.
- For shock analysis as time increases, the displacement initially increases, reaches a maximum and then decreases for a two layer mode, for five layered the deflection v/s time for five layer mode where the displacement initially decreases, reaches a minimum and then increases as the time progresses.

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