Design and Material Optimization of Leaf Spring using FEA

Lovepreet Singh[1], Er. Gora Ram Sharma[2*]

[1,2*]Department of Mechanical Engineering, Bhai Maha Singh College of Engg., Sri Muktsar Sahib

Abstract: The design and material of leaf spring are important consideration for effective performance of leaf spring and achieving weight reduction. The objective of current research is to investigate the strength of composite leaf spring using techniques of Finite Element Analysis. The CAD model and structural analysis is conducted using ANSYS software. The composite materials used in the analysis are metal matrix composites made of aluminium and magnesium. The stresses and elastic strain are evaluated for both the materials.The FEA simulation results have shown that significant weight reduction of mono leaf spring is obtained from the analysis. By using aluminium composite materials nearly 67% - 68% weight reduction is possible without much compromise in strength.

Key Words: *Leaf spring, Stress, FEA*

1. INTRODUCTION:

The leaf springs are based on concept of energy absorption when loaded and the recovers to its initial shape on removal of load. Leaf springs are "mainly used in suspension systems to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems" [9]. The leaf springs are being used in various machines dating back to medieval times. The leaf spring offers certain advantages over helical coil spring and it can be guided along a definite path as shown in figure 1 below. The shape of semi-elliptical leaf spring is of "slender arc shape" made of rectangular cross section.

Figure 1: Leaf spring assembly [9]

The leaf spring is mounted at the center of the arc which is also the place for axle mounting as shown in figure 1 above. The leaf spring also has tie holes provided at the ends in order to attach vehicle body. The leaf spring can be modeled using number of leaves for heavy vehicles which can efficiently dampen shock vibrations. The limitation of multileaf spring is sticking motion between laminates which is not present in mono leaf spring.

2. LITERATURE REVIEW

Vinkel Arora, et al. [1] has conducted FEA analysis of conventional mono leaf spring using ANSYS software. In the design of mono leaf spring, the standard eye is replaced with casted eye and the effect of these variation on equivalent stress, normal stress and deformation is evaluated. By making these design changes the equivalent stress reduced by 2.4% and normal stress increased by 19.08%. The FOS also reduced by 13.1%.

Kumar Krishan, et al.[2] has conducted numerical investigation on SUP9 steel multi leaf spring using ANSYS 11 software. The CAD model steel multi leaf spring is developed in CATIA V5 software. The total number of leaf springs laminates was seven. The FE analysis was conducted under full loading conditions to determine bending stress and deformation. The findings have shown that .632% variation is observed for deformation and 17.95% variation is observed for bending stress.

Davood Rezaei[3] has conducted design optimization of leaf spring by replacing steel material leaf spring with composite material leaf spring in order to achieve weight reduction. The leaf spring analysed was of 4 leaves used in rear suspensions of heavy motor vehicles. The FEA results obtained from ANSYS software was in close agreement with experimental and analytical solutions. The research findings have shown that composite leaf spring has lower stresses as compared to steel leaf spring. The weight of composite leaf spring is nearly 80% lower than steel leaf spring.

E. Mahdi a, O.M.S. Alkoles[4] has conducted experimental and numerical investigation of elliptical leaf spring by varying elliptical ratio (a/b). The elliptical ratio varies from 1 to 2. The findings have shown that by increasing the wall thickness the spring rate increases and weight saving is achieved. The maximum ellipticity ratios of a/b 2 has shown maximum spring rate.

A.F. Golestaneh[5] has conducted FEA analysis on composite elliptical leaf spring to determine fatigue life characteristics subjected to static loading conditions. The analysis was conducted on heavy truck leaf spring using ANSYS software. The weight reduction is achieved using composite material as compared to conventional steel spring.

Dev dutt Dwivedi and V.K.Jain[6] has conducted numerical investigation on mono leaf spring using ANSYS software using E-glass/epoxy composite material. The leaf spring was made of three-layer composite material and significant weight reduction is achieved. The equivalent stress in E-glass epoxy material is lower than conventional leaf spring material.

3. OBJECTIVE

The objective of current research is to investigate the strength of composite leaf spring using techniques of Finite Element Analysis. The composite materials used in the analysis are metal matrix composites made of aluminium and magnesium. The stresses and elastic strain are evaluated for both the materials.

4. METHODOLOGY

The FEA analysis involves three stages which are pre-processing, solution and post processing. The preprocessing stage involves designing of leaf spring using extrude tool in ANSYS design modeler.

Table 1: Dimensions of leaf spring [7]

Length of leaves	965mm
Number of leaves	01
With of all leaves	45mm
Thickness of leaves	30mm

Inner radius	23mm
Outer radius	50mm

The modeled leaf spring is shown in figure 2 below. The inner radius, outer radius and cylindrical support structures are designed as per dimension given in table 1 above.

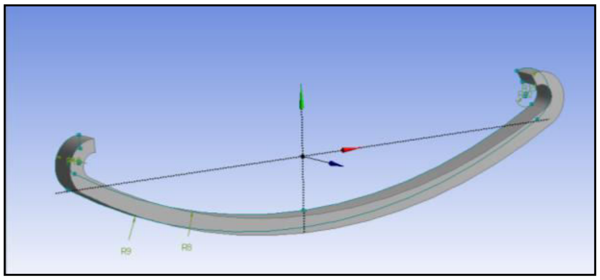

Figure 2: Model of leaf spring

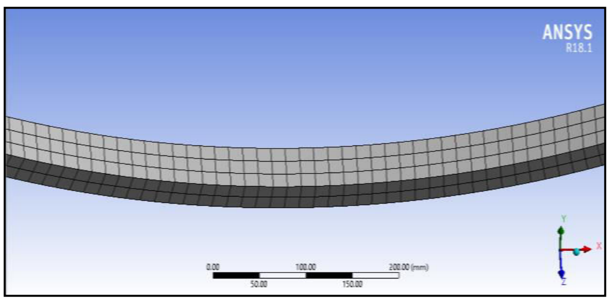

Figure 3: Meshed model of leaf spring

The CAD model of leaf spring is meshed using brick elements. "Meshing is one of the key components to obtaining accurate results from an FEA model. The elements in the mesh must take many aspects into account to be able to discretize stress gradients accurately. Typically, the smaller the mesh size, the more accurate the solution as the designs are better sampled across the physical domains. The trade-off is that the higher the accuracy, the larger the simulations become and thus solve times are extended" [8].

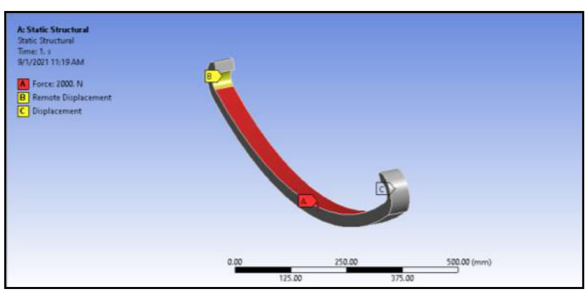

Figure 4: Boundary conditions applied on leaf spring

The boundary conditions are applied on mono leaf spring as shown in figure 4 above. The boundary conditions involve applying displacement support on one end of mono leaf spring which restricts the translational motion along x, y and z directions. After applying boundary conditions, the FEA simulation is run to generated stiffness matrix associated with each element. These element stiffness matrix is assembled to form global stiffness matrix followed by inversions and multiplications.

5. RESULTS AND DISCUSSION

After running FEA simulation, the equivalent stress plot is generated for different materials i.e. aluminium composite and magnesium composite. The contour plot of equivalent stress for structural steel is shown in figure 5 below.

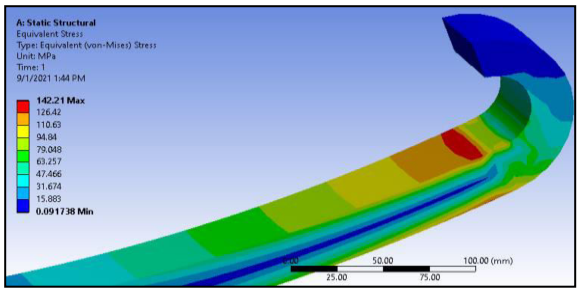

Figure 5: Equivalent stress plot for steel

The equivalent stress is maximum near the remote displacement support region of leaf spring which is represented by red color with magnitude of nearly 142Mpa. The stress at the nearby zone is nearly 110Pa and it reduces further towards center.

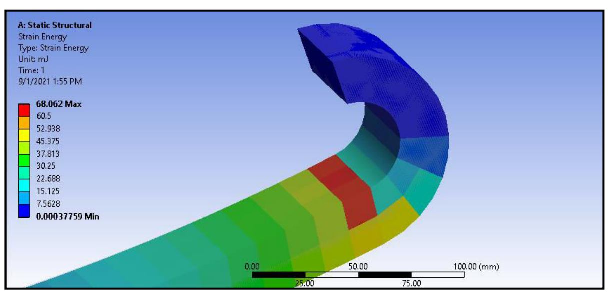

Figure 6: Strain energy plot of mono leaf spring

Similar stress and strain energy plot is also generated for aluminum composites and magnesium composites.

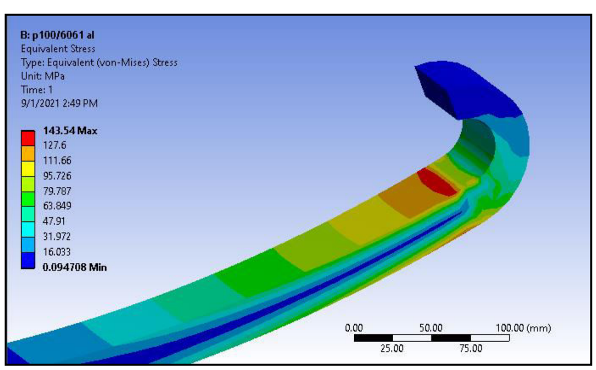

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Figure 7: Equivalent stress plot of mono leaf spring using aluminium composite material

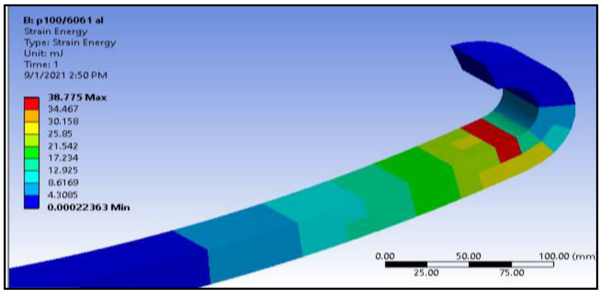

Figure 8: Strain energy plot of mono leaf spring using aluminium composite material

The equivalent stress and strain energy plot is generated for aluminium composite leaf spring which is shown in figure 7 and figure 8 above. The maximum equivalent stress and strain energy is observed near the displacement support zone which is represented in red colour. The maximum equivalent stress using aluminium composite material is 143.54Mpa and maximum strain energy generated is 38.77mJ. The optimization variables are selected for Taguchi Design of Experiments which are inner radius and outer radius. The design points are generated using optimal space filling design scheme.

Table 2: DOE table of mass

Design Points	P10 - Solid Mass (kg)
1	11.22849499
2	10.84217001
3	15.73881277
4	13.50322938
5	13.84255871
6	13.46531935
7	15.36489901
8	13.12244557
9	16.11051096

Table 3: DOE table of strain energy

Design Points	P6 - Strain Energy Maximum (mJ)
1	99.59695435
2	111.4430847
3	38.82689285
4	58.53635025
5	52.99075699
6	57.98820877
7	41.74377823
8	64.3328476
9	36.16467285

The design of experiments table is generated for mass and strain energy. The optimization results have shown that significant mass reduction of mono leaf spring is possible using optimal space filling optimization scheme of response surface optimization method. The weight of generic design of mono leaf spring is 12.767kg and minimum weight of mono leaf spring after optimization is 10.84Kg (Table 2 above) which shows that by using optimization technique 15.1% of weight could be reduced. As per optimization results, the corresponding dimensions for minimum weight are inner radius 999.16mm and outer radius dimensions is 1023.8mm.

6. CONCLUSION

The structural analysis and design optimization is conducted on mono leaf spring using aluminium and magnesium composite materials. These composite materials possess good combination of strength, ductility, and fracture toughness. The FEA simulation results have corroborated the same and significant weight reduction of mono leaf spring is obtained from the analysis. By using aluminium composite materials nearly 67% - 68% weight reduction is possible depending upon fiber concentration. The weight reduction is also achieved using optimization which is nearly 15.1% without much compromise in strength of mono leaf spring.

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