“Analysis & Optimization of Multi-Leaf Spring of Small Segments by Using Composite Materials”

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ABSTRACT

Leaf Spring Suspension System is used in every automobile vehicle Fuel efficiency is an important factor for running the vehicle. To impact the vehicle to be more economical in terms of fuel, the weight of the vehicle to be reduced by reducing component weight. So, out of many components, one of the components of the automobile, the leaf spring which uses for carried out the whole weight of the vehicle is the best option for the replacement of steel material with composite material. The materials selected for leaf spring are E-glass/epoxy, Carbon epoxy, and Graphite epoxy composite material which is more economical with similar mechanical and geometrical properties to the steel leaf spring. The leaf Spring is designed using both the materials of steel and composites for the same set of loads. The Simulation is prepared for both the models and the FEA test is done showing the stress and detection analysis of Steel and Composite leaf Spring. The springs are tested experimentally by tension and bending test and validating its results with the simulation results. A Comparative study is been made for both the materials, showing the difference in dimensions, stresses, and deflections.

Therefore, the introduction of composite materials enables the weight reduction in the leaf spring, which leads to a better riding performance of the vehicle as well as a reduction in vehicle cost. In practice, the structure of the leaf spring's main body used in automobiles is mainly categorized into four types, including that with constant width and thickness, constant width and variable thickness, constant thickness and variable width, and variable width and variable thickness. Specifically, the leaf spring with constant width and thickness is easy to fabricate but it is weak in the thin middle part.

The design of spring body structure is one of the most important problems in the design theory of composite leaf spring, as the body structure primarily determines the weight, the stress distribution state, the shape of the mold cavity, and the ply scheme framework of the spring, and hence it directly affects the performance and the manufacturing cost of the composite leaf spring. Extensive efforts have been made on the structural design and optimization of the composite leaf spring body using genetic algorithm (GA) and FE approaches. Specifically, a GA was used to optimize the dimensions of a glass fibre-reinforced epoxy composite leaf spring with variable width, variable thickness, and equal cross-section. Notably, a composite leaf spring for a solar-powered light vehicle was designed by FE, and the maximum stress, deflection, and stiffness met the design requirements of the composite leaf spring. Meanwhile, a composite leaf spring made from glass fibre with epoxy resin was designed and optimized using the FE approach, and the optimized composite leaf spring possessed much lower stresses and 80% lower spring weight compared with the steel spring. These previous studies have provided valuable information on the structural design of the composite leaf spring using GA and FE approaches, but the design method of composite leaf spring with variable width and variable thickness is still not fully investigated and requires a more comprehensive investigation.

Keywords: Leaf spring, composite material, FEA analysis.

1. INTRODUCTION

1.1 Introduction

Now a day the fuel efficiency and emission gas regulation of automobiles are two important issues. To fulfil this problem the automobile industries are trying to make a new vehicle that can provide high efficiency with low cost. The best way to increase fuel efficiency is to reduce the weight of the automobile. The weight reduction can be achieved primarily by the introduction of better material, design optimization, and better manufacturing processes. The achievement of weight reduction with an adequate improvement of mechanical properties has made composite a very good replacement material for conventional steel.

In an automobile car out of many components, one of the components of an automobile that can be easily replaced is leaf spring. A leaf spring is a simple form of spring, commonly used for the suspension in wheeled vehicles. The suspension of leaf spring is the area that needs to focus to improve the suspensions of the vehicle for comfort ride. The suspension leaf spring is one of the potential items for weight reduction in the automobile as it accounts for 10 to 20% of the unsparing weight.

1.2 Suspension System:

Suspension is the system of tires, tire air, springs, shock absorbers, and linkages that connects a vehicle to its wheels and allows relative motion between the two. Suspension systems must support both road holding/handling and ride quality, which is at odds with each other. The tuning of suspensions involves finding the right compromise. The suspension needs to keep the road wheel in contact with the road surface as much as possible because all the road or ground forces acting on the vehicle do so through the contact patches of the tires. The suspension also protects the vehicle itself and any cargo or luggage from damage and wear. The design of the front and rear suspension of a car may be different. The suspension system involves the use of different springs and Piston Cylinder arrangement. Some of the common springs are,

1. Helical springs

2. Conical and volute springs

3. Torsion springs

4. Disc or Belleville springs

5. Special purpose springs

6. Laminated or leaf springs

1.3 Leaf Spring:

Leaf spring (also known as at springs) is made out of a plate. The advantage in leaf spring over helical spring is that the ends of the spring may be guided along with a definite path as it deflects to act as a structural member in addition to the energy absorbing device. Thus, the leaf springs may carry lateral loads, brake torque, driving torque, etc., in addition to shocks.

Fig.1.1 multi-leaf spring

The leaf spring commonly used in automobiles is of semi-elliptical form as shown in figure 1.1 It is built up of several plates (known as leaves). The leaves are usually given an initial curvature or cambered so that they will tend to straighten under the load. The leaves are held together using a band shrunk around them at the centre or by a bolt passing through the centre. Since the band exerts a stiffening and strengthening effect, therefore the effective length of the spring for bending will be the overall length of the spring minus the width of the band. In the case of a centre bolt, the two-third distance between centres of the U-bolt should be subtracted from the overall length of the spring to find the effective length. The spring is clamped to the axle housing by utilizing U-bolts. The Longest leaf is known as the main leaf or master leaf has its ends formed in the shape of an eye through which the bolts are passed to secure the spring to its supports. Usually, the eyes, through which the spring is attached to the hanger or shackle, are provided with bushings of some anti-friction material such as bronze or rubber. The other leaves of the spring are known as graduated leaves. To prevent digging in the adjacent leaves, the ends of the graduated leaves are trimmed in various forms as shown in figure 1.1. Since the master leaf has to withstand vertical bending loads as well as loads due to sideways of the vehicle and twisting, therefore due to the presence of stresses caused by these loads, it is usual to provide two full-length leaves and the rest graduated leaves as shown in figure 1.1. Rebound clips are located at intermediate positions in the length of the spring, so that the graduated leaves also share the stresses induced in the full-length leaves when the spring rebounds.

1.4 Applications of Leaf Spring:

1. To cushion, absorb, or control energy due to either shock or vibration as in the car springs, railway buffers, air-craft landing gears, shock absorbers, etc. dampers.

2. To apply forces, as in brakes, clutches, and spring-loaded valves.

3. To control motion by maintaining contact between two elements as in cams.

4. To measure forces, as in spring balances and engine indicators.

1.5 Characteristics of Leaf Spring:

1. The leaf spring acts as a linkage for holding the axle in position and thus separate Linkage is not necessary. It makes the construction of the suspension simple and Strong.

2. The positioning of the axle is carried out by the leaf springs so it makes it disadvantageous to use soft springs i.e., a spring with a low spring constant.

3. This type of suspension does not provide good riding comfort. The inter-leaf friction between the leaf springs affects the riding comfort.

4. Acceleration and braking torque cause wind-up and vibration. Also, wind-up causes rear-end squat and nose-diving.

1.6 Material Requirement of Leaf Spring:

1. The spring material requires greater strength and therefore greater load capacity.

2. It should have a greater range of deflection and better fatigue properties.

3. It should have high Fatigue Strength, creep resistant and Bending Strength

4. It should be high ductile and Resilience.

5. It should be lighter in weight.

The material used for leaf springs is usually plain carbon steel having 0.90 to 1.0% carbon. The material goes on with the process of Forming and Heat Treatment.

1.7 Problem Definition:

Design Optimization of a multi-leaf spring using composite material to increase the strength and reduce the weight of vehicle". The suspension leaf spring is one of the potential items for weight reduction in the automobile as it accounts for 10 to 20% of unsprung weight. As the composite materials are lighter in weight, so ultimately the spring weight can be reduced thereby reducing the weight of the vehicle. It is well known that springs are designed to absorb shocks. So the strain energy of the material becomes a major factor in designing the springs. Since the composite material has a high strength to weight ratio and has more elastic strain energy storage capacity as compared with steel. It can be easily observed that material having lower density and modulus will have a greater specific strain energy capacity. Thus, composite material offers high strength and lightweight.

1.8 Objectives:

1. To replace the spring material of steel with composite material.

2. To obtain more fatigue Strength.

3. To reduce the weight of the Suspension System thereby reducing the weight of the vehicle.

1.9 Scope:

1. Composite materials are flexible and complicated shapes are easily generated.

2. Reducing the weight of components can thereby reduce the vehicle weight which increases the fuel economy of the vehicle.

3. Manufacturing and processing cost of Steel springs are comparatively more than that of composites. Hence, we can reduce the cost of Vehicle.

1.10 Design Methodology:

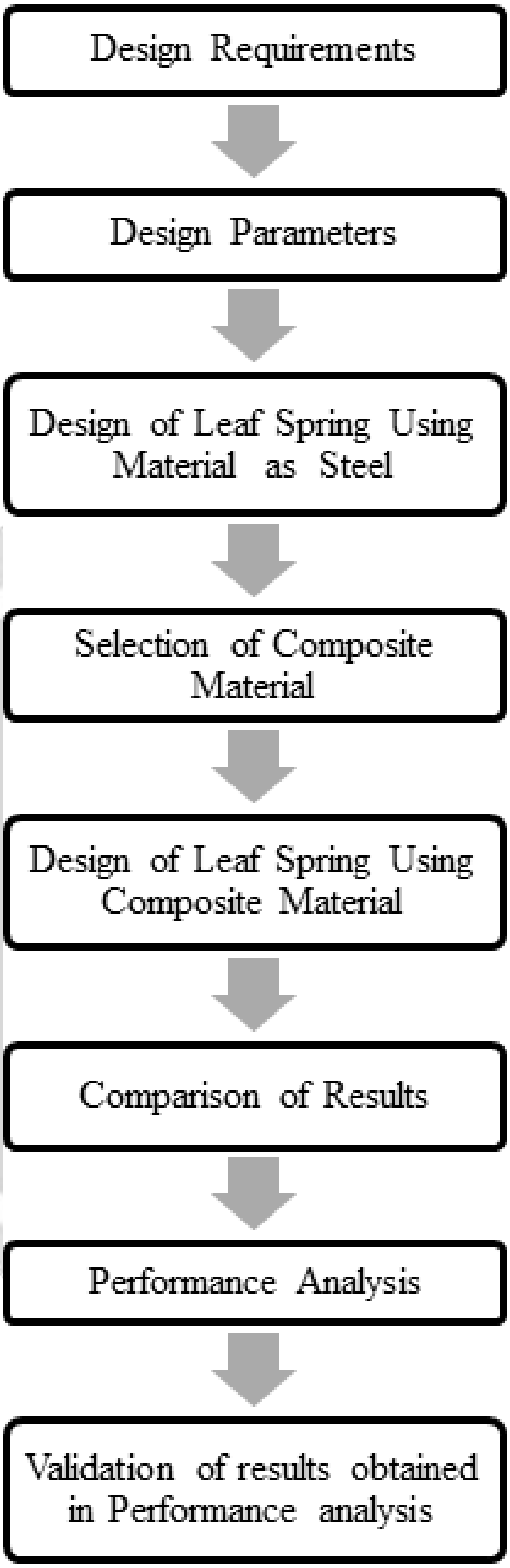

Fig 1.2 Flowchart for achieving design objective

Design Parameters:

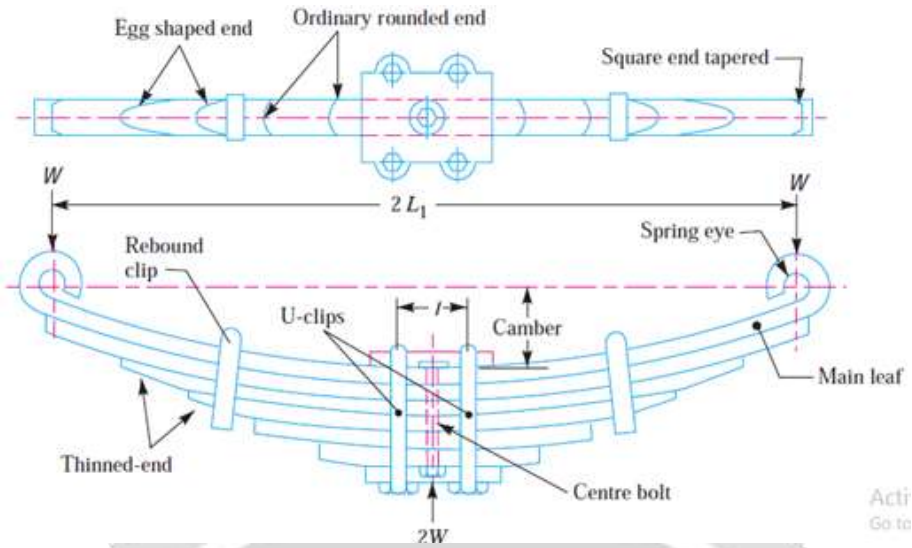

Fig Assembled view of leaf spring

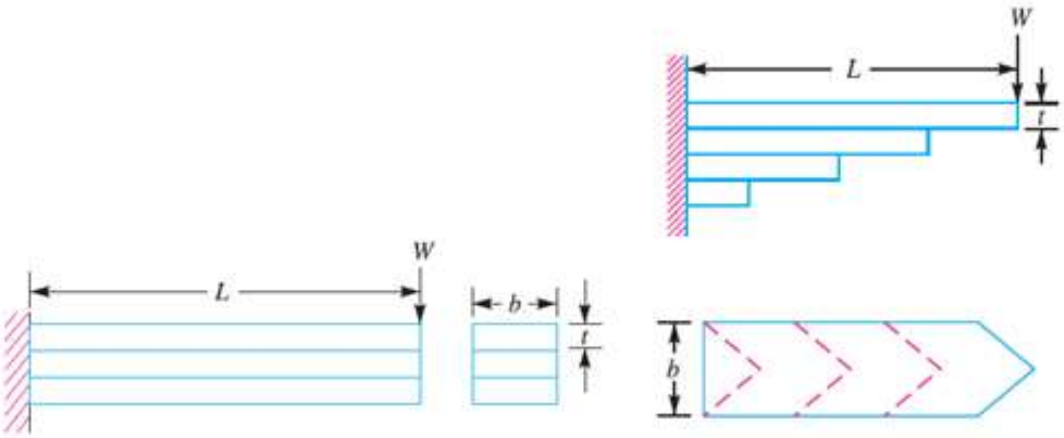

Fig Terminology of leaf spring

LITERATURE REVIEW

Lakhwinder Singh [1] explains the Latest Developments in Composite Materials. The authors have stated how the composite materials have changed all the material engineering. Composite materials are finding their applications in the aerospace industry, automobile sector, manufacturing industries, etc. This paper focuses on the importance of composite materials in mechanical engineering, the terminology used in composite materials, various definitions, classification, and the latest developments in composite materials in different parts of the world. The term composite could mean almost anything if taken at face value since all materials are composed of dissimilar subunits if examined in close enough detail. But in modern materials engineering, the term usually refers to a “matrix” material that is reinforced with fibres. For instance, the term \FRP" (Fibre Reinforced Plastic) usually indicates a thermosetting polyester matrix containing glass fibres, and this particular composite has the lion's share of today's commercial market This paper introduces basic concepts of stiffness and strength underlying the mechanics of fibre reinforced advanced composite materials. In this paper the classification of composite is described, namely, polymer-matrix composites (PMCs), metal-matrix composites (MMCs), and ceramic-matrix composites (CMCs). In this paper, the authors have explained how Composites have attractive mechanical and physical properties that are now being utilized in industry and aerospace on a grand scale worldwide. New fibres, polymers, and processing techniques for all classes of composites are constantly being developed. Research is also ongoing to improve repair techniques, recyclability, and the bonding between fibres and matrix materials.

DESIGN AND ANALYSIS OF STEEL LEAF SPRING

Bending Stress Induced Leaf Spring:

Bending Stress is defined as the stress produced due to resistance of bending load which tends to bend the component applied at distance called `eccentricity'. From Bending Equation i.e., Flexural Formula of beam, we can say that,

$(\sigma b/y) = (E/R) = (M/I)$

$(\sigma b/y) = (M/I)$

$(\sigma b/y) = (My/I)$ and $I/y = Z$

Bending Stress = Moment of Resistance / Section Modulus) $\sigma b = M/Z$

$M = W*L$ and $Z = (bt2)/6$

So, $\sigma b = [W*L]/ [bT2)/6]$

Hence, bending stress induced in the leaf spring assembly can be calculated by the equation as,

$\sigma b = [W*L]/ [n* (bt2)/6]$

n = Total Number of Leaves

2L = Effective length of Spring = 2L1 - l (when central band is used)

2L = Effective length of Spring = 2L1 - (2/3) l (when U-Bolt is used)

2. Deflection in Spring:

The deflection can be given as,

$\delta = [W * L3] = [3 *E *I]$

E = Modulus of Elasticity in N/mm2

I = Moment of Inertia in mm4 = (bT3)/12 Hence, deflection produced in the leaf spring assembly can be calculated by the equation as,

$\delta = [W *L3] = [n *3 *E *I]$

3. Bending Stress Induced in Full Length Leaves (σf):

The master leaf is the leaves that are bounded on top of the leaf spring assembly. The length of the master leaf is the largest of all leaves. As the leaf spring is an assembly of various leaves. Hence the stress developed will be cumulative for all the leaves. The stress developed in full length or Master leaf can be calculated from,

$\sigma f = [18 *W *L] = [bt2(2ng + 3nf)]$

4. Bending Stress Induced in Graduated Leaves (σg):

Graduated leaves are the leaves that are bounded beneath the leaf spring assembly. The length of these leaves is less than that of the master leaf and is arranged in decreasing order of their lengths. The stress developed in Graduated leaves varies as to that of master leaf due to variation in sizes. Hence the stress-induced in graduated leaves can be calculated from,

$\sigma g = [12*W*L] = [bt2(2ng + 3nf)]$

ng & nf are number of graduated and full length leaves respectively.

5. Deflection Induced in Full and Graduated Leaves (δ 1):

The deflection in total leaf spring assembly will not be the same as that of individual leaves separately. Hence it is necessary to determine the deflection in each leaf separately. Hence the deflection in full length and graduated leaves can be calculated as,

[12 *W *L3] = [Ebt3(2ng + 3nf)]

6. Radius of Curvature (R):

Radius of curvature is the curve which is produced on leaf while bending,

R = $L1^2$=2y

Fig Mahindra MM40 Jeep

Sr. No	Notation	Value
1.	W	4.3 KN
2.	t	3.7 mm
3.	T	37 mm
4.	b	47 mm
5.	L (U – bolt)	670 mm
6.	2L1	850 mm
7.	l	270 mm
8.	n	10
9.	nf	2
10.	ng	8
11.	y	128 mm

Table Dimensions of Spring

Simulation of Steel Leaf Spring using Creo 2.0:

CREO 2.0 software is used for simulation purposes. The Finite Element analysis test for different stress is been carried out using the same software. By the same dimensions on which the stress are calculated using the analytical method, referring to table 4.1 and Length of all the leaves, the prototype models for Spring, U-Clip and bolt is prepared

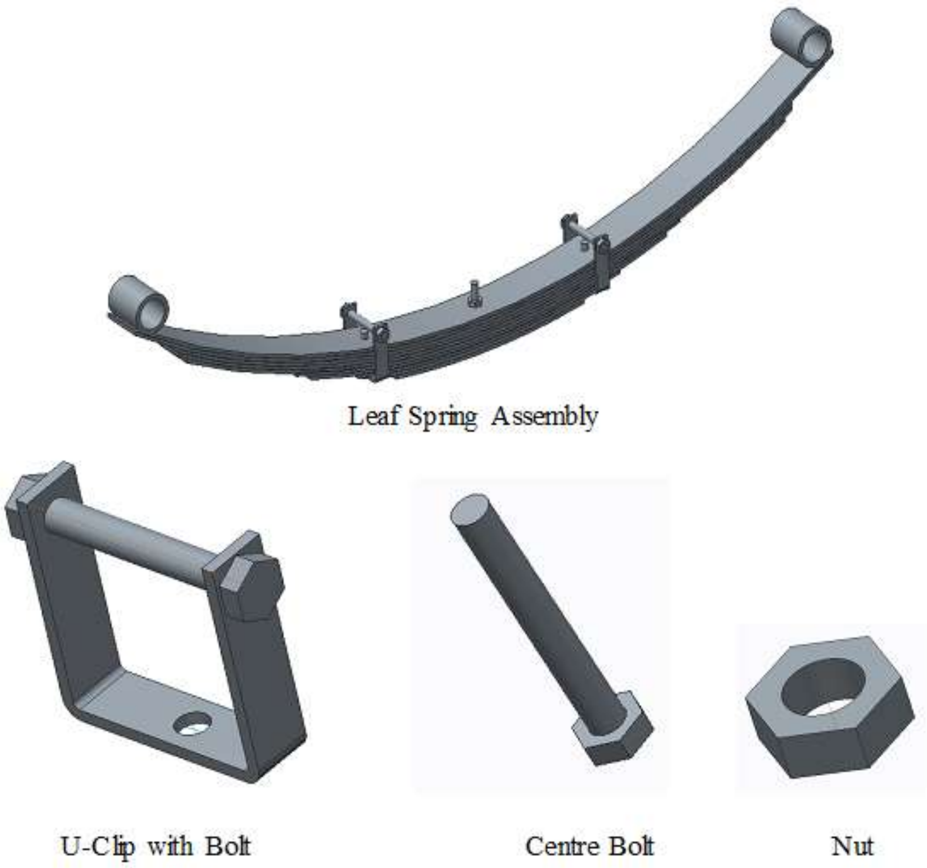

Fig : Assembly of leaf spring using creo 3.0

The separate leaves are prepared and separate models are assembled and by selecting appropriate materials, the FEA test is been carried using the same set of loads as that done previously using the analytical method.

CONCLUSIONS

The Leaf Spring has been selected which is used in Mahindra Jeep. The material of the spring is AISI 6150 Steel. The properties of this material have been collected and sorted in tabulated form. All the Design Equations and Strength equations of spring have been formulated using reference books and research papers. The dimensions of Leaf's have been carefully measured from some corners to sections and the Solid Model is prepared using Creo software and FEA is done in the same software. The FEA is done for ANSI Steel as well the composites materials for E-Glass, S-Glass, Kevlar and Carbon Fibre. Amongst these materials, E-glass has been selected for the experimental approach considering the criteria's for, stress, deformation, Strength to weight, costing, and availability of material. E-glass shows similarity in stress distribution but a comparatively better performance concerning deformation as that of steel. For the weight criteria, the weight of E-glass is approx. 2 kg and that of steel is 8kg. Hence the usage of E-glass fibre can reduce the weight of spring by 75%. By using the shape optimization technique, the optimal E-glass leaf shows better performance than that of Multi-leaf E-glass and Steel Spring. Optimizing the shape of the leaf spring increases the stress performance and deformation thereby decreasing the weight of spring. For conductance of experimentation, the specimen of steel, as well as E-glass, has been undergone through transverse bending test using Universal Testing Machine. The deflection and stress found in the E-glass specimen are found to be very low as that of
the steel specimen. Hence material satisfies the strength criteria and can be used Hence the objective of reducing the weight of the spring and increasing the strength is achieved using Shape and Material Optimization. Using low weighing spring can decrease the weight of a vehicle to some extent thereby increasing the fuel economy.

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