

Design and Analysis of Glass Fiber Reinforced Polymer (GFRP) Leaf Spring

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Abstract- Weight reduction is now 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 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 material selected is glass fibre reinforced plastic (GFRP) and the epoxy resin can be used which is more economical to reduce total cost of composite leaf spring with similar mechanical and geometrical properties to the multileaf spring. The composite leaf spring is fabricated by hand lay-up technique and tested. The testing was performed experimentally with the help of UTM and by (FEA) using ANSYS software showing stresses and deflections were verified with analytical and experimental results. Compared to the steel spring, the composite spring has stresses that are much lower, the spring weight is nearly 74% lower.

Keywords: Leaf spring, Composite material, FEM, GFRP.

I. INTRODUCTION

A spring is a mechanical component that can bear larger elastic deformation than other mechanical parts. Springs are generally used in different forms in engineering applications. One of the major applications of spring use in the industry is the leaf spring. It is widely used as automotive suspension. The rear or back suspension is usually in the form of a simply supported semielliptical beam. It is designed for vertical loading. The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for ten to twenty percent of the unsprung weight, which is considered to be the mass not supported by the leaf spring.

Advantage of composite leaf spring is this achieves the vehicle with more fuel efficiency and improved riding quality. The introduction of composite materials has made it possible to reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness. So, composite materials are now used in automobile industries to take place of metal parts. Since; the composite

materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to those of steel.

The leaf spring, like all other springs, serves to absorb and store energy and then to release it. It has an advantage to serve as a structural member in the suspension mechanism together with a spring function. Generally, the automotive suspension has two different categories. The front suspension is in the form of a cantilever and is subjected to the transverse loading along with vertical loading.

A. Objects of Suspension

- To prevent the good shocks from being transmitted to vehicle components.
- To safe guard the occupants from the road shocks.
- To preserve the stability of vehicle in pitching or rolling while in motion.

B. Function of Suspension Springs

Springs are placed between the road wheels & the body when the wheels come across a bump on the road, it raises & deflects the springs, thereby storing

energy therein. On releasing, due to elasticity of spring material, it rebounds there by expanding the stored energy. In this way spring starts vibrating, of course, with amplitude decreasing gradually on account of internal friction of the spring material & the friction of the suspension joints, till vibrations die down.

II. REVIEW OF LITERATURE

GulurSiddaramanna Shiva Shankar, Sambagamvijayarangan, In this paper A single leaf with variable thickness and width for constant cross sectional area of unidirectional glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multileaf spring, was designed, fabricated (hand-lay up technique) and tested. The computer algorithm for design for variable with and variable thickness mono composite leaf spring is explained. Three-dimensional finite element analysis is used for verification of result obtained from experiment. In which the solid 45 element is used for steel leaf spring and solid layered 46 element is used for composite leaf spring .for the fabrication of mono composite leaf spring of E-glass /epoxy hand lay up technique is used. The experimental test are carried on both steel and composite leaf spring and compared the result .It is observed that composite leaf spring is more superior than steel with a large weight reduction.

Mouleeswaaran Senthil Kumar, SabapathyVijayarangan, In this paper composite leaf spring is design on basis of fatigue failure .Theoretical equation for prediction fatigue life is formulated using fatigue modulus and its degrading rate. The dimensions and number of leaves for both steel leaf spring and composite leaf spring are considered to be same. The stress analysis is performed using finite element method .The element selected for analysis is solid 45 which behave like a spring. For the fabrication of each leave the filament winding machine is used and assembled this leaves together with the help of center bolt and four side clamps. The testing of steel multi leaf spring and composite multi leaf spring are carried out with the help of an electro-hydraulic leaf spring test rig. Design and experimental fatigue analysis of

composite multi leaf spring are carried out using data analysis. It is found that composite leaf spring has 67.35% lesser stress, 64.95% higher stiffness and 126.98% higher natural frequency and also 68.15% weight reduction is achieved.

[3] Mahmood M. Shokrieh *, Davood Rezaei, In this paper a four-leaf steel spring used in the rear suspension system of light vehicles is analyzed using ANSYS V5.4 software. The finite element results showing stresses and deflections verified the existing analytical and experimental solutions. Using the results of the steel leaf spring, a composite one made from fiberglass with epoxy resin is designed and optimized using ANSYS. Main consideration is given to the optimization of the spring geometry. The objective was to obtain a spring with minimum weight that is capable of carrying given static external forces without failure. The design constraints were stresses (Tsai–Wu failure criterion) and displacements. The results showed that an optimum spring width decreases hyperbolically and the thickness increases linearly from the spring eyes towards the axle seat. Compared to the steel spring, the optimized composite spring has stresses that are much lower, the natural frequency is higher and the spring weight without eye units is nearly 80% lower.

[4] J.P. Hou, J.Y. Cherruault, I. Nairne, G. Jeronimidis, R.M. Mayer, This paper presents the design evolution process of a composite leaf spring for freight rail applications. Three designs of eye-end attachment for composite leaf springs are described. The material used is glass fibre reinforced polyester. Static testing and finite element analysis have been carried out to obtain the characteristics of the spring. Load–deflection curves and strain measurement as a function of load for the three designs tested have been plotted for comparison with FEA predicted values. The main concern associated with the first design is the delamination failure at the interface of the fibres that have passed around the eye and the spring body, even though the design can withstand 150 KN static proof load and one million cycles fatigue load. FEA results confirmed that there is a high interlaminar shear stress concentration in that region. The second design feature is an additional transverse bandage around the region prone to

delamination. Delamination was contained but not completely prevented. The third design overcomes the problem by ending the fibres at the end of the eye section.

[5] H.A. Al-Qureshi, in this paper a single leaf spring with variable thickness of glassfiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multileaf steel spring was designed, fabricated and tested. Glass fiber reinforced plastic (GFRP) presents advantages over graphite/epoxy such as lower sensitivity to cracks, impact and wear damage. The leaf spring model was considered to be a parabolically tapered, constant width beam carrying a concentrated load and assumed to be symmetrical with different cord lengths for the two limbs of the spring. A finite element program is used to model the behavior of leaf spring. In addition analytical analysis can be used to develop an expression which is a function of thickness and position along the spring. In present work the hand lay-up vacuum bag process was initially employed and mandrels (male and female) were made from plywood according to the desired profile and the glass fiber fabric was cut to the desired lengths, so that when deposited on the mandrel, would give the calculated thickness. The operation was simply performed by depositing impregnated glassfiber with epoxy resin over the rotating mandrel in a hoop pattern. The spring was subjected to a series of laboratory static loading tests. This study demonstrated that composite can be used for leaf spring for light trucks (jeeps) and meet the requirement, together with substantial weight saving.

[6] E. Mahdi ,O.M.S. Alkoles , A.M.S. Hamouda , B.B. Sahari , R. Yonus , G. Goudah

In this paper, the influence of ellipticity ratio on performance of woven roving wrapped composite elliptical springs has been investigated both experimentally and numerically. A series of experiments was conducted for composite elliptical springs with ellipticity ratios (a/b) ranging from one to two. Mechanical performance and failure modes of composite elliptical spring elements under static load conditions are reported. Key design parameters, such as spring rate and failure load, are measured as

a function of spring thickness. Parallel with the experimental work, numerical simulation for fatigue calculations was performed. The simulation was designed to calculate numerically spring constants of elliptical subjected to the compressive load along a major axis of the tubes and to calculate the cycle life of the elliptical composite spring. The simulation was performed using a commercial available finite element package (LUSAS). Eight-noded QTS8 was used since they are expected to give an accurate stress and strain results. Composite elliptical spring with ellipticity ratios of a/b 2.0 displayed the highest spring rate. The present investigation verified that composites can be utilized for vehicle suspension and meet the requirements, together with substantial weight saving. It is also believed that hybrid composite elliptical springs have better fatigue behavior than the conventional and composite leaf and coil spring.

[7] Reaz A. Chaudhuri , K. Balaraman, In this Paper hand lay-up technique for fabrication of fiber reinforced plastic (FRP) laminated plates, using glass fibers in the form of continuous roving, is presented. Fabricating the glass fiber roving reinforced epoxy (GFRRE) laminated plates, three sub-methods have been implemented in the present investigation: (a) resin flow method, (b) resin transfer method, and (c) impregnation method. Among the three techniques discussed here, the impregnation method is the most effective, while the resin transfer method is quite satisfactory. In this study, a new hand lay-up method has been developed by which any plate having arbitrary number of layers with arbitrary fiber orientation angles, can be fabricated. The impregnation method has the potential to fabricate FRP laminates, which will compare favorably with most structural materials and, especially, with other types of FRP laminates as far as the strength-to-weight and modulus-to-weight ratios are concerned.

III. SELECTION OF MATERIAL

Materials constitute nearly 60 to 70% of vehicle cost and contribute to the quality and performance of vehicle even a small amount in weight reduction of vehicle, may have a wider economic impact. The strain energy of the material becomes a major factor

in designing the springs. The relationship of the specific strain energy can be expressed as,

Where σ is the strength, ρ the density and E the Young's modulus of the spring material. The stored elastic strain energy in a leaf spring varies directly with the square of maximum allowable stress and inversely with the modulus of elasticity both in the longitudinal and transverse directions. The composite materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to those of steel. Composite materials are proved as suitable substitutes for steel thus composite material have been selected for leaf spring.

A. Fibre Reinforced Polymer (FRP) Composites

Fibers are the important class of reinforcements, as they satisfy the desired conditions and transfer strength to the matrix constituent influencing and enhancing their properties as desired. Glass fibers are the earliest known fibers used to reinforce materials. Ceramic and metal fibers were subsequently found out and put to extensive use, to render composites stiffer more resistant to heat. Fibers fall short of ideal performance due to several factors. The performance of a fiber composite is judged by its length, shape, orientation, and composition of the fibers and the mechanical properties of the matrix.

B. Glass Fiber

Glass is the most common fiber used in polymer matrix composites. Its Advantages include its high strength, low cost, high chemical resistance. The main types are E-glass (also called "fiberglass") and S-glass. The "E" in E-glass stands for electrical because it was designed for electrical applications. However, it is used for many other purposes now, such as decorations and structural applications. The "S" in S-glass stands for higher content of silica. It retains its strength at high temperatures compared to E-glass and has higher fatigue strength.



Fig.1 Glass Fiber

C. Functions of a Matrix

In a composite material, the matrix material serves the following functions:

- Holds the fibres together.
- Protects the fibres from environment.
- Distributes the loads evenly between fibres so that all fibres are subjected to the same amount of strain.
- Enhances transverse properties of a laminate.
- Improves impact and fracture resistance of a component.
- Helps to avoid propagation of crack growth through the fibres by providing alternate failure path along the interface between the fibres and the matrix.

D. Characteristics of Fibre Reinforced Polymer (FRP) Composites.

Many factors must be considered when designing a fiber-reinforced composite, including length, diameter, orientation, amount and properties of the fiber; the properties of matrix; and the bonding between the fibers and matrix.

Fiber Length and Diameter

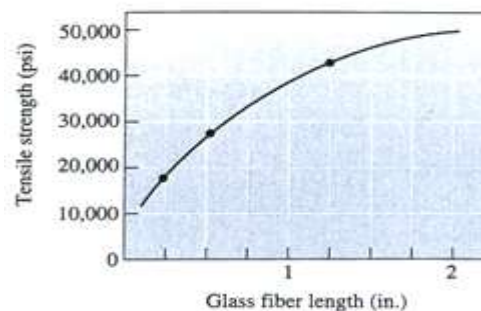


Fig. 2 Increasing the length of chopped E-glass fiber in an epoxy matrix increases the strength of composite.

Fibers can be short, long even continuous. Their dimensions are often characterized by aspect ratio l/d , where l is the fiber length and d is the diameter. Typical fiber have diameter varying from $10\mu\text{m}$ ($10 \times 10^4 \text{ cm}$) to $150\mu\text{m}$ ($150 \times 10^4 \text{ cm}$)

2) Amount of Fiber

A greater volume fraction of fiber increases the strength and stiffness of the composite, as we would expect from the rule of matrix. However, the maximum volume fraction is about 80%, beyond which fiber can no longer be completely surrounded by matrix.

3) Orientation of Fiber

The orientation of the fiber in the matrix is an indication of the strength of the composite and the strength is greatest along the longitudinal directional of fiber. This doesn't mean the longitudinal fibers can take the same quantum of load irrespective of the direction in which it is applied. Optimum performance from longitudinal fibers can be obtained if the load is applied along its direction. The slightest shift in the angle of loading may drastically reduce the strength of the composite. Unidirectional loading is found in few structures and hence it is prudent to give a mix of orientations for fibers in composites particularly where the load is expected to be the heaviest.

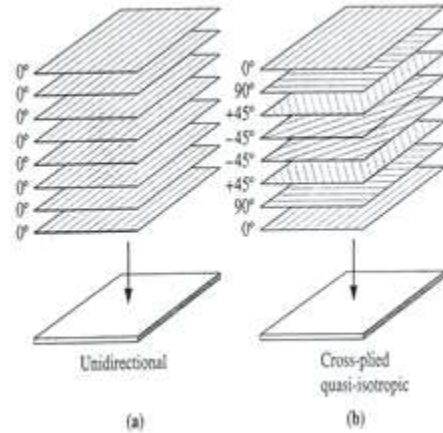


Fig. 3 Effect of Fiber Orientation on the tensile strength of E-glass fiber reinforced epoxy composite

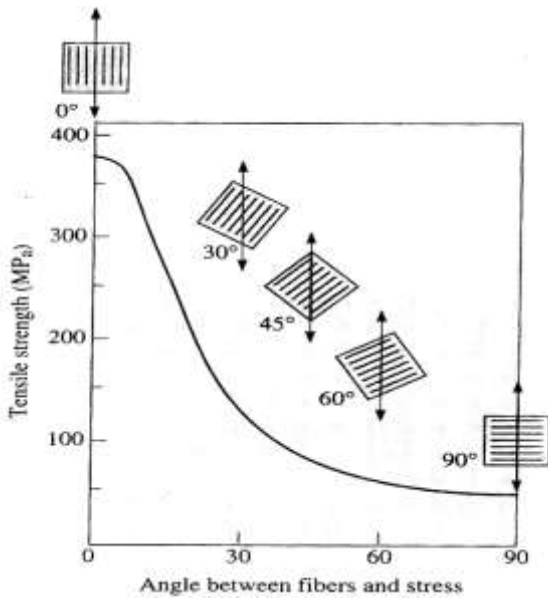
4) Fiber Properties

In most fiber-reinforced composite, the fibers are strong, stiff, and lightweight. If the composite is used at elevated temperature, the fiber should also have a high melting temperature. Thus specific strength and specific modulus of the fiber the specific modulus fiber are important characteristics.

Specific Strength = TS/ρ

Specific Modulus = E/ρ

Where TS is the tensile strength, ρ is the density, and E is the modulus of elasticity



IV. PROPERTIES OF E-GLASS/EPOXY

Table 1 Typical Properties of Glass Fibers (SI System of Units)

Property	Units	E-Glass
Axial Modulus	Gpa	85
Transverse Modulus	Gpa	85
Axial Poisson's Ratio	—	0.20
Transverse Poisson's Ratio	—	0.20
Axial Shear Modulus	Gpa	35.42
Axial Coefficient Of Thermal Expansion	M/M/°C	5
Transverse Coefficient Of Thermal Expansion	M/M/°C	5
Axial Tensile Strength	Mpa	1550
Axial Compressive Strength	Mpa	1550
Transverse Tensile Strength	Mpa	1550

Transverse Compressive Strength	Mpa	1550
Shear Strength	Mpa	35
Specific Gravity	Mpa	2.5

Table 2 Typical Properties of Matrices (SI System of Units)

Property	Units	Epoxy
Axial modulus	GPa	3.4
Transverse modulus	GPa	3.4
Axial Poisson's ratio	—	0.30
Transverse Poisson's ratio	—	0.30
Axial shear modulus	GPa	1.308
Coefficient of thermal expansion	μ m/m/°C	63
Coefficient of moisture expansion	m/m/kg/kg	0.33
Axial tensile strength	MPa	72
Axial compressive strength	MPa	102
Transverse tensile strength	MPa	72
Transverse compressive strength	MPa	102
Shear strength	MPa	34
Specific gravity	MPa	1.2

Table3 Chemical Composition of E-Glass

Material	% Weight
Silicon oxide	54
Aluminum oxide	15
Calcium oxide	17
Magnesium oxide	4.5
Boron oxide	8
Other	1.5

A glass/epoxy lamina consists of a 70% fiber volume fraction. From the Table 4.1 and 4.2 the Longitudinal elastic modulus E1, Transverse Young's modulus, E2 Major Poisson's ratio, v12 Minor Poisson's ratio v21 In-plane shear modulus, G12 are calculated.

Longitudinal elastic modulus of the unidirectional lamina is calculated by

$$E_1 = E_f V_f + E_m V_m$$

Longitudinal elastic modulus of the unidirectional lamina is calculated by

$$\frac{1}{E_2} = \frac{V_f}{E_f} + \frac{V_m}{E_m}$$

Major Poisson's ratio, v12 calculated by

$$v_{21} = v_{12} \frac{E_2}{E_1}$$

In-plane shear modulus of the unidirectional lamina is

$$\frac{1}{G_{12}} = \frac{V_f}{G_f} + \frac{V_m}{G_m}$$

f and m represent fiber and matrix.

Table 4 Properties of E/glass epoxy

Property	Units	Eglass/epoxy
Longitudinal elastic modulus E1	GPa	60.52
Transverse Young's modulus, E2	GPa	11
Major Poisson's ratio, v12		0.230
Minor Poisson's ratio v21		0.03941
In-plane shear modulus, G12	GPa	4.014

V. FEM ANALYSIS OF GFRP LEAF SPRING

The models made up of GFRP materials are not directly developed for the composite materials; we feed the data in the matrix form or layered form. GFRP analysis SOLID46 element is used. SOLID46 is a layered version of the 8-node, 3-D solid element. It is designed to model thick layered shells or layered solids and allows up to 250 uniform-thickness layers per element. An advantage with this element type is that you can stack several elements to model more than 250 layers to allow through-the-thickness deformation slope discontinuities. The user-input constitutive matrix option is also available. The deformation result of the GFRP is 97 mm at 3000N load and the Vonmises Stress 247 MPa.

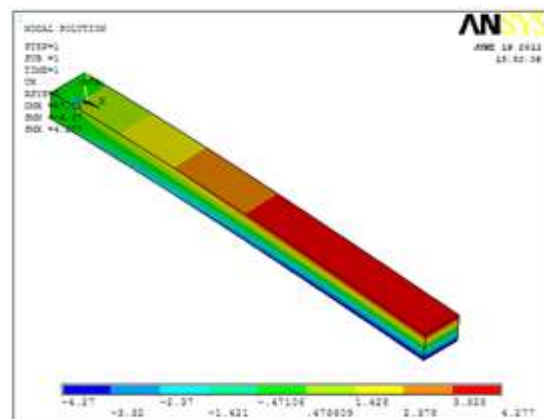


Fig. 4 Total Deformation

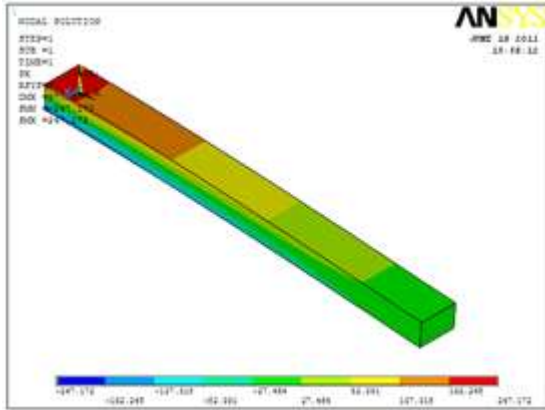


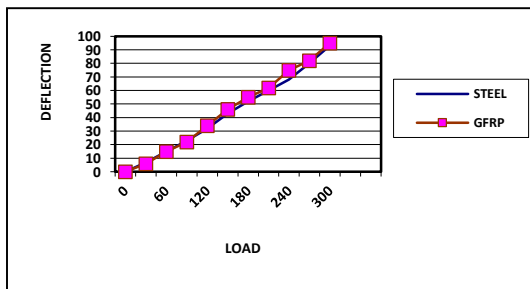
Fig. 5 Vonmises Stress

VI. FABRICATION OF GFRP LEAF SPRING

For Fabrication of GFRP leaf spring Hand Lay-up Technique is used The hand (wet) lay-up is one of the oldest and most commonly used methods for manufacture of composite parts. Hand lay-up composites are a case of continuous fibre reinforced composites. Layers of unidirectional or woven composites are combined to result in a material exhibiting desirable properties in one or more directions.

VII. EXPERIMENTAL TEST

In the experimental analysis the comparative testing of GFRP leaf spring and the steel leaf spring are taken. The deflection or bending tests of both the spring for comparative study is taken on the universal testing machine (UTM). The load is gradually applied on steel and GFRP leaf spring and the following graph are obtain from the testing.



Graph Load Vs Deflection

For steel leaf spring the deflection come for the load of 3000N is 93 mm and for the same loading condition the GFRP leaf spring deflection is 97 mm.



Fig. 6 Load applying on GFRP Leaf spring

VIII. CONCLUSION

Experimental results from testing the leaf springs under static loading containing the stresses and deflection are calculated. These results are also compared with FEA. Testing has been done for unidirectional E-Glass/Epoxy GFRP leaf spring only. Since the GFRP leaf spring is able to withstand the static load, it is concluded that there is no objection from strength point of view also, in the process of replacing the conventional leaf spring by GFRP leaf spring. Since, the GFRP leaf spring is designed for same stiffness as that of steel leaf spring, both the springs are considered to be almost equal in vehicle stability. The objective was to obtain a spring with minimum weight which is capable of carrying given static external forces by constraints limiting stresses and displacements.

The weight of the leaf spring is reduced considerably about 74 % by replacing steel leaf spring with FRP leaf spring. Besides the reduction of weight, the fatigue life of composite leaf spring is predicted to be satisfactory. Thus, the objective of reducing the unsprung mass is achieved to a larger extent. The stresses in the GFRP leaf spring are much lower than that of the steel spring.

REFERENCES

1. Shiva Shankar,Vijayarangan, Mono Composite Leaf Spring for LightWeight Vehicle Design, End Joint Analysis and Testing, Materials Science Vol. 12, No. 3. 2006.
2. "Mechanics of composite material" second edition by Autar K. Kaw,Taylor & Francis Group, LLC
3. 3. Mouleeswaaran Senthil Kumar, SabapathyVijayarangan, Design and experimental fatigue analysis of composite multi leaf spring , Composite Structures 75 (2006) pp 24–28Dr.Kirpal Singh, "Automobile Engineering", Standard publishers, Volume – 1. pp 204-208
4. A.Al-Qureshi, Automobile leaf springs from composite materials, Journal of Materials Processing Technology 118 (2001) pp 58-61.
5. Mahmood M. Shokrieh, Davood Rezaei Analysis and optimization of a composite leaf spring, Composite Structures 60 (2003) pp 317–325
6. J.P. Hou, Evolution of the eye-end design of a composite leaf spring for heavy axle loads, Composite Structures 78 (2007) pp 351–358
7. The Science and Engineering of Material by Donald R. Askeland, pradeepP.Phule
8. Practical Finite Element Analysis by nitin S gokhale, Sanjay S Deshpande, Sanjeev V Bedekar, Anand N Thite.
9. 9. Hiroyuki Sugiyama, Ahmed A. Shabana , Mohamed A. Omar , Development of nonlinear elastic leaf spring model for multibody vehicle systems , Comput. Methods Appl. Mech. Engrg. 195 (2006) 6925–6941
10. 10. Mouleeswaran Senthil Kumar, SabapathyVijayarangan, Analytical and Experimental Studies on Fatigue Life Prediction of Steel and Composite Multi-leaf Spring for Light Passenger Vehicles Using Life Data Analysis, Materials Science (MEDŽIAGOTYRA). Vol. 13, No. 2. 2007,ISSN 1312–1320.