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Static and Fatigue analysis of Glass Fiber Reinforced Plastic (GFRP) mono leaf spring.

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ABSTRACT

In recent years, the fiber reinforced springs drawn the attention of automobile industries because of its special feature high strength to weight ratio. This spring is one of the potential components in automobile. It is subjected to various loading conditions during operation. These loads include axial, torsion and bending, etc. As the static analysis determines the safe load and its corresponding stresses, it is not sufficient to understand the dynamic behavior. To study the dynamic behavior an experimental fatigue analysis is preferred, but it is most expensive and time consuming. In order to overcome this issue the virtual fatigue analysis is carried out under the various fluctuating loads. In this paper, the glass fiber reinforced plastic is chosen for the finite element analysis to know the dynamic behavior of the leaf spring.

Keywords— Fiber reinforced springs, static analysis, experimental fatigue analysis, Leaf spring virtual fatigue analysis.

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I. INTRODUCTION

The vehicles need a good suspension system that can deliver a good ride and handling. At the same time, the component must have an excellent fatigue life. Fatigue is one of the major issues in automotive components. It must withstand numerous numbers of cycles before it can fail, or never fail at all during the service period. Leaf spring is widely used in automobiles and one of the components of suspension system. As a general rule, the leaf spring must be regarded as a safety component as failure could lead to severe accidents. The leaf springs may carry loads, brake torque, driving torque, etc. During normal operation, the spring compresses to absorb road shock. The leaf springs bend and slide on each other allowing suspension movement. Fatigue failure is the predominant mode of in-service failure of many automobile components. This is due to the fact that the automobile components are subjected to variety of fatigue loads like shocks caused due to road irregularities traced by the road wheels, the sudden loads due to the wheel travelling over the bumps etc. The leaf springs are more affected due to fatigue loads, as they are a part of the unstrung mass of the automobile.

The aim of the project undertaken was to increase the load carrying capacity and life cycles with the help of Static and fatigue analysis of glass fibre reinforced plastic (GFRP) In this paper, the glass fibre reinforced plastic is chosen for the finite element analysis to know the dynamic behaviour of the leaf spring. The leaf spring was analysed over its full range from 10kG to 20 kG. Bending stress and deflection are the target results.

In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturer in the present scenario. Weight reduction can be achieved primarily by the introduction of better material, design optimization. Mono leaf springs are simple forms of springs, commonly used for the suspension system in wheeled vehicles. Vehicle suspension system is made out of springs that have basic role in power transfer, vehicle motion and driving.

II. LITERATURE REVIEW

In the paper, 'Premature fracture in automobile leaf springs' by J.J.Fuentes , H.J. Aguilar , J.A. Rodr´ıguez , E.J. Herrera , the origin of premature fracture in leaf springs used in Venezuelan buses is studied. To this end, common failure analysis procedures, including examining the leaf spring history, visual inspection of fractured specimens, characterization of various properties and simulation tests on real components, were used. It is concluded that fracture occurred by a mechanism of mechanical fatigue, initiated at the region of the central hole, which suffered the highest tensile stress levels. Several factors (poor design, low quality material and defected fabrication) have combined to facilitate failure. Preventive measures to lengthen the service life of leaf springs are suggested [1].

The paper by C.K. Clarke and G.E. Borowski on 'Evaluation of a Leaf Spring Failure' gives the determination of the point of failure during an accident sequence of a rear leaf spring in a sport utility vehicle is presented in terms of fracture surface analysis and residual-strength estimates. Marks at the scene of the accident pointed to two possibilities for the point of failure: marks in the roadway at the start of the accident sequence and a rock strike near the end of the sequence. Evidence from rust and chemical contamination on the fracture pointed to the spring having been cracked in half prior to the accident. Extensive woody fracture and secondary cracking at the mid plane of the spring was evidence for segregation and weakness in the spring. Stress estimates for the effect of both the weakness and prior cracking on the residual strength of the spring revealed reductions in strength of the spring that could produce fracture at the start of the accident sequence. The point of failure of the spring was placed at the start of the accident sequence [2].

'Automobile Compression Composite Spring' is studied by G. Goudah, E. Mahdi, A.R. Abu Talib, A.S. Mokhtar and R. Yunus. An automotive suspension system is designed to provide both safety and comfort for the occupants. When a vehicle encounters a road surface irregularity, the tire deforms and the suspension displaces. The result of such disturbance will cause some energy lost which will be dissipated in the tires and the shock absorber while the remainder of the energy is stored in the coil spring. In this paper, Finite element models were developed to optimize the material and geometry of the composite elliptical spring based on the spring rate, log life and shear stress. The influence of elasticity ratio on performance of woven roving wrapped composite elliptical springs was investigated both experimentally and numerically, the study demonstrated that composites elliptical spring can be used for light and heavy trucks with substantial weight saving. The results showed that the elasticity ratio significantly influenced the design parameters. Composite elliptic spring with elasticity ratios of a/b= 2 displayed the optimum spring model [3].

'Analytical and experimental studies on Fatigue Life Prediction ofcomposite leaf Spring for Light Passenger Vehicles Using Life Data Analysis' is carried by MouleeswaranSenthil Kumar, SabapathyVijayarangan. This paper describes static and fatigue analysis of steel leaf spring and composite multi leaf spring made up of glass fibre reinforced polymer using life data analysis. The dimensions of an existing conventional steel leaf spring of a light commercial vehicle are taken and are verified by design calculations. Static analysis of 2-D model of conventional leaf spring is also performed using ANSYS 7.1 and compared with experimental results. Same dimensions of conventional leaf spring are used to fabricate a composite multi leaf spring using E-glass/Epoxy unidirectional laminates. The load carrying capacity, stiffness and weight of composite leaf spring are compared with that of steel leaf spring analytically and experimentally. The design constraints are stresses and deflections. Finite element analysis with full bump load on 3-D model of composite multi leaf spring is done using ANSYS 7.1 and the analytical results are compared with experimental results. Fatigue life of steel leaf spring and composite leaf is also predicted. Compared to steel spring, the composite leaf spring is found to have 67.35 % lesser stress, 64.95 % higher stiffness and 126.98 % higher natural frequency than that of existing steel leaf spring. A weight reduction of 68.15 % is also achieved by using composite leaf spring. It is also concluded that fatigue life of composite is more than that of conventional steel leaf spring [4].

'Design and Analysis of Fibre Reinforce Polymer (FRP) Leaf Spring - A Review' paper by Bhushan B. Deshmukh , Dr. Santosh B. Jaju tells about weight reduction , the main issue in automobile industries. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The introduction of FRP material has made it possible to reduce the weight of spring without any reduction on load carrying capacity. The achievement of weight reduction with adequate improvement of mechanical properties has made composite a very good replacement material for conventional steel. Selection of material is based on cost and strength of material. The composite materials have more elastic strain energy storage capacity and high strength to weight ratio as compared with those of steel, so multi-leaf steel springs are being replaced by mono-leaf composite springs. The paper gives the brief look on the suitability of composite leaf spring on vehicles and their advantages. The objective of the present work is design, analysis and fabrication of mono composite leaf spring. The design constraints are stress and deflections. The finite element analysis is done using ANSYS software. The attempt has been made to fabricate the FRP leaf spring economically than that of conventional leaf spring [5].

Fatigue life prediction is based on knowledge of both the number of cycles the part will experience at any given stress level during that life cycle and another influential environmental and use factors. The local strain-life method can be used pro-actively for a component during early design stage [6]. Fatigue failure always starts with crack-growth. The crack can initiate from the surface or at a depth below the surface depending on the materials processing conditions [7]. Fatigue crack contact under cyclic tensile loading was observed in Elbe's work. This simple observation and crack-closure concept began to explain many crack-growth characteristic .Research on fatigue continue and in 2008, Fuentes et al. did a study which is subjected to leaf spring failure. They make a conclusion, i.e. the premature failure in the studied leaf springs which showed the fracture failure on a leaf was the result of mechanical fatigue and it was caused by a combination of design, metallurgical and manufacturing deficiencies.

Fatigue test using constant amplitude loading is a commonly practiced to predict the fatigue life properties of materials. Recently, only fatigue test data or/and fatigue curve under constant amplitude loading have been given in many handbooks of the fatigue and mechanical properties of metals. To get more accurate fatigue life prediction, the actual case condition also needs to be considered. Many models have been developed to predict the fatigue life of components subjected to variable amplitude loading. The earliest of these are based on calculations of the yield zone size ahead of the crack tip and are still widely used [8].

The major reason for carrying out variable amplitude loading test is the fact that a prediction of fatigue life under this complex loading is not possible by any cumulative damage hypothesis [9].In the case of parabolic spring, this was representing by different road surface and driving condition of the vehicle. Using constant amplitude loading, test were performed in controlled condition. But in VAL, lot of parameter need to be consider like cycle range and sampling frequency. Traditionally, fatigue life at variable amplitude is predicted by using material properties from constant amplitude laboratory test together with the Palmgren-Miner damage accumulation hypothesis [10].

There is the demand for spring excellent in sag resistance and fatigue properties, along with the increase in loaded stress on the springs. Strengthening for spring material would be effective in improving fatigue property, from the point of fatigue limits. However, when a spring material is strengthened, the defect sensitivity of the spring tends to be high, and that sometimes makes the fatigue life of the spring shorten [11].

The objective of the study carried by F.N.AhmadRefngah, S.Abdullah, for their paper 'Life Assessment of a Parabolic Spring Under Cyclic Strain Loading' is to simulate the variable amplitude loading for the fatigue life analysis. Service loading of parabolic spring has been collected using data acquisition system. The finite element method (FEM) was performed on the spring model to observe the distribution stress and damage. The experimental works has been done in order to validate the FEM result [12].

The ASME Standard specification of design data handbook [13]

III. EXPERIMENTATION SETP UP OF COMPOSITE LEAF SPRING

Fig.1 Experimentation set up of composite leaf spring

Properties of composite Leaf spring used in suspension light vehicle are shown in Table 1.

TABLE 1

S.No	Properties	Value
1	Tensile modulus along X-direction (Ex), MPa	34000
2	Tensile modulus along Y-direction (Ey), MPa	6530
3	Tensile modulus along Z-direction (Ez), MPa	6530
4	Tensile strength of the material, MPa	900
5	Compressive strength of the material, MPa	450
6	Shear modulus along XY-direction (Gxy), MPa	2433
7	Shear modulus along YZ-direction (Gyz), MPa	1698
8	Shear modulus along ZX-direction (Gzx), MPa	2433
9	Poisson ratio along XY-direction (NUxy)	0.217
10	Poisson ratio along YZ-direction (NUyz)	0.366
11	Poisson ratio along ZX-direction (NUyz)	0.217
12	Mass density of the material (ρ), Kg/mm3	$2.6x10^{3}$
13	Flexural modulus of the material, MPa	40000
14	Flexural strength of the material,	1200

The stress and deflection of spring under load are calculated

IV. DESIGN PROCEDURE OF COMPOSITE LEAF SPRING

Design of composite leaf spring of motor vehicle is considered. Total load taken in the sum of weight of the vehicle and extra luggage. It is assumed that total load is equally sheared by each of the four leaf springs of a vehicle. The calculation of stress and deflection is done by considering spring is a cantilever beam. The specification is as per follow Span length – 2L = 900 mm, Full bump load P

= 2800 N, Camber height h= 87mm, Thickness of leaf t = 18 mm, width of leaf b = 80 mm, Design stress without considering sudden impact f = 725 N/mm2, Ineffective length IL = 60mm, Effective length EL = 840 mm, Diameter of eye end = 20 mm.

V. MANUFRATURING PROCESS OF COMPOSITE LEAF SPRING

Lay up selection – For fabrication of leaf spring hand lay-up technique is used. The lay-up is selected to be bi-directional along the longitudinal direction of the spring. The pattern is made up of plywood. The mixture is applied on the mould and the resign is applied again this is continued for many layers. After the lay-up is finished, it is kept undistributed for 24 hrs at room temperature.

VI. SOLID MODELING OF COMPOSITE LEAF SPRING

CAD Modelling of any project is one of the time consuming process. CAD Modelling is the base of any project. Finite Element software will consider shapes, whatever is made in CAD model. CAD modelling of the complete structure is performed by using CATIA V5 software. CAD model of leaf spring test rig consist of different parts which are assembled together in assembly design to make a complete test rig model. The CAD model of leaf spring usedforanalysis is shown in Fig-1

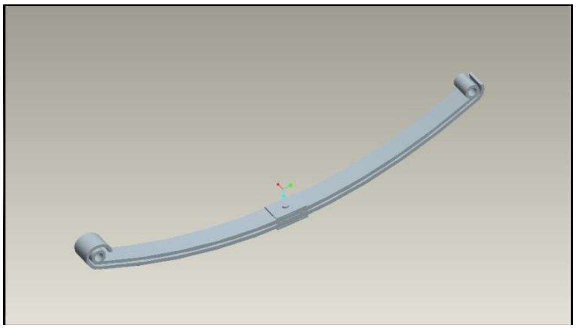

Fig.1 modeling of leaf spring by Catia

VII. ANALYSIS USING ANSYS

Mono leaf spring was modeled using commercial software and all the specifications were accordingly followed the relevant drawing standard. The spring geometry consists of master leaves and graduated leaves. As a preliminary study here, several assumptions have been made i.e. the chosen material was homogeneous, the frictional effect has not been taken into account, shackle and bush was not modeled, to reduce the complexity of simulation. Shackle and bushing only presented by boundary condition. The whole assembly is pre-processed in ANSYS 14. The ages file is imported to ANSYS 14, wherein finite element modeling is executed. A finite element model is the complete idealization of the entire structural problem including the node location, the element, physical and material properties, loads and boundary conditions. The purpose of the finite element modeling is to make a model that behaves mathematically as being modeled and creates appropriate input files for different finite element solvers.

To represent the pivoted boundary condition at front eye, a master node was created at the central axis of front eye. This master node was connected to remaining nodes of eye with rigid body element RBE2. At master node all degrees of freedom except rotational DOF about y-axis were constrained. To represent the boundary condition at rear eye, a master node was created at the central axis of rear eye. This master node was connected to remaining nodes of eye with rigid body element RBE2. At master node all degrees of freedom except rotational DOF about y-axis and translation in x were constrained. Model of mono leaf spring was partitioned into small regions for easier meshing as shown in fig. 2.

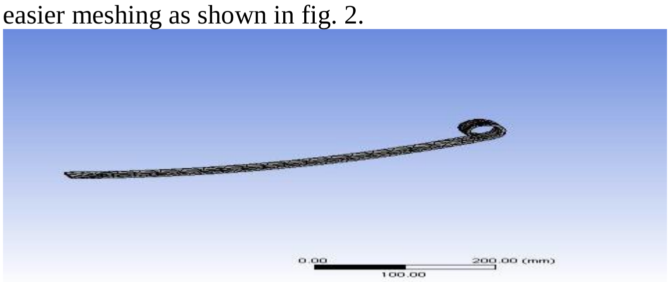

Fig.2. : Meshing of Model

The boundary condition are set according to static load acting on the front eye causing rotation about y axis, rear eye is constrained in y and z translation, x and z rotations, allowing free x translation and y rotation. Vertical load is applied at the center of mono leaf spring. The FEA results for steel leaf spring and mono composite leaf spring are shown in fig. 3 and 4 respectively and tabulated in table 2.

Setting boundary conditions- The boundary conditions are applied by taking into consideration the experimental loading conditions.Boundary condition for Leaf Spring, **Fixed End**-Linear movement: X, Y, Z axes constrained (Fixed).Rotational movement: Rotation about X & Z constrained (Fixed) and rotation about Y free.**Shackle End:-**Linear movement: X, Y axes constrained (Fixed), translatory motion along Z axis. Rotational movement: rotation about X & Z constrained (Fixed) and rotation about Y free.

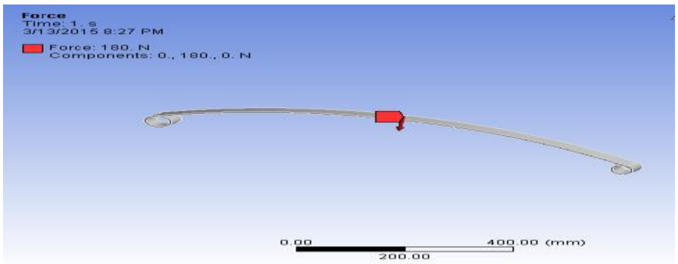

Fig.3 :Force stress analysis of composite material (FEA Analysis)

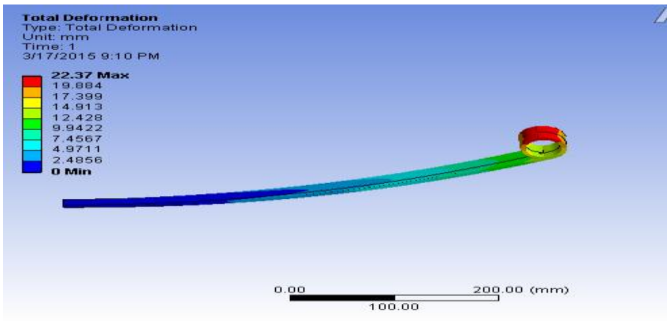

fig.5 :TotalDeformation analysis of composite material (FEA Analysis)

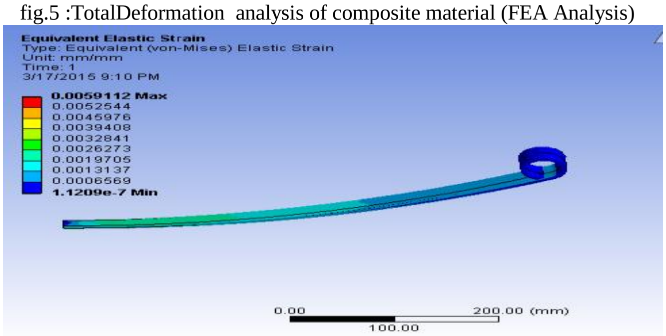

Fig6 :Equivalent elastic strain of composite material (FEA Analysis)

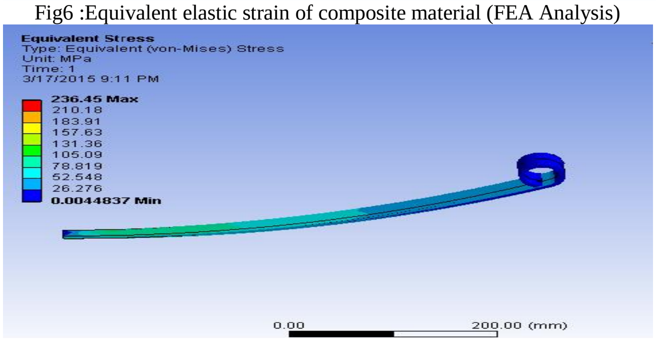

Fig7 :Equivalent stress analysis of composite material (FEA Analysis)

VIII. RESULTS

Load is applied till the spring become flat.Analytically, spring deflection of composite spring at load 20 N by putting values is 31.33 mm.The tensile strength of composite leaf spring is 900 MPa, hence maximum stress induced is under the limits. Maximum deflection is allowed only 40.5 mm, but induced deflection is too high. So by changing thickness we shall get require output. If we increase thickness up to 12 mm, we shall get deflection in limit.

The followings are the results of the composite leaf spring to acting various load conditions, its deformations, maximum stresses and strains.

Calculate analytically, by taking thickness 12 mm and keep other dimensions same as before, Maximum deflection = δ_{max} = 36.68mm

TABLE 2.

Sr. No.	Parameter (for uniform width)	Load (kg)	Stress induced σ_{max} (Mpa)	Deflection δ_{max} (mm)
1	Composite	18	33.33	38.5

VI. CONCLUSION

The fatigue life prediction is performed based on finite element analysis and fatigue life simulation method. FEM gives the prediction of critical area from the viewpoint of static loading. The results of static analysis of 3D model of the leaf spring using the commercial solver and results shows better correlation. The stiffness of the leaf spring is studied by plotting load versus deflection curve for whole working load range which shows the linear relationship. Using the constant amplitude loading, the damage and fatigue life of the spring has been predicted. From the damage contour, the highest damage value is in acceptable range.

This study will help to understand more the behavior of the spring and give information for the manufacturer to improve the life of the spring using CAE tools. It can help to reduce cost and times in research and development of new product.

As the static analysis determines the safe load and its corresponding stresses, it is not sufficient to understand the dynamic behaviour. As the fatigue analysis is to study the dynamic behaviour an experimental analysis is preferred, but it is most expensive and time consuming. In order to overcome this issue the virtual analysis is carried out under the various fluctuating loads.

In this paper, the glass fibre reinforced plastic is chosen for the finite element analysis to know the dynamic behaviour of the leaf spring

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REFERENCES

[1] J.J.Fuentes, H.J. Aguilar , J.A. Rodr´ıguez, E.J. Herrera Premature fracture in automobile composite leaf spring Engineering FailureAnalysis, P .P . 648–655, 2009.C.K. Clarke and G.E. Borowski, Evaluationofa Leaf Spring Failure ASM International p.p. 54-63l, 2005.

[2] C.K. Clarke and G.E. Borowski, Evaluationof a Leaf Spring Failure ASM International p.p. 54-63l, 2005.

[3] G. Goudah, E. Mahdi, A.R. Abu Talib, A.S Mokhtar and R. Yunus automobile compression composite Elliptic Spring International Journal Of Engineering and Technology, Vol. 3, No.2, 2006, pp.139-147.

[4] MouleeswaranSenthil Kumar, SabapathyVijayarangan Analytical and Experimental Studies on Fatigue Life Prediction of Steel and Composite leaf Spring for Light Passenger Vehicles Using Life Data Analysis ISSN 1392–1320, Materials Science . Vol. 13,No. 2.2007

[5] Bhushan B. Deshmukh, Dr. Santosh B. JajuDesigh and Analysis of FibreRainforce Polymer (FRP) leaf spring – A Review intEnggTechsciVol 2() 2011, 289-291

[6] Lee, Yung-Li, Pan, J., Hathaway and R. Barkey

M., 2005 Fatigue testing analysis, theory and practice, UK, Elsevier Butterworth – Heinemann.

[7] B.R. Kumar, D.K. Bhattacharya, Swapan K. Das, S.G. Chowdhury 2000. Permature fatigue failure of a Spring due to quench cracks. Engineering failure analysis Vol 7, Issue 6, 377-384.

[8] X. Huang, M. Torgeir, W. Cui, 2008. An engineering model of fatigue crack growth under variable amplitude loading International p.p. 54 – 631, 2005.

[9] Sonsino, C.M. 2007. Fatigue test under variable loading, International Journal of fatigue 29:1080-1089.

[10] Johanneson, P. Sevensson, T, de, Mare, J,2005, Fatigue life prediction based on variable amplitude test – methodology International Journal of Fatigue, 27 : 54 – 965.

[11] Suda, S. & Ibaraki, N. 2007. Steel for spring being excellent to setting and fatigue characteristic.Pub. No. US 2007/0163680 A1.

[12] F.N.AhmadRefngah, S.Abdullah, Life Assessment of a Parabolic Spring Under Cyclic Strain Loading European Journal ofScientific Research ISSN 1450-216X Vol.28 No.3 ,pp.351-363,2009.

[13] ASME Standard specification of design data handbook