AUTOMOBILE COMPRESSION COMPOSITE ELLIPTIC SPRING

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ABSTRACT

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 ellipticity 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 ellipticity ratio significantly influenced the design parameters. Composite elliptic spring with ellipticity ratios of a/b= 2 displayed the optimum spring model.

Keywords: *composite spring, finite element, spring rate, ellipticity ratio, log life, shear stress*

INTRODUCTION

To meet the needs of natural resource conservation and energy economy, the automobile manufacturers have been attempting to reduce the weight of vehicles in recent years [1]. Fiber reinforced polymers are making inroad in many applications, principally because of the potential for weight saving. Other advantages of using fiber reinforced polymers instead of steel are (a) the possibility of reducing noise, vibrations and ride harshness (NVH) due to their high damping factors; (b) the absence of corrosion problems, which means lower maintenance cost; and (c) lower tooling cost, which has favourable impact on the part of manufacturing cost [2]. Springs are crucial suspension elements on cars, necessary to minimize the vertical vibrations, impacts and bumps due to road irregularities [3]. The function of the suspension springs for an automobile are to keep the control stability good and to improve riding comfort [4].

Generally, simple replacement of steel parts by composite materials yields significant weight savings, but as with many new materials, design and manufacturing problems arises; for example the change from relatively isotropic-homogeneous steel alloys to anisotropic inhomogeneous fiber reinforcement plastic (FRP). As a result, it is not an easy task to replace steel by composite materials [5]. Engineers can design a metal suspension and to use composite spring only for its spring properties. This allows very refined mechanical suspension concept composite spring by vertical load control. [6]

A composite suspension of curved beam type was developed in 1981 to provide for family cars [7, 8]. Charrier et al [9-11] invented another composite suspension of circular and elliptic rings. They have calculated numerically spring constants of elliptic rings subjected to the compressive load along a principal radius of the ring by using the finite element method, their results showed good agreement between the predicted and the experiments [10]. The elliptic composite springs described by Mallick [12, 13] represent a new concept of fiber reinforced elliptic springs for automotive applications. Mallick designed and constructed Elliptic spring elements with inside major diameter of six inches and inside minor diameter of four inches. Materials used were unidirectional and quasi-isotropic with E-glass fiber reinforced epoxy. Key design parameters, such as spring rate and failure load was measured as a function of spring thickness as well as modes of joining spring elements by means of bolts [13]. Akasaka et al. [14] evaluated the spring constants of elliptic composite springs by using energy method. Their results showed good agreement between the analytical and experimental results.

ISSN 1823-1039 ©2006 FEIIC

MATERIALS AND METHODS

Design Concept

It is well known that a vertical load on a coil spring creates torsional as well as direct shear stresses in the coil [15, 16]. Because of the poor resistance to shear stress in the fiber reinforced plastic composites in general, it is essential to control the composites failure by utilizing their strength in principal direction instead of shear. In the case of the new configuration of composite elliptic spring, the layers experience self compression state and the failure is dominated by the tensile properties of the fiber eliminating the delamination and over riding the weakness of matrix properties [17].

The New Configuration of Composite Elliptic Spring

In this new configuration, load is applied between A and B, the external side of the spring experiences pure tension state while the internal surface experiences pure compression state. Analyzing the forces (see Figure 1) one can observe that F_c and F_d resolved into f_{1cy} and f_{2dy} which cancel each other, and f_{1cx} and f_{2dx} sum up each other and push the cell left-ward against it's neighbour. This will thus eliminate any hypothesis of delamination [17].

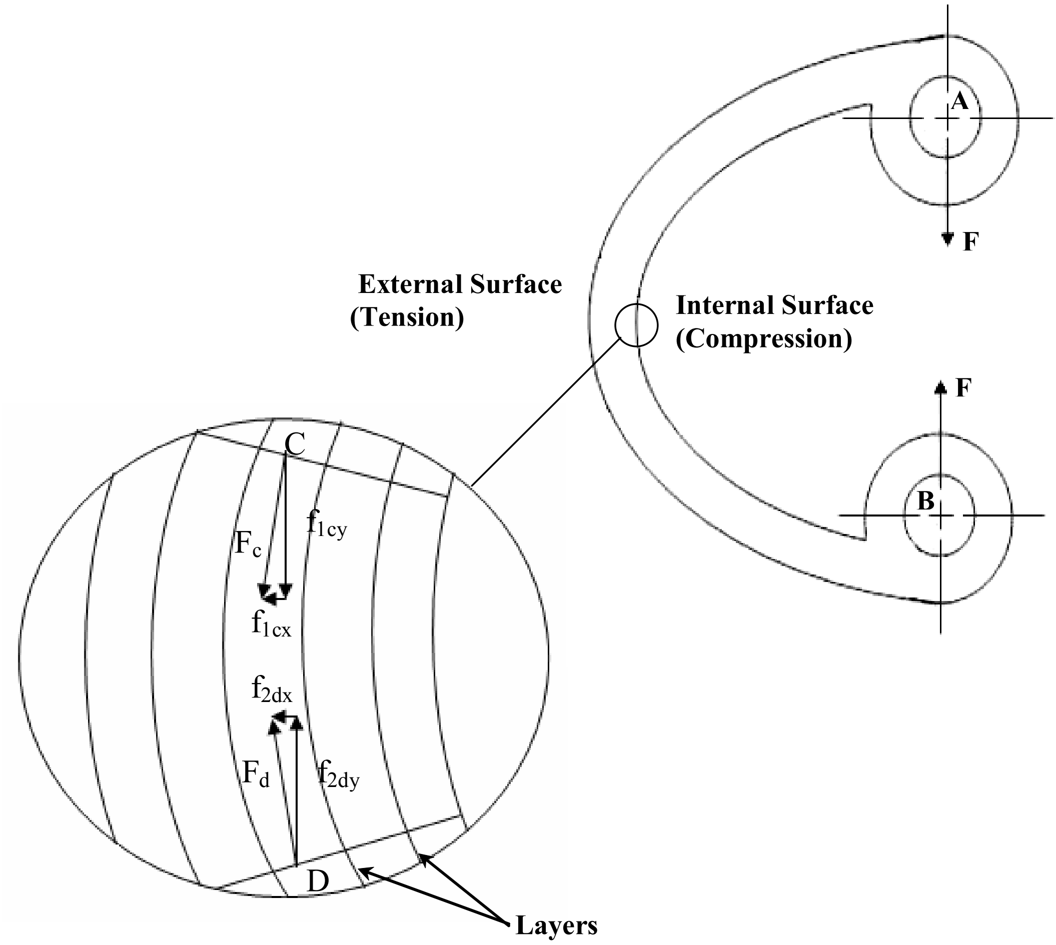

Figure 1: Force Analysis in the New Composite Semi Elliptic Spring Configuration

Finite Element Modeling (FEM)

Detailed three dimensional finite element models of woven roving E-glass Fabric composite elliptic spring was developed using LUSAS finite element package (version 13.57). Two shell element types are included in the LUSAS library for thin-shell applications. Eight-nodded QTS8 was been used since they are expected to give accurate results. This type of element includes also transverse shear effects [18]. Different ellipticity ratios were varied from 0.5 - 2.5 to find out the optimum model. All elements were quadrilateral in shape. There are 640 elements and 3655 nodes in the model with a = 150 mm and b = 75 mm; and the thickness was varied from 13 to 20 mm. Figure 2 shows the optimized model with the deformed mesh.

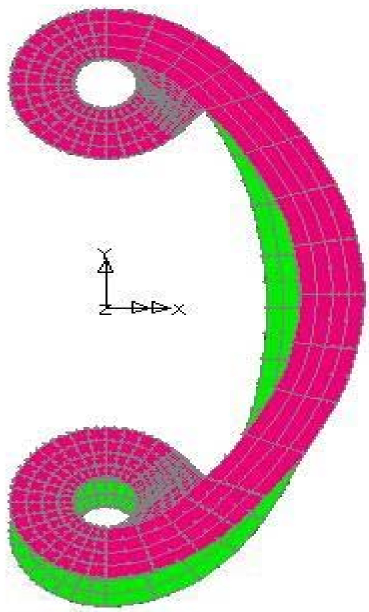

Figure 2: The Deformed Mesh for Optimized Composite Elliptical Spring

The material used for this project is Woven fiberglass fabrics. This is because it has the widest range and the best control over thickness, weight and strength of all forms of fibreglass textiles. This offers the materials engineer a wide choice of controlling fabric properties to satisfy design needs and objectives. The mechanical properties of woven roving glass/epoxy are E_{11} = 20 GPa, E_{22} = 19 GPa, $G_{12} = G_{13} = G_{23}$ = 4.2 GPa, $\nu_{12} = \nu_{13} = \nu_{23}$ = 0.13. Table 1 gives information about the optimized model and Figure 3 shows the materials stacking sequences for the optimized model.

Table 1: Finite Element Model

Element Type	Thick Shell
Element Shape	QTS8
Loading	Global distributed in Y direction
Support	Fully fixed, fixed in X and Z
Material	E-glass Fabric V_f=50%

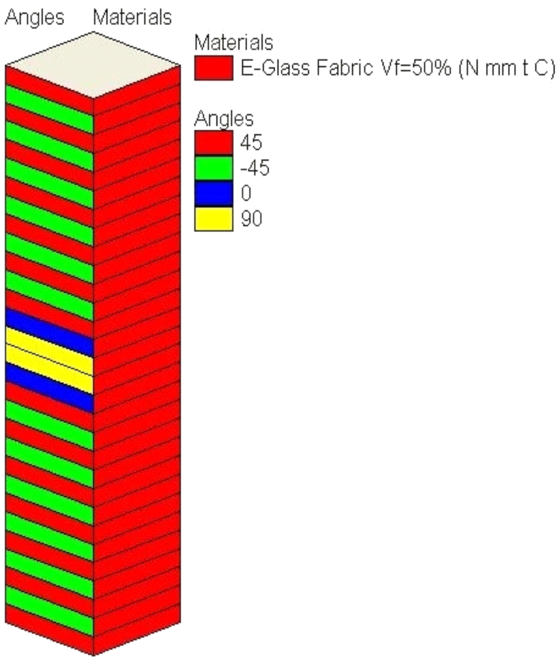

Figure 3: Laminate Stacking Sequence

Fabrication Process

The analysis of the finite element model help to give optimum configuration and best semi ellipticity ratio for the composite semi elliptic spring. Using the findings of the analysis, the optimized model was prepared using the base and epoxy resin, mixed together with the hardener in a ratio 4:1. The fabricated semi elliptic springs was cured at temperature (32^{o}C) for 24 hours to provide optimum hardness and shrinkage. Further, the cured semi elliptic springs was extracted from the mould manually and then cut as shown in Figure 4 below. The final fabricated composite elliptic spring model weighs ≈1.2 Kg which improve the weight saving. The initial weight of the current suspension ≈10 Kg

Figure 4: The Composite Elliptic Spring

RESULTS AND DISCUSSIONS

The design parameters, such as spring rate, shear stress and the fatigue analysis were measured as a function of ellipticity ratio.

Spring Rate

Spring rate is the force required to compress a linear spring by one mm. Spring rates can be calculated from the slope of load-displacement curves in the pre crush and linear stage, using the formula

$$K = \frac{\Delta F}{\Delta \delta}, \quad (1)$$

Where F is the load and δ is the spring displacement [13].

Progressive springs have progressive spring rate that rise as the spring load increases. The spring elements are capable of absorbing large deformations, yet exhibit a linear behaviour until the first interlaminar shear failure occurs. The results showed that the ellipticity ratio significantly influenced the spring rate [18]. Figure 5 shows that the lower spring rate occurs at the ellipticity ratio of a/b=1 and increases gradually until it reaches its maximum rate at the ellipticity ratios of a/b=2.

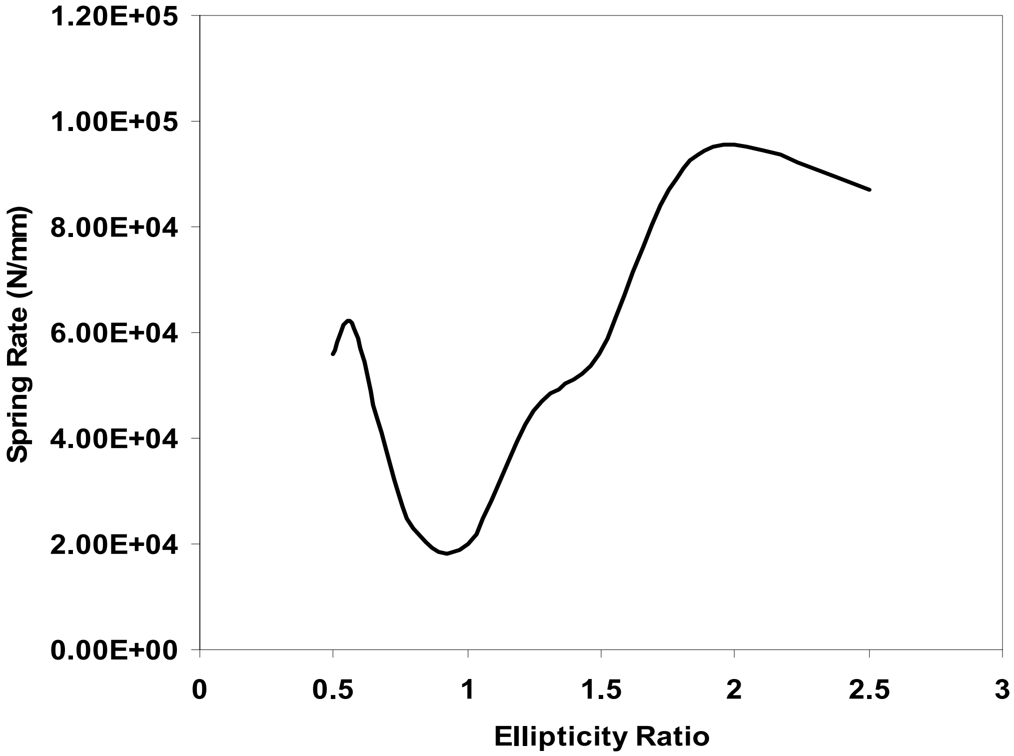

Figure 5: Effect of Ellipticity Ratio on Spring Rate of Composite Elliptical Spring

Stress Analysis

For an elliptic spring subjected to concentrated loads at the ends of its minor diameter, the maximum bending moment occurs at the ends of its minor diameter. Due to symmetry geometry as well as loading, the shear force is zero at the ends of the major diameter while it increases near the minor diameter [6].

The maximum absolute and shear stress from the finite element analysis models for the composite elliptic spring with different ellipticity ratios varied from 0.5 – 2.5 and different layers varied from 20-30 layers were plotted as shown in Figure 6 , 7. From figure 6, it appears that the inner surface of the model is under compression while the outer surface is under tension which supports our assumption. The ellipticity ratio of a/b=2 gave the lowest stresses.

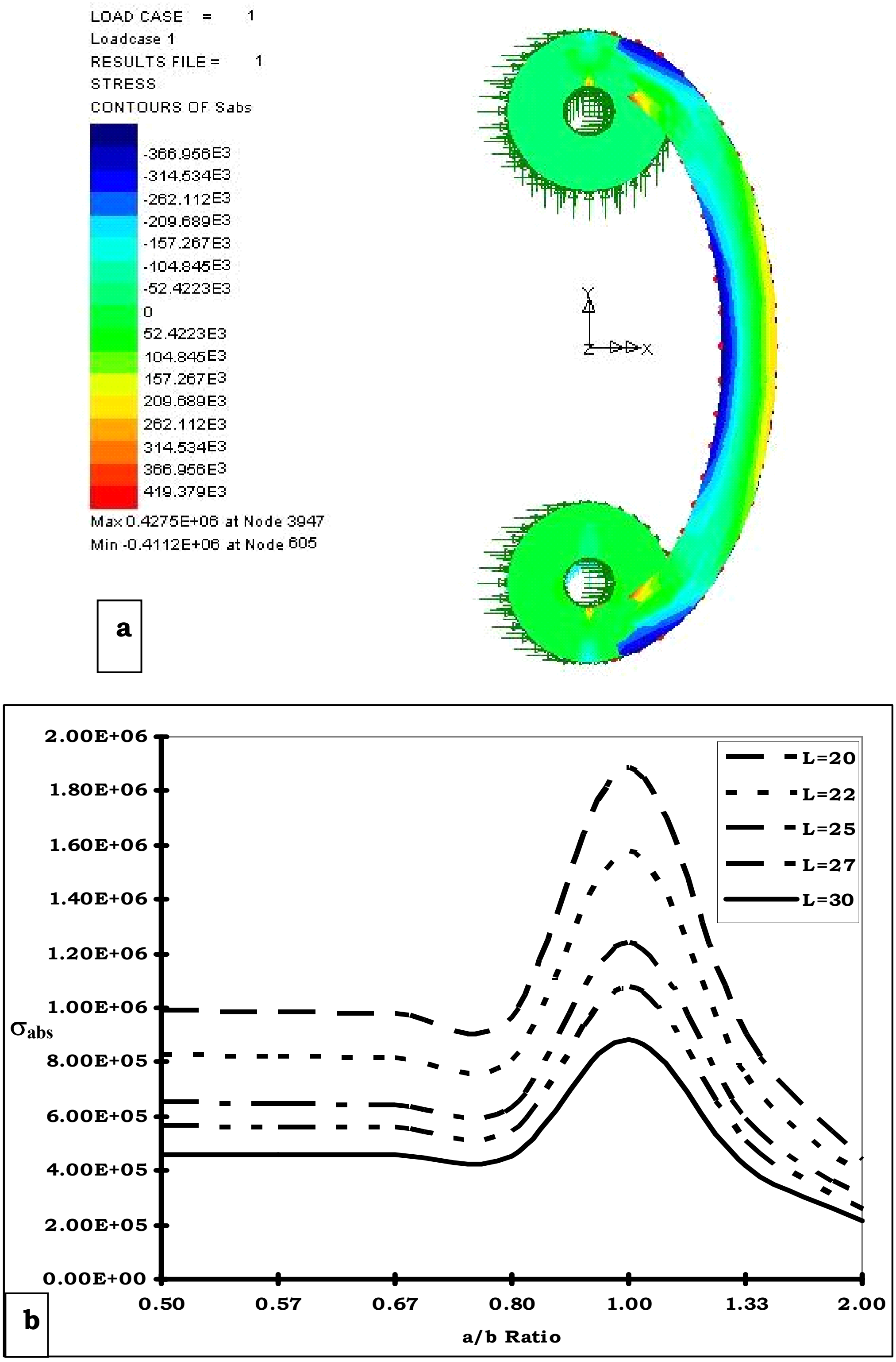

Figure 6: FEA Model Analysis for Contours of the Absolute Stress

Figure 7 shows the finite element analysis of the composite elliptic spring for the shear stress. The model with the ellipticity ratio of a/b=2 gave the lowest shear stress which eliminate the effect of any failure caused by shear stress.

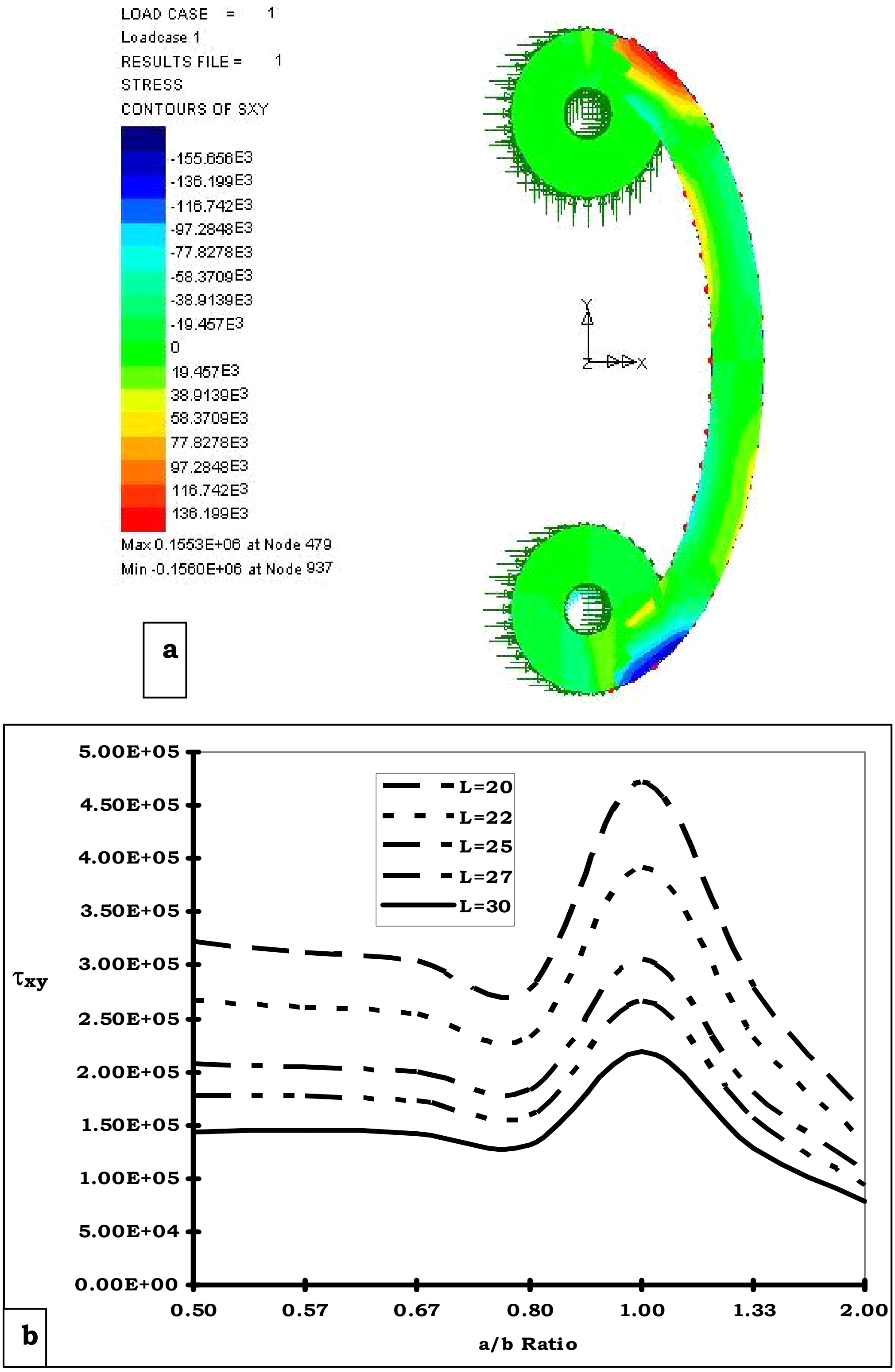

Figure 7: FEA Model Analysis for Contours of Shear Stress

Fatigue Analysis

The fatigue log life may be expressed in terms of the damage that is done to the structure by a prescribed loading sequence or as the number of repeats of the sequence that will cause failure of the structure. Log life is the log10 of the life expectancy of the structure according to the level of loading and number of cycles specified the ellipticity ratio a/b=2 gave the highest life for the composite elliptic spring. Figure 8 depicts a log life data against the ellipticity ratio (a/b) varied from 0.5-2.5 and different layers varied from 20-30 layers for the composite elliptic spring model.

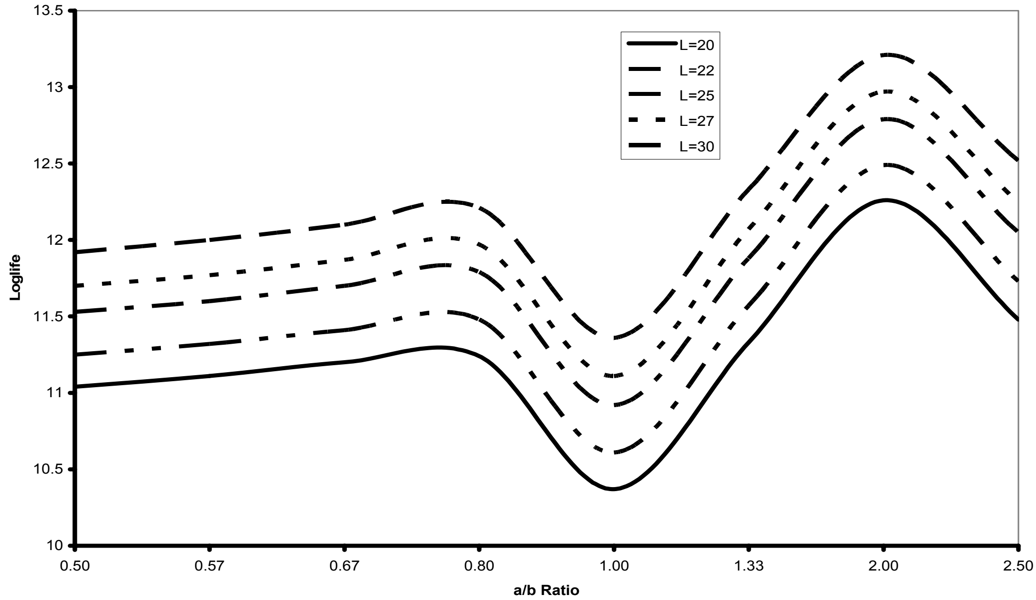

Figure 8: Log life Results

CONCLUSIONS

In general, this paper developed the finite element models to optimize the material and geometry of the composite elliptical spring based on the spring rate, log life and shear stress and presents an investigation verifying that composites can be utilized for vehicle suspension with substantial weight saving. It also showed that the ellipticity ratio significantly influenced the spring rate and the life expectancy of the structure according to the level of loading and number of cycles specified. The results showed that composite elliptical springs have better fatigue behaviour than the conventional composite leaf and coil spring. Elliptical configuration successfully eliminates any hypothesis of delamination. The fabricated composite elliptic spring was constructed based on the optimization developed from the finite element analysis which has the ellipticity ratio of (a/b=2) and resulting in a substantial weight saving.

ACKNOWLEDGEMENT

The first author would like to thank university Putra Malaysia and the government of Malaysia for the financial support.

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NOMENCLATURE

a	The major axis of the ellipse (mm)
b	The minor axis of the ellipse (mm)
a/b	The ellipticity ratio
V_f	Volume friction
E_{11}, E_{22}	Young's moduli in the principal directions (GPa)
G_{12}, G13, G_{23}	Shear moduli in the principal directions (GPa)
ν_{12}, ν_{13}, ν_{23}	Poisson's ratio in the principal directions
F	The force (N)
δ	The spring displacement (mm)
κ	The spring rate (N/mm)

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