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Research Paper

MANUFACTURING AND EXPERIMENTATION OF COMPOSITE HELICAL SPRINGS FOR AUTOMOTIVE SUSPENSION

T S Manjunatha[1]* and D Abdul Budan[1]

*Corresponding Author: **T S Manjunatha,** ✉ tsmdvggmit@rediffmail.com

This paper deals with the applicability of fiber reinforced plastic in springs. Three different types of springs were manufactured using glass fiber, carbon fiber and glass/carbon fiber in +45 degree orientation. Tests were conducted on the springs to study the mechanical behavior. The spring rate of the carbon fiber spring is found to be 24% more than the glass fiber spring and 10% more than the glass/carbon fiber spring. Stresses acting on the composite springs were less compared to steel spring. The weight of the composite spring is almost 70% less than that of the steel spring. The specimen preparation and experiments were carried out according to ASTM standards.

Keywords: Composite helical springs, Suspension system, Spring constant, Load bearing capacity

INTRODUCTION

Springs, in general, are designed to absorb and store energy and than release it. Hence, 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 $U = \sigma^2/\rho E$, Where σ is the strength, ρ the density and E the Young's modulus of the spring material. It is observed that material having lower modulus and density will have a greater specific strain energy capacity. Hence, composite materials become a very strong candidate for such applications.

The replacement of steel parts by composite materials yields, significant weight savings. But as with many new materials, design and manufacturing problems arise. The main reason is that fiber reinforced plastic composites are anisotropic materials, which are quite different from traditional materials. Hence the applications of composites in the manufacture of springs are not yet popular.

[1] Department of Mechanical Engineering, GM Institute of Technology, PB Road, Davangere 577006.
[2] Department of Studies in Mechanical Engineering, UBDT College of Engineering, Davangere 577004.

To meet the needs of natural resource conservation and energy economy, automobile manufacturers have been attempting to reduce the weight of vehicles in recent years. Fiber reinforced polymers have been developed for many applications, mainly because of the potential weight savings, the possibility of reducing noise, vibrations and ride harshness due to their high damping factors, the absence of corrosion problems, which lowers maintenance costs, lower tooling costs, which has favorable impact on the manufacturing costs (Mallick, 1997).

Erol Sancatkar et al have designed and manufactured a functional composite spring for a solar powered light vehicle (Erol and Mathieu, 1999). Recently, a very refined mechanical suspension concept composite spring by vertical load control was introduced (Sardou and Patrica, 2000). A new type rectangular wire helical springs (Kotaro *et al.*, 2001) is contrived which joins the first coil part and the second coil part with twisting part. If the spring is used for suspension of rally cars the control stability can be kept good while absorbing impact from the load. The free vibration (Yildrim, 2001) problem of unidirectional composite helical springs is modeled theoretically as continuous systems considering the rotary inertia, shear and axial deformation effects. A single leaf (Al-Qureshi, 2001) with variable thickness and width for constant cross sectional area of unidirectional Glass fiber reinforced plastic with similar mechanical and geometrical properties to the multi leaf spring was designed, fabricated and tested. A four leaf steel spring used in passenger cars is replaced with a composite spring made of glass/epoxy composites (Shokreih and Razaei, 2003). Wong *et al.* (2004) investigated the feasibility of utilizing the nickel-titanium alloy wires in altering the spring rates of a composite circular spring. 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 (Goudah *et al.*, 2006). Gulur *et al.* (2006) have fabricated low cost mono composite leaf spring with bonded end joints. Mahdi *et al.* (2006) have fabricated springs in elliptical configurations using woven roving composites and investigated on controlling the failure by utilizing their strength in principal direction instead of shear. Chang-Hsuan *et al.* (2007) have investigated the mechanical behaviors of helical composite springs. They have developed four different types of springs made of unidirectional laminates, rubber core unidirectional laminates, unidirectional laminates with a braided outer layer and rubber core unidirectional laminates with a braided outer layer. Faruk (2009) Investigated the dynamic behavior of composite coil springs of arbitrary shape. Abdul *et al.* (2010) have investigated the influence of ellipticity ratio on the performances of woven roving wrapped composite elliptical springs both experimentally and numerically.

Many researchers have investigated on elliptical springs, leaf springs, *C* springs and sulcated springs. Research on fiber reinforced composite helical springs is not popular due to manufacturing difficulties. This paper discusses the feasibility of using fiber reinforced composite helical spring for automobile suspension. It is well documented in the literature that the energy storage capacity of rectangular springs is more; also it is found that a less amount of work is carried out on this variety of springs. Hence for the experimentation rectangular cross section is chosen. The mechanical behavior of the rectangular FRP spring with different reinforcements is evaluated.

MATERIALS AND METHODS

Materials

The fibers chosen for the spring design are E-glass in the form of mat due to their high extensibility, toughness and PAN based carbon fiber mat. In order to facilitate the wetting of fibers, epoxy resin with 2 h pot life is selected. L-12/K-6 Lapox epoxy system for laminating applications is used. The properties of the material are given in Table 1.

Fabrication

The manufacturing process followed in this work is a variation of filament winding process. In this method a mandrel as shown in Figure 1 is prepared with cast iron or any other metal.

Table 1: Properties of Material

Properties	E-Glass Fiber	Carbon Fiber	Epoxy Resin
Shear Modulus	30 GPa	50 GPa	1.6 GPa
Elongation	4.88%	1.3%	2%
Density	2.5 g/cc	1.8 g/cc	1.2 g/cc
Elasticity Modulus	73 GPa	230 GPa	3.45 GPa
Tensile Strength	2.5 GPa	3.6 GPa	1.3 GPa
Specific Strength	–	2.70 GPa	36 MPa

Figure 1: Mandrel

This mandrel having the shape of the spring profile is fixed between the centers of the lathe. A mould release agent silicone gel is applied on the mandrel. Since the load acting on the compression spring is shear, the fibers are cut in +45 degree orientation as shown in Figure 2. The measured quantity of epoxy resin matrix material is taken. The fiber tape after dipping in the epoxy resin is wound on the mandrel. This process of winding the tape on the mandrel is continued till the required thickness of spring is obtained on the mandrel. After the completion of winding, the shrink tape is wound on the mandrel as shown in Figure 3. The

Figure 2: Fibers Cut into +45 Degree Orientation

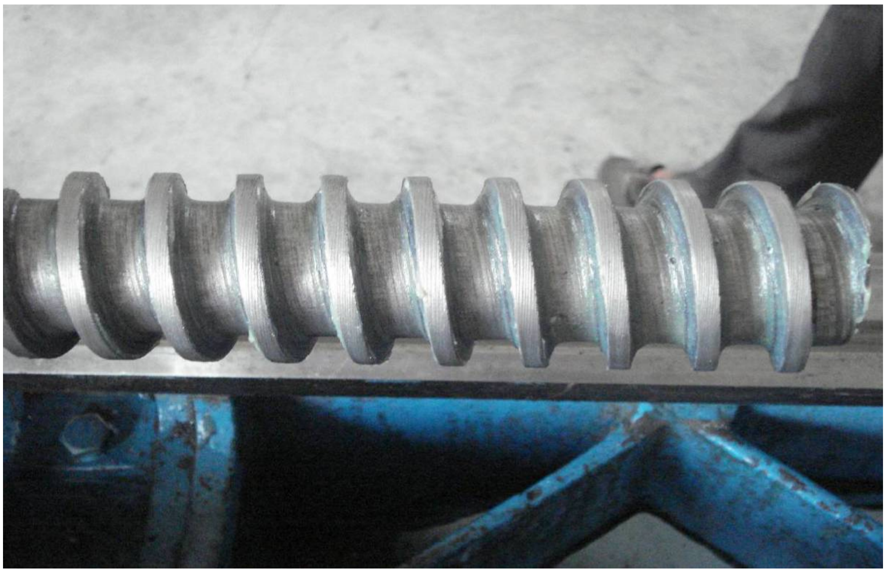


Figure 3: Shrink Tape Wound on Mandrel

mandrel with the fibers kept for curing in atmospheric temperature for 24 hours. After curing the spring is removed from the mandrel. The cured spring has the dimension of L = 200 mm, Do = 55 mm, D = 47 mm, b = 8 mm, t = 10 mm, n = 9. The same procedure is followed for glass fiber and carbon fiber springs. And for glass/carbon fiber springs, one layer of carbon fiber and one layer of glass fibers are to be bonded with resin for winding on the mandrel. Fabricated springs are shown in Figure 4.

Figure 4: The Springs After Curing

Experimental Methods

The main parameters to be considered in the application of springs are spring stiffness, failure load, maximum compression and physical dimensions. There is no deviation obtained in the physical dimension of the fabricated spring. Experiments were conducted as per ASTM standards and the results are shown in Table 2.

Table 2: The Mechanical Properties of Three Types of Composite Helical Springs

Properties	Glass Fiber	Carbon Fiber	Glass/Carbon Fiber
Spring Constant (N/mm)	4.83	6.36	5.75
Maximum Compression (mm)	83	80	77
Load at Max Compression (N)	388.80	511.75	459.76
Failure Load (N)	1000	1500	1200
Shear Stress (N/mm^2)	83.00	79.67	95.49
Fiber Volume Fraction (%)	60.20	61.23	62.46
Weight of Spring (g)	237.46	200.50	224.59

Measurement of Spring Constant, Failure Load and Maximum Compression

According to JIS B2704, the spring constant of a helical spring can be determined by two measured points, corresponding to deflection at both 30% and 70% of the full loading, on the load deflection curve from the compression test of a helical spring. In general, the spring constant depends mainly on its shape, dimensions, and material properties. In this study a digital spring testing machine is used which automatically records the data of applied load and the corresponding compression in each regular interval, and thus provides the load-deflection curve for each spring. The spring constant and maximum compression can than be evaluated. In addition the failure load of the spring beyond the maximum compression is also recorded by testing the springs in the universal testing machine.

Measurement of Fiber Volume Fraction

The fiber volume fraction is determined as per ASTM D3171, by taking a specimen of about 1 gram in a solution of 30 ml nitric acid with more than 90% concentration, and it is than inserted into the oven with temperature at 75+1 degree Celsius. The specimen is taken out after five hours and cleaned with acetone and distilled water. The weight of the fiber is measured after baking for 30 minutes in an oven at 10 degree Celsius. The fiber volume fraction is then calculated by knowing the density of resin and fibers.

RESULTS AND DISCUSSION

The objective of this experimental investigation is to study the feasibility of using fiber reinforced composite helical springs for automotive suspension and to study their mechanical properties. Three types of composite springs were fabricated. In order to improve relative reliability of the experimental results three sets of springs were fabricated in each type and tests were conducted on these springs. The average values of these test results were taken for analysis.

Load Carrying Capacity of FRP Springs

The measured load-deflection curves for the three types of springs are shown in Figures 5-7. A linear curve is obtained for all the three types of the springs. A small variation is observed in the curves of the specimens in all the three types of springs. This variation is due to the dimensional variations in the fabrication process. This variation can be reduced by standardizing the fabrication methods. The average values of the load and deflection of all the three types of springs are given in Table 3 and the corresponding curves are shown in Figure 8. The load bearing capacity of the carbon fiber springs is more compared to other two types of springs. This is due to the high strength of the carbon fibers. Carbon fiber springs carry nearly 25% more load than the glass fiber spring and 10% more than the glass/carbon fiber spring. The maximum load carrying capacity of the carbon fiber springs is 500 Newtons.

Spring Constant

The spring constant or spring rate is the force required to compress a spring by one mm. Spring rates depends on the rigidity modulus, no of coils and dimensions of the spring.

Figure 5: Load Deflections of Glass Fiber Spring

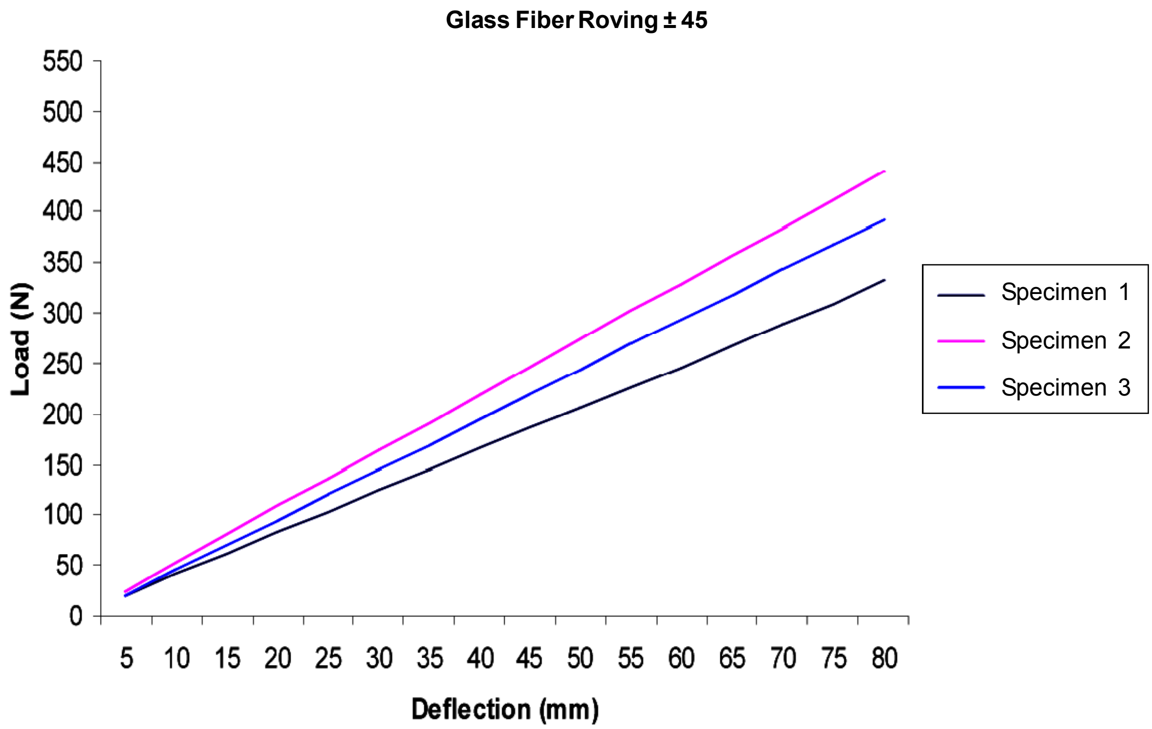


Figure 6: Load Deflections of Carbon Fiber Spring

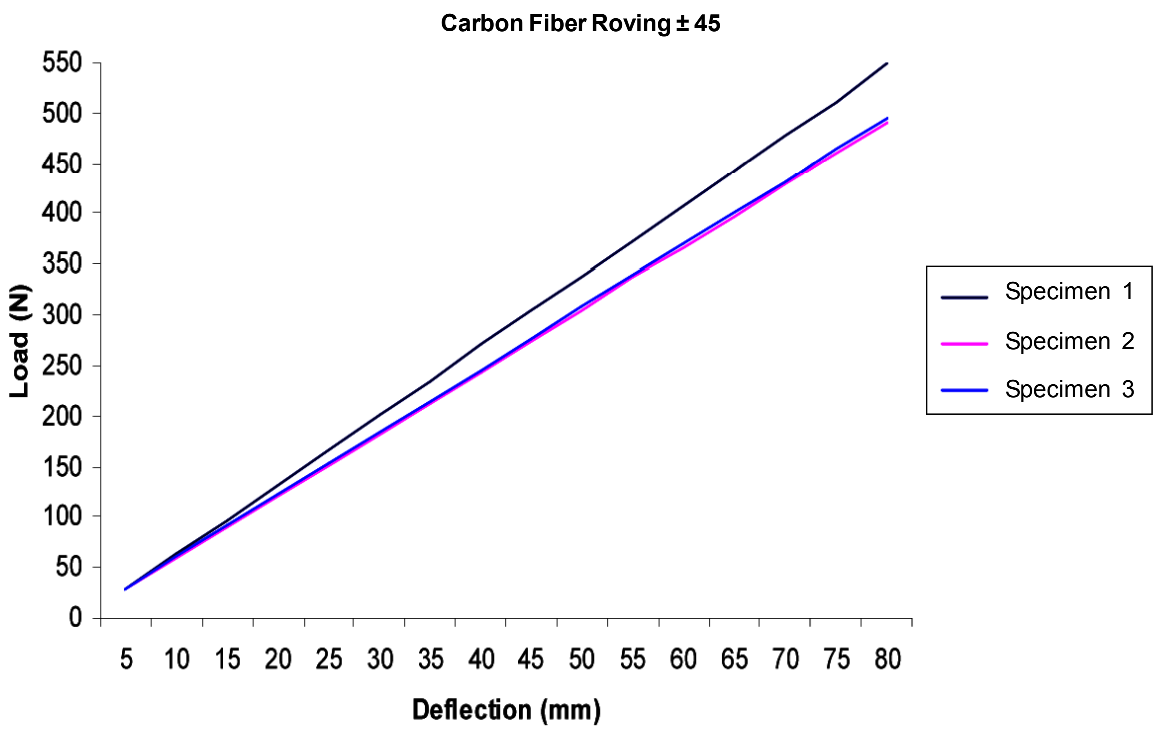


Figure 7: Load Deflections of Glass/Carbon Fiber Spring

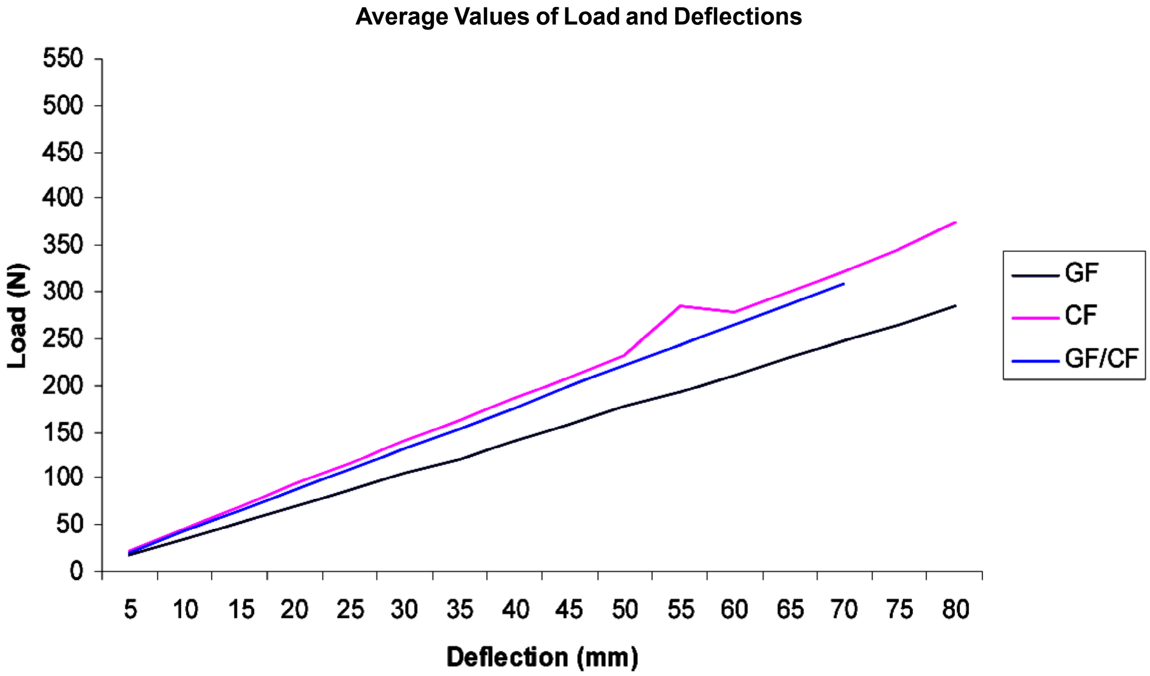
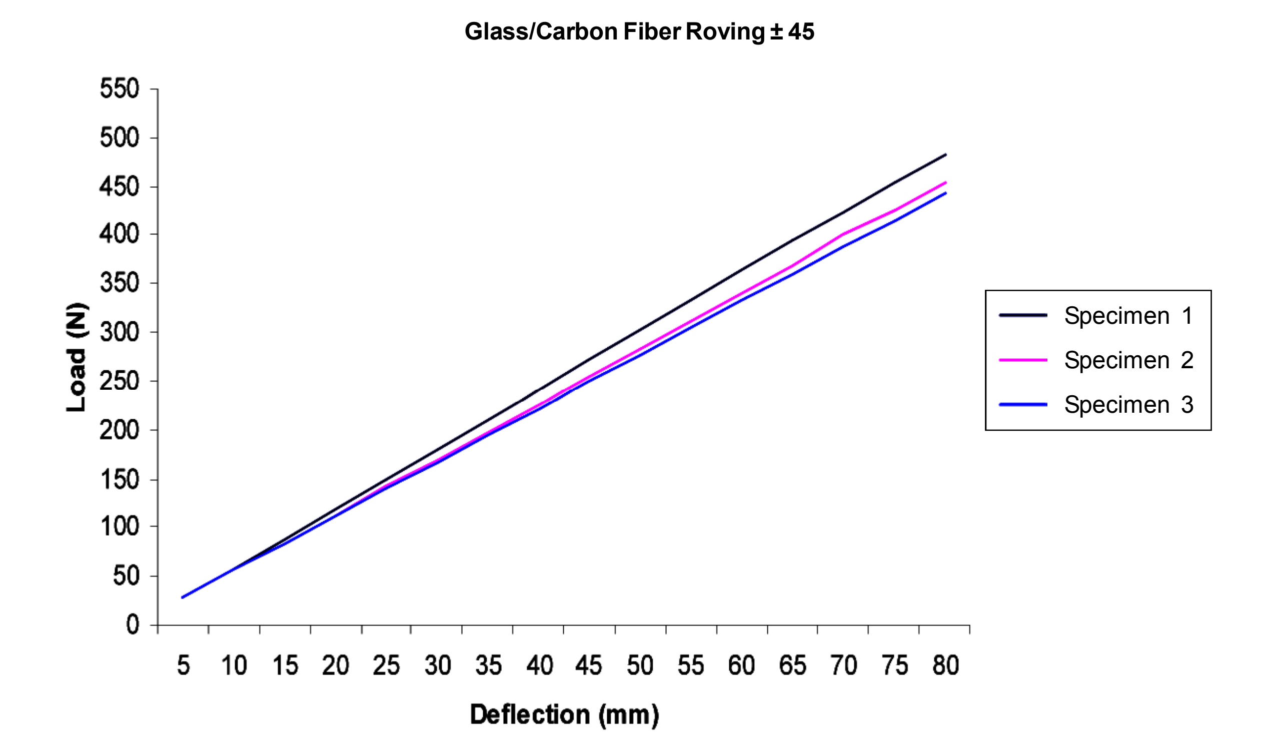


Table 3: The Average Values of the Load and Deflections of the Three Types of Springs

Load (N)			Deflection mm
Glass Fiber	Carbon fiber	Glass/Carbon Fiber	
21.58	29.10	28.11	5
46.43	61.14	56.89	10
70.96	93.19	85.34	15
95.48	125.23	114.12	20
120.00	156.95	143.22	25
144.20	189.00	172.00	30
192.92	221.04	200.77	35
192.92	253.42	229.22	40
217.12	285.47	257.99	45
241.97	317.18	287.10	50
265.84	349.56	315.87	55
289.72	381.60	344.98	60
314.23	413.65	373.75	65
338.70	446.02	403.84	70
363.30	478.39	430.98	75
388.80	511.75	459.76	80

Figure 8: Load Deflections of All Three Types of Spring



Rigidity modulus plays a major role in the spring rates. Rigidity modulus of E-glass-epoxy is 3.9 GPa, Carbon fiber-epoxy is 5.2 GPa and glass fiber/Carbon fiber epoxy 4.7 GPa. The spring rates are determined from the load deflection curves and are evidently very stable and almost constant. The calculated bar charts are shown in Figure 9. As observed from the results the spring rates of the carbon fiber springs are 24% more than the glass fiber spring and 10% more than the glass fiber/carbon fiber spring. Again this is due to the higher rigidity modulus of carbon fibers and more load carrying capacity of the carbon fiber springs due to its superior mechanical properties. Spring rates were also calculated using rigidity modulus. The values obtained for glass fiber springs is 4.81 N/mm, carbon fiber springs 6.41 N/mm and glass/carbon fiber spring 5.80 N/mm. Experimental results were compared with theses results and there is less variations observed which can be ignored.

Failure Load and Compressibility

The failure loads and maximum compression of the three types of springs are shown in Figures 10 and 11. The load before failure of the carbon fiber spring is 34% more than the glass fiber spring and 20% more than the GF/CF spring. The maximum compression obtained is 83 mm which is sufficient for the application of light vehicles. There is no much difference in the maximum compression of the three springs which also depends upon the manufacturing conditions. Springs were tested beyond their maximum compression to determine the failure load. After its maximum compression spring acts like a solid rod and the load applied to the spring is carried by the

Figure 9: Spring Rates of the Three Types of Types of Springs

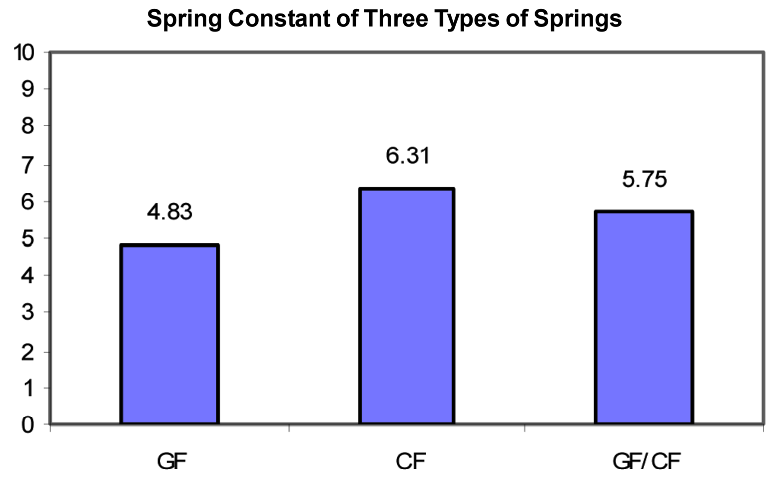


Figure 10: Failure Loads of Three Types of Springs

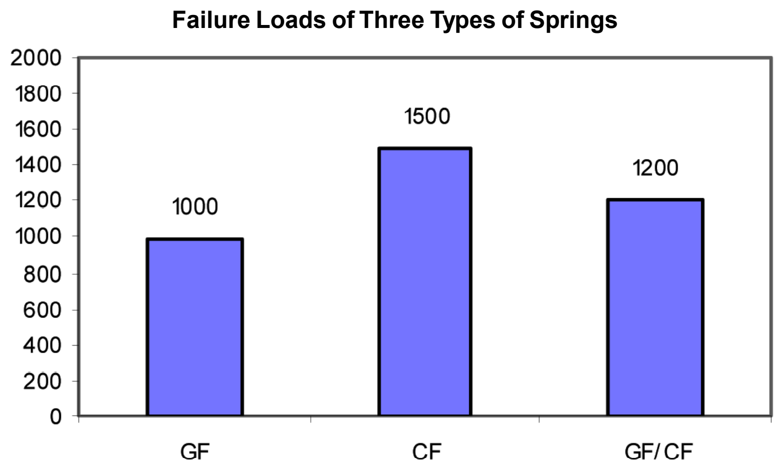
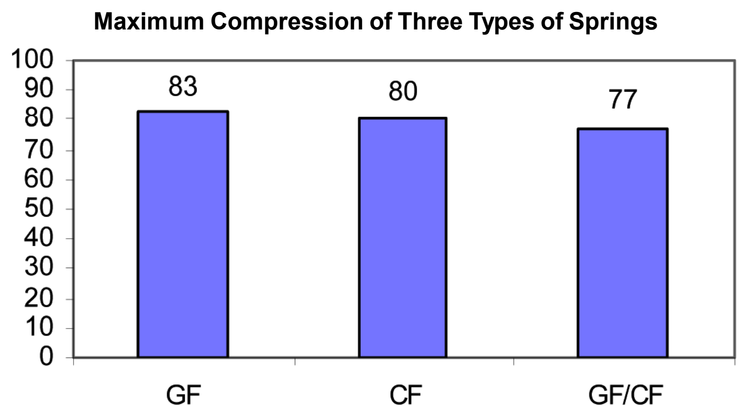


Figure 11: Maximum Compression of Three Types of Springs



materials and not due to its spring action. Carbon fiber springs start delaminating after a load of 1500 N with a small cracking sound. The same situation is observed for the other two types of the springs. Glass fiber springs fails at 1000 N and glass/carbon fiber springs fail at 1200 N. The failure loads are very higher than the practical load application of the spring. Hence the fiber springs can be safely used.

The weight of the composite springs is approximately 70% less than the steel springs of the same dimensions. The weight of the carbon fiber spring is 15% less than glass fiber spring and 11% less than glass/carbon fiber spring. This is due to the lower density of the carbon fibers.

Shear stresses are determined by knowing the load acting on the spring and the dimensions of the spring. Stresses acting on the carbon fiber spring are 4% less than the glass fiber spring and 15% less than glass/ carbon fiber spring. Stresses acting on the fiber springs are less than the steel spring. This can be explained by the stress distribution in the structure of the helical spring subjected to an applied compressive loading. When a helical metal spring is under the action of a compressive force, a shear stress distribution will be induced on its coil cross section, and stress concentration will also occur on the inner rim of the spring coil due to its helical bending shape, and therefore the inner rim of the spring coil is under the action of the maximum shear stress considering the effect of curvature. Because of inter twinning of fibers in +45 degree orientation fiber springs resists higher shear load.

It is evident from the above results the spring rate, failure load, maximum compression and shear stress acting on the spring depends upon the material characteristics. Since the properties of carbon fiber are high specific tensile strength, high modulus, low density, low coefficient of thermal expansion, heat resistant, chemical stability, and self lubricity the springs made from these fibers exhibit better properties.

CONCLUSION

As observed from the experimental results the use of fiber reinforced composite materials for automotive suspension are preliminarily feasible and the following conclusions were derived.

- The method used for manufacturing the composite helical springs is simple using conventional machine tools. The method can be made automated for mass production by using CNC tape winding. The application of the composite material for automobiles can only be justified by producing the composite components in mass which will reduce the cost of the composite parts.
- The weight of the spring manufactured from fibers is less than steel spring. However the cost of the composite springs is higher than the steel springs. This can be justified by the amount of fuel saved by using the fiber springs in automobiles.
- The stiffness of the carbon fiber springs is greater than the other two types of composite coil springs. As compared to steel springs of the same dimensions, the stiffness of composite coil springs is less. In order to increase the stiffness of the spring the dimensions of the composite

spring is to be increased which in turn increases the weight of the spring.

- An optimum design of composite spring is required to balance the weight and stiffness. Hence the application of the composite coil springs can be limited to light vehicles which require less spring stiffness, e.g., electric vehicles, solar vehicles and hybrid vehicles.
- By using two carbon fiber springs of the above types which will withstand approximately 1000 N, they can be successfully used for the application of light vehicle.
- Since the stresses acting on the composite coil springs are less the fatigue life of the fiber spring will be more compared to steel spring.

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