Performance Evaluation of Alloy Wheel-Based Suspension in Lightweight Vehicles under Static and Vibration Loads

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***Abstract*—The suspension system plays a vital role in vehicle performance, safety, and comfort. This study presents the design and analysis of a suspension system integrated with an alloy wheel for lightweight vehicle applications. A 3D model is developed using SolidWorks and analyzed in ANSYS using Finite Element Analysis (FEA) to evaluate stress, deformation, and strain under different loading conditions. Various materials such as spring steel, titanium alloy, and composite materials are considered to optimize performance. The results show that material selection and design parameters significantly influence strength, weight, and vibration behavior. The study concludes that optimized design improves durability and overall system efficiency.**

I. INTRODUCTION

The automobile has become an essential part of modern transportation, requiring continuous improvements in safety, comfort, and performance. Among various vehicle subsystems, the suspension and steering systems play a crucial role in maintaining stability, controlling motion, and ensuring a smooth ride over different road conditions. An efficient suspension system absorbs road shocks while maintaining proper tire contact with the surface, whereas the steering system ensures accurate directional control. With the increasing demand for lightweight and fuel-efficient vehicles, the integration of suspension components with alloy wheels has gained significant importance. Lightweight designs reduce overall vehicle mass, improve fuel efficiency, and enhance handling performance. However, reducing weight without compromising strength and durability remains a major engineering challenge.

Advancements in Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE) tools have enabled engineers to analyze complex systems effectively before physical implementation. Software such as SolidWorks and ANSYS are widely used to develop accurate three-dimensional models and perform Finite Element Analysis (FEA) to evaluate stress, deformation, and vibration characteristics under real-time loading conditions.

In this study, a suspension system integrated with an alloy wheel is designed and analyzed using simulation techniques. Different materials and design parameters are evaluated to improve strength-to-weight ratio, vibration damping, and overall system performance. The objective is to develop an optimized and reliable suspension system suitable for modern automotive applications.

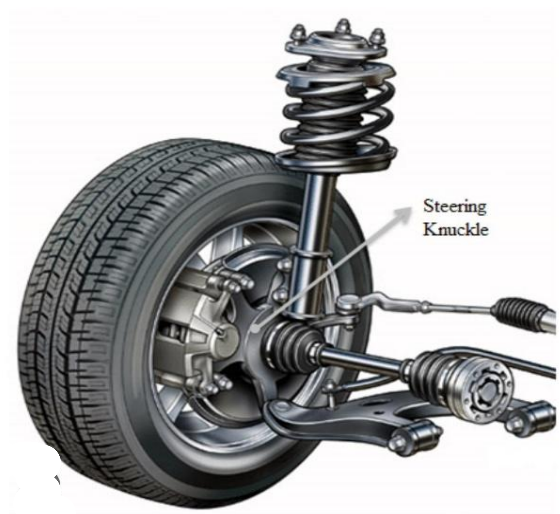


Fig 1.1: Shock Absorber and Steering Knuckle Assembly

II. LITERATURE REVIEW

Several researchers have investigated the performance of automotive components such as suspension systems, alloy wheels, and related assemblies using analytical and simulation-based approaches. The structural integrity, vibration characteristics, and material behavior of these components have been widely studied to improve vehicle safety and performance.

Smith et al. (2018): Smith et al. conducted a study on vehicle suspension struts, focusing on optimizing coil spring parameters for lightweight performance. They used FEA simulations to analyze stress and deformation under dynamic loading. The results highlighted the importance of spring pitch and diameter in controlling vibrations.

Kumar and Patel (2019): Kumar and Patel analyzed steering knuckle joints under torsional and bending loads. They compared forged steel and aluminum alloy knuckles using ANSYS simulations. Results showed that aluminum reduced weight but required careful geometric design to prevent failure

Lee et al. (2020): Lee et al. studied alloy wheel design for passenger cars, focusing on stress distribution during braking and cornering. Using FEA, they demonstrated that spoke geometry significantly affected load transfer and fatigue resistance. Aluminum-magnesium alloys were found to be ideal for reducing unspring mass.

Johnson and Clark (2017): Johnson and Clark investigated shock absorber damping characteristics in relation to ride comfort. They performed numerical simulations on various gas-charged and twin-tube designs. The study found that damping coefficient optimization improved vehicle stability during cornering. Excessive stiffness reduced comfort, while low damping caused oscillations.

Zhang et al. (2021): Zhang et al. focused on coil spring optimization for compact cars. They used MATLAB-based parametric modeling to vary coil diameter, pitch, and wire thickness. The study concluded that slight adjustments in geometry could reduce weight significantly without compromising structural integrity. FEA analysis confirmed lower stress concentrations in optimized designs.

Ahmed and Singh (2018): Ahmed and Singh performed a vibration analysis on strut assemblies using real-time vehicle data. Their ANSYS simulations identified natural frequencies and mode shapes of the assembly under dynamic loads. Results showed that improper coil geometry led to resonance issues affecting ride comfort. Material properties of the strut and knuckle were critical in controlling vibrations.

Chen et al. (2019): Chen et al. analyzed steering knuckle fatigue life using cyclic load simulations. They studied the effects of load magnitude, direction, and joint geometry on stress distribution. High-strength aluminum alloys were found to be suitable for reducing weight while maintaining safety. Optimization of fillets and cross-sections decreased stress concentration.

III. METHODOLOGY

The methodology adopted in this study involves a systematic approach that includes design, material selection, modeling, and analysis of the suspension system integrated with an alloy wheel. The objective is to evaluate the structural performance of the system under various loading conditions using simulation tools. Material option is not a process which generally results in a seven probability of cures to the identical concern. This might be discussed by issue of basic fact that very same part doing very same sort function, but created by several industries businesses and consequently are generally created by utilizing different materials at the same time as by a variety of processing strategies. With this analysis, the actions of element choice approach are actually in flow chart identified below

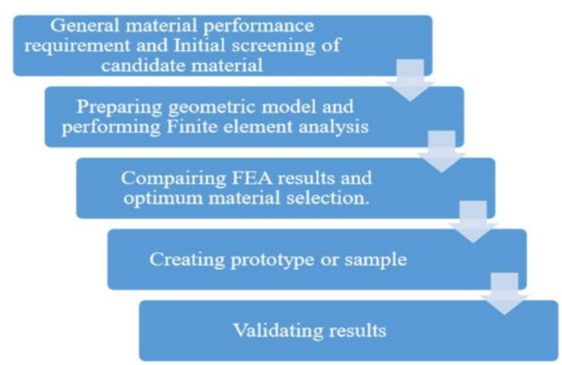


Fig 3.1:Material Selection

The chart of components option is a promising product when set alongside a diverse quantity of compounds in the concept layout stage which may be mirrored to the basic associations involving specific content abilities and also explore a choice of ingredients perfect for a particular system. The main objective of this specific attempt is actually choosing just one or perhaps choice of very best certain compound for brake disc rotor and also additionally to assess the winter behaviour of disk braking mechanism, winter stress and deformation due to high heat division which was carried out throughout the part.

A detailed three-dimensional model of the suspension assembly is developed using SolidWorks. The model incorporates all major components and is designed according to standard dimensions and design parameters. After modeling, the geometry is imported into ANSYS for Finite Element Analysis (FEA).

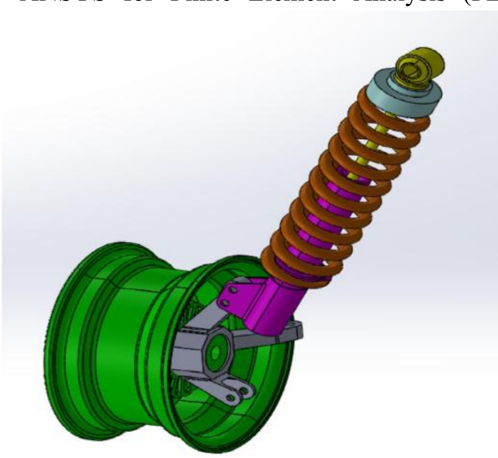
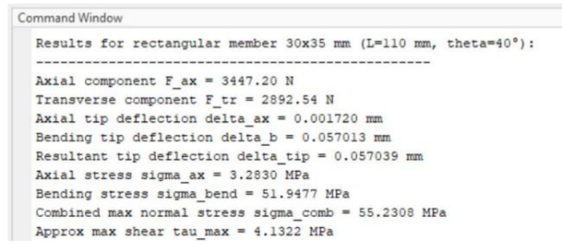


Fig 3.2: Suspension system assembly

In the analysis phase, appropriate boundary conditions and loading conditions are applied to simulate real-world operating environments. Static structural analysis is performed to determine deformation, stress, and strain, while modal analysis is conducted to evaluate vibration characteristics. Different design parameters such as coil diameter and pitch of the spring are varied to study their influence on system performance. MATLAB is used to analyze the static and vibration response of the spring and strut under loading conditions. The displacement-time response is obtained to study vibration behavior and damping characteristics. The damping ratio is calculated using the logarithmic decrement method. The output results obtained from MATLAB are shown in Fig 3.3&3.4 and are used to validate the ANSYS results.

```
Command Window
Helical Coil Spring Results:
------------------------------
Spring Index (C)        = 5.00
Wahl Factor (K)         = 1.3105
Deflection (δ)          = 45.80 mm
Max Shear Stress (τ)    = 500.57 MPa
Shear Strain (γ)        = 0.00637
Spring Stiffness (k)    = 98.25 N/mm
fx >>
```

Fig 3.3: Mat lab code for Spring design.



```
Command Window
Results for rectangular member 30x35 mm (L=110 mm, theta=40°):
-------------------------------------------------
Axial component F_ax = 3447.20 N
Transverse component F_tr = 2892.54 N
Axial tip deflection delta_ax = 0.001720 mm
Bending tip deflection delta_b = 0.057013 mm
Resultant tip deflection delta_tip = 0.057039 mm
Axial stress sigma_ax = 3.2830 MPa
Bending stress sigma_bend = 51.9477 MPa
Combined max normal stress sigma_comb = 55.2308 MPa
Approx max shear tau_max = 4.1322 MPa
```

Fig 3.4: Mat lab code for Strut design.

IV. FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) is carried out to evaluate the structural and vibration performance of the suspension system integrated with the alloy wheel under different loading conditions. The analysis is performed using ANSYS software after importing the three-dimensional model developed in SolidWorks.

Initially, the geometry of the suspension assembly is discretized into finite elements through meshing. A fine mesh is generated to improve the accuracy of results while maintaining computational efficiency. Appropriate material properties such as Young's modulus, Poisson's ratio, and density are assigned for different materials including spring steel, titanium alloy, and composite materials.

Fig 4.1: Finite element model of Suspension system

There are different types of boundary conditions that can be applied to edge or faces. In this there is generally fixed support, displacement, remote displacement and frictionless support are used in ANSYS workbench.

To run an analysis for a structure, loading plays a vital role. The loading given to perfect loading and prefect direction is very important. In ANSYS workbench, loading can be given to edge, face and body. This has point load, pressure load, hydrostatic load, joint load, bolt penetration loading etc, are available. After the load and boundary conditions are applied, we have to click solve radian button to solve the analysis as shown in Fig 4.2.

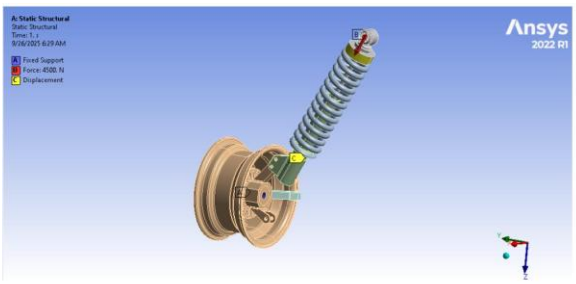


Fig 4.2: boundary condition on Suspension system.

The deformation of 15mm coil dia and 25 mm pitch of coil after 4500 N load is applied and the red indicate the maximum deformation and blue indicates minimum deformation. Maximum deformation occurs at the top location of observer. Minimum deformation appears at the shaft location and we can clearly able to see in the Fig 4.3. All together maximum deformation is 47.19 mm. This deformation is much of considerable deformation.

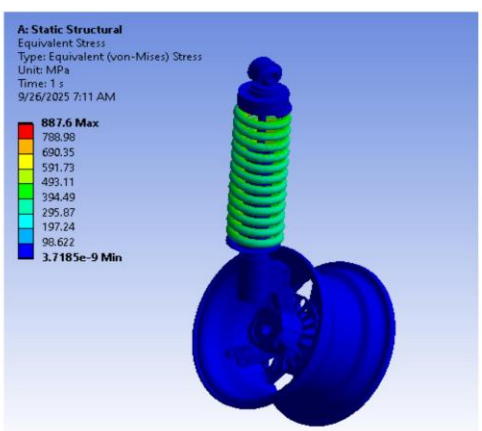


Fig 4.3: stresses on 15 mm coil dia and 25 mm pitch of coil for steel.

In the Fig 4.4. shows the Stress on 15 mm coil dia and 25 mm pitch of coil after 4500 N load is applied and the red indicate the maximum Stress and blue indicates minimum Stress.

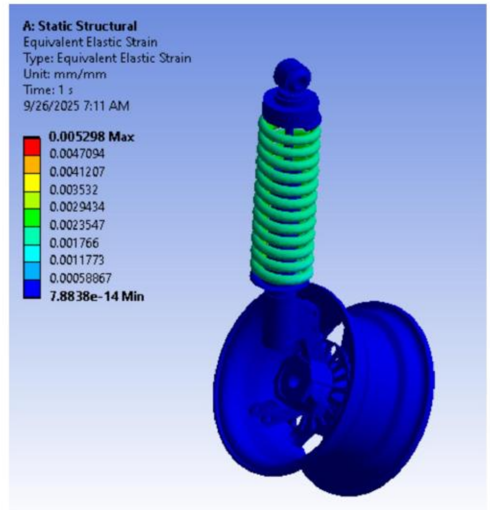


Fig 4.4: strain on 15 mm coil dia and 25 mm pitch of coil for steel.

In the Fig 4.5. shows the Strain on 15 mm coil dia and 25 mm pitch of coil after 4500 N load is applied and the red indicate the maximum Strain and blue indicates minimum Strain.

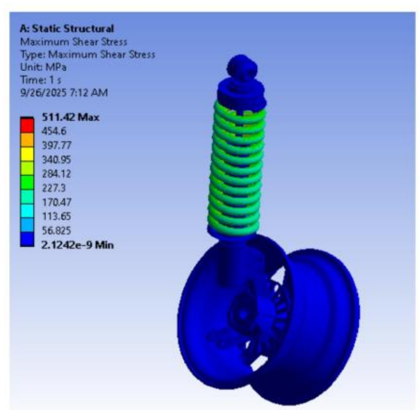
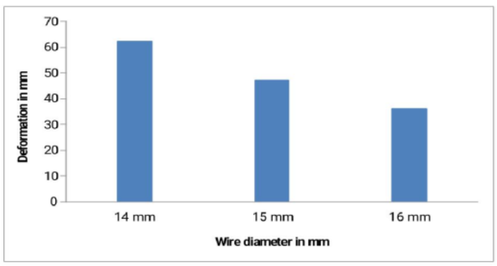


Fig 4.5: shear stress on 15 mm coil dia and 25 mm pitch of coil for steel.

V. Results and discussion

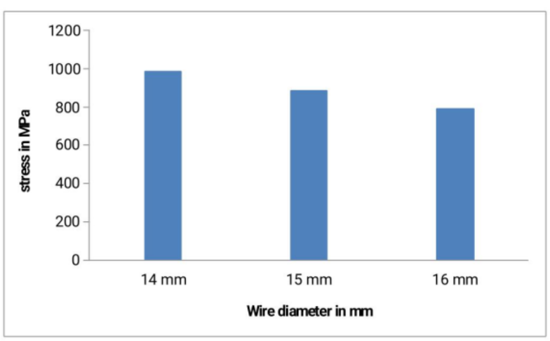
In this study, the performance of the vehicle strut assembly, including the suspension spring, knuckle joint, and alloyed wheel, was evaluated using SolidWorks modeling, ANSYS simulations, and

MATLAB-based optimization. The results of the analysis are presented in tabular form and graphical representations to provide a comprehensive understanding of the system' s behavior under real-time loading conditions. Various parameters such as deformation, stress, strain, and shear stress were analyzed for different coil diameters, wire thicknesses, spring pitches, and materials. The tabular data provide a clear comparison between different design configurations, while the graphs visually illustrate trends and relationships, making it easier to identify the impact of design variations on structural performance.



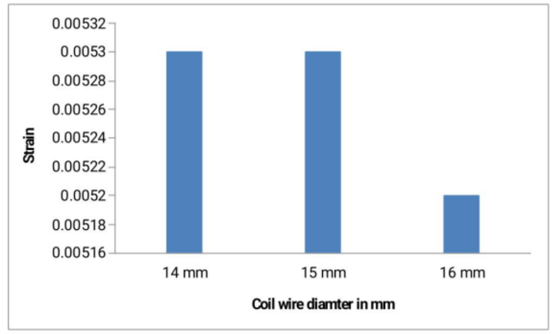
Graph 5.1: Deformation for different coil dia.

The Graph 5.1 represents the deformation behavior of the suspension spring for different wire diameters when the coil pitch is kept constant at 25 mm. The results clearly indicate that as the wire diameter increases, the overall deformation of the spring decreases.



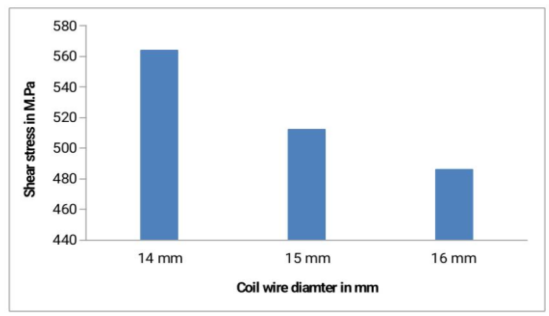
Graph 5.2: Stress for different coil dia.

The Graph 5.2 represents the stress distribution in the suspension spring for different wire diameters at a fixed coil pitch of 25 mm. It is observed that the stress decreases as the wire diameter increases.



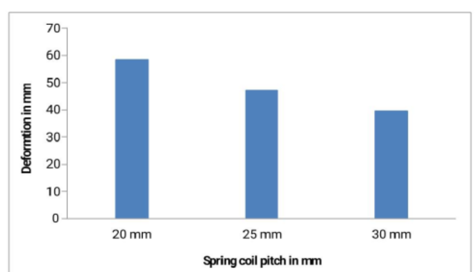
Graph 5.3: Strain for different coil dia.

The Graph 5.3 shows the strain values of the suspension spring for different wire diameters when the coil pitch is fixed at 25 mm. Interestingly, the results indicate that strain remains almost constant for different coil diameters, with only a very slight reduction as the wire thickness increases.



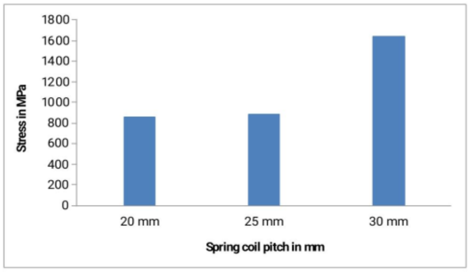
Graph 5.4: Shear stress for different coil dia.

The Graph 5.4 provides the shear stress values corresponding to different coil diameters of 14 mm, 15 mm, and 16 mm at a fixed pitch of 25 mm. It is observed that the shear stress decreases gradually as the coil diameter increases.



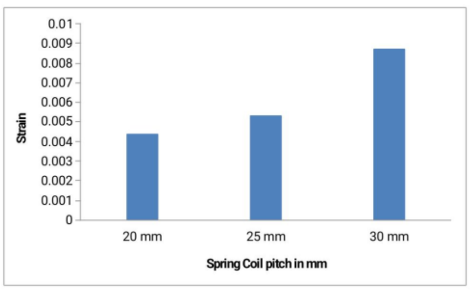
Graph 5.5: Deformation for different Pitch of spring.

The table presents the deformation values for a spring with a fixed coil diameter of 15 mm, considering different pitches of 20 mm, 25 mm, and 30 mm. It can be observed that the deformation decreases as the pitch of the spring increases.



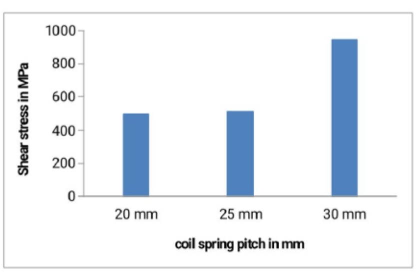
Graph 5.6: Stress for different Pitch of spring.

The table shows the stress distribution for a spring with a constant coil diameter of 15 mm under different pitch values of 20 mm, 25 mm, and 30 mm. At a 20 mm pitch, the stress is 863.6 MPa, which slightly increases to 889 MPa when the pitch is increased 67 to 25 mm.



Graph 5.7: Strain for different Pitch of spring.

The table illustrates the strain distribution for a spring with a 15 mm coil diameter under varying pitch values of 20 mm, 25 mm, and 30 mm. At a 20 mm pitch, the strain value is 0.0044, which increases to 0.0053 at 25 mm pitch. When the pitch is further raised to 30 mm, the strain increases significantly to 0.0087.



Graph 5.8: Shear stress for different Pitch of spring.

The table presents the shear stress values for a spring with a 15 mm coil diameter when subjected to different pitch values of 20 mm, 25 mm, and 30 mm. At a 20 mm pitch, the shear stress is 498.5 MPa, which slightly increases to 512.29 MPa at a 25 mm pitch.

VI. CONCLUSIONS

In this work, a lightweight vehicle strut assembly including the suspension spring, alloyed wheel, and knuckle joint was modelled and analyzed using Solid Works and ANSYS software. The dimensions for the components were obtained from a real-time Swift car model to ensure accuracy and practicality. The 3D models were carefully created with precise geometric features, including the spring wire diameter, coil diameter, and strut dimensions. Following the modelling phase, the assembly was constrained using coincidence and offset mates in Solid Works, and the final model 71 was exported as a STEP file to ANSYS for structural and stress analysis. Various simulations were conducted under real-time loading conditions to evaluate deformation, stress, strain, and shear stress across different coil diameters, pitch values, and materials.

The optimization of the suspension spring was performed using MATLAB with Linear Programming to determine the most effective combination of coil diameter, wire thickness, and pitch while ensuring safety and performance. The results revealed that a coil diameter of 75 mm, a wire diameter of 15 mm, and a pitch of 25 mm provided the optimum balance between deformation, stress, and strain. Material selection was also evaluated, comparing Steel, Ti6, and SiC + Carbon Fiber.

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