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DESIGN AND ANALYSIS OF COMPOSITE MONO LEAF SPRING : A REVIEW

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Abstract: This paper reviews some of the general study on the design, analysis and fabrication of composite mono leaf spring. Leaf spring plays a major role in the suspension system of the vehicle. This literature has demonstrated the currently growing demand and interest on replacing the conventional steel spring with composite leaf spring. The behaviour of vehicle and its characteristics such as stability, riding quality and others depends upon the suspension system. Due to varying stress cycles the suspension system may lead to fatigue failure. To overcome this and to improve its performance, lot of materials were used to design the leaf spring with better performance. Among those it is found that fibreglass material provides better strength and also has advantage of light weight than any other steel leaf spring. In this paper, the author reviewed some papers that focus on finding alternate materials of leaf spring and its performance.

Keywords: steel leaf spring, composite mono leaf spring, fiber glass, E-glass epoxy.

I. INTRODUCTION

Introduction to springs: A spring is an elastic body, which is used to soak up and launch energy when the load is applied or acted on [1].Clamping effect and interleaf contact makes the leaf spring performance to be complicated. Along with absorbing shock, it also has lateral loads, brake and driving torque. A good riding quality of car depends on the spring which reduces the vertical vibrations, jerks due to irregular road condition [2, 3]. The load-carrying capability and performance of suspension machine depend on the kind of material, geometry and mechanical properties of leaf spring [4, 5].Suspension system consists of two springs namely leaf spring and helical spring. Leaf springs were employed in heavy vehicles and automobiles. While helical springs are used in light automotive motors like small cars, motor cycles, bicycles and railway suspension systems [6, 7].

Leaf spring: Leaf spring is a semi-elliptical structure. Leaf spring is a flattened steel bar involves in the suspension system of vehicles like car which plays a major role in absorbing energy. The design is to improve the load carrying capacity ,stresses and conserving weight by using composite leaf spring than steel leaf spring[8, 9].Load carrying capacity and stiffness can be increased by using variety of leaves which will increase the average weight vehicle [10, 11]. Mono-leaf springs are employed in light weight automobiles whereas multi-leaf springs in heavy loading motors. The spring is situated over the axle of the vehicle. The leaf spring carries the overall weight of the vehicle. The front end of the spring is connected to the frame by means of simple pin joint, while the rear end is connected at the shackle. Shackle provides a connection between leaf spring rear eye and frame which is flexible. Deflection of the spring occurs when the vehicle passes the projection on the road surface through which the wheels move upwards. Thus the length between the spring and eyes were changed. The length cannot be changed if those ends were fixed. So that shackle is connected at one end to provide enough flexibility. The front eye of the leaf spring is constrained in all the directions, whereas rear eye is not constrained in X-direction and connected to the shackle. During loading the spring deflects and moves in the direction perpendicular to the load applied [12].It is found that the steel leaf springs are manufactured by EN45, EN45A, 60Si7, EN47, 50Cr4V2, 55SiCr7 and 50CrMoCV4 etc from the past data that are recorded by industrial visits. These materials are widely used for production of the parabolic leaf springs and conventional multi leaf springs [13]. The structure of a new fabric which can provide better performance can be designed in microscopic scale using materials like metals and non-metals[14, 15]. The composite fabric is good in maintaining its personal mechanical, physical and chemical properties. These materials are chosen for their benefits over metals due to its lightweight, strength, life time and better mechanical properties[16, 17].Composite substances is comprised of two materials which includes matrix and reinforcement. Reinforcement is usually stronger, more difficult and highly stiffer when compared to matrix. Matrix carries the load and distributes to the reinforcement and to the total part [18, 19]. It is known that the

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failure nature of steel leaf springs is usually catastrophic. It is very important to reduce accidents and to replace steel leaf springs by gradually failing FRP (fibre reinforced polymer) composite material [20]. Another point is to reduce weight of the vehicle while required strength is maintained, which is possible by FRP composite materials [21].The automobile manufacturers mainly focuses on conserving the natural resources from exploitation and to make energy economic by reducing the weight of vehicles. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes [22].The achievement of weight reduction with adequate improvement of mechanical properties has made composite a very good replacement material for conventional steel [23]. A high performance fiber such as carbon, Kevlar, graphite or glass were used to design a composite leaf spring in a matrix material which on combining provides better properties than individual materials [24]. The composite materials are applied in areas such as in aircraft, space, automotive, for sporting goods, and marine engineering. The various type of glass fibers available are Carbon fiber, C-glass, S-glass and E-glass[25, 26]. Carbon epoxy material is better than other fiber, however it has a limited applications due to its high . Favourable relation between cost and properties of a material can be obtained with E-glass fiber/epoxy[27, 28].The specimen consists of nine leaves, two eye pins, centre bolt with nut etc CAE tools are being used to analyze the robustness and performance of components and assemblies by using numerical method known as finite element method (FEM). Multi leaf spring is modeled with the help of discrete building blocks known as elements using FEA. Each element has some equations that describe how it responds to certain loads [29].The total response of the design is analyzed by the sum of the responses of all the elements in model. CAE relays on the actual assumptions of the assembly which is considered to be a input data. CAE has become an important technology with benefits such as lower costs and a shortened design cycle [30].

II. COMPOSITE LEAF SPRING

E. Mahdi a, O.M.S. Alkoles (2006) et al..,presented work on light composite elliptic springs for vehicle suspension. This paper focuses between an elliptical configuration and the woven roving composites. They investigated the elasticity performance of woven roving wrapped composite elliptical springs on its elasticity ratio and it has been investigated both experimentally and numerically. It is achieved by conducting series of experiments for composite elliptical springs with elasticity ratios (a/b) ranging from one to two. This research also faced failure mechanism in history. Wall thickness increases with increase in spring rate and maximum failure rate. It is demonstrated that the composite elliptical spring can be used in both light and heavy trucks along with reducing weight. The results showed that the spring rate and failure load depends on elasticity ratio. The highest elasticity ratio was found to be a/b 2.0 [31].

Ghodake A.P, Patil K.N. (2013) searched new material for leaf spring. In present study the glass fiber reinforced plastic (GFRP) material was chosen and the conventional steel is replaced with polyester resin (NETPOL 1011). A simple and economical technique called hand lay-up was used to fabricate a spring of constant width and thickness. Numerical analysis can be done by using software called ANSYS software. Deflection, strain, energy and stresses were compared between composite leaf spring and steel leaf spring. From the results, it is found that the composite leaf spring is lighter and more economical than the conventional steel leaf spring. It is also observed that the weight is reduced by 84.94% in mono leaf spring of composite than steel. Since the composite materials have high energy storing capacity caused by elastic strain and high strength-to-weight ratio than steel, it is found that the deflection and strain energy of the composite material is higher when compared to that of steel material [32].

R M Patil et al.., (2013) Presented work on fabrication of the composite leaf spring material for light passenger vehicle which has higher strength to weight ratio along with corrosion resistance. They compared the load carrying capacity and stiffness of the composite leaf spring with conventional leaf spring. This study involves the analysis of composite leaf spring performance by observing under actual working conditions. In this paper, they have fabricated thermoset matrix material epoxy with E glass fibre by hand- layup vacuum bugging technique. The stiffness of the composite leaf spring is then tested by applying static load in centre of master leaf and concluded that the stiffness is 18.78% lower than metallic leaf spring. Although the fabricated leaf spring reduces weight by 57.23% with higher fuel efficiency in light weight vehicles [33].

Ajay B.K, Mandar Gophane, P Baskar (2014) aims to replace steel material for leaf spring, the material used is glass fiber reinforced plastic. The composite spring has reduced stresses and weight than steel leaf spring. The 3-D modelling of multi leaf spring is done and analyzed for different arrangements of steel leaves with composite leaves. A contrast study is done for 4 models for Deflection and stresses. Same models are designed for factor of safety of 2.5. Leaf spring is analytically designed and shows factor of safety 2.8. Four models are analysed in **ANSYS** and maximum deflection, stress and ultimate strength are calculated. It proxy of composite leaves provides similar strength as that of conventional steel leaves with more advantages. Also implementation of 3 steel leaves instead of 4 leaves, gives better results than alternate arrangement of steel and composite leaves. IV model arrangement shows better result than other two arrangements [34].

Atul J. Pawar, Prof.S.N.Bansode Professor (2015) works on application of FEA concept to compare three materials for leaf spring and proposed the material having best strength to weight ratio among them. Three materials used for

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comparing are the conventional steel, composite E-Glass Epoxy and Carbon Epoxy. This present work is to estimate and compare the deflection, bending stress induced in the leaf spring by these materials. The leaf spring, which is used for analyzing, is a mono leaf spring of Light passenger vehicle. A model of such leaf spring has been designed from actual steel leaf spring and analyzed using ANSYS in this paper. E-glass/epoxy composite leaf spring can be suggested for replacing the steel leaf spring from stress and stiffness point of view. A comparative study has been made between steel and composite leaf spring with respect to strength and weight. Composite mono leaf spring reduces the weight by 30 % for E-Glass/Epoxy, and 55 % for Carbon/Epoxy over conventional leaf spring [35].

M. Venkatesan, V. C. Sathish Gandhi, E. Janarthan (2015) studies the Finite element method is used for analysing the composite spring for different parameters such us stress, deformation and mode frequencies for three different ratios of epoxy and E-fibreglass materials.. The epoxy and E-fiber glass composite is selected in the following compositions which includes 40% epoxy and 60% E-fiber glass (Specimen), 60% epoxy and 40% E-fiber glass (Specimen-II), 70% epoxy and 30% E-fiber glass (Specimen-III). The results shows that the 40% epoxy and 60% E-fiber glass is having high value of tensile stress, bending stress, deformation, and natural frequency compare with rest of composition of materials in both experimental and Simulation. From the results, it is concluded that the best composition of material for design and manufacturing of leaf spring was found to be 40% epoxy and 60% E-fiber glass (Specimen-I)for this application [36]

Syambabu Nutalapati(2015) aims to compare the stresses, deformations and weight saving of composite leaf spring with that of steel leaf spring. The design focuses on stiffness. A glass fiber reinforced polymer (E-glass/epoxy) is material selected in order replace conventional steel. Main objective is to reduce the weight of composite leaf spring than steel leaf spring by means of selecting and analysing the design parameters. From the fatigue analysis results, the usage factor of E-glass/Epoxy is very much less compared to steel. Hence it is advantageous to replace steel leaf spring with E-glass/Epoxy [37].

Subhash Khamkar, Prof. P.A. Narwade 2016. The single leaf springs and multi leaf spring both are used to support vertical loading due to the weight of the vehicle and payload. The Glass fiber reinforced plastics (FRP) composite mono leaf spring reduces weight of the machine element without reducing the load carrying capacity. It has high strength-to weight ratio that those of steel. Also a multi-leaf steel spring is replaced by mono leaf FRP spring. The project work is to design and construct composite leaf spring. The analysis is conducted for durability and results contrast with steel leaf spring. Comparison of composite leaf spring and steel spring was done based on their working on actual road condition. The stiffness of both leaf springs is determined and shown that composite leaf spring gives better result than conventional steel leaf spring [38].

Prasanna Nagasai B, Srikanth S, Tarun D (2020) Presented work on design and analysis of composite leaf spring by using glass fibre reinforced polymer. Main objective of this paper is to increase load carrying capacity, stiffness and conserving energy by reducing weight of the leaf spring. On comparing, composite material is superior by its low specific gravity, strength weight ratio and modulus weight ratio than metallic materials. It is found that the epoxies were the best resins due to inter laminar shear stress along with good mechanical properties. It is then analyzed by applying same load is on both steel and epoxy in which epoxy resulted less mass when compared to steel. Hence it is concluded that the strength of the epoxy material is greater than steel material. It also has a advantage of reduced weight which conserves energy and higher strength to weight ratio [39].

III. MATERIALS AND MANUFACTURING

Material used for leaf spring

By using composite material for leaf spring, there are so many characteristics which provide good fatigue strength, better corrosion resistance, high strength to weight ratio and natural frequency. Then the application of composite material for leaf spring is to reduce the weight of leaf spring without reducing the stiffness and load carrying capacity in the suspension system [40, 44].

Type of composite material	Researcher
S2-glass fiber/ Epoxy and E-glass/ Epoxy	W.J. Yu. Kim[1988]
E-glass fibre with two layer of bidirectional fabric	Erol Sancatar [1999]
E-glass/Epoxy and carbon fiber/Epoxy	H.A.Al. Qureshi[2001]
E-glass/Epoxy and Woven roving/ Epoxy]	G Gular Siddaramanna et.al[2006]
Woven glass fiber Baric	E.Mahdi et.al [2006]; Abdul Rahim [2010]
20% glass fiber reinforced polypropylene	C.Subhramian ,et.al [2011]
Glass/Epoxy, Graphite/Epoxy, arbon/Epoxy	B.Ragu Kumar et.al [2013]
E-Glass/Epoxy, CGlass/Epoxy, SGlass /Epoxy	B.Vijaya Lakshmi I.

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	Satyanarayana[2012]
Carbon/epoxy	Parkhe Ravindra ,Sanjay Belkar [2014]
C-glass/epoxy composite leaf spring	Mhaske Raman, Nimbalkar et.al [2014]
Epoxy LY 556	Thippesh L[2016]
Chromium vanadium E-47 steel	Miss payals. Tajanpure et.al[2017]
Carbon/glass epoxy/EN45	Jenarthanan et.al[2018]
55Simn90/glass epoxy/EN45	S.Seralathan et.al[2020]
Epoxy/glass and fiber composite	Ekhlasedan kalder et.al[2021]

Layup Selection-The amount of elastic energy that can be stored by a leaf spring varies directly with the square of maximum allowable stress and inversely with the modulus of elasticity both in the longitudinal direction. Composite materials like the E-Glass/ Epoxy in the direction of fibres provides a higher strain storing energy which makes its characteristics more effective. Hence the layup is should be in unidirectional way along the spring which is in longitudinal direction the unidirectional layup may weaken the spring at the mechanical joint area and require strengthening the spring in this region [20].

Hand Layout Moulding-Hand lay-up moulding is the method by which the reinforcement fabrics can be layer down and desired thickness can be obtained by painting with matrix resin layer by layer. In this method, composite processing requires more time and labour. Even though the majority of aerospace composite products is made by this method with the addition of autoclave method. Hand assembly in the lay-up procedure can allows us to align long fibres with controlled directional quality. The irregular-shaped products can also be accommodated by using this method. These added advantages can be employed in low performance composites such as fibre - glass boat and bath tub manufacturing. An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it [20, 42].

Fabrication-The first step of fabrication involves plastic bagging of steel leaf spring as per the available dimensions. The bagging is required to leak proof fabrication or the resin should not be in contact with the steel leaf spring. Resin is sticky in nature and hence the contact to steel leaf spring should be avoided. It is proceeded by mounting the first sheet over steel leaf spring and to apply a matrix on it in such a way that removes all the air must be removed. Now second lamina is mounted over applied matrix and the matrix should be applied again as discussed above. This procedure must be continued till the last fiber sheet. After completion of 20 layers keep above it again with Plastic bagging. Finally arrangement is allowed to dry at least for 24 hrs. The curing time of this matrix is 24 hrs [43, 44].

Equipment required-Fabrication and testing of composite springs required various equipments. Universal Testing machine (UTM) is used for tensile and flexural testing of composite leaf spring [45, 46].

Constant amplitude rig test-In addition to the vertical loading scenario, the longitudinal loading scenario also differs due to air suspension system kinematics and compliance behaviours. Z type leaf springs have dominant loadings on both vertical and longitudinal direction. To construct a specific test, a SN curve should be constructed and damage on the leaf spring should be calculated, meaning that the parts should be analyzed specifically until a generic test methodology is established[47, 48].

Tensile Test-Tensile strength was measured using a controlled electro-mechanical testing device. Loading the ASTM D638 samples to fracture with a constant load of 30 kN at 5 mm/min speed and 50 mm span length. Tensile strength and deformation were calculated considering the stress strain curves. Three samples of each composite were tested and then the average was considered for all blend and composite sample to have the best evaluation of the tensile tests [49].

Hardness Test-Enabling the assessment of the properties of a material and helping to identify the appropriate materials for the required purpose hardness testing was considered as a quality control test [49]

Flexural test-The flexural test is carried out using the universal testing machine. The test specimen was prepared according to ASTM D standard [50, 51].

Hardness test-The test was conducted using Rockwell L- scale, which is especially for plastic materials, Bakelite and vulcanized rubber [50].

MODELING AND ANALYSIS

Design carried out using Catia V5, and imported geometry in Hypermesh and mid surface of leaf was been constructed, later then global element size was decided as 10and selected element as E-type shell 181 and FE model was done. FE modeling by using Hypermesh[52].

Finite element analysis: Finite element analysis of Hybrid Composite Leaf Spring is done using ANSYS. Both Static and Dynamic Structural Analysis are done for both Steel and Hybrid FRP Composite. In ANSYS Workbench before

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solving the analysis, we have to provide proper fixtures to simulate component in near exact environment. Regarding the Constraints, both the eye ends are constrained with remote displacement fixed end, all translations are constrained as well as rotations except z-axis. In Shackle end, translation along x-axis and rotation along z-axis are released while all other DOFs are arrested [53].

Loading & Boundary Conditions:

Fixed Support: Fixed support has restriction to move in X and Y direction as well as rotation about that particular point. One eye end of the leaf spring is fixed to the chassis of the vehicle and another eye end to a fixed support for analyzing the leaf spring model. Therefore the eye end of the leaf spring can't able to move in any directions by which all the degrees of freedom were blocked.

Cylindrical support: As there is shackle provided at other end of the leaf spring because of which the leaf spring only translates in one plane and other movements i.e. degree of freedom are blocked. So with the reference of this a cylindrical support is applied to the other eye end of leaf spring model. This support allows the movement of the leaf spring in X axis, rotation about Z axis and fixed along Y axis [50].

IV. CONCLUSION

From the researches and studies, it is found that the composites mono leaf spring is the best one when compared to conventional steel spring. Among various composite materials such as S-glass epoxy, C-epoxy and graphite epoxy, the strength of E-glass fiber epoxy is higher and it can be effectively used in light and heavy vehicles than others. Since it provides higher load carrying capacity, stiffness, reduced weight and stresses, better riding quality, etc... In addition weight and higher strength weight ratio.

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