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Design and Analysis of Leaf Spring Using Chrome Silicon Steel and Life Span Prediction through Machine Learning

D. Jagan[1], CH. Raju[2], K. Jagadeesh[3], K. Rishi chandra[4], B. Ravi[5]
Assistant Professor, Department of Mechanical Engineering, ACE Engineering College, Ghatkesar, India[1,2]
Students, Department of Mechanical Engineering, ACE Engineering College, Ghatkesar, India[3,4,5]

Abstract: *Leaf springs are vital components of a vehicle's suspension system, designed to absorb shocks and ensure a smooth ride. In this Project, the leaf spring is designed using CATIA V5, where the geometry Is precisely modeled based on available journals. The spring, made from chrome silicon steel a Material recognized for its high strength, flexibility, and durability then analyzed using ANSYS, Where Finite Element Analysis (FEA) is employed to simulate its behaviour under various loading Conditions, focusing on deflection, stress distribution, and fatigue performance. Chrome silicon Steel's excellent resistance to fatigue and wear makes it ideal for vehicles carrying heavy loads. To Estimate the spring's lifespan, machine learning techniques are applied to datasets involving stress, Load cycles, temperature, and material properties obtained from the simulations. By training Predictive models, the expected life of the spring can be estimated accurately without extensive Physical testing. The integration of CATIA design, ANSYS simulation, and machine learning Provides a more efficient, intelligent, and reliable method for performance evaluation, reducing Development time and cost while significantly improving the accuracy of durability predictions.*

Keywords: Suspension system, Leaf Spring, Finite element analysis, Stress distribution, Machine Learning.

I. INTRODUCTION

Leaf springs are important components of a vehicle suspension system that absorb shocks, support vehicle weight, and maintain stability and comfort. They work by bending under load and returning to their original shape after the load is removed. Their performance depends on design parameters such as length, width, thickness, number of leaves, and material used. Proper design is necessary to achieve good strength, stiffness, and fatigue life.

Chrome silicon steel is widely used for leaf springs because of its high tensile strength, high yield strength, and excellent fatigue resistance. It can withstand heavy loads, repeated stress, and high temperatures better than conventional steels. The presence of chromium improves hardness and wear resistance, while silicon increases strength and elasticity, resulting in longer service life and better reliability.

Finite Element Analysis (FEA) is used to study stress, strain, deformation, and factor of safety of the leaf spring under different loads. Using ANSYS, the model can be analysed to find critical stress regions and compare results with theoretical calculations, reducing testing time and cost.

Machine learning is used to predict the life span of the leaf spring using data such as load, stress, strain, and deformation. By combining FEA results and machine learning, accurate life prediction can be achieved without long physical testing.

Thus, the design and analysis of a chrome silicon steel leaf spring with FEA and machine learning helps in improving strength, durability, and reliability while reducing development time and cost.

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II. METHODOLOGY AND MATERIAL

2.1 Methodology

The methodology of this project involves the design, modelling, analysis, and life span prediction of a leaf spring made of chrome silicon steel using theoretical calculations, Finite Element Analysis (FEA), and machine learning techniques. First, the design problem is defined to develop a leaf spring with sufficient strength, stiffness, and durability. Chrome silicon steel is selected as the material due to its high tensile strength, good toughness, and excellent fatigue resistance, and the required material properties are taken from standard data books. The dimensions of the leaf spring are determined using standard design formulas, and theoretical calculations are performed to find stress, deflection, and factor of safety to ensure the design is safe. Based on these values, a three-dimensional model of the leaf spring is created using CAD / ANSYS Design Modeler including all leaves and eye ends. The model is then imported into ANSYS for Finite Element Analysis, where material properties are assigned, meshing is generated, and proper boundary conditions are applied by fixing one end and applying load at the required position. The analysis is carried out to obtain total deformation, equivalent stress, equivalent strain, and factor of safety, and the results are compared with theoretical values to verify accuracy. After completing the analysis, a dataset is prepared using the obtained results, which includes parameters such as stress, strain, deformation, and safety values. This dataset is used to train a machine learning model using Python libraries, which helps in predicting the life span of the leaf spring without repeated analysis. Finally, the predicted results are compared with simulation values, and the combined use of theoretical calculation, FEA, and machine learning improves design accuracy, reduces testing time, and increases the reliability of the leaf spring for automotive suspension applications.

2.2. MECHANICAL PROPERTIES

`Property	Symbol / Unit	Typical Value
Density	ρ	7.8 g/cm³
Young's Modulus	E	200 GPa
Ultimate Tensile Strength	σ	1200-1600 MPa
Hardness	HRC	50–55
Poisson's Ratio	ν	0.3
Elongation at Break	%	8-12%
Fatigue Strength	MPa	450-700 MPa

Table 1 Material Properties of chrome silicon steel

III. DESIGN OF LEAF SPRING

The design of the leaf spring is created using CATIA V5 by following a systematic modelling procedure. First, a new part file is created in the Part Design workbench. A sketch is drawn on the XY plane to create the rectangular profile of the master leaf using the required length and width obtained from design calculations. The Pad command is used to give the required thickness to the leaf. Edge fillet is applied to the corners to reduce stress concentration and to obtain a smooth surface finish. After creating the master leaf, the eye ends are designed by sketching circles at both ends and using pad or pocket features to form the eye section required for mounting the spring in the suspension system.

Additional leaves are then created by copying the master leaf and reducing the length step by step according to the design specifications. Each leaf is positioned carefully so that the curvature and alignment are maintained properly. The Assembly workbench is used to place all the leaves together and constraints are applied to ensure correct positioning of each leaf in the stack. A centre bolt hole is also created to represent the clamping arrangement used in actual leaf springs. If required, clamps and supports can be modelled to make the design closer to real conditions.

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After completing the modelling, all dimensions such as length, thickness, and spacing are checked using the measure tool to ensure that the model matches the theoretical design values. The final model is visually inspected to confirm that there are no geometric errors. The completed leaf spring model is then saved and exported in IGES

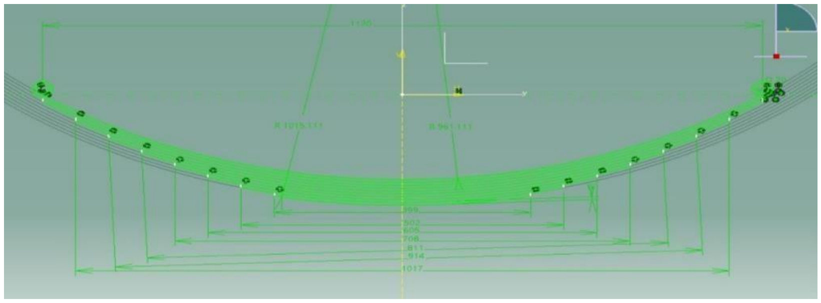

Fig. 1 Design of Leaf Spring using CATIA V5

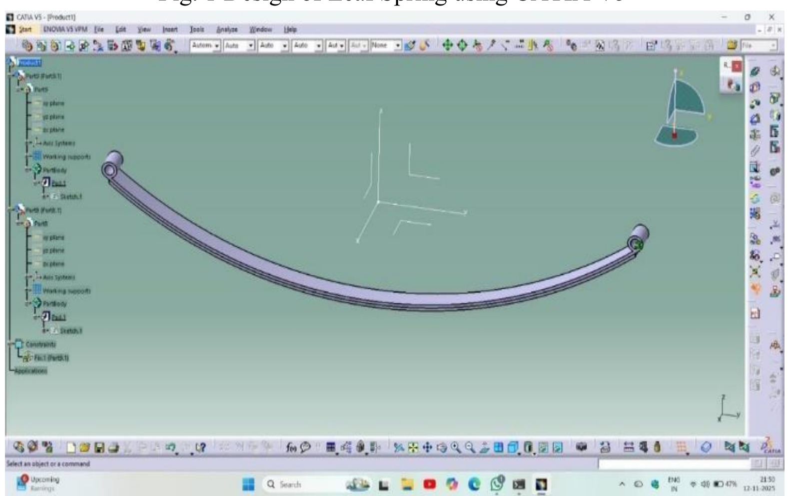

Fig.2 Full length leaves

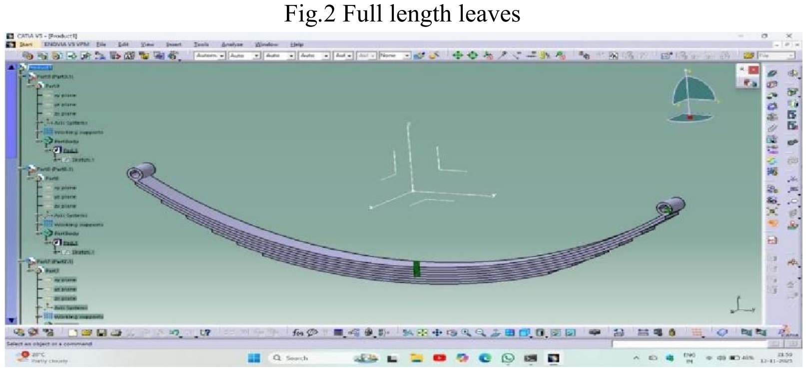

Fig 3. Assembly of leaf spring

IV. ANALYSIS

The analysis of the leaf spring was carried out using ANSYS Workbench to evaluate the structural performance under different loading conditions. The 3D model of the leaf spring created in CAD software was imported into ANSYS, and the material properties of chrome silicon steel such as Young's modulus, Poisson's ratio, density, and yield strength were assigned. Proper boundary conditions were applied by fixing one end of the spring and applying load at the centre

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to simulate actual working conditions of a vehicle suspension system. A suitable mesh size was selected according to the student version limit to ensure accurate results without exceeding the node limit. Static structural analysis was performed by applying loads of different magnitudes such as 3000 N, 4500 N, and 6000 N to study deformation, equivalent stress, strain, and factor of safety. The results obtained from ANSYS showed that the maximum stress occurs at the centre region of the leaf spring, while the maximum deformation occurs at the free end. The obtained results were compared with theoretical calculations, and the variation was found to be within acceptable limits, which confirms that the design is safe for the given loading conditions. The analysis also helps in predicting the performance and life span of the leaf spring, which can be further used for machine learning based life prediction.

Meshing :

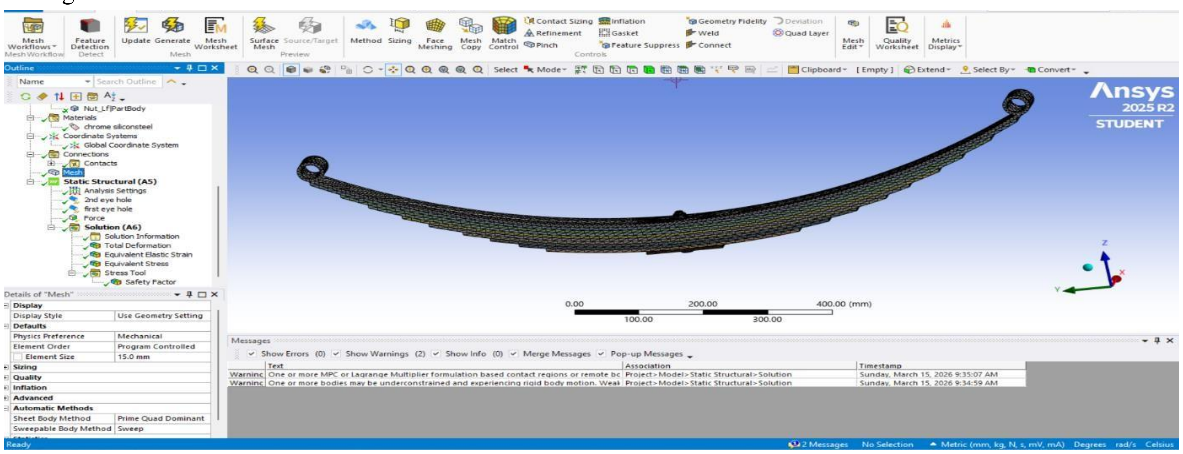

Fig 4 Applying Meshing to the leaf spring

Total Deformation :

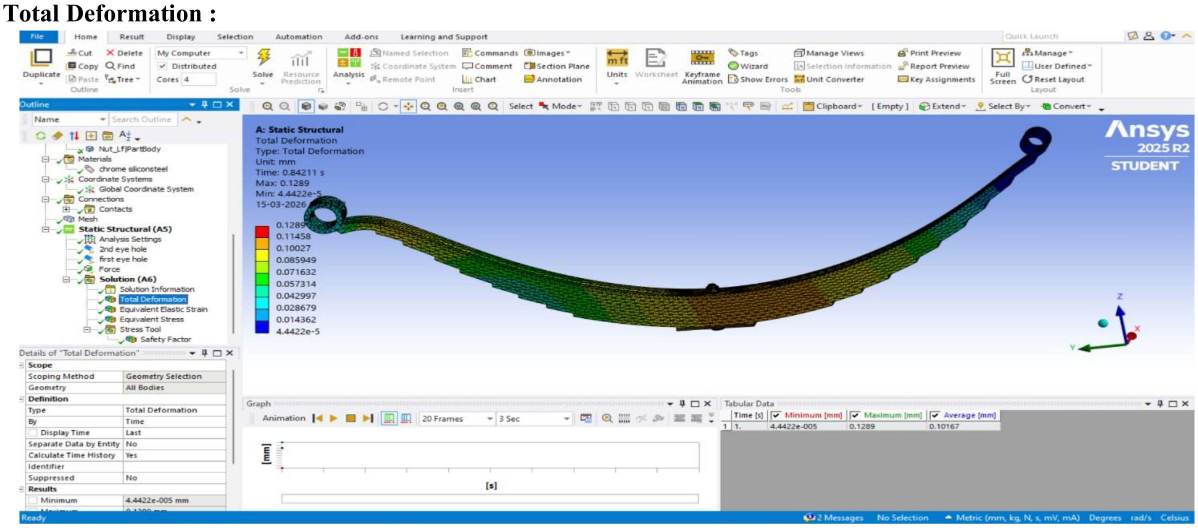

Fig 5 Total deformation

The static structural analysis of the leaf spring was carried out using ANSYS Workbench by applying a load of 3000 N at the centre while fixing both eye ends to simulate actual working conditions. The total deformation result shows that the maximum deformation occurs at the middle region of the leaf spring, while minimum deformation is observed near the fixed supports, indicating proper load distribution. The obtained deformation value is 0.128mm within the

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allowable limit, which confirms that the leaf spring made of chrome silicon steel is safe for the applied load and suitable for suspension applications.

Equivalent Elastic Strain :

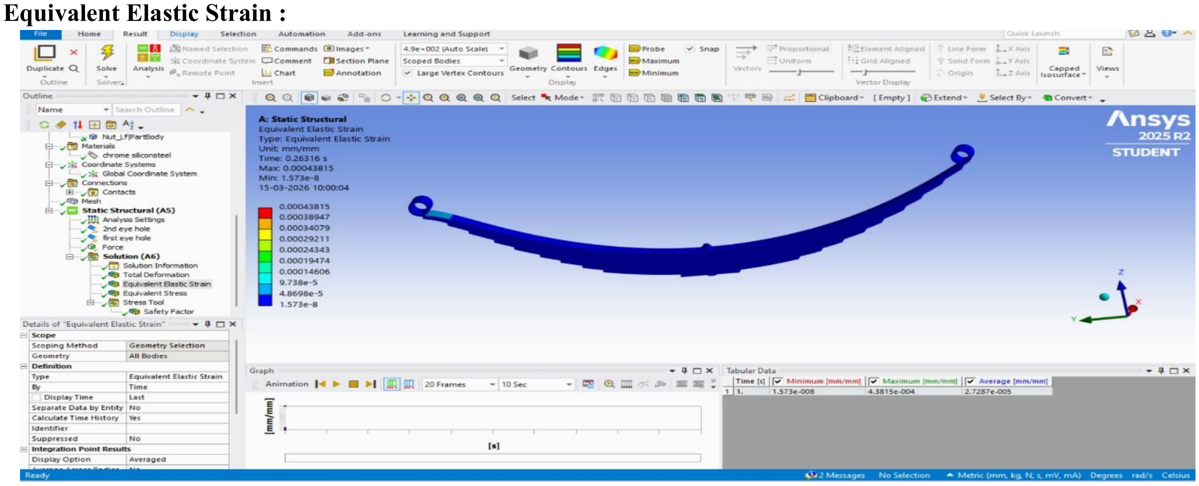

Fig 6 Equivalent Elastic strain

The equivalent elastic strain of the leaf spring was analysed in ANSYS by applying a 3000 N load at the centre with both ends fixed. Maximum strain occurred near the centre, while minimum strain was observed at the eye ends.The obtained strain value 0.00043815 is within the allowable limit of chrome silicon steel.

Equivalent Stress :

The leaf spring can safely withstand the applied load without permanent deformation. On-Mises stress analysis in ANSYS with 3000 N load shows maximum stress near the eye end and centre. The maximum stress 77.803 MPa is within the allowable limit of chrome silicon steel. Hence, the designed leaf spring is safe.

Factor of Safety :

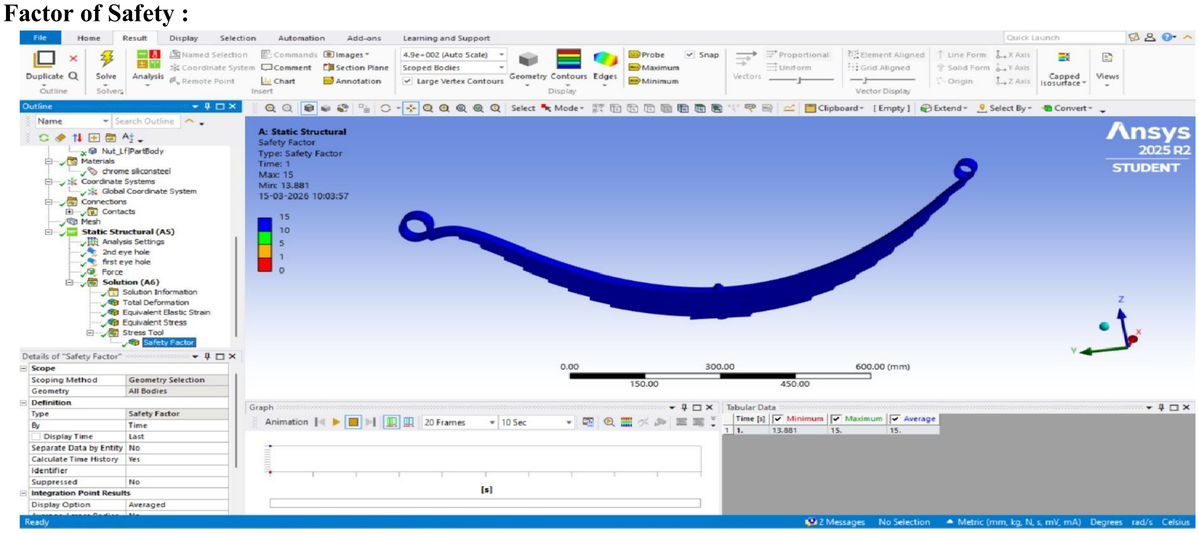

Fig 7 Factor of safety

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The factor of safety result obtained from ANSYS shows a minimum value of 13.881, which is greater than one for the entire leaf spring. The minimum value occurs near the central region where bending is higher. Since the factor of safety is greater than one, the chrome silicon leaf spring is safe under the applied load.

Similarly for different loads

Sl.No	Load	Total Deformation	Equivalent Elastic strain	The equivalent (von-Mises) stress	Factor of safety
1.	4500 N	0.1887mm	0.00071949 mm	125.36 MPa	8.61
2.	5000N	0.20967 mm	0.0007994 mm	139.29 MPa	7.75
3.	6000N	0.2578 mm	0.00087631 mm	167.14 MPa	6.46
4.	10000N	0.41934 mm	0.0015988 mm	278.57 MPa	3.87

Table 2. Different loads

Result

The results obtained from ANSYS Workbench were compared with the theoretical calculations for different loads such as 4500 N, 5000 N, 6000 N, and 10000 N to verify the accuracy of the analysis. The deformation, stress, and strain values obtained from simulation are close to the theoretical values with only small variation due to meshing and boundary condition assumptions. In all cases, the factor of safety obtained from ANSYS is greater than one and is also in agreement with theoretical calculations, which confirms that the leaf spring made of chrome silicon steel is safe under the given loading conditions. Therefore, both theoretical and numerical results validate that the proposed leaf spring design can withstand the applied loads without failure.

V. MACHINE LEARNING

Type of Model Used:

Supervised Machine Learning Regression model is used for predicting the life span of the leaf spring. Since the output is numerical (number of cycles), a regression method is used. The model is trained using ANSYS simulation dataset.

Type of Library Used:

Python libraries such as Scikit-learn, NumPy, Pandas, Joblib, Matplotlib, and Flask are used. Scikit-learn is used to train the machine learning model, Joblib is used to save and load the model, and Flask is used to create the web application for life span prediction.

RESULT

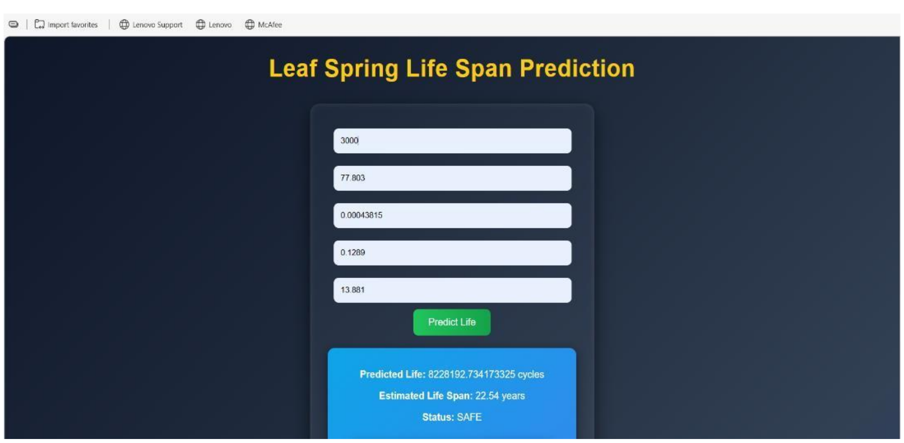

Fig 8 Machine learning life span prediction

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The machine learning model predicts the leaf spring life span using stress, strain, deformation, load, and factor of safety.

The predicted fatigue life is 8228192.734 cycles, equal to 22.54 years of service. The result shows cycles, duration, and SAFE status, confirming the spring is within allowable stress limit.

VI. CONCLUSION

The present work focused on the design and analysis of a leaf spring made of chrome silicon steel to evaluate its strength, deformation, and durability. Finite Element Analysis was performed using ANSYS Workbench to study the structural behaviour of the leaf spring and to determine stress, strain, deformation, and factor of safety. The results showed that the selected material provides high strength and good fatigue resistance, making it suitable for suspension applications. The simulation results were further used to develop a machine learning model for predicting the life span of the leaf spring. The trained model successfully predicted the number of cycles and service duration with good accuracy when compared with ANSYS results. This approach reduces the need for repeated simulations and helps in faster design validation. Therefore, the combination of chrome silicon steel, finite element analysis, and machine learning provides an efficient method for designing strong, reliable, and long-life leaf springs for automotive suspension systems.

VII. ACKNOWLEDGMENT

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