



IJEAST

INTERNATIONAL JOURNAL
OF ENGINEERING APPLIED SCIENCE
AND TECHNOLOGY



VOLUME : 10 ISSUE : 07 Print / Issue Publication Date: 28-Jan-2026



ISSN : 2455-2143



DOI : 10.33564/IJEAST.2025.v10i07.009

Indexed In



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DESIGN AND ANALYSIS OF A LEAF SPRING WITH STEEL ALLOYS USING ANSYS

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Abstract— In now a days the fuel efficiency and emission gas regulation of automobiles are two important issues. To fulfill this problem the automobile industries are trying to make new vehicle which can provide high efficiency with low cost. The best way to increase the fuel efficiency is to reduce the weight of the automobile. The weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The achievement of weight reduction with adequate improvement of mechanical properties has made metal alloys a very good replacement material for conventional steel. The automobile vehicles have number of parts which can be able to replace by composite material, but due to the improvement of mechanical properties of composite material. It has more elastic strength and high strength to weight ratio has compared with those of steel material. So, out of many components one of the components of automobile, the leaf spring which use for carried out the whole weight of the vehicle is best option for replacement of steel material by composite material. For reduce the weight of leaf spring the analysis was carried out on the model of Mahindra Pickup's leaf spring with same dimensional geometry. The material selected for leaf spring are chromium vanadium steel, nickel chromium molybdenum steel, silicon manganese steel, tungsten chromium steel which are considered to be high strength and economical with similar mechanical and geometrical properties to the existing steel leaf spring. The analysis was carried out on ANSYS 16.0. A comparative study has been made between steel and alloys of steel leaf spring with respect to strength and weight, in order to finalize the best suitable material for real time applications.

Keywords: Leaf Spring, Alloy Steel, Structural Analysis, Finite Element Analysis, Weight Reduction Deformation Analysis.

I. INTRODUCTION

The objective of this project is to design a leaf spring and perform a comparative analysis of its mechanical behaviour using different steel alloy materials. The study focuses on evaluating the structural performance of the leaf spring under static loading conditions by analysing parameters such as total deformation, von Mises stress, strain distribution, and weight. The materials considered include conventional structural steel and alternative high- strength alloys like Chromium Vanadium Steel, Nickel Chromium Molybdenum Steel, Silicon Manganese Steel, and Tungsten Chromium Steel. These materials are selected for their superior mechanical properties and potential to reduce weight while maintaining or improving performance. Using 3D modelling in SolidWorks and finite element analysis in ANSYS Workbench, the project aims to determine the most suitable material that offers optimal strength-to-weight ratio, durability, and reliability for automotive suspension systems. The final goal is to identify an alloy that can effectively replace traditional steel in leaf springs, thereby enhancing vehicle efficiency and performance.

II. OBJECTIVE

The primary objective of this project is to design and perform a comparative structural analysis of a conventional steel leaf spring and various steel alloy leaf springs using finite element analysis. The aim is to evaluate the mechanical performance of each material under similar loading conditions in order to identify a suitable replacement that offers enhanced strength, reduced weight, and better durability.

This study focuses on analyzing the total deformation, stress distribution, and strain characteristics of the leaf spring using materials such as Chromium Vanadium Steel, Nickel Chromium Molybdenum Steel, Silicon Manganese Steel, and Tungsten Chromium Steel. By using ANSYS 16.0 for simulation and SolidWorks for modeling, the project intends to recommend the most effective material alternative that improves the performance of leaf springs in real-time automotive applications.

III. PROBLEM STATEMENT

In the automotive industry, reducing vehicle weight is a crucial factor for improving fuel efficiency and meeting stringent emission regulations. One of the key components contributing to a vehicle's weight is the leaf spring, which is traditionally made from structural steel. While structural steel offers sufficient strength, it adds significant mass to the suspension system, negatively impacting overall performance and efficiency.

There is a growing need to identify alternative materials that can replace conventional steel in leaf springs without compromising strength, stiffness, or durability. The challenge lies in selecting materials that not only reduce weight but also maintain or enhance mechanical properties under static loading conditions. Therefore, a detailed study involving the design and finite element analysis of leaf springs made from high-strength steel alloys is necessary to determine the most suitable material for automotive applications.

IV. METHODOLOGY

Flow Diagram

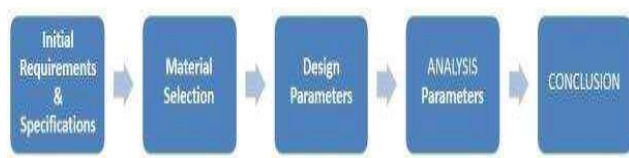


Fig 1: Flow Diagram

1) Initial Requirements & Specifications

The project begins by identifying the basic design and performance requirements of the leaf spring, using the Mahindra Pickup vehicle as the reference. The leaf spring's dimensions, loading conditions, and functional role in the suspension system were studied. The objective was to improve the overall performance by reducing weight and maintaining structural integrity under real-world conditions. These initial specifications guided the entire design and analysis process.

2) Material Selection

To explore better material alternatives, various high-strength steel alloys were considered in addition to conventional structural steel. The selected materials were Chromium Vanadium Steel, Nickel Chromium Molybdenum Steel, Silicon Manganese Steel, and Tungsten Chromium Steel. These materials were chosen based on key mechanical properties such as high tensile strength, good elasticity, corrosion resistance, and lightweight characteristics. Material selection was crucial to ensure both performance enhancement and cost-effectiveness in real-time

applications.

3) Design Parameters

A 3D model of the leaf spring was created using SolidWorks. The design included a semi-elliptical shape with multiple leaves, where the master leaf had eye ends for mounting, and the supporting leaves were placed below it. Features such as bolt holes, clamps, and gripping fixtures were included to replicate actual assembly conditions. Various SolidWorks tools like Extrude, Sweep, Flex, Chamfer, Fillet, and Mirror were utilized to model each part accurately, maintaining the standard geometry used in vehicle suspension systems.

4) Analysis Parameters

The designed model was then imported into ANSYS Workbench 16.0 for static structural analysis. Mesh generation was performed to divide the geometry into small elements for more precise results. Fixed supports were applied at both eye ends, while a uniformly distributed load (UDL) was applied at the center, simulating real-world axle forces. Material properties such as Young's modulus, Poisson's ratio, and density were defined in the software for each alloy. The analysis focused on determining total deformation, equivalent (von Mises) stress, strain distribution, and the overall mass of the leaf spring for each material.

5) Conclusion

Upon completing the simulations for all five materials, the results were compared in terms of strength, deformation, and weight. Chromium Vanadium Steel emerged as the best performing material, offering an optimal combination of strength and weight reduction. This makes it a highly suitable replacement for conventional structural steel in automotive leaf spring applications, enhancing vehicle efficiency without compromising durability or safety.

V. LITERATURE REVIEW

Several studies have been conducted on the design and performance improvement of leaf springs using advanced materials and finite element analysis. Leaf springs are essential components in vehicle suspension systems, subjected to repeated stress cycles that can lead to fatigue failure. As a result, researchers have explored alternatives to conventional steel to reduce weight while maintaining or enhancing performance.

5.1. DESIGN AND ANALYSIS OF COMPOSITE LEAF SPRING FOR LIGHT VEHICLES

Pankaj Saini, Ashish Goel, Dushyant Kumar

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. In this paper we describe design and analysis of composite leaf spring. The objective is to compare the stresses and weight saving of composite leaf spring with that of steel leaf spring. The design constraint is stiffness. The Automobile Industry has great interest for replacement of steel leaf spring with that of composite leaf spring, since the composite materials has high strength to weight ratio, good corrosion resistance. The material selected was glass fiber reinforced polymer (E-glass/epoxy), carbon epoxy and graphite epoxy is used against conventional steel. The design parameters were selected and analyzed with the objective of minimizing weight of the composite leaf spring as compared to the steel leaf spring. The leaf spring was modeled in Auto-CAD 2012 and the analysis was done using ANSYS 9.0 software.

5.2. A REVIEW PAPER ON DESIGN & ANALYSIS OF LEAF SPRING

Priyanka Kothari, Amit Patel

This paper reviews some of the general study on the design, analysis and fabrication of composite leaf spring. Leaf springs are one of the oldest suspension components they are still frequently used, especially in commercial vehicles. The literature has indicated a growing interest in the replacement of steel spring with composite leaf spring. The suspension system in a vehicle significantly affects the behavior of vehicle, i.e. vibration characteristics including ride comfort, stability etc. Leaf springs are commonly used in the vehicle suspension system and are subjected to millions of varying stress cycles leading to fatigue failure. A lot of research has been done for improving the performance of leaf spring. Lot of materials are used for leaf spring. But it is found that fiberglass material has better strength characteristic and lighter in weight as compare to steel for leaf spring. In this paper the author is reviewed few papers on use of alternate materials and effect of material on leaf spring performance.

5.3. DESIGN AND ANALYSIS OF A LEAF SPRING FOR AUTOMOBILE SUSPENSION SYSTEM

Baviskar A. C., Bhamre V. G., Sarode S. S.

A review on the design and analysis of leaf springs in automobile suspension systems. The study highlights the impact of suspension components on ride comfort, stability, and vibration characteristics. Leaf springs experience cyclic stresses that can lead to fatigue failure. The authors observed a growing interest in replacing steel springs with composite materials, especially fiberglass, due to its high strength-to-weight ratio. The paper reviews various research efforts on improving fatigue life and performance of leaf springs. Finite Element Analysis (FEA) using ANSYS is discussed as a key tool in modern design validation. The

study emphasizes that CAE tools now reduce the need for physical prototypes, saving cost and time. Analysis of failure modes is also included. The research supports composite alternatives for enhancing vehicle safety and durability.

5.4. DESIGN AND ANALYSIS OF LEAF SPRING WITH DIFFERENT ARRANGEMENTS OF COMPOSITE LEAVES WITH STEEL LEAVES

Ajay B.K., Mandar Gophane, P Baskar

This study focuses on a multi-leaf spring with eight leaves used in a commercial vehicle. To reduce cost and weight, the researchers replaced the steel leaf spring with a composite made from glass fiber reinforced plastic (GFRP). Springs with constant width and thickness were analyzed using various composite arrangements. All models were designed with a factor of safety of 2.5 and analyzed using ANSYS. Results showed significantly lower stresses and reduced weight in the composite spring compared to steel. The study also highlighted how the use of dissimilar materials influences the overall stiffness and performance of the spring design.

5.5. DESIGN AND ANALYSIS OF COMPOSITE LEAF SPRING

Y. N. V. Santhosh Kumar & M. VimalTeja

In these paper, composite structures for conventional metallic structures has many advantages because of higher specific stiffness and strength of composite materials is discussed. The automobile industry has shown increased interest in the replacement of steel spring with fiberglass composite leaf spring due to high strength to weight ratio. This work deals with the replacement of conventional steel leaf spring with a Mono Composite leaf spring using E-Glass/Epoxy. The design parameters were selected and analyzed with the objective of minimizing weight of the composite leaf spring as compared to the steel leaf spring. The leaf spring was modeled in Pro/E and the analysis was done using ANSYS Metaphysics software.

VI. INTRODUCTION TO SOLIDWORKS

SolidWorks is a parametric 3D CAD software used for designing mechanical components with precision and efficiency.

In this project, SolidWorks was used to create a detailed 3D model of a multi-leaf semi-elliptical leaf spring.

The modeling process started with a base sketch, which was extruded to form individual leaf layers.

Features such as gripping fixtures, bolt holes, and symmetrical components were created using tools like:

FILE FORMAT:

SolidWorks files use the Microsoft Structured Storage file

format. This means that there are various files embedded within each SLDDRW (drawing files), SLDPRT (part files), SLDASM (assembly files) file, including preview bitmaps and metadata sub-files. Various third-party tools (see COM Structured Storage) can be used to extract these sub-files, although the sub files in many cases use proprietary binary file formats.

COMMONLY USING TOOLS FOR MODELLING IN SOLIDWORKS:

- 1) Extrude
- 2) Extrude cut
- 3) Revolve
- 4) Revolve cut
- 5) Sweep
- 6) Sweep cut
- 7) Fillet
- 8) Chamfer
- 9) Mirror

The completed SolidWorks model was used as a base for conducting finite element analysis in ANSYS Workbench.

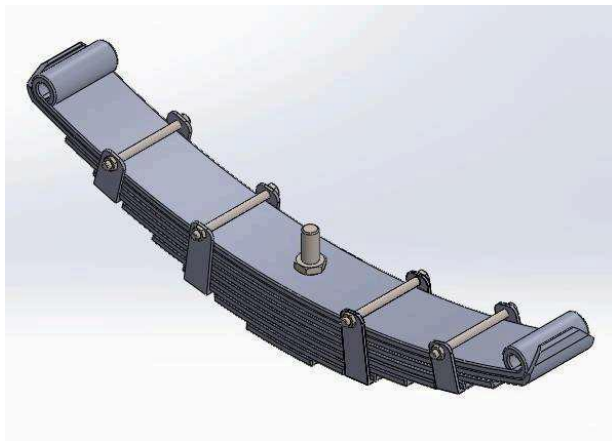


Fig.2. Leaf Spring 3D Model

VII. ANSYS WORKBENCH

ANSYS Workbench combines the strength of our core simulation tools with the tools necessary to manage your projects. You will work with your ANSYS Workbench project on the main project workspace, called the Projecttab. The project is driven by a schematic workflow, represented visually on a flowchart like diagram called the Project Schematic. To build an analysis, you add building blocks called systems to the Project Schematic; each system is a block of one or more components called cells, which represent the sequential steps necessary for the specific type of analysis. Once you have added your systems, you can link them together to share and/or transfer data between systems. From the cells in the Project Schematic, you can

work with various ANSYS applications and analysis tasks. Some of these open in tabs within the Workbench environment, while others open independently in their own windows.

ANALYSIS SYSTEMS

One way to start an analysis in ANSYS Workbench is to select an analysis system from the Toolbox. When you select one of these analysis types, the corresponding system will appear in the Project Schematic, with all the necessary components of that type of analysis. Some analysis types offer different solvers, noted in parentheses. The features available can differ from one solver to another.

Available analysis systems include:

1. Design Assessment
2. Explicit Dynamics
3. Fluid Flow (CFX)
4. Fluid Flow (Fluent)
5. Fluid Flow (Polyflow)

When you either double-click or drag an analysis system onto the Project Schematic it appears in the Project Schematic as a system. Components for that analysis type's system are listed as individual cells.

For example, a typical structural analysis might have the following components/cells:

- Engineering Data
- Geometry
- Model/Mesh
- Setup

VIII. MATERIAL SELECTION

STRUCTURAL STEELS are iron-base alloys that contain a minimum of about 12% Cr, the amount needed to prevent the formation of rust in unpolluted atmospheres (hence the designation stainless). Few stainless steels contain more than 30% Cr or less than 50% iron.

Chromium vanadium is a popular type of steel made by alloying chromium, carbon, vanadium, and other metals. SMSC provides chromium vanadium springs for various industrial applications. These springs offer benefits of specific load tolerances, hardness, corrosion resistance, and stress reliever characteristics due to their typical chemical composition.

Nickel Chromium Molybdenum alloy steel has high toughness and strength. It contains low carbon content to achieve good welding characteristics.

Silicon Manganese Steel is a high-performance alloy steel commonly used in the manufacturing of automotive components such as leaf springs and suspension systems. It primarily consists of carbon, silicon, and manganese, with

typical compositions including 0.55–0.75% carbon, 0.15–0.35% silicon, and 1.0–1.6% manganese.

IX. RESULT & DISCUSSION STRUCTURAL ANALYSIS

The structural analysis is a mathematical algorithm process by which the response of a structure to specified loads and actions is determined. This response is measured by determining the internal forces or stress resultants and displacements or deformations throughout the structure. The structural analysis is based on engineering mechanics, mechanics of solids, laboratory research, model and prototype testing, experience and engineering judgment. The basic methods of structural analysis are flexibility and stiffness methods. The flexibility method is also called force method and compatibility method. The stiffness method is also called displacement method and equilibrium method. These methods are applicable to all type of structures; however, here only skeletal systems or framed structures will be discussed. The examples of such structures are beams, arches, cables, plane trusses, space trusses, plane frames, plane grids and space frames. The skeletal structure is one whose members can be represented by lines possessing certain rigidity properties. These one-dimensional members are also called bar members because their cross-sectional dimensions are small in comparison to their lengths. The skeletal structures may be determinate or indeterminate.

Analysis Procedure

- Model Import
- Meshing
- Applying Boundary Conditions
- Loading Conditions
- Material Selection
- Static Structural Analysis
- Result Comparison
- Conclusion

Fig.3. RESULTS OF LEAFSPRING MADE OF CHROMIUM VANADIUM STEEL

RESULTS OF LEAFSPRING MADE OF NICKEL CHROMIUM MOLYBDENUM STEEL

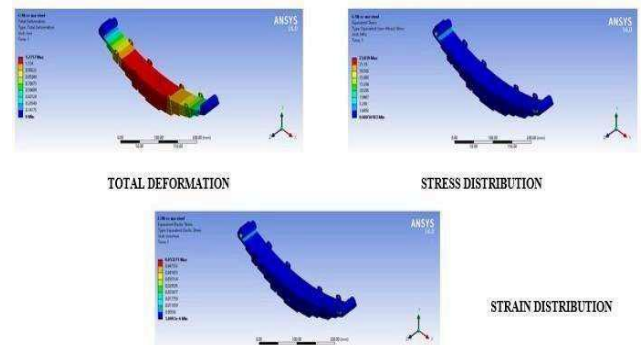


Fig.4. RESULTS OF LEAFSPRING MADE OF NICKEL CHROMIUM MOLYBDENUM STEEL

RESULTS OF LEAFSPRING MADE OF SILICON MANGANESE STEEL

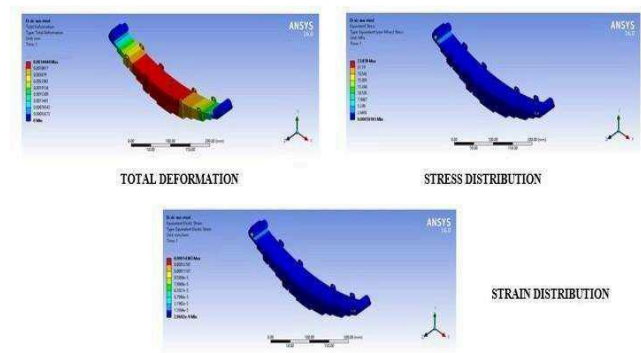


Fig.5. RESULTS OF LEAFSPRING MADE OF SILICON MANGANESE STEEL

RESULTS OF LEAFSPRING MADE OF TUNGSTEN CHROMIUM STEEL

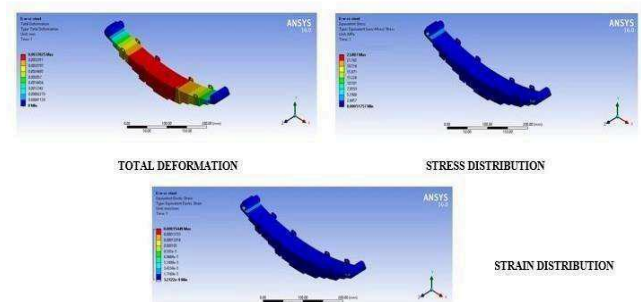


Fig.6. RESULTS OF LEAFSPRING MADE OF TUNGSTEN CHROMIUM STEEL

TABULATED RESULTS

MATERIAL	TOTAL DEFORMATION(MM)		STRESS (MPa)		STRAIN		MASS (KG)
	MIN	MAX	MIN	MAX	MIN	MAX	
STRUCTURAL STEEL	0	3.4E-3	5.49E-4	23.73	3.02E-9	1.43E-4	4.45
CHROMIUM VANADIUM STEEL	0	3.27E-3	5.24E-4	23.79	2.85E-9	1.36E-4	4.42
NICKEL CHROMIUM MOLYBDENUM STEEL	0	1.27	5.01E-4	23.83	1.09E-9	0.053	4.99
SILICON MANGANESE STEEL	0	3.44E-3	5.01E-4	23.83	2.96E-9	1.43E-4	3.57
TUNGSTEN CHROMIUM STEEL	0	3.7E-3	5.17E-4	23.8	3.21E-9	1.54E-4	4.4

Result and Discussion

The results of the static structural analysis for different materials used in the leaf spring design reveal important insights into their performance. Among the tested materials, **Nickel Chromium Molybdenum Steel** exhibited the **least deformation** (1.27 mm), indicating high stiffness, while maintaining a high stress capacity of 23.83 MPa. **Chromium Vanadium Steel** showed slightly lower deformation (3.27e-3 mm) than **Structural Steel** (3.4e-3 mm) and demonstrated a significantly higher stress resistance (23.79 MPa compared to just 5.49e-4 MPa for structural steel). **Silicon Manganese Steel** and **Tungsten Chromium Steel** had deformation values of 3.44e-3 mm and 3.7e-3 mm, respectively, with similar stress levels around 23.8 MPa.

Overall, **Chromium Vanadium Steel** offered the best **strength-to-deformation ratio**, making it the most suitable and efficient replacement for conventional structural steel in leaf spring applications.

Key Observations

Validated Use of Alloy Steels for Automotive Applications: The project demonstrated that specific alloy steels can effectively replace conventional steel in automotive suspension systems, maintaining structural integrity under load.

Reduction in Deformation without Compromising Safety: The alloy materials, particularly Chromium Vanadium, exhibited reduced deformation under identical loading conditions, suggesting better durability and performance over time.

Material Selection Guide for Future Development: The comparative analysis offers a reliable reference for engineers to select the most suitable leaf spring material based on performance-to-cost ratio in real-time applications.

X. CONCLUSION

The design and static structural analysis of both conventional steel and alloy steel leaf springs were successfully carried out. Using the same design and load-carrying conditions, a comparison was made between the performance of the standard steel leaf spring and those made from various alloy steels. The analysis, conducted using ANSYS, calculated both the stress and displacement for each material type.

Results revealed that the maximum displacement for the structural steel leaf spring was 3.4e-3 mm. In comparison, the displacements for the alloy variants were as follows: Chromium Vanadium Steel -3.27e-3 mm, Nickel Chromium Molybdenum Steel - 1.27 mm, Silicon Manganese Steel – 3.44e-3 mm, and Tungsten Chromium Steel 3.7e-3 mm. Regarding stress, the structural steel experienced a von-Mises stress of only 5.49e-4 MPa, whereas the alloy steels handled much higher stresses: Chromium Vanadium 23.79 MPa, Nickel Chromium Molybdenum 23.83 MPa, Silicon Manganese 23.83 MPa, and Tungsten Chromium - 23.80 MPa.

All alloy leaf springs demonstrated allowable stress levels, showing better performance than conventional steel. Based on both strength and weight considerations, Chromium Vanadium Steel was identified as the best replacement material, offering the most favourable balance of low deformation and high strength.

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