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An Overview of Design and Development of Fiber Reinforced Polymer Composite Coiled Spring for Automobile Applications

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Abstract- *The automobile industries show the attention in improvement of fuel efficiency of vehicles by reducing the weight of the vehicle. The reduction in weight of the vehicles is attained by replacing the heavy metallic parts. The usage of high performance Fiber Reinforced Polymer (FRP) composite materials can replace the heavy metallic parts. The helical springs made of conventional metallic materials are widely used in the automobiles. Some of the researchers are developed the FRP composite helical springs. This paper attempts to review and study the feasibility of implementation the FRP composite material for manufacturing helical coil spring.*

I. INTRODUCTION

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 and better manufacturing processes [1]. The helical springs are widely used in the suspension system in automobiles. Both front and rear suspensions in present-day automobiles utilize steel coil springs in conjunction with shock absorbers. These two components act in a complementary fashion to reduce the transmission of road surface vibration into the vehicle structure and passengers within. The principal function of the spring is to isolate the vibration while that of the shock absorber is to dampen the oscillation in the spring [2].

Among the different types of mechanical springs, helical springs are commonly integrated as parts of many mechanical systems, such as shock absorbers. According to the different ways of loading applied, helical springs can be divided into three kinds: compression springs, tension springs and torsion springs, and they are mainly with either round section or square section. [3].

Traditionally, springs are made of metal materials. Due to the advancements and advantages of the FRP Composites, there is a possibility of making the composite helical springs. The advanced composite materials seem to be ideally suitable for making coil springs for a heavy duty vehicle suspension. Their properties can be tailored to increase the strength and the properties at which they operate. Advanced composite fibres, such as glass, graphite, and Kevlar-reinforced suitable resins, are expected to be widely used in vehicle suspension system applications so that springs of different shapes can be obtained. This refers to the high specific strength (strength-to-density ratio) and high specific modulus (modulus-to-density ratio) of these advanced composite materials. Several design variables that have an influence on the mechanical properties of springs have been considered, e.g. the braiding angle, the fibre volume fraction, and other standard design parameters of helical springs. Design goals are set for standard metallic springs, e.g. weight reduction with a high stiffness [4].

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The present paper reviews the previous works for design and development of Fiber Reinforced Polymer Composite Coiled Spring for Automobile Applications and also to study feasibility of implementation the FRP composite materials for manufacturing helical coil spring.

II. Design

The main factor to be considered in the design of a spring is the strain energy of a material used. Specific strain energy in the material can generally be expressed as,

$$U = \frac{\sigma^2}{\rho E} \tag{1}$$

This indicates that a material with lower young's modulus (E) or Density (ρ) will have higher specific strain energy under the same stress (σ) condition. Thus the composite materials offer high strength and light weight. The deflection and stress plays the imperative role during the design of the helical springs. The deflection of the helical compression spring for circular cross-section is calculated by the formula

$$Deflection\ \delta = \frac{8WC^3 n}{Gd} \tag{2}$$

Where 'W' is Load, 'C' is Spring Index 'D/d', 'n' =Number of turns, G is Modulus of rigidity and'd' is diameter of wire. The helical compression spring with rectangular cross-section is shown in the Fig.1. The deflection of the helical compression spring for circular cross-section is calculated by the formula given below,

$$Deflection\ \delta = \frac{2.5WD^3 n}{Gb^3(t-0.56b)} \tag{3}$$

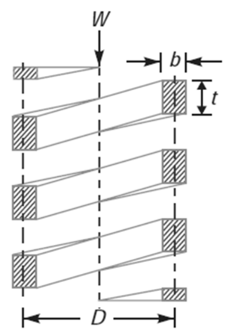

Fig.1 Spring of rectangular cross-section[5]

Where 'D' is mean diameter of the spring, 'b' is width of the wire,'t' is depth of the wire. The shear stress induced in the helical compression spring for circular cross-section is calculated using the formula,

$$Shear\ stess, \tau = k\frac{8WC}{\pi d^2} \tag{4}$$

Where 'k' is the Whal's factor. The shear stress induced in the helical compression spring for non-circular cross-section is calculated using the formula

$$Shear\ stess, \tau = k\frac{8WD(1.5t+0.9b)}{b^2+t^2} \tag{5}$$

This expression is applicable when the longer side (i.e. t > b) is parallel to the axis of the spring. But when the shorter side (i.e. t < b) is parallel to the axis of the spring, then maximum shear stress,

$$Shear\ stess, \tau = k\frac{8WD(1.5b+0.9t)}{b^2+t^2} \tag{6}$$

For springs made of square wire, the dimensions b and t are equal [5].

A composite spring is generally designed to match the physical dimensions of a corresponding steel spring if the composite spring is intended to replace the steel spring. In this case, the steel spring dimensions and rate would be determined in order to initiate the design of a corresponding composite spring. After determining the desired properties of the composite spring, the fiber band angle or angles around the wire or plastic core together with the fiber modulus are determined as the most significant parameters that will determine the final rate of the spring together with the helix pitch and composite core diameter. For example, changing the fiber angle above or below 45 degrees will increase or reduce the final spring rate. As a result, changing or varying the winding angle allows

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significant variability in the spring properties for a final geometry. In addition, the following modifications may be made to the process to incorporate desired properties:

- ✓ The fiber angle can be changed along the length of the spring to tailor the final properties and/or to provide different properties along the length of the spring including torsional and bending strength.
- ✓ The wet fiber cord may be laid down using a braiding process;
- ✓ The spring may have a non-circular cross-section;
- ✓ The spring may utilize different composite fibers in different layers [6].

III. Manufacturing

A manufacturing method (Fig.2) for a composite coil spring includes the following steps: preparing a mold, coil former around a mandrel of the mold, winding composite material pre-preg, opening the mold and detaching the mandrel and the coiled coil former. A mandrel is prepared with cast iron or any other metal. 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. 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. The 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[7].

Fig. 2 Filament Winding Method [7]

The method used for the production of the springs is a variation of the RTM (Resin Transfer Moulding) process. Through this method, the dry braids are positioned in the mould before being impregnated with the resin, making production very clean and simple. In this case, an open mould consisting of a helically grooved mandrel was used, and the braids are impregnated by plunging in a bowl filled with resin. The production process (Fig. 3) can be described in few steps:

- ✓ A silicon tube is filled with sand in order to let the braids keep a circular shape when winded. The number of socks needed to achieve the required thickness is then superimposed on the silicone tube.
- ✓ The braids are then wound around the mould.
- ✓ The mould is put in the oven to warm up together with the resin, in order to facilitate the impregnation.
- ✓ After the curing time the mould is then easily removable from the mould. The figure shows the product when extracted from the mould [8].

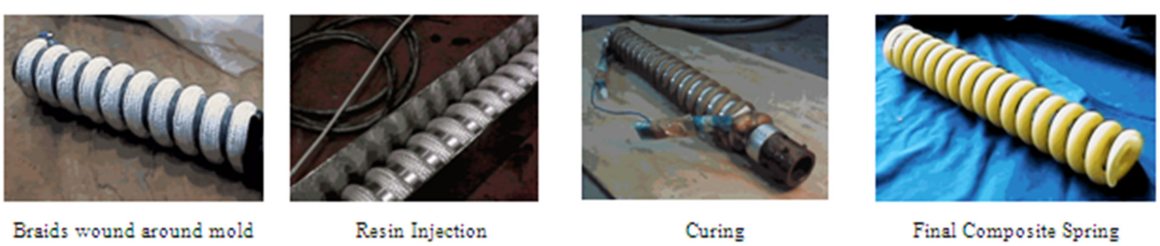

Fig. 3 Resin Transfer Molding Process [8]

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Chang-Hsuan Chiu etal manufactured four different kinds (Table-1) FRP composite helical springs which includes several steps the fabrication of FRP composite helical springs can generally be divided into several steps, as shown in Fig. 4. First, pre-impregnated fibers are fabricated with fibers along ±45° directions. Next, prepregs are packed into laminates and then the laminates are trimmed. Third, the trimmed laminates are coiled into four kinds of cylinder bars. Fourth, the coiled laminates are outer braided one layer with resin impregnated 3K carbon fiber. In the fifth step, the preformed composite bars are further put into the helical spring mold with a square cross-section, which is polished with mold release agent in advance. The preformed composite bars are then formed into helical composite springs under high temperature and high pressure by a hot press machine. After the drawing of the mold, the flash of resin on helical composite springs has to be removed. Then, a 10 mm pre-compression is applied to the helical composite springs three hundred times, to remove the internal stresses induced by possibly existing infinitesimal surface defects. The final product (L = 90 mm, D = 40 mm, n = 3 and a = 10 mm)

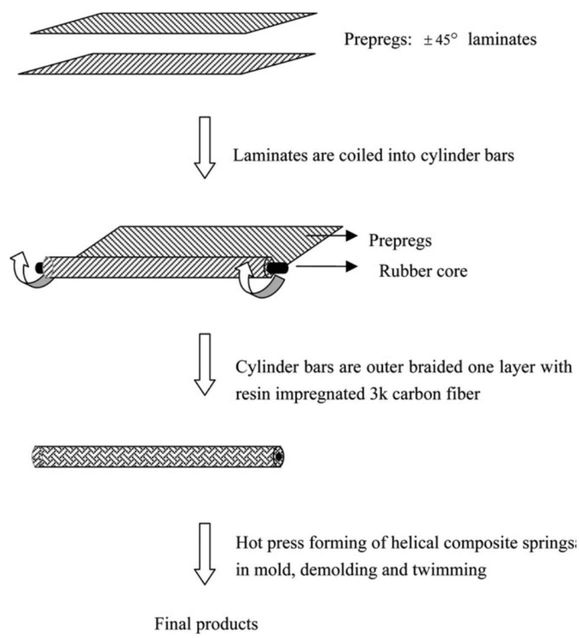
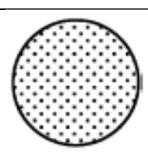
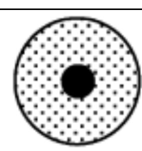
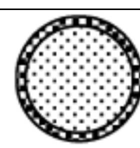
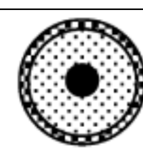


Fig.4 Manufacturing of Laminated Composite Helical Spring [3]

Table I Four different types of composite helical spring [3]

Name of the structure	**AU**	**UR**	**BU**	**BUR**
Materials in the structure	All unidirectional	Unidirectional + Rubber core	Outer braid + Unidirectional	Outer braid + Unidirectional + Rubber core
Cross-section				
Dimensions	76.53 · 41.5 cm^2	76.53×37.5 cm^2: w3 mm rubber core	3K carbon fiber outer braid (one layer): 76.53×37.5 cm^2	3K carbon fiber outer braid (one layer): 76.53 · 37.5 cm2: w3 mm rubber core

III. Experimentation

The conventional spring testing machine can used to test the composite which records the deflection and load applied on the spring is used. The load deflection curve can be drawn from these data. The spring rate, maximum compression and failure load can be evaluated from the load deflection curve. A special fixture is also used to hold the spring in the spring testing machine. The mechanical behavior of the FRP composite helical spring is illustrated in the Table-2

Table II Mechanical properties of FRP composite helical springs

Materials Used	Spring Constant (N/mm)	Maximum Compression (mm)	Load at Max Compression (N)	Failure Load (N)	Shear Stress (N/mm^2)	Weight of Spring (g)	References
60% Glass+ epoxy	4.83	83	388.80	1000	83.00	237.46	[7]
61% Carbon+ epoxy	6.36	80	511.75	1500	79.67	200.50	
(62% Glass+ Carbon) + epoxy	5.75	77	459.76	1200	95.49	224.59	
All unidirectional (60% carbon+epoxy)	14.03	21.37	-	275	-	90	[3]
Unidirectional + Rubber core (56% carbon+epoxy)	14.31	24.47	-	300	-	90	
Outer braid + Unidirectional (59% carbon+epoxy)	16.23	21.03	-	320	-	90	
Outer braid + Unidirectional + Rubber core(55% carbon+epoxy)	16.27	22.10	-	340	-	90	

III. Conclusion

For the purpose of saving energy and improving the performance of vehicles, composite materials with light weight and high quality have been widely used for today's vehicles. Due to its light weight, high modulus and high strength, strong anti-chemical capability, high degree of freedom for design and high processability, FRP composites have gradually replaced steels or traditional composites, and become the key materials for the research and development of automobile parts recently. In this study the various design and manufacturing methodologies for manufacturing of FRP composite helical spring is reviewed and following conclusions are made:

(a) The weight of the springs manufactured from carbon fiber roving is less than the glass fiber and glass fiber/carbon fiber roving springs. The stiffness of the carbon fiber springs is greater than the other two types of composite coil springs. The springs developed from the glass fiber/carbon fiber roving does not exhibit a favourable results compare to other two types of springs.[9]

(b) The helical composite spring with a 'Braided + Unidirectional + Rubber core' structure have the higher mechanical properties than 'Unidirectional', 'Unidirectional+ Rubber core', and 'Outer braid + Unidirectional' [3].

(c) Feasibility of composite materials is checked, composite helical springs can be easily replaced in light weight vehicles with slight sacrifice of the size. In regular vehicles, combination of springs with composite and conventional material can be used to overcome low stiffness of composite materials and weight of spring can be optimized [10].

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