Fabrication, Design Optimization, And Stress Analysis Of Mono Leaf Spring Using Metal-Matrix Composites

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Abstract—Weight is an important and contributing factor in an automobile in improving riding qualities. About ten to twenty percent of the weight of the system is provided by the leaf spring alone. Composite materials have the major advantage of high strength to weight ratio, with continuously decreasing travel cost in addition to other advantages like excellent corrosive resistance, superior fatigue strength and high specific strain energy storage capacity. The present work aims to evaluate the usage of composite material for the leaf spring of automobiles in order to reduce the effective weight of the suspension system, by this it is expected to improve the riding qualities of the automobile. A composite mono-leaf spring weighing about 3kgs is used to replace a steel leaf spring whose weight is about 12kgs. The present study also aims to compare the performance of the composite leaf spring with that of the conventional steel leaf spring and to suggest the suitability of using composite materials in automobile industry. In this approach static and dynamic analysis were conducted with the help of ANSYS 16 analysis software. The performance results are compared with steel leaf spring. Finally it is concluded that the composite leaf spring, which is 70% less in weight, is performing better than conventional steel leaf spring. It allows the traveler running leaf springs to be consistent night after night without having to constantly measure, monitor and change their springs for loss of sagging. The initial cost is a value based on the incredible service life. The composite material is mainly used to reduce the weight and increase the strength, stiffness etc Stir casting process is mainly used to manufacturing of reinforced with metal matrix composite. The manufacturing of aluminum alloy based on stir casting method its used to one of the most economical method of processing MMC. The main project the operating parameter of the composite as its control the properties of the composite material. This paper present overview of stir casting process, parameter & preparation of MMC study on mechanical behavior of metal matrix composite with varies composition of reinforcement particles of graphite or Nano particle B4Cand Al2O3 composite produced by the stir casting technique. The leaf is modeled using CATIA modeling and finite element analysis is done for same model utilizing ANSYS 16.0 software for Aluminum (Al-B4C) and the results were discussed. Key words: Stir-Casting, Process

Keywords—Composite Leaf Spring; Dynamic Analysis

1. INTRODUCTION

To meet the needs of natural resources conversion, energy economy and improving riding qualities most of the automobile manufacturers and their subcontractors are attempting to reduce the weight of the vehicles in recent years. To reduce vehicle weight, three techniques have been studied rationalizing the body structure, utilizing lightweight materials for parts and decreasing the size of the vehicles. To achieve these attempts are being made by replacing existing material with low cost, high strength to weight ratio materials. In this approach by introducing composite materials into automobile industries, which is having low cost, high strength to weight ratio and excellent corrosive resistance can fulfill the requirement. The suspension leaf spring is one of the potential items for weight reduction in automobiles as it results in large un-sprung mass. It is anticipated that their weight reductions will lead to improvements in riding qualities and in noise and vibration characteristics. The introduction of fiber reinforced plastics (FRP) made it possible to reduce the weight of the product without any reduction on load carrying capacity and spring rate. Because of the materials high strain energy storage capacity and high strength-to-weight ratio compared to steel, multi-leaf springs are being replaced by mono-leaf FRP spring. FRP springs also have excellent fatigue resistance and durability. The leaf spring has to sustain the major road loads and crash loads. In addition they must deliver an acceptable level of vehicle dynamics making the passenger to enjoy a comfortable ride. The use of FRP in Indian automobiles is very limited. There is also no organized effort to develop automotive components using FRP, although it is advantageous over traditional materials such as steel. Composite leaf spring is designed according to the design procedure but it is not completely confirmed that it is withstanding static and dynamic loads. This is because it is very difficult to find the mechanical properties accurately.
II. LITERATURE SURVEY

Investigation of the composite leaf spring in the early 1960's failed to yield production reality because of inconsistent fatigue performance and absence of strong need for mass reduction. Recent emphasis on mass reduction and new developments in materials and processing technology has led to proven production-worthy vehicle component. Development of composite leaf springs first began during the period from 1963 through 1967. Emphasis of vehicle weight reduction in 1977 justified a new look at composite leaf springs. Prior to introduction on first production application, three and a half years of testing were conducted accumulation 58 million laboratory fatigue cycles and over five million vehicle test kilometers. The leaf spring suspension is a popular choice for the rear of trucks and some sport utility vehicles. It has been used for some heavy-duty truck front suspension and the rear of passenger cars, but the leading application is the truck with the non independent rear axle. The leaf spring has several leaves—simply adding leaves increases the load carrying ability of the suspension. The top leaf typically is the longest and each end of that leaf is formed into an eye, into which a rubber bushing is installed. The spring eyes are bolted to the chassis in front and attached at the rear through a hinge joint called a shackles. The shackles permit the spring to effectively change its length as it flexes to absorb impacts. The leaf spring also attaches (through U-bolts) to the solid rear axle, so it locates the axle without the use of arms, an important function. This permits a simple suspension design with obvious packaging benefits. However, these advantages are offset in passenger cars and some trucks by the superior ride qualities of the coil spring, which merely supports the vehicle and simply compresses and expands as it absorbs the impacts.

III. DESIGN REQUIREMENTS FOR COMPOSITE LEAF SPRING

The main aim of the project is to replace 7-leaf rear suspension steel leaf spring in light commercial vehicles with Mono-leaf spring. The weight of the steel leaf spring is about 15Kgs. To compare the performance of the steel leaf spring with composite leaf spring for light commercial vehicles the design requirements are taken as almost the same as that of the conventional steel leaf spring of an Ambassador car rear suspension.

The design requirements are given below: [1]

Maximum deflection allowable, \( \delta_{\text{max}} = 120 \text{mm}. \)

Static load acting on the spring, \( W = 3850 \text{N}. \)

Distance between eyes, (span) \( 2L = 1190 \text{mm}. \)

Camber required for the spring, \( C = 120 \text{mm}. \)

Spring rate of the leaf spring, \( K = 32 \text{KN/m}. \)

As per the design requirements that are given in the above section the design is made on the basis of constant cross-sectional area design. In constant cross-sectional design both the thickness and width are varying throughout the length of the leaf spring, such that cross-sectional area remains constant throughout the leaf spring. The step-by-step approach of the design of the composite leaf spring is given as follows:

**Step 1:** Assume the reasonable corresponding values of \( k_{\text{req}}, b_{\text{m}}, t_{\text{m}} \).

\[ b_{\text{m}} = 45\text{mm}, \quad t_{\text{m}} = 150\text{mm}, \quad k_{\text{req}} = 32\text{mm} \]

Constant cross sectional area \( = 45 \times 150 \text{mm}^2 \)

**Step 2:** Applying factor of safety:

Allowable bending stress, \( \sigma_a = [\sigma_{\text{max}}]/(\text{factor of safety}); \)

Maximum allowable bending stress for composite material

\[ [\sigma_{\text{max}}] = 450 \text{Mpa}. \]

Factor of safety = 2.0

\[ \sigma_a = 225 \text{Mpa}. \]

**Step 3:** Check for bending stress:

Calculating the stress from the bending moment equation

\[ \sigma/y = \frac{M/I}{l}; \]

\[ \sigma = 6 \times W \times L/(b_{\text{m}} \times t_{\text{m}}^2); \]

\[ \sigma_a \geq \sigma = 6 \times W \times L/(b_{\text{m}} \times t_{\text{m}}^2); \]

\[ \sigma = 13.574 \text{Mpa} \]

\[ \sigma/a < \sigma_a \]

**Step 4:** Check for maximum deflection:

Maximum deflection of the spring permitted

\[ (\delta_{\text{max}}) = 120 \text{mm}. \]

\[ \delta_{\max} \geq \delta = (W \times L)/(3 \times E \times I); \]

The tensile modulus of the material \( (E) = 34000 \text{ Mpa} \)

\[ I = t_{\text{m}} + b_{\text{m}})/2 = (b_{\text{m}} \times t_{\text{m}} + (t_{\text{m}}^2 + t_{\text{m}}^2))/24 \text{ mm}^4 \]

\[ \delta = 1.232 \text{ mm} < \delta_{\text{max}} \]

**Step 5:** Calculating the distance from the center to which the width varies with thickness for constant stress:

\[ a = 0.73 \times L = 434.35 \text{mm} \]

**Step 6:** To calculate thickness and width at any point \( x \) from the center for constant stress.

\[ 3W*(L-X)/(b_{\text{m}} \times t_{\text{m}}^2) = 3W/L/(b_{\text{m}} \times t_{\text{m}}^2) \]
\[ T_x = (L-X) \cdot t_x / L \]

\[ t = 150 \text{mm at } x = 0; \]
\[ t = 89.49 \text{mm at } x = 240; \]
\[ t = 24.28 \text{mm at } x = a(434.35 \text{mm}); \]

**Figure 1 Leaves before assembly**

**Figure 2 Leaf Spring assembly**

**IV. FINITE ELEMENT ANALYSIS**

The term “Finite Element” distinguishes the techniques from the use of the infinitesimal “differential equations” used in calculus, and partial differential equations. The method is also distinguished from finite difference equations, for which although the steps into which space is divided are finite in size, there is a little freedom in the shapes that the discreet steps can take. Modal analysis was performed by considering the following material properties such as Modulus of elasticity was taken as 34600 N/mm² and density was taken as 1.85e-6 Kg/mm³. The element type was taken as tetrahedral 92.

**Modal Analysis**

A modal analysis is used to determine the natural frequencies and mode shapes of a structure. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions. Another useful feature is modal cyclic symmetry, which allows you to review the mode shapes of a cyclically symmetric structure by modeling just a sector of it. From the various mode extraction methods, Block Lanczos method is selected for the present analysis.

Modal analysis is done to check the natural frequencies and corresponding mode shapes. Natural frequencies values were obtained from analysis must not lie around the theoretical value.

Here \( \text{Frequency (f)} = n/60 \)

The values obtained from analysis do not lie around the theoretical value (50 Hz). Then the spring has passed the analysis. Values are tabulated in table 1 and mode shapes are shown in figure 1.

<table>
<thead>
<tr>
<th>MODE SHAPES</th>
<th>( n ) (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.2671</td>
</tr>
<tr>
<td>2</td>
<td>7.7746</td>
</tr>
<tr>
<td>3</td>
<td>12.878</td>
</tr>
<tr>
<td>4</td>
<td>20.139</td>
</tr>
<tr>
<td>5</td>
<td>21.100</td>
</tr>
</tbody>
</table>

**Stress Analysis**

The static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects such as those caused by...
time varying loads. Static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not include significant inertia and damping effects. A static analysis can, however, include steady inertia loads as gravity, spinning and time varying loads that can be approximated as static equivalent loads such as static equivalent wind, seismic loads. Stress distribution is shown in figure 2

V. RESULTS AND DISCUSSION

For the same design requirements and same loading conditions that are taken the comparison is made for static loading conditions. The characteristics of steel multi leaf spring and MMC mono leaf spring is given in table 2

<table>
<thead>
<tr>
<th>Contents</th>
<th>Steel leaf spring</th>
<th>Composite leaf spring (MMC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum stress</td>
<td>473.805 MPa</td>
<td>310.684 MPa</td>
</tr>
<tr>
<td>Safety factor</td>
<td>1.5-2.0</td>
<td>3.0-4.0</td>
</tr>
<tr>
<td>Spring rate</td>
<td>32N/mm</td>
<td>32N/mm</td>
</tr>
</tbody>
</table>

VI. COMPARISON OF WEIGHT

The conventional leaf spring, which is, satisfying the design requirements as mentioned earlier weighs around 26Kgs.

The material that is used for two leaf spring is

\[=1500g+1500g+220g\]

= 6220g.

Each leaf spring along with its eyes weighs around \(= \frac{6220}{2} = 3110\) gram

Each eye weighing 500 grams.

Therefore the weight of each leaf spring

\[= 3110g + 2*500g\]

= 4110g

= 4.11Kg

Percentage reduction in weight achieved is 84.19 %

VII. REFERENCES


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