

Finite element analysis and optimization of a mono parabolic leaf spring using CAE software

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ABSTRACT

Parabolic leaf spring is one of the vital components in vehicle suspension system, and it is commonly used in heavy vehicles. It needs to have an excellent static load bearing capacity and fatigue life too. The purpose of this work is to make computer aided engineering (CAE) analysis of mono parabolic leaf spring and to see the effect of change of material in the optimized leaf. A mono steel leaf spring and a mono leaf spring made of composite material have been selected for this comparative analysis. The material of the mono steel leaf spring is EN45A and Glass Reinforced Plastic (GRP) as composite material which is having high strength to weight ratio. The mono leaf spring model is having one full length leave with eyes at both ends, two pins in each eye end and a rubber pad on the upper face of leave center. The CAD modelling of parabolic leaf spring has been done in CATIA and for analysis the model is imported in ANSYS workbench. It was shown that the use of composite material instead of steel resulted into large deflection, small variation in stresses and also a large amount of weight reduction.

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1. Introduction

CAE software has been a popular tool to analyze the robustness and performance of components and assemblies. The finite element analysis (FEA) is a computing method implemented to find approximate solutions to the boundary value problems in engineering. It applies a numerical techniques named the finite element method (FEM). The component is modelled based on FEA using the discrete building blocks named elements. Each element contains some equations, which explain how it responds to certain loads. The sum of the response for all the elements in the model yields the total response of the design. CAE depends on actual assumptions of the assembly, which plays as input data. The component selected for this work is a parabolic leaf spring, which locates widespread application in

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automotive industry. Leaf springs also play essential role in whole automotive vehicle body. It is well recognized that springs are designed to absorb shocks so the strain energy of the material becomes an important factor in designing the springs. Automotive organizations have been interested in weight reduction of different components by the introducing new materials having better properties, optimization of design and better manufacturing processes. It can be considered that materials having lower modulus and density could have a bigger specific strain energy capacity. As the composite materials maintain more elastic strain energy storage capacity and higher strength-to-weight ratio compared with steel, the introduction of composite materials makes it possible to reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness. Therefore, analysis of composite material leaf springs has become necessity in demonstrating the comparative results with conventional steel leaf springs. Aggarwal and Chawla (2007) explained that fretting fatigue between leaves could be reduced by careful control of shot peening parameters. The bending strength of EN45A parabolic leaf spring is determined to be higher as compared with semi-elliptic leaf spring. Corvi (1990) investigated a PC program for the preliminary design of composite beams using composite mechanics and the finite element method (FEM). Applications to an automotive leaf spring have demonstrated the feasibility of applying the program as a tool in building the initial design considerations and in developing preliminary designs. Refngah et al. (2009) investigated fatigue life prediction based on FEA and variable amplitude loading (VAL). Service loading of parabolic spring has been gathered using data acquisition system and FEA was executed on the spring model so stress and damage distribution could be observed, and experimental works were executed to validate the FEA result. Shankar and Vijayarangan (2006) applied a computer algorithm for the design of constant cross-section leaf spring. They designed, fabricated and tested a single leaf with variable thickness of unidirectional glass fiber reinforced plastic with similar mechanical and geometrical properties to the multi-leaf spring. Kumar and Aggarwal (2013) performed FEA simulation for a three layers EN45A parabolic leaf spring and validate the CAE results with experimental results by comparing the maximum displacement, directional displacement, equivalent stress and weight of the assembly. Patnaik et al. (2012) performed an investigation on a parabolic leaf spring of a mini loader truck. The spring was analyzed by using load and the corresponding values of stress and displacement were computed. They detected camber and leaf span of a parabolic leaf spring for optimized stress and displacement value using artificial neural networks. Yadav et al. (2012) analyzed a leaf spring whose thickness was differed from the center to the outer side following a parabolic pattern. Initially the magnitude of stress pertaining to parabolic leaf spring was measured by finite element method and then the approach to minimizing the stress was executed effectively with help of local algorithm for constants and priorities. Jayaswal and Kushwah (2012) discussed practical means of facilitating participatory steps executed in productivity enhancement with the emphasis on rejection minimization programs in parabolic Leaf Spring Manufacturing Unit in India. They discussed various methods for productivity improvement with the emphasis on reduction of rejections in terms of end gap and camber less in leaf spring in parabolic leaf spring manufacturing. Patunkar and Dolas (2011) applied modelling and analysis of composite mono leaf spring and compared its results. Kumar and Vijayarangan (2007) explained static and fatigue analysis of steel leaf spring and composite multi leaf spring made up of glass fiber reinforced polymer based on life data analysis. The dimensions of an existing conventional steel leaf spring of a light commercial vehicle were taken and verified by design calculations. The design constraints were stresses and deflections. Dewangan et al. (2012) explained basic structure, stress characteristics, engineering finite element modelling for investigating high stress zones. The equivalent von-misses stresses were plotted for the parabolic leaf spring. Patel et al. (2012) reviewed the design, analysis and fabrication of composite leaf spring through the literature survey. They tried to see the performance of epoxy glass fiber reinforced materials used in leaf spring by predicting fatigue life. Yu and Kim (1988) studied fundamental properties of the dimensioning of the double tapered FRP leaf spring. Prototype longitudinal type double tapered leaf springs to replace four leaf steel springs were made from glass fiber and epoxy. Prototype GRP leaf springs indicated a superior endurance and fail-safe characteristics. From the above literature we may conclude that CAE has become an important technology with benefits such as lower costs and a shortened design cycle. In future CAE system will

be major information provider to assist design professionals in decision making. The objective of present work is to analyze a mono parabolic leaf spring by using CAE tools. The primary objective is on comparison of the optimized model with the conventional one by considering displacement, equivalent stress and weight.

2. Material properties and design specifications

2.1 Material Properties

The material of conventional model is EN45A spring steel having chemical composition by % weight is 0.61 C, 1.8 Si, 0.79 Mn, 0.02 S, 0.024 P, with unidirectional or isotropic behavior with respect to material properties which are shown in the Table 1. While on the other hand Glass Reinforced Plastics (GRP) is a composite material in which the volume fraction of glass fiber is 48%. It is assembled using knitting machinery to form a unidirectional glass tape of constant width. It consists of 97% glass in longitudinal direction and 3% in transverse direction. The material properties of the composite are measured at the Institute of Polymer Mechanics in Latvia (see Table 2). The low density and high elastic strain of the composite provides high specific strain energy capacity. So the material properties of GRP are as shown in table below.

Table 1

Material Properties of Steel (EN45A)

Parameter	Steel
Nature	Isotropic
Material selected	EN45A
Young's Modulus, E	2.1×10^5 N/mm ²
Poisson's Ratio	0.266
BHN	400-425
Tensile strength-Ultimate	1272 MPa
Tensile strength-Yield	1158 MPa
Density	0.00000785 kg/mm ³

Table 2

Material Properties of GRP

Parameter	GRP
Nature	Orthotropic
Young's Modulus, E_{xx}	38000 MPa
Young's Modulus, E_{yy}	13000 MPa
Young's Modulus, E_{zz}	13000 MPa
Poisson's Ratio, ν_{xy}	0.31
Poisson's Ratio, ν_{yz}	0.05
Poisson's Ratio, ν_{zx}	0.31
Modulus of Rigidity, G_{xy}	1000 MPa
Modulus of Rigidity, G_{yz}	16 MPa
Modulus of Rigidity, G_{zx}	60 MPa
Mass density	0.00000185 kg/mm ³
Tensile strength-Yield	900 MPa

2.2 Design Specifications

The geometrical specification of leaf spring are as follows,

Span length = 940 mm, Seat Length = 100 mm,

Number of leaf = 1, Rated load = 1800 N,

Width of leaf = 60 mm,

Centre Rubber Pad=100mm X 50mm X 5mm, Camber = 36 mm.

3. CAD modeling and FEA

CAD modeling software is associated with the specialized job of 3D-modeling. CAD modelling of this Mono Leaf Spring is executed by applying CATIA V5 R17 software. CATIA is having special capabilities in creating surface design to construct typical surfaces, which are later converted into solid models. Solid model of all parts of the structures are then assembled to make a complete structure. The process of assembly is very much analogous to general process of fabricating structures while real production. The CAD model of mono leaf spring applied for FE Analysis is demonstrated in Fig. 1.

A stress-deflection analysis is executed by applying FEA and the complete procedure of analysis has been performed using ANSYS workbench. To build FEA, the general process of FEM should be clear.

Finite Element method simulates a physical part or assembly's behavior by dividing the geometry of the part into a number of elements of standard shapes, applying loads and constraints, then calculating variables of interest – deflection, stresses, temperature, pressures etc. The behavior of an individual element is usually explained by a relatively simple set of equations. Just as the set of elements would be joined together to construct the whole structure, the equation explaining the behaviors of the individuals elements are joined into a set of equations, represent the behaviors of the whole structure. A finite element program takes the elements defined earlier, lists the equations for each unknown value, puts them together as a matrix equation, and then solves all these for the values of the unknown parameters. The equilibrium equation is of the form:

$$[\mathbf{K}] \{\mathbf{u}\} = \{\mathbf{f}\}. \quad (1)$$

Since it is analogous to the equations of spring deflection, \mathbf{K} is often called stiffness matrix, \mathbf{u} is called the deformation vector, and \mathbf{f} is called the load vector. \mathbf{K} is a square matrix, with one row and column for each unknown variable in the problem definition. To build finite element analysis, the general process of FEA is divided into three main phases, preprocessor, solution, and postprocessor.

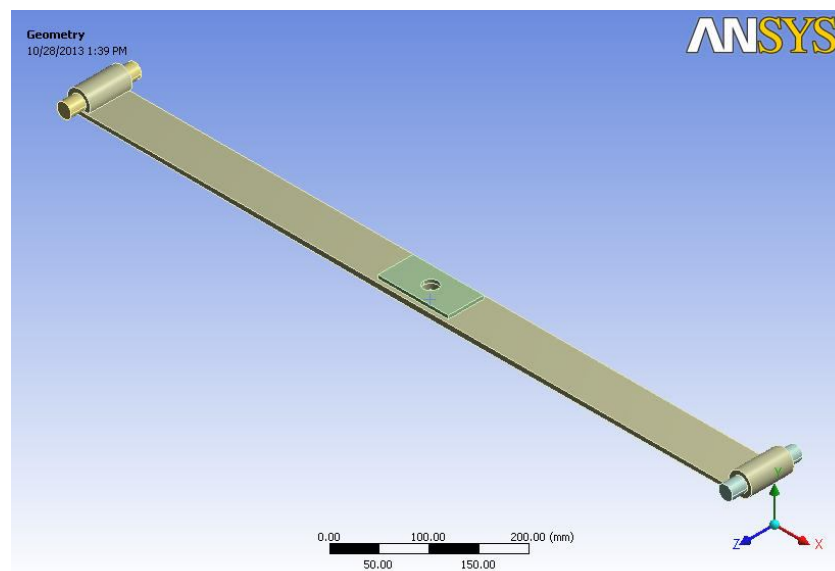


Fig. 1. CAD Model in ANSYS

Meshing of the model is executed in which model is discretized into finite number of elements and nodes as in Fig. 2. This mesh along with material properties is used to mathematically represent the stiffness and mass distribution of the structure.

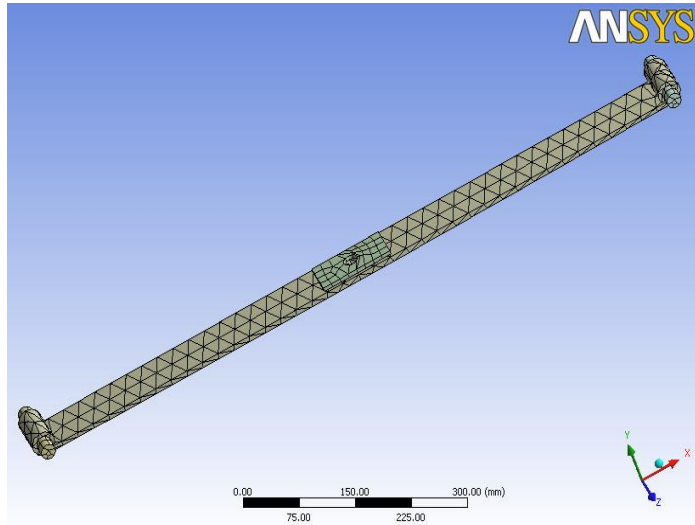


Fig. 2: Meshing showing nodes & elements

Table 3
Details of Steel Model

Object Name	<i>Geometry</i>
State	Fully Defined
Definition	
Length Unit	Meters
Element Control	Program Controlled
Bounding Box	
Length X	972. mm
Length Y	78. mm
Length Z	100.32 mm
Properties	
Volume	5.3444e+005 mm ³
Mass	4.0607 kg
Statistics	
Active Bodies	4
Nodes	2771
Elements	877

The boundary condition is the collection of various forces, pressure, velocity, supports, constraints and every condition required for complete analysis. Applying boundary condition is one of the most typical processes of analysis. A special care is required while assigning loads and constraints to the elements.

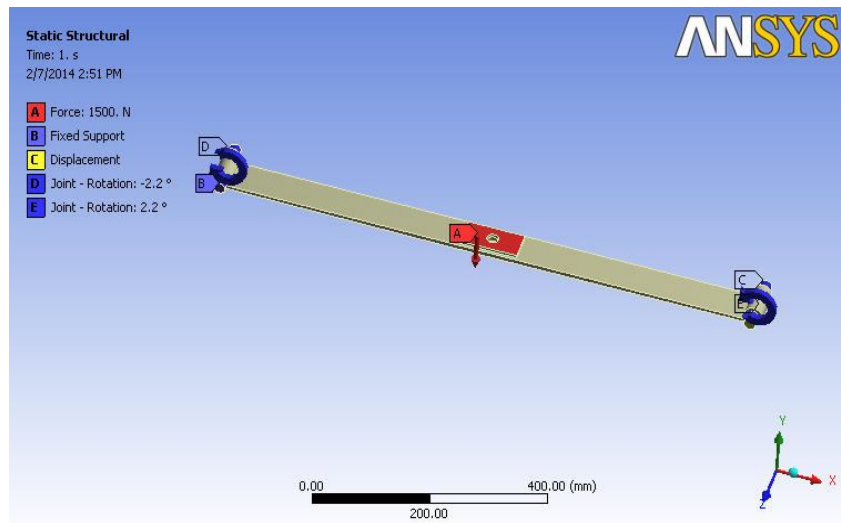


Fig. 3. Boundary Conditions

Boundary condition of the leaf spring involves the fixation of one of the revolute joint and applying displacement support at the other eye end of leaf spring. A joint rotation of 2.2° has been taken for both revolute joints considering the no load camber. Loading conditions involves applying a load at the

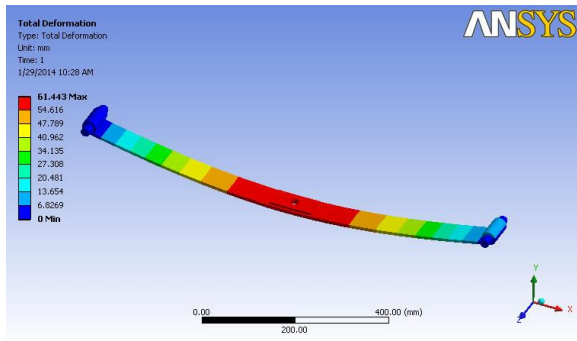


Fig. 4. Deflection in steel leaf spring

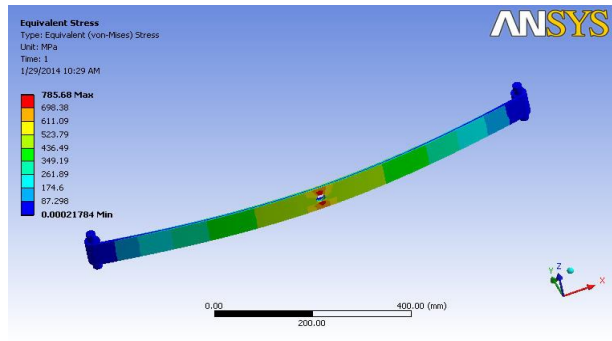


Fig. 5. Von-mises stress in steel leaf spring

Figs. 6 and 7 also shows the FEA results for the GRP leaf spring.

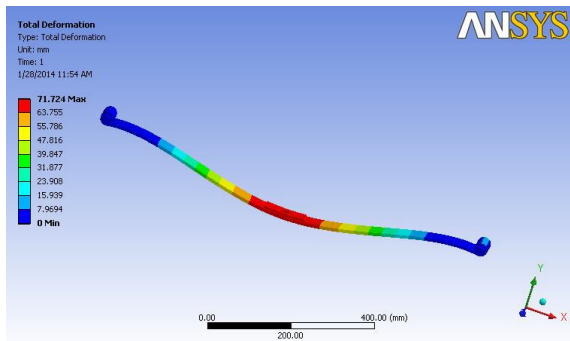


Fig. 6. Deflection in GRP leaf spring

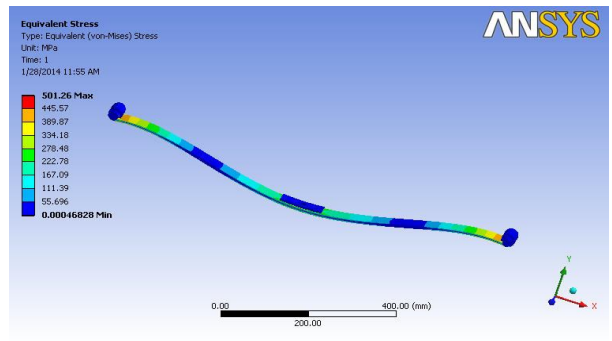


Fig. 7. Von-mises stress in leaf spring

From the FEA result data a comparison of both i.e. steel and GRP Leaf spring may be summarized as the following Table (Table 7):

Table 7
Result Comparisons

Parameters	Steel Leaf Spring	GRP Leaf Spring
Normal Static Load	1500 N	1500 N
Deflection	61.443 mm	71.724 mm
Von-Mises Stress	785.68 MPa	501.26 MPa
Mass	4.0607 kg	1.3716 kg

From the above comparison Table it has been observed that when a mono steel parabolic leaf and a mono GRP parabolic leaf analyzed with FEA, for the same static load and boundary conditions, the deflection in the case of steel is 61.443 mm while in case of GRP it is 71.724 mm which shows that a composite leaf has a little bit more deflection in comparison to steel. On the other hand the value of von-mises stress has been decreased from the 785.68 MPa to 501.26 MPa in steel and GRP leaves respectively. At the same time a large weight reduction is also experienced i.e. weight in case of steel is 4.0607 kg while of GRP leaf is 1.3716 kg.

4. Conclusion

From the results obtained from FE Analysis, some discussions have been made and it will be concluded that,

1. When steel leaf spring is replaced by composite material (GRP), the deflection of the leaf has been increased by a small amount which is acceptable.
2. The Von-mises stress in case of GRP Leaf spring is decreased by large amount which makes it much more beneficial to the design point of view.
3. When comparing steel & GRP parabolic leaf spring, there is a material saving of 66.12% by weight which also proves it an optimized design.

Computer Aided FEA has become an important technology with benefits such as lower costs and a shortened design cycle. In future it will be the major information provider to help design professionals in decision making.

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