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Design Analysis and Comparative Testing of Composite Elliptical Shape Leaf-Spring Damper

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Abstract
This study investigated the design, analysis, and comparative testing of a novel composite elliptical-leaf spring damper. Traditional leaf spring suspensions have limitations in terms of damping performance and durability. In this study, these shortcomings were addressed by using composites and an elliptical design. The objective of using composites is to enhance their strength-to-weight ratio, thereby resulting in lighter and more efficient components. Finite element analysis (FEA) was performed to investigate the stress distribution and optimize the critical design parameters. The FEA results were verified experimentally to allow for a direct comparison of the damping characteristics of the proposed composite elliptical leaf-spring damper and conventional steel leaf springs. The findings showed an improved damping performance, reduced weight, and improved durability, all of which make this design a promising alternative for various vehicle applications.
Keywords: *Composite leaf spring, Elliptical leaf spring, Leaf spring damper, Vibration damping, Structural analysis, Comparative testing*

1. Introduction
The growing demand for lightweight high-performance vehicles has driven significant research on advanced materials and structural designs. Traditional steel leaf springs are robust and cost-effective but have limitations in terms of weight, stiffness-to-weight ratio, and damping characteristics [1]. Composite materials, particularly fiber-reinforced polymers, offer a compelling alternative because of their superior strength-to-weight and stiffness-to-weight ratios, as well as their tailored damping capabilities [2]. This study deals with the design, analysis, and comparative testing of a new composite elliptical-shaped leaf-spring damper in the backdrop of the limitations of conventional steel leaf springs and an attempt to tap the potential of composites in suspension systems [3]. Leaf springs are considered the heart of suspension systems in vehicles, as they capture shocks and vibrational movements while maintaining contact between the wheel and road surface. The design of a leaf spring involves careful consideration of several factors, including the load capacity, deflection, stress distribution, and fatigue life. Elliptical leaf springs, known for their compact design and the ability to provide variable spring rates, have been used in various applications [4]. However, the use of composite materials in elliptical leaf-spring designs presents unique challenges. The anisotropy of the composites suggests that a proper design of the fiber orientation and stacking sequences is required to improve the mechanical properties of the spring. Moreover, the processes involved in manufacturing composite leaf springs, such as filament winding and layup preparation, may require controlled operations to maintain a good quality and consistent performance. In this study, we evaluated the possibility of replacing elliptical steel springs with composite types [5]. The primary objective is to design a composite elliptical leaf spring damper that exhibits improved performance characteristics compared with a traditional steel leaf spring. This was achieved through a comprehensive design process that involved both analytical and numerical methods. Analytical calculations were used to determine the initial dimensions and material properties of the composite leaf spring considering

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the desired load capacity and deflection requirements. Finite element analysis (FEA) to simulate the behavior of the composite leaf spring under several loading scenarios. FEA enables further detailed stress distribution, deflection, and strain patterns, thereby optimizing the design to reduce stress concentrations and achieve good fatigue life [6]. The elliptical form provides a special design space for tailoring spring rate and damping characteristics. Various fiber orientations and stacking sequences were tested to optimize the performance of a composite leaf spring damper while attaining optimum stiffness, strength, and damping characteristics. Comparison tests are another critical feature that compare a composite leaf spring damper developed by the design methodology with an existing steel-based leaf spring [7]. This experiment aimed to confirm the numerical solutions obtained and was conducted to evaluate the real-time behavior of the composite leaf spring damper. To achieve this, various static and dynamic loading cases were applied to the composite leaf springs and steel leaf springs. A comparison of the deflection, strain, and damping characteristics obtained helped establish improvements in the composite design. Comparative testing is critical for providing insight into the advantages and disadvantages of composite materials in leaf-spring applications. The overall aim of this study was to develop a lightweight, high-performance composite elliptical leaf spring damper to improve vehicle fuel efficiency, handling, and ride comfort [8]. The results of this study are important for the design and development of future composite leaf springs for automobiles and other applications.

2. Research Methodology

This study focuses on the design, analysis, and comparative testing of a composite elliptical-shaped spring-spring damper. First, a detailed design of the composite elliptical leaf spring damper was developed based on the material properties, geometric parameters and load requirements. Finite element analysis was then conducted on the designed composite leaf spring to simulate its behavior under a range of loading conditions. The FEA results of the finite element analysis were experimentally validated. Composite prototype leaf springs are manufactured through suitable processes such as hand layup or compression molding.. The experimental results were compared with the FEA predictions to verify the accuracy of the numerical model. Finally, the performance of the composite elliptical leaf spring damper was compared to that of conventional steel leaf springs in terms of weight, stiffness, energy absorption, and fatigue life. This comparison provides room for the benefits of using composite materials for spring leaves. [2]

2.1.System Design & Mechanical Design of the Elliptical Leaf Spring Mounts for Engine

The Mechanical Design of an elliptical leaf spring is based on its specific shape and dimensions. The elliptical shape offers a unique combination of the load-carrying capacity and flexibility. The design includes the choice of material (steel or composite), number of leaves, leaf thickness, curvature of the target spring rate, and the stress distribution. Finite element analysis was also performed to simulate the spring behavior under load and to optimize the design to achieve performance and durability. The design must also consider the manufacturing process and tolerances required to ensure quality and performance consistency. In addition, the design should include features that make the assembly and maintenance easier. [3]

2.1.1. Mathematical Modeling of the Vibration Isolator

A mathematical model of a vibration isolator, such as a composite elliptical leaf-spring damper, describes the system's dynamic behavior using equations. The first step was to define the degrees of freedom of the system, which represent the independent coordinates required to describe its motion. For the leaf-spring damper, this would likely include the vertical displacement of the isolated mass and possibly the rotation of the leaf spring. Next, suitable constitutive equations were selected for the material behavior of the composite leaf spring with respect to the stiffness and damping characteristics. Newton's second law or Lagrange's equations were used to obtain the equations of motion by relating the forces acting on the system to its acceleration. These usually involve parameters such as mass, stiffness, and damping coefficients, which can be determined experimentally

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or analytically. The resulting mathematical model can be used to describe the performance of the isolator in terms of natural frequency, damping ratio, and transmissibility. This eventually enables the optimization of the design parameters to satisfy the desired vibration isolation characteristics. Comparisons with other vibration isolation systems were also performed.

2.1.2. Mathematical Modeling of the Vibration Isolator

Vibration control is the design or modification of a system to suppress unwanted vibrations or reduce force or motion transmissions. The design parameters include inertia, stiffness, damping, and system configuration, including the number of DOF.

Vibration control can be performed best by vibration isolation, where vibration isolators are used either to protect a foundation from large forces developed during the operation of a machine or to protect a machine from accelerations induced by the motion of its base. A parallel elastic spring served as a vibration isolator. [4]

If the machine is subjected to an excitation F(t) that induces a displacement x(t), the force transmitted to the foundation through the isolator is given by:

$F_t = kx + cx$ -------(1)

If the base of the system is subject to displacement y(t)., the acceleration transmitted to the machine of mass m is determined as

$\bar{\bar{a}} = (c z + k z) / m$ ---------(2)

Where,

$\bar{\bar{a}}$ = acceleration transmitted to the machine m/sec2

z = displacement of the machine relative to its base, and is equal to the total displacement of the isolator.

Input Data:

- Weight of machine = 4.6 kg
- Max Speed = 800 rpm (operating speed of machine after reduction gear box)
- Power input = 1096 watt (considering engine operated at 7500 speed max)
- Operating speed of the device = 560 rpm
- Maximum acceleration = 7.7 m/sec2

Therefore,

Angular speed (ω) = 2 π N/ 60 --------(3)

(ω) = 2 π x 560 / 60 =58.64 rad/sec

Let, F0=Force transmitted to machine handle / foundation

$F_0 = m_0\, e\, \omega^2$ ---------(4)

(m_0 e) = Rotating imbalance owing to cutting action.

Now,

Power = 2 π N T/ 60 ----------(5)

T = 60 P /2 π N

T = 60 x 1096 / 2 π x 560 =18.7N-m = 1.9 kg-m

Thus, m_0 e = 1.9

W = T/ e = 1.9 / 0.0055 = 345kg

2.1.3. Modeling of Equivalent Stiffness of the Damper

Modeling the effective stiffness of an elliptical leaf spring composite offers modeling of geometrical and material changes along its length. Sometimes, Castigliano's theorem is applied or through energy methods that evaluate tip deflection during a load. The energy of the strain absorbed in the case of a spring made of an ellipsoidal laminate was averaged along its length. This integration accounts for the varying bending stiffness due to the changing width and thickness of the elliptical profile. The equivalent stiffness is determined by relating the load applied to the calculated deflection. The effective modulus of elasticity is key for composite materials because it depends on the fiber orientation and volume fraction in each layer. Classical lamination theory can be used to determine the effective modulus. The model should include any pre chamber or initial curvature of the leaf spring. Thus, the model was validated. This could be done with experimental testing, whereby the load-deflection behavior of the manufactured damper is measured and compared to the model prediction. Thus, the parameters in the model could be fine-tuned to ensure that they accurately represented the actual stiffness of the damper. [5]

Thus ;

$F_0 = m_0\, e\, \omega^2$

F0= 1.9 x 58.642

$F_0 = 6.533 \times 10^3$ N

Considering the maximum transmitted ratio as;

$T = F_T / F_0$

The maximum permissible amplitude of force transmitted not to exceed 4800 N

$T = 4800 / 6.533 \times 10^3$

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T= 0.735
Now as T<1,
T = 1/(r2-1)
r = Sq. rt (1 +1/0.735) = 1.536
Now ,
Natural frequency (ωn) = ω /r
(ωn) = 58.64/ 1.536 = 37.177 rad /sec
Now Equivalent stiffness of the damper is given by ,
Keq = m ωn2
Keq = 4.6 x 37.1772
Keq = 6.358 x103 N/m
3.1.4 Determination of Maximum Theoretical Displacement Of System:
Keq = W/ δ
δ = W / Keq
δ = (345x9.81) / 6358= 0.5323mm
Thus maximum displacement of the system δ =0.5323 mm
δ =0.5323 mm

3. Different Material Selection

The performance of the composite elliptical leaf-spring damper primarily depends on the material selection. In this study, we aimed to optimize the design of composite materials based on various composites. Among these FRPs, their attractive high strength-to-weight ratios for lightweight applications make it important to consider various types of them FRPs, CFRP, and hybrid composites. The GFRP is the most commonly used method because it offers a good balance between cost-effectiveness and mechanical properties. CFRP is more expensive, but provides higher stiffness and strength, which are ideal for high-performance applications. Hybrid composites were designed to optimize cost and performance by placing CFRP in high-stress regions and GFRP. The choice is based on factors such as the stiffness, strength, fatigue resistance, damping characteristics, and cost. A comparative analysis of these materials will determine the optimal choice for the specific requirements of the elliptical leaf-spring damper, balancing the performance with manufacturability. analysis of these materials will determine the optimal choice for the specific requirements of the elliptical leaf-spring

4. Modeling

A parametric feature-based methodology is used by Solid Works, a parametric solid- based solid modeler, to generate models and assemblies. The constraints whose values dictate the model's or assembly's shape or geometry are referred to as parameters. Line lengths and circle diameters are examples of numerical parameters. Other types of parameters include geometric parameters like tangent, parallel, concentric, horizontal, or vertical, among others. Utilizing relations, numerical parameters can be linked to one another, enabling them to capture design intent. Below (Figure 1) shows a design of the composite elliptical leaf spring. (Figure 2)

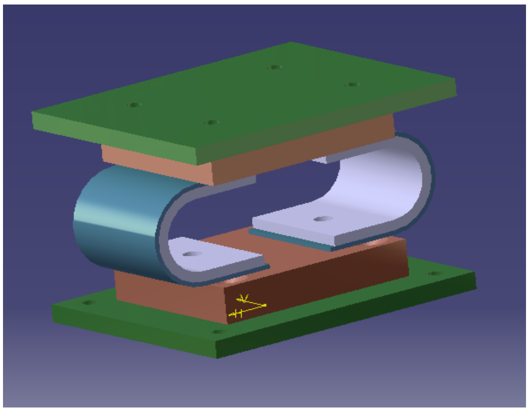

Figure 1 CAD Model of the Composite Elliptical Leaf Spring

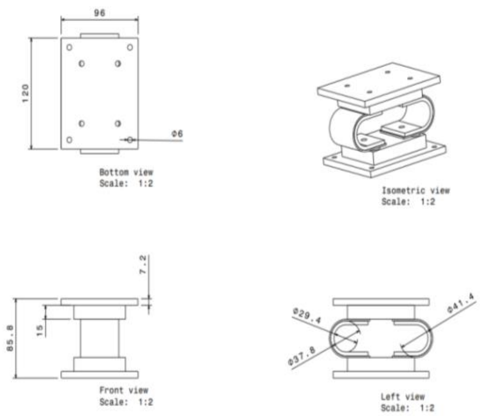

Figure 2 CAD Model

4.1.Analysis

The foundation for the most comprehensive and extensive array of sophisticated engineering simulation technology in the market is the ANSYS Workbench platform. The entire simulation process

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is connected by an inventive project schematic view that uses drag-and-drop simplicity to lead the user through even the most intricate multiphysics studies. With the help of the ANSYS Workbench platform's bidirectional CAD connectivity, robust, highly automated meshing, project-level update mechanism, ubiquitous parameter management, and integrated optimization tools, Simulation-Driven Product creation is made possible. Now we can do analysis of each component of composite elliptical leaf spring (Figure 3)

4.1.1. Design Analysis of Top Base

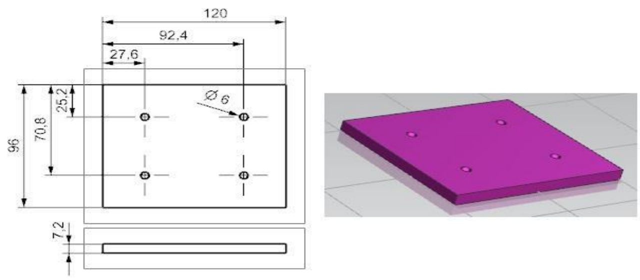


Figure 3 **Design Analysis of Top Mounting Plate**

Table 1 **Material Selection: -Ref:- (PSG 1.10, 1.12 & 1.17)**

Designation	Textile Strength N/Mm^2	Yield Strength N/Mm^2
C45	540	410

Top mounted plate figure 1 was subjected to a direct compressive load under an equivalent dynamic load of 345 kg at a full-rated load.

Hence the load on top plate = Total load/ No of plates

No of plates = 2 ---(top and bottom plates included)

Hence load on top plate = 345/ 2 kg = 172.5 kg = 1692.2N

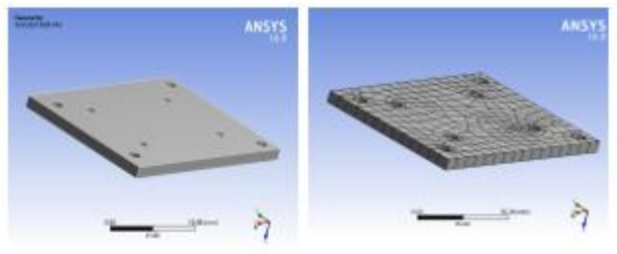
Direct Tensile or Compressive stress due to an axial load :-

fc act =

⇒ fc act = 0.148 N/mm2

Because fc act < fc all , the Top Base is safe for compression.

4.2. Analysis of Top Mounting Plate



Geometry **Meshing**

Figure 4 **Geometry & Meshing**

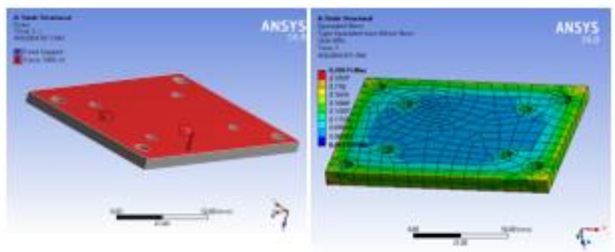


Figure 5 **Boundary Conditions & Maximum Stress**

Figure 2 Analysis of Top mounting plate Figure 2 shows maximum stress induced in the top plate was 0.209 Mpa which is far below the allowable limit. Therefore, this part was considered safe. [6]

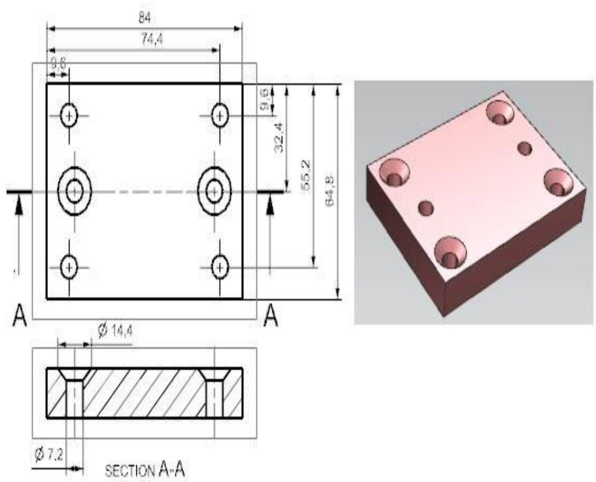


Figure 6 **Design of top base.**

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Table 2 UHMW Material Specification

Designation	Density	Tensile Strength N/Mm^2
UHMW	0.034 to 0.93	40

UHMW is the ideal material for many wear parts in machinery and equipment. Polyethylenes are semi-crystalline materials with excellent chemical resistance, good fatigue and wear resistance, and a wide range of properties

The top base Figure 3 was subjected to a direct compressive load under an equivalent dynamic load of 345 kg at the full rated load.

Hence the load on top plate = Total load/ No of plates

No of plates = 2 ---(top and bottom plates included)

Hence load on top plate = 345/ 2 kg = 172.5 kg = 1692N

Direct Tensile or Compressive stress due to an axial load:-

fc act =

⇒ fc act = 0.325 N/mm2

As fc act < fc all , the top base is safe for compression.

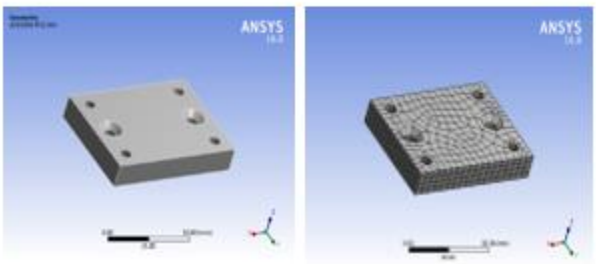

Figure 7 Geometry & Meshing

Material Selection for figure 5 is as per the table 2

The Bottom Mount Figure 5 was subjected to a direct compressive load under the action of an equivalent dynamic load of 345 kg, at a fully rated load.

Hence the load on Bottom Mount =Total load/ No of platesNo of plates = 2 ---(top and bottom plates included) Hence load on top plate = 345/ 2 kg = 172.5 kg = 1692N

Now we calculate Direct Tensile or Compressive stress due to an axial load:-

fc act =

⇒ fc act = 0.325 N/mm2

As fc act < fc all, the top base is safe for compression.

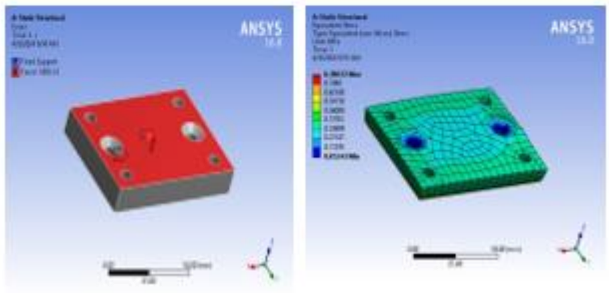

Figure 8 Boundary Conditions

4.3.Analysis of Top Base

Figure 9 shows that the maximum stress induced at the top was 0.786 Mpa which is far below the allowable limit. Therefore, this part is considered safe.

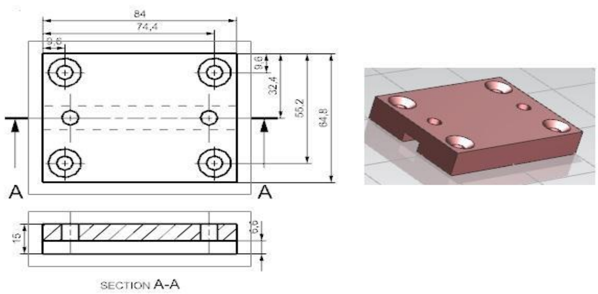

Figure 9 Design Bottom Mount

4.4.Analysis of Bottom Mount

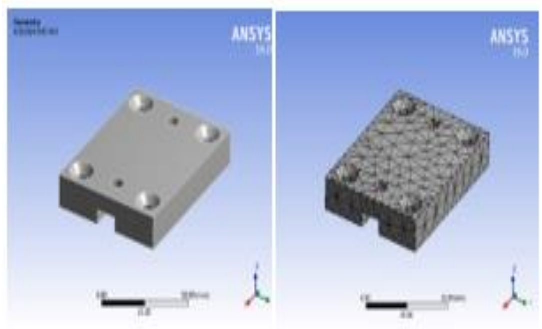

Figure 10 Geometry & Meshing

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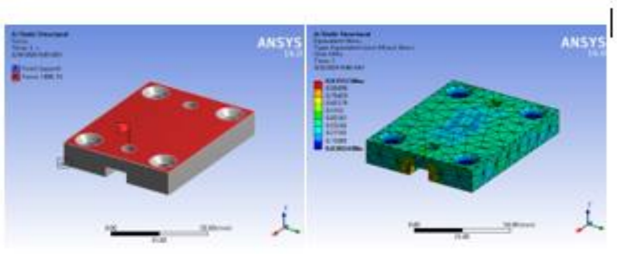

Figure 11 Boundary Conditions

Figure 11 Analysis of bottom mount shows that the maximum stress induced in the top plate was 0.93557 Mpa which is far below the allowable limit. Hence, this part is considered safe. [7]

4.5.Design of Bottom Base

Table 4 Material Selection: - Ref :- (PSG 1.10, 1.12 & 1.17)

Designation	Textile Strength N/Mm^2	Yield Strength N/Mm^2
C45	540	410

The Bottom Base plate was subjected to a direct compressive load under an equivalent dynamic load of 345 kg, at a fully rated load Hence the load on Bottom Base = Total load/ No of plates

No of plates = 2 ---(top and bottom plates included)

Hence load on top plate = 345/ 2 kg = 172.5 kg = 1692.2N

Now calculate Direct Tensile or Compressive stress due to an axial load :-

$f_{c\,act}$ =

$\Rightarrow f_{c\,act} = 0.148$ N/mm2

Because $f_{c\,act} < f_{c\,all}$, the Bottom Base is safe for compression.

4.6.Analysis of Bottom Base

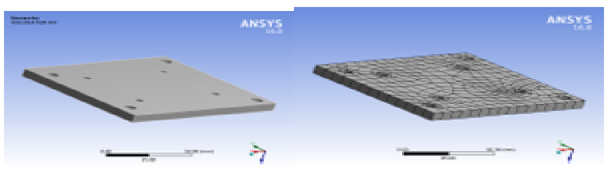

Figure 12 Geometry & Meshing

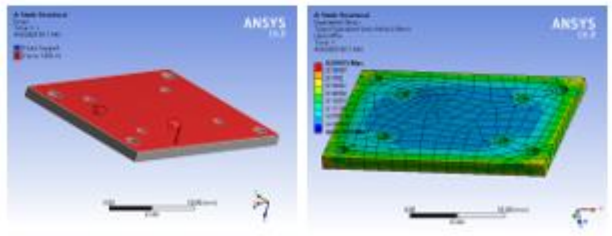

Figure 13 Boundary Conditions

Figure 7 shows that the maximum stress induced at the Bottom Base are 0.209 Mpa which is far below the allowable limit; hence, this part is safe.

4.7.Design of Lh Steel Spring

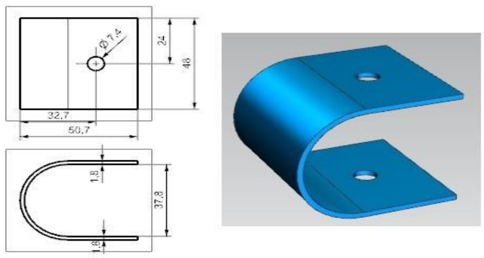

Figure 14 Design of Steel Spring

Steel spring figure 8 was subjected to a direct compressive load under action with an equivalent dynamic load of 345 kg at a fully rated load.

Hence the load on Steel spring = Total load/ No of plates

No of plates = 2 ---(top and bottom plates included)

Hence load on top plate = 345/ 2 kg = 172.5 kg = 1692.2N

Direct Tensile or Compressive stress due to an axial load :-

$f_{c\,act}$ = W (51 x48 –{1 [(/4) 7.42]

$f_{c\,act} = 0.703$ N/mm^2

As $f_{c\,act}$ on $< f_{c\,all}$, the LH steel spring is safe for compression The steel spring shown in Figure 10 was subjected to a direct compressive load under action, with an equivalent dynamic load of 345 kg at the full-rated load. Hence the load on top plate = Total load/ No of plates the maximum stress induced in the top plate was 23.99 Mpa which is far below the allowable limit. Therefore, this part is considered safe.

Table 5 Raw Material Specifications-Grade 525A60 & EN 48

CHMICAL COMPOSITIONS (Mass Weight - %)						
Material Category: Alloy Spring steel				Material Specifications: BS 970-2-1988		
C (%) 0.57~0.62	SI (%) 0.20-0.35	Mn (%)0.05~1.00	P(%) 0.035	S(%) 0.035	Cr (%) 0.80~0.95	Mo (%) ≤0.06
Tensile strength, MPa: 1225			Elongation, 82(%): 9.0		Reduction of area, (%): 20.0	

4.8.Analysis of Lh Steel Leaf Spring

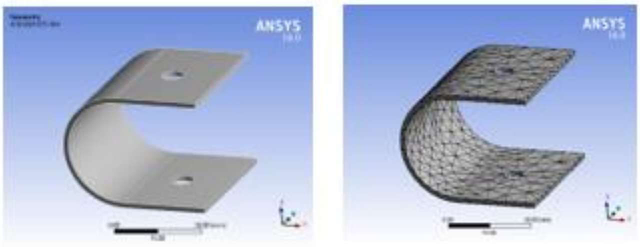

Figure 15 Geometry & Meshing

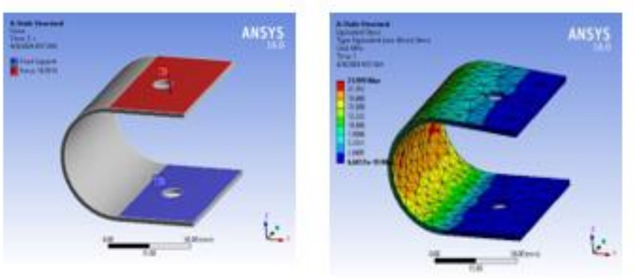

Figure 16 Boundary Conditions

4.9.Design of Rh Steel Spring

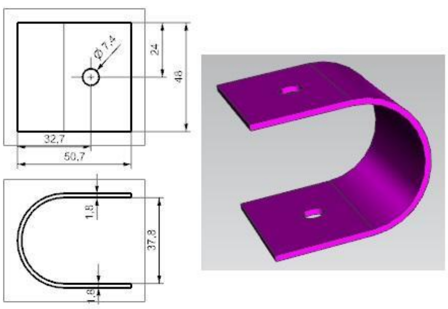

Figure 17 Design of RH Steel Spring

The Rh Spring Liner Was subjected to a direct compressive load under action, with an equivalent dynamic load of 345 kg at a fully rated load.

Hence the load on top plate = Total load/ No of plates

No of plates = 2 ---(top and bottom plates included)

Hence load on top plate = 345/ 2 kg = 172.5 kg = 1692.2N

Direct Tensile or Compressive stress due to an axial load:-

fc act =

fc act = 0.703 N/mm2

As fc act < fc all, the RH Spring Liner is safe for compression.

4.10. Analysis of Rh Spring Liner

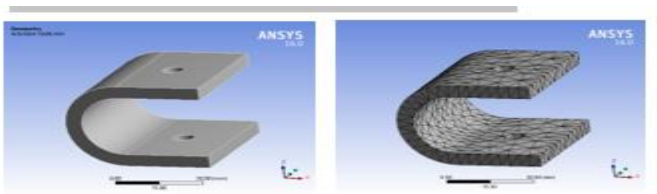

Figure 18 Geometry & Meshing

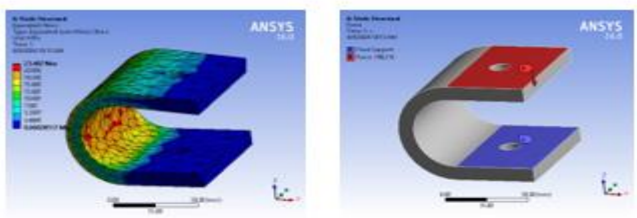

Figure 19 Boundary Conditions

The maximum stress induced in the top plate was 23.402Mpa which is far below the allowable limit. Hence, this part is considered safe [8]

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4.11. Design of Lh Spring Liner

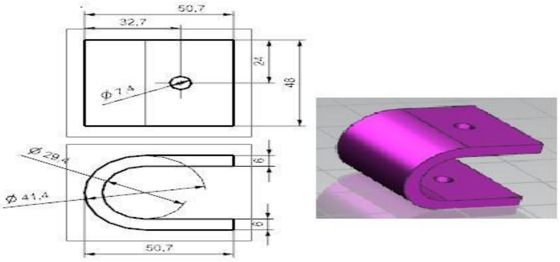

Figure 20 LH Spring Liner

The steel spring was subjected to a direct compressive load under action with an equivalent dynamic load of 345 kg at a fully rated load. Hence the load on top plate = Total load/ No of plates No of plates = 2 ---(top and bottom plates included)Hence load on top plate = 345/ 2 kg = 1692.2N

Direct Tensile or Compressive stress due to an axial load:-

fc act =

⇒ fc act = 0.703 N/mm2

Because fc act < fc all , the LH_ Spring Liner is safe for compression.

4.12. Analysis of Lh Spring Liner

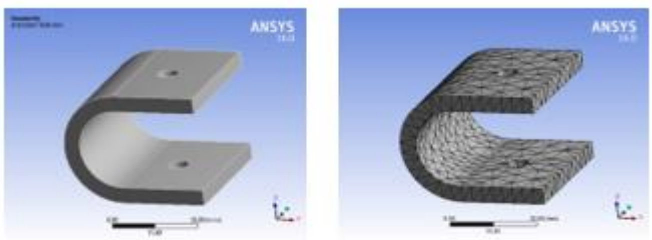

Figure 21 Geometry & Meshing

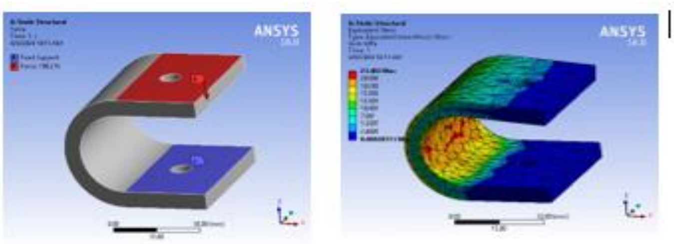

Figure 22 Analysis of LH Spring Liner

the maximum stress induced in the top plate was 23.402Mpa which is far below the allowable limit. Therefore, this part is considered safe.

4.13. Manufacturing of Spring Liner

For the composite spring manufacturing technique, we used the traditional method for manufacturing the product, as shown in Figure 14. Before actual manufacturing begins, we use a 3D printing method to create a model such that we can cut the required shape and size using this 3D printed model, as shown in figure 15. Therefore, we used this 3D printed model as a mold for spring manufacturing. [9]

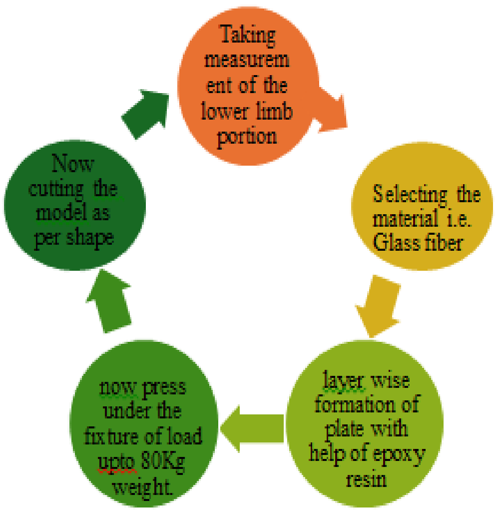

Figure 23 Flow Diagram of Manufacturing of Composite Spring Mold

The 3-d modelling of the mold was performed using UG-NX and a stereolithography CAD file (. stl) were exported shown in (Figure 23)

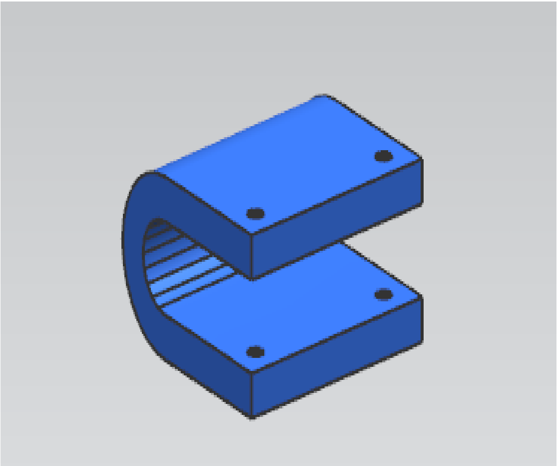

Figure 24 3-D Cad Model of Mold

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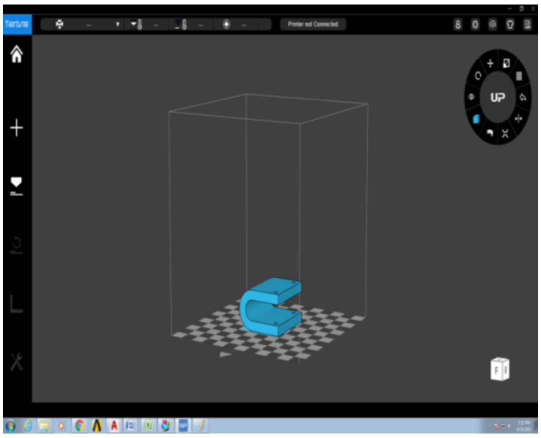

Figure 25 **3D Printing**

The stereolithography CAD files (. stl) was imported to the UP-mini 3.0 software, and the foot plate was 3-d printed using ABS polymer, as shown in (Figure 25)

5. Results and Analysis

5.1. Test and Trial on Brush Cutter Agriculture Implement Without Damper Conventional Mount

Tests and trials of farm implements, particularly those without dampers, will be conducted to determine their performance and identify areas of improvement. Field-based tests vary with realistic operating conditions and often mimic real tasks designed through implementation. The measured performance metrics included the working width, depth of operation, rate of work, and fuel consumption. The trials further tested durability and reliability by subjecting the implement to different soil types and operation intensities. Observations were made regarding structural weaknesses, wear, tears, or operational difficulties. User feedback from farmers or operators is extremely useful in identifying practical problems and design changes. Comparative testing against existing implementations or a standard design is also helpful for quantifying the advantages and disadvantages of the new design. These comprehensive tests and trials provided data that validated the design calculations, optimized the performance, and demonstrated the suitability of the implementation for intended applications in agriculture. For damping less implements, interest generally lies in the knowledge of the effects of vibration and shock loading on the performance and longevity of the machine, as shown in (Figure 25)

Figure 26 **Implementation**

Table 5 **Result table Conventional Mount**

Sr. No	Speed	Displacement (mm)	Acceleration(m^2/Sec)
1	590	0.636	5.73
2	680	0.686	5.98
3	770	0.712	6.23
4	860	0.768	6.68
5	970	0.824	6.92
6	1080	0.870	7.24

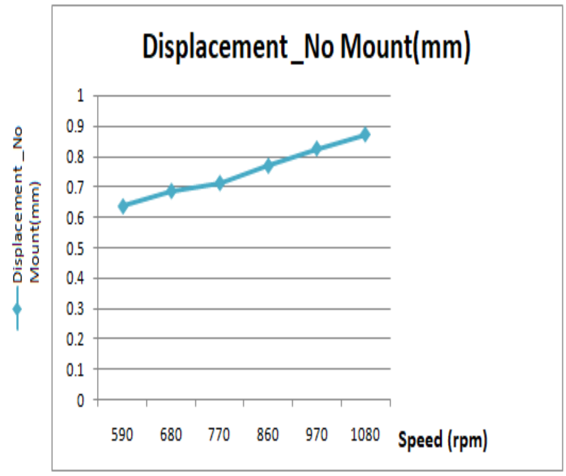

Figure 27 **Graph of Displacement Vs Speed (without mount)**

The displacement increased with increasing speed, indicating a higher amplitude of vibration with increasing engine speed, as shown in Table 1 and Figure 28

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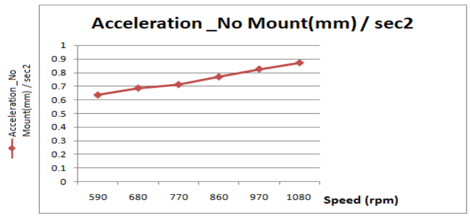

Figure 28 Graph of Acceleration Vs Speed (without mount)

The acceleration increases with increasing speed, indicating a higher amplitude of vibration with increasing engine speed, as shown in figure 19.

5.2. Test and Trial on Brush Cutter Agriculture Implement with Conventional Rubber Mount.

Testing and trials on agricultural implements with conventional rubber mount dampers, as shown in figure 20, are important for establishing a baseline performance before assessing the proposed composite elliptical leaf-spring damper. These preliminary tests (figure 21) concentrate on determining the vibration characteristics and damping behavior of the existing system under typical operating conditions. Data were collected on the vibration amplitude and frequency at key positions on the implement, both loaded and unloaded, during various field operations, such as tillage or harvesting. Performance metrics, such as ride comfort to the operator, implementation stability, and potential for damage to the implement or crop were evaluated. These tests also established the life and service conditions of the rubber mounts, thereby establishing a standard against which composite leaf spring dampers can be compared. These baseline data allow for a direct, quantifiable comparison, so that the benefits (or drawbacks) of the new design in terms of improved damping, reduced vibration, enhanced durability, and overall implementation performance can be established in the same agricultural context.

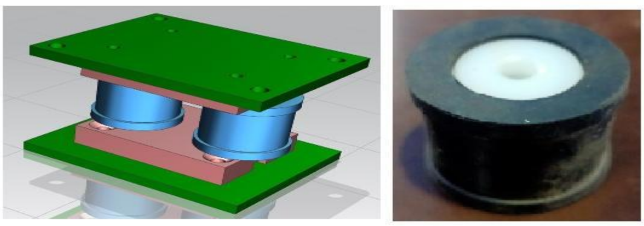

Figure 29 Conventional Rubber Damper

Figure 30 Machine Under Test with Conventional Rubber Mount

Table 6 Result Table Vibration Analysis Results of Conventional Rubber Mount

Sr. No.	Speed	Displacement (mm)	Acceleration (m^2/Sec)
1	590	0.486	4.13
2	680	0.514	4.35
3	770	0.623	4.46
4	860	0.684	4.78
5	970	0.724	4.92
6	1080	0.810	5.24

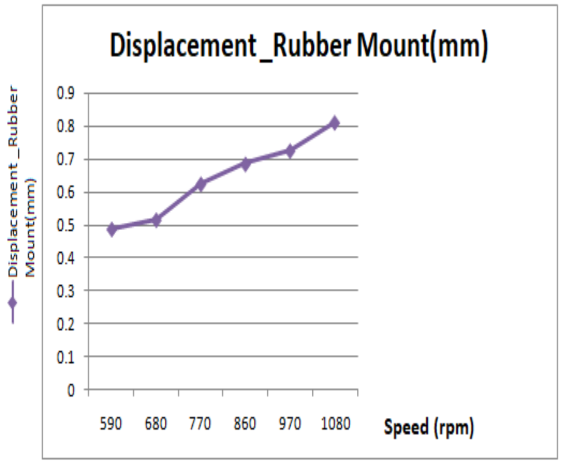

Figure 31 Graph of Displacement Vs Speed (Conventional mount)

The displacement increased with an increasing speed, indicating higher amplitude of vibration with increasing engine speed, Figure 31 shows that the acceleration increases with speed, indicating higher amplitude of vibration with an increase in engine speed. [10]

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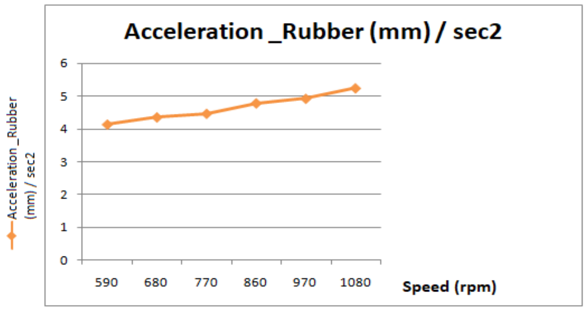

Figure 32 Graph of Acceleration Vs. Speed (Conventional mount)

5.3.Test and Trial on the Brush Cutter Agriculture Implement with E-Glass Fiber Composite Leaf Spring

Testing and trials of a brush cutter (figure 25) employing an e-glass fiber composite elliptical leaf spring are important to validate its performance and reliability. Initial tests were conducted to determine the mechanical properties of the spring. Stiffness, load-bearing capacity, and fatigue life under simulated operating conditions. This may be owing to static or dynamic loading and the resulting deflection or stress distribution. Subsequent tests combined the composite leaf spring with a brush cutter mechanism. The performance was evaluated based on cutting efficiency, vibration levels, and general operational stability in common usage scenarios, such as changing terrain and vegetation density. Durability tests were conducted to subject the brush cutter to prolonged use, simulate real-world conditions, and identify the signs of wear, damage, or performance degradation in the composite spring. These tests and trials were intended to generate data that would optimize the design to meet the required performance and reliability standards for brush cutter applications, as shown in figure 25.

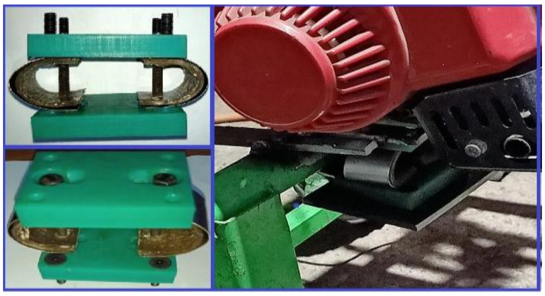

Figure 33 E-Glass Fiber Composite Leaf Spring

Figure 34 Machine Under Test with E-Glass Fibre Composite Leaf Spring

Table 6 Result Table Vibration Analysis Results of Composite Leaf Spring

Sr. No.	Speed	Displacement (mm)	Acceleration (m^2/Sec)
1	590	0.378	1.72
2	680	0.416	1.89
3	770	0.472	2.14
4	860	0.516	2.56
5	970	0.549	2.96
6	1080	0.586	3.26

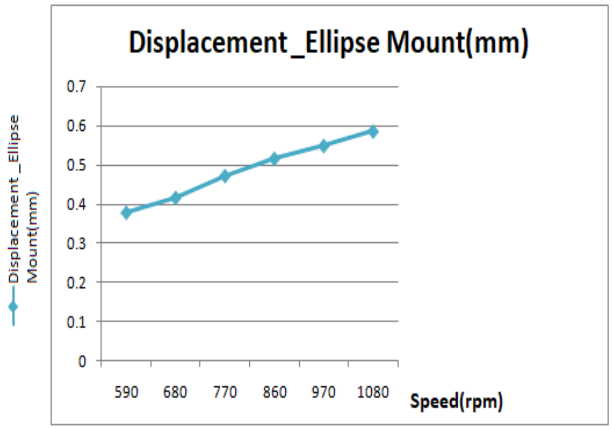

Figure 35 Graph of Displacement Vs Speed (Composite Mount)

The displacement was observed to increase with increasing speed, indicating a higher amplitude of vibration with increasing engine speed, as shown in figure 26 and Table 3.

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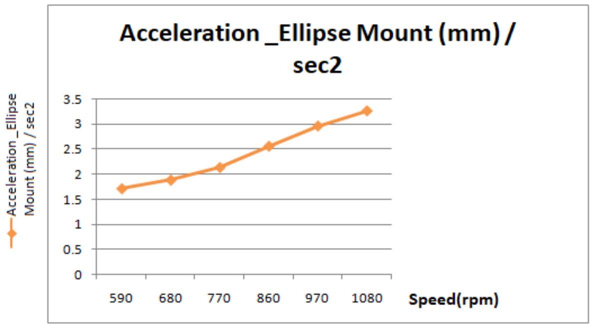

Figure 36 Graph of Acceleration Vs Speed (Composite Mount)

The acceleration increased with a decrease in speed after the load increased, indicating a higher scale of vibration with an increase in the load on the engine, as shown in figure 36.

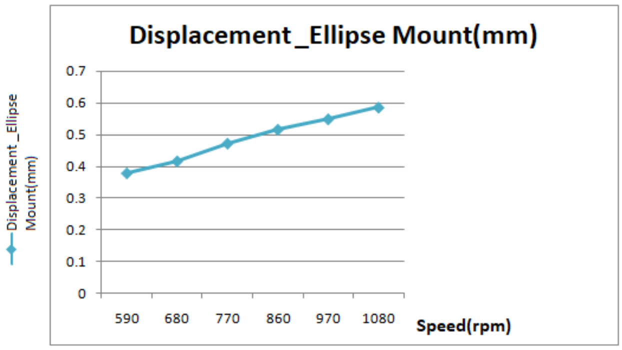

Figure 37 Comparison Graph of Displacement Vs Speed

The displacement of the vibration with the elliptical leaf spring was considerably lower than that with the conventional rubber mount, proving the effectiveness of the modified spring, as shown in figure 37

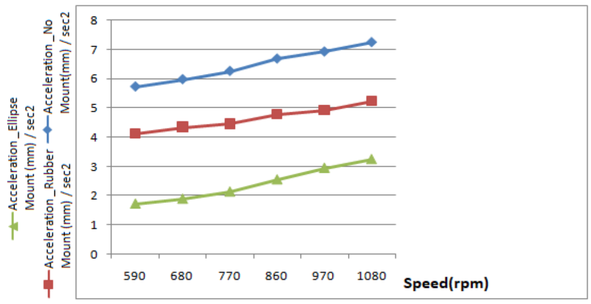

Figure 38 Comparison Graph of Acceleration Vs Speed

The acceleration of the vibration with the elliptical leaf spring was considerably lower than that with the conventional spring, proving the effectiveness of the modified spring, as shown in Figure 37.

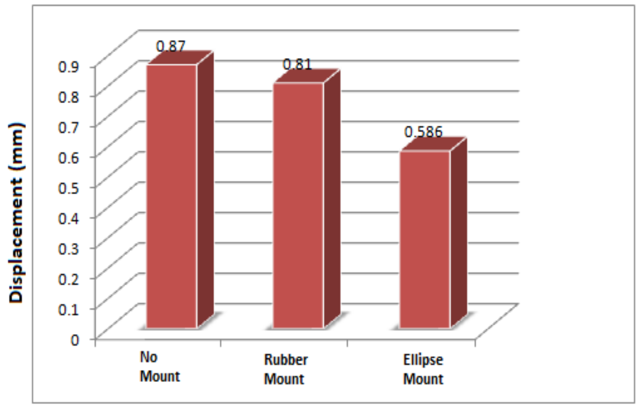

Figure 39 Comparison of Maximum Displacement

The lowest vibration displacement is observed to be 0.586 mm, and the percentage reduction in was 31.5 %, as shown in figure 30.

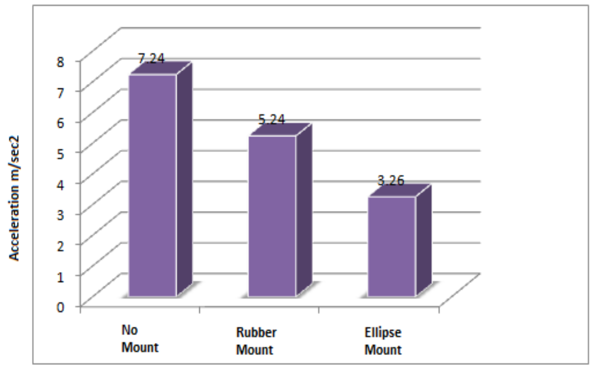

Figure 40 Comparison of Maximum Acceleration

The lowest vibration acceleration is observed to be 3.26 mm and the percentage reduction in was 54.9 %, as shown in Figure 40

6. Conclusion and Future Scope

This study presents a complete design analysis and comparative testing of a novel composite elliptical leaf spring damper. In this study, the potential benefits of using a composite material and elliptical leaf spring configuration over traditional steel leaf springs in damper-related applications are examined.

The performance characteristics of the proposed design were assessed and compared with those of a conventional steel leaf spring damper through analytical modeling, finite element analysis, and experimental validation. The findings of this study confirm the viability of a composite elliptical leaf spring damper as an alternative to the traditional steel dampers. With composite materials, significant weight savings can be achieved for many applications. Weight reduction is considered key for applications in the automotive and aerospace industries. Elliptical leaf spring, coupled with the tailorable nature of composite materials, gave an added dimension of enhanced energy absorption properties along with good damping behavior. Experimental testing validated the analytical and FEA models, demonstrating the predicted behavior of the damper and providing valuable insights into its performance under various loading conditions. From a comparative analysis, the superiority of the composite elliptical design was established mainly based on the high specific stiffness attained by the design, significantly improved fatigue life, and even higher damping capacity. All of these translate into the potential benefits of reduced vehicle weight, ride comfort, and overall vehicle handling. This study sets a strong foundation for understanding the behavior and potential of composite elliptical leaf spring dampers; however, many research avenues still need to be explored. Therefore, studies on the long-term durability and reliability of composite materials under actual operating conditions are required. This includes the environmental effects of temperature, humidity, and ultraviolet (UV) radiation on the material properties and performance of the damper. In addition, research on various composite material systems and layup configurations may be used to fine-tune the design to meet the specific requirements of an application. Determining the dynamic behavior of the damper across a range of frequencies and vibration amplitudes is also important for characterizing its overall performance. More work is needed to integrate the composite elliptical leaf spring damper with other vehicle systems such as suspension and steering systems. Further improvements in the overall performance of the vehicle can be achieved by analyzing the interaction between the damper and these systems. Advanced manufacturing techniques for the fabrication of composite leaf springs can lead to cost reductions and improved production efficiency. Finally, real-world field trials of the new damper were conducted for different applications and provided indispensable data on the performance and reliability of the actual operating conditions. Thus, this is an essential step in widespread industrial uptake in various areas. Future research in these areas will contribute to the further development and refinement of composite elliptical leaf spring dampers, paving the way for increased utilization in a wide range of applications. However, there are some new challenges in analyzing and designing composite elliptical leaf springs. There are studies related to the analysis of the stress distribution in elliptical composite leaf springs using FEA and the optimization of their geometry. Studies comparing elliptical and rectangular composite leaf springs have shown encouraging results for elliptical configurations in terms of stress reduction and improvement in the fatigue life. Furthermore, the capability of incorporating a damping function into the spring leaf has been studied to further enhance the suspension system performance. Conventional leaf springs require separate dampers to contain the vibrations generated by oscillations. The addition of damping directly within the spring simplified the suspension system and further reduced its weight. Various methods have been proposed including the use of viscoelastic materials and friction dampers. Integrating them into composite elliptic leaf springs will result in enduring and effective dampers for further research. The overall interaction between a composite material with an elliptical geometry and in-built damping must be further investigated to realize its real potential. The results include a detailed analysis of the dynamic behavior of the leaf spring, the effectiveness of the damping mechanism, and the long-term durability of the integrated system. [11]

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