ADDIS ABABA UNIVERSITY

INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

DEVELOPMENT OF HELICAL COIL SPRING FOR LIGHT WEIGHT VEHICLE

A Thesis Submitted to the Graduate School of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science

In

Mechanical Engineering (Mechanical Design)

By: Kidane Hadgu

Advisor: Dr. Daniel Tilahun

October, 2013

Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

Development of Composite Helical Coil Spring for Light Weight Vehicle

By

Kidane Hadgu

Approved by Board of Examiners

Daniel Tilahun (Dr.)	____________________	____________________
Advisor	Signature	Date
Bahailu Mamo	____________________	____________________
Internal Examiner	Signature	Date
Araya Abera	____________________	____________________
External Examiner	Signature	Date
Getasew Ashagre	____________________	____________________
Chairman of the School	Signature	Date

Abstract

Development of composite helical coil spring for light weight vehicle

Kidane Hadgu

Addis Ababa University 2017

The main objective of this thesis is development of composite helical coil spring for light weight vehicle. The candidate materials are E-Glass, Carbon fiber and Epoxy resin. The selection of an appropriate weight fraction for both chopped carbon and glass fiber composition between 0.4:0.6, 0.5:0.5, 0.6:0.4 is conducted through analytical (Advanced rule of mixture) and laboratory experiment (Tensile testing machine. Chopped carbon fiber with 0.4 weight fraction of epoxy resin and 0.6 weight fraction of fiber composition is selected for our spring through composition property of the composite material. The 3D model has done using SOLID WORK 2016. The equivalent elastic strain and maximum stress were considered at the static condition using ANSYS 2016. The static analysis were developed using fixed support on the lower end of the spring. Comparison has been done in terms of stiffness, deflection, specific strain energy, and strength to weight ratio of the spring for each spring using chopped carbon and glass fiber, and the composite chopped carbon fiber with 0.4:0.6 composition is found to be better with the desired property of a spring material compared with conventional structural steel and glass fiber.

Key words

Elastic object, helical coiled spring, stiffness of spring, conventional coiled spring, and carbon fiber reinforced composite helical coiled spring.

Acknowledgment

My heartfelt thanks to my advisor Dr. Daniel Tilahun and my Co-advisor Addisu Workiyea for their valuable advices, motivations and guidance during my study.

I would like to express my deep gratitude to Captain Fitwi Gebrenigus and Mr. Kassahun G/Silase. (Ethio plastic industry) for providing E glass fiber with epoxy for test sample and final prototype of the spring and Captain Kinfe and Ms.Sabe L. (Dejen Aviation Industry, unmanned air vehicle department) for providing carbon fiber with epoxy and different equipment's for test sample for providing all the necessary materials & equipment for manufacturing of the samples.

Finally, I would like to thank Mr. Araya Abera and Mr.Nathnael Abebaw who were supporting and motivating me for the achievement of this paper.

Table of Content

Table of Contents **Page**

List of Figures

List of Tables

List of Abbreviations and Acronyms

CHCS	Conventional helical coil spring
CFCM	Carbon fiber composite material
GFCM	Glass fiber composite material
CCF	Chopped carbon fiber
CGF	Chopped glass fiber
ASTM	America society for testing and material
UD	Uni directional
cc	Cubic centimeter
Eq.	Equation
Davi	Dejen aviation industry
UTM	universal testing machine

Nomenclature

V_m Matrix Volume fraction

V_f Fibers Volume fraction

VM Volume of matrix. (cc)

VF Volume of fibers (cc)

V_c Volume fraction of composite

W_f Fiber weight fraction

W_m Matrix weight fraction

WF Weight of fiber (g)

WM Weight of matrix (g)

ρ_m Density of matrix (g/cc)

ρ_f Density of fiber (g/cc)

σc Fracture stress of composites.

C spring index

K spring rate

G Shear modulus (GPa)

E Young's modulus (GPa)

V Poisson's ratio

A area of cross-section (cm^3)

lc Critical fiber length (mm)

n active number of coils

CHAPTER 1 –INTRODUCTION

1.1. Back Ground of the Study

Springs are mechanical shock absorber system. A mechanical spring is defined as an elastic body which has the primary function to deflect or distort under load and to return to its original shape when the load is removed. [1] It has an elastic property whose function is to store energy when deflected by force and return equivalent amount of energy on being released. Springs are mainly used in the industry for absorbing shock member energy and for resetting the part at its initial position upon displacement for a given function. Helical Compression springs are helical coil springs that resistance to a compressive force. Helical Compression springs having shapes like cylindrical, conical, tapered, concave or convex etc. Coil compression springs are wound in a helix usually out of round wire. The springs are designed to withstand the effect of loading or unloading during operation.

Figure 1.1: Conventional helical coiled spring (source: Photo taken from Tesfu Garage Addis Ababa 6 Killo)

Always minimizing vibrations and decreasing interferences with the ground will reduce the fatigue of the travelers. Regarding the comfort, it is very important for the driver, because it will make possible to maintain concentration levels, and therefore safety. The suspension system is on charge of keeping the best transporting conditions. Besides, it must maintain the tire and the road in contact. This is the most important function, due to the fact that enables the facility to control the vehicle. [2]

All types of existing vehicles have been developed in order to transporting, which must be done in the best possible conditions for people as well as for cargo. In the present scenario the automobile industry is regularly trying to reduce the fuel consumption of the automobile vehicles. Fuel efficiency of automobiles can be maximized by lowering the weight of the vehicle. The suspension system of an automobile is one of the important segments of the automobile vehicle. Till date the use of steel helical coil spring in suspension system is in general practice by the automobile manufacturers. As it is well known that, the spring of the suspension system plays an important role for a smooth and jerk free ride. So it required to design the springs very precisely. The use of conventional steel as spring increases the weight and with the current scenario the automobile manufacturers are interested in replacing steel springs with light weight composite materials. [4] Composite materials are very light weight and also possess corrosion resistance; it can also withstand high temperature. But manufacturing composite material is quite costly than the steel spring. The use of composite material is beneficial if it can increase the efficiency of the vehicle and hence overcome the material cost. [1, 4]

Structural steel

Depending upon the applications the classification of materials are done for various types of metallic springs. Initially there is no application of load but later on the load is applied in an ascending order. The spring which we are using for the analysis is compression helical spring in other words known as open coil spring. These springs are used in shock absorbers of suspension systems in automotive vehicles and some other applications such as drum brake springs for maintaining the force between contacting surfaces. The strain energy of the material of the spring is an important factor to be considered.

Generally, springs made of hardened steel are used. Small springs can be wound from pre hardened stock while larger ones are made from annealed steel and hardened after fabrication. Non-ferrous metals are also used such phosphor bronze and titanium for parts requiring corrosion resistance and beryllium copper for springs carrying electrical current because of its low electrical resistance. [3, 5]

Kevlar fabric spring Kevlar

Is a para-aramid fiber which displays excellent dimensional stability over a wide range of temperatures for prolonged periods, even at temperature of 320F. Kevlar shows essentially no strength loss Kevlar fiber does not melt or support combustion but will start to decompose at about 800F. Currently, Kevlar has many applications, ranging from bicycle tires and racing sails to body armour because of its high tensile strength to weight ratio by this measure it is five times stronger than steel on an equal weight basis. [5]

Carbon fiber fabric spring

To form a composite carbon fibers are mixed with other materials. Plastic resin is combined with carbon fiber by wounding or molding methods to form carbon fiber reinforced polymer which is also known as carbon fiber which has a very high strength to weight ratio. The rigidity of this material is extremely high which can also be considered as brittle material. Hence carbon fibers can also be mixed with some other materials like graphite to form carbon-carbon composite which has high heat tolerance [4]. The carbon fiber has high stiffness, high tensile strength, high chemical resistance, high temperature tolerance, low thermal expansion and low weight. Hence it is in demand in aerospace structural applications, automotive applications and military purpose as well as in sports. The only drawback of carbon fiber is they are very expensive compared to glass fibers and plastic fibers. In the manufacturing of carbon fiber the carbon atoms are bonded together in crystals and alignment is made parallel to long axis of the fiber. This alignment gives the fiber high strength to volume ratio which is very strong for its size like this many carbon fibers are bundled together to form a tow which is further used in woving into a fabric [15]

The front suspension helical coil compression spring used for four wheeler front suspension in light weight vehicle has high in weight [12] so it needs to optimize in weight. Optimization the weight of the spring corresponding with the strength will have on utilizing and optimizing the fuel consumption of the automobile. In addition to this currently many researchers have been investigated on elliptical springs, leaf springs and C springs. Research on fiber reinforced composite helical spring is not popular due to manufacturing difficulties. Since, the project will discuss the feasibility of using composite material specially carbon fiber reinforced composite helical coiled spring for light vehicle suspension system including easy recommended manufacturing system relative with other types of helical coiled springs.

1.2. Problem of the Statement

The helical coiled spring as a suspension system that are commonly used for light vehicle made of conventional steel has a lower spring strength to weight ratio .This will have an effect on the total weight of the automobile which finally maximize fuel consumption [2, 7].In addition to this the manufacturability of helical coil spring using structural steel is difficult in our locally [7]. To overcome this gap, it is better to introduce a new suspension system made up of composite material with advanced mechanical property. It is expected that, the new suspension system composed of carbon reinforced composite material will be safe in the desired aspect including a minimum weight, require less economically for further fabrication in our local area and a better choice to keep the quality of the vehicle comfortable on any road condition comparing with the conventional and glass fiber helical coiled spring.

1.3. Objective of the Study

The general objective of the study is development a helical coiled spring using composite material for light vehicle.

The specific objective of this thesis include

- To develop a geometry of the helical coiled spring using structural steel by considering loading condition.
- To analysis the conventional helical coiled spring using ansys work bench including the equivalent elastic strain and equivalent stress at static condition.
- To determine the specific fiber and matrix content of the composite material using analytical and lab experiment using carbon and glass composite material
- Analyzing the mechanical property of selected composite material such as modules of elasticity and shear modules using lab experiment.
- Analyzing the deflection, weight, specific strain energy and spring rate of spring made of composite material using lab experiment result.
- To validate new material with the existing material.
- Compare experimental result with analytical and show its relation.
- To develop helical coil spring using composite material.

1.4. Challenges

Among the many, major obstacles while conducting this work were the following

- Absence of long carbon fiber as UD for developing a helical coil spring in the country level.
- Experimental set up for testing the stiffness of the spring.
- There is no a full data on the profile geometry of coil spring locally.

1.5. Organization of the Thesis

This paper is organized in to five main chapters. The first chapter discusses the introduction of suspension system with its application in automobile. On this chapter background, objectives, statement of problem and limitation of the thesis is identified. On the second chapter two is the review of literature that includes journals, articles and publications that related to the research paper work. Additionally on this chapter some literature work is also seen that related to field of study to strength the paper based on the material, manufacturing method. On chapter three the 3D model including the full design analysis of the conventional helical coiled spring plus the new HCS made of CRC material, development of a new composite material with varying volume and weight fraction for the specified application through analytical and lab experiment is analyzed. In addition to this the design of the new helical coil spring made of CFRC material with full manufacturing processes and overall cost of the product comparing with the conventional helical coil spring and glass fiber composite material is also listed. The justification for replacing the conventional helical coiled spring by the new CFRC material is also included in this chapter through developing a new a prototype of the spring using glass fiber. On fourth chapter the final result and discussion is performed. The result is obtained from analytical and lab experiment plus the simulation of the new helical coil spring made of composite material relative with the conventional helical coil spring is also investigated in this chapter. The software provide basic solutions that helps to determine the require answers for the study and the lab experiment helps to determine the exact volume and weight fraction of the composite material for further manufacturing of the spring based on the results the discussion follows. On the final chapter, conclusion and recommendation including future work and limitation of the study is placed.

CHAPTER 2: LITERATE REVIEW

2.1. Composite Materials

Currently the need for a material with light weight and high performance is increasing day to day. The improvement of the performance for a material is limited when there is only one composition. Therefore, there have to be a new material with high performance which constitutes two or more conventional materials.

According to [27], Composite materials refers to materials in which two or more distinct materials are combined together but remain uniquely identifiable in the mixture, having strong fibers surrounded by a weaker matrix material. The matrix serves to distribute the fibers and also to transmit the load to the fibers [27, 28].

According to [27, 29] generally composite materials are classified and related to constituents as depicted in *figure 2.1.as follow.*

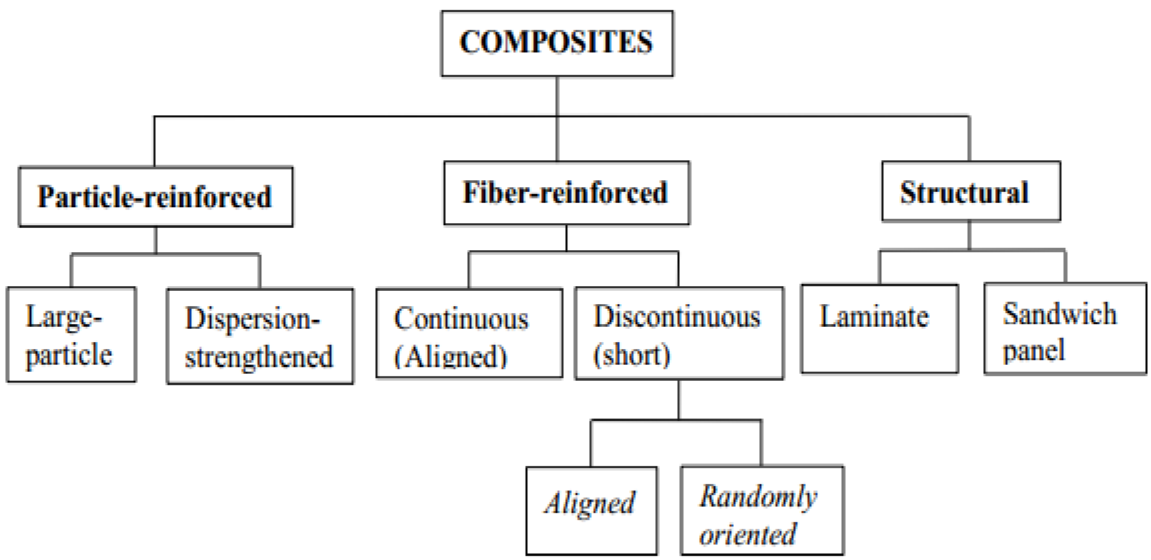


Figure 2.1: Composite material classification

The selection of the composite material for the specified application is chopped carbon and glass fiber that have a specific critical length and random fiber orientation with the desired property obtained from analytical and lab experiment result.

2.1. Previous Work Related with Helical Coil Spring using Composite Material

Many research's has been conducted on the analysis of weight, deflection and stiffness of spring made up of composite material. The research work related with helical coil spring, which are assisting to introduce the current study. Some of them are direct and the others are indirectly related to the current study. The journals and papers discussed on this sub title are categorized under the materials, method of manufacturing and test method

2.2.1. Material

Abdul Budan, T.S.Manjunathathe et.al (2010) [1, 17] checked feasibility of replacing the metal coil spring with the composite coil spring. Three different types of springs were made using glass fibre, carbon fibre and combination of glass fiber and carbon fibre. The objective of the study was to reduce the weight of the spring. According to the experimental results the spring rate of the carbon fiber spring is 34% more than the glass fiber spring and 45% more than the glass fibre/carbon fiber spring. The weight of the carbon fiber spring is18% less than the glass fiber spring, 15% less than the Glass fibre/carbon fibre spring and 80% less than the steel spring. Three types of composite coil springs have been developed in this study; they are lighter than steel spring and the stiffness achieved in these springs are less than the steel springs. (Spring rate of the same dimension steel spring is approximately 14 N /mm and weight of the steel spring is 1.078 kg). The following conclusions can be drawn from the analysis of experimental results of these springs. 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 favorable results compare to other two types of springs.

The cost of the glass fiber springs are 25% more than the steel springs and the cost of the carbon fiber springs is 200% more than the steel springs. The selection of the glass fiber or a carbon fiber springs depends upon the cost and application of the spring which can be compensated by saving the fuel from weight reduction. 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. Hence the application of the composite coil springs can be limited to light vehicles, which requires less spring stiffness, e.g. electric vehicles and hybrid vehicles.

P.K. Mallick et.al (2012) [1, 18] has fabricated and conducted the performance test for the composite elliptic springs The composite leaf springs are successfully used in the suspension of the light vehicles The fibers used in these are unidirectional E-glass due to their high extensibility, toughness and low cost. The composite leaf spring is designed and analyzed using ansys. The results showed that an optimum spring width decreases hyperbolically and the thickness increases linearly from the spring eye towards the axle seat.

Compared to steel springs the optimized composite spring has strength that are much lower, the natural frequency is high and the spring weight is nearly 80% lower. From this the experiment has been conducted only to cheek the weight reduction of the leaf spring without any consideration for fabrication purpose and the overall manufacturing cost for the whole component. Since it may be better to consider the recommended manufacturing processes of the whole system by considering the manufacturing cost of the component. [1, 18]

2.2.2. Manufacturing Method

Mehdi Bakhshesh and Majid Bakhshesh in their paper studied replacement of a helical steel spring by three different composite helical springs. Numerical results have been compared with theoretical results and found to be in good agreement. Compared to steel spring, the composite helical spring has been found to have lesser stress and has the most value when fiber position has been considered to be in direction of loading. Weight of spring has been reduced and has been shown that changing percentage of fiber, especially at Carbon/Epoxy composite, does not affect spring weight. Longitudinal displacement in composite helical spring is more than that of steel helical spring and has the least value when fiber position has been considered to be in direction of loading. The most safety factor is related to case that fiber position has been considered to be perpendicular to loading and it is for Carbon/Epoxy composite helical spring. Resin transfer molding process is used for manufacturing spring. [2, 11]

2.2.3. Test Method

Md Musthak and M. Madhavi developed high strength carbon epoxy spring with tape winding. Composite spring is manufactured using Carbon fiber in 45 degree orientation. Tests were conducted to study mechanical behavior. Spring is tested on UTM machine to determine deflections for various loads. A helical compression spring was developed for 1400N Payload and 30mm deflection. Three different types of spring were selected; glass fibre, carbon fibre and combination of both. The deflection and axial stresses are the design constraints for selection of fibre orientation in carbon pre-peg epoxy based spring. The results indicate that carbon pre-peg springs are superior in structural parameters. Load deflection results shows large variations in deformations reduced as there is lesser gap between coils. It is concluded that due to high strain energy capacity and corrosive resistance composite helical springs may be used for high strength Engg application .[7]

2.2.4. Finite Element Modeling

Steel helical spring has been replaced by three different composite helical springs including E-glass/Epoxy, Carbon/Epoxy and Kevlar/Epoxy. The loading conditions are assumed to be static. Spring Shear stress has been obtained using FEM and has been compared with steel helical spring. Composite spring properties have been studied with changing fiber angle relative to spring axial. The element is SOLID 46, which is a layered version of the 8-nodes structural solid element to model layered thick shell or solids. The element has three degree of freedom at each node and allows up to 250 different material layers. From results it is concluded that spring has the most Shear stress when fiber position has been considered to be in direction of loading. With changing fiber angle, Shear stress reduces so that it reaches the least value when fiber position has been considered to be perpendicular to loading. [11]

James M. Meagher et al. (1996) the author presented the theoretical model for predicting stress from bending agreed with the stiffness and finite element model within the precision of convergence for the finite element analysis. The equation was calculated by principal stresses and von misses stress and it was useful for fatigue studies. A three dimensional finite element model was used for two coil of different wire model, one was MP35N tube with a 25% silver core and other a solid MP35N wire material helical conductor and the result was compared with the proposed strength of material model for flexural loading[8]. M. T. Todinov (1999) author had given for helical compression spring with a large coil radius to wire radius ratio, the most highly stressed region was at the outer surface of the helix rather than inside. The fatigue crack origin was located on the outer surface of the helix where the maximum amplitude of

Ahana Dweepan [4, 12] studied material selection for conventional coil springs and found that use of composite material is beneficial if it can increase the efficiency of the vehicle and hence overcome the material cost. Other spring materials can be suggested for enhancements of fatigue life prediction. Modified design needs to be manufactured and tested for deformation and stress results. Model created in Pro E is exported to ANSYS by converting it to IGES format. The imported model is meshed in

ANSYS and boundary constrains are defined. With the Boundary constrains, the stresses and strain of the bone can be determined and the values are tabulated. And again by changing the material of the model the analyzing of the optimized model is done. Thus the investigation of stress and strain is carried out using ANSYS and better design is achieved.

Suresh.G, Vignesh.R, Aravinth.B, Padmanabhan.K, A.Thiagararajan done design and experimental analysis of composite helical spring made of fiber reinforced polymer of Woven Roving Fiber (WRF), and Thermo set polymer (Epoxy Resin) with Nano clay. The addition of nano clay provides unique mechanical and tribological properties combined with low specific weight and a high resistance to degradation in order to ensure safety and economic efficiency. A Comprehensive study was carried out a series of Nano composites containing varying amount of nano particles (Nano clay). The objective was to compare the load carrying capacity, stiffness and weight savings of composite helical spring with that of steel helical spring. The design constraints are stresses and deflections. The dimensions of an existing conventional steel helical spring of a light commercial vehicle are taken. Same dimensions of conventional helical spring are used to fabricate a composite spring. [3, 4]

The types of composite coil springs had been developed in this study; they are lighter than steel spring and the stiffness achieved in these springs are less than the steel spring. 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. Hence the application of the composite coil springs can be limited to light vehicles, which requires less spring stiffness, e.g. electric vehicles and hybrid vehicles. The manufacturing of the composite coil springs is also difficult and time consuming compare to steel spring, however with the use of CNC winding machine and automated process which can be made easy and also the manufacturing cost can be reduced if produced in mass. [3]

However in this study since the following points are not included during the study, the development and manufacturing techniques obtained is not satisfactory with the current trend of chopped fiber orientation of composite material.

Lab experiment on the composition of the composite material for development of helical coil spring is not addressed. Furthermore, the spring rate of the helical coil spring is analyzed using STM spring rate analyzer instead of analyzing using the composition of the composite material. Moreover comparison on the design and development of composite spring is done with the same composite type instead with the helical coil spring made of structural steel.

CHAPTER 3: MATERIAL, METHODS AND CONDITIONS

3.1. Materials

In this work materials such as structural steel (property) for design aspect; E-glass fibers, high modules carbon fiber, jelcot, Epoxy resin with its hardener are utilized directly for developing composite preparation for both testing and prototype development . E-glass fibers, epoxy resin with its hardener and jelcot are obtained from Ethio plastic industry, Addis Ababa Ethiopia, whereas high modules carbon fiber is obtained from Dejen Aviation (Davi) under Bishoftu, Ethiopia;

3.1.1. Fiber Glass

Fiber glass materials mostly have chopped structure with different fibers orientations in the reinforcing glass layers. Various glass fibers orientations result in anisotropy of the material properties in the plane parallel to the fiber orientation.

E-glass fibers are, by far, the most common types found in chopped form. These types have good combinations of chemical resistance, mechanical and insulating properties.

Furthermore, E-glass offers the more attractive economics. E-glass has the following advantages as compared to other types of glass fibers. [5]

- ✓ E-glass fiber is cheap in price
- ✓ E-glass fiber has good electrical insulator characteristic
- ✓ E-glass fiber has higher mechanical strength than other glass fiber types.
- ✓ E-glass is low susceptibility to moisture (resists attacks from water)

E-glass fibers are usually exist in three principal types including, continue glass fiber, chopped glass fiber and unidirectional glass fiber. The types of chopped E-glass fiber which is used in this study and Uni directional glass fiber is shown in figure below.

Figure 3.1:UD and chopped E glass fiber

3.1.2. Carbon Fiber

Carbon fiber, alternatively graphite fiber, carbon graphite or CF, is a material consisting of fibers about 510 μm in diameter and composed mostly of carbon atoms. The carbon atoms are bonded together in crystals that are more or less aligned parallel to the long axis of the fiber. The crystal alignment gives the fiber high strength-to-volume ratio (making it strong for its size). Several thousand carbon fibers are bundled together to form a tow, which may be used by itself or UD into a fabric. [7, 8]

Carbon fiber is a high-tensile fiber or whisker made by heating rayon or polyacrylonitrile fibers or petroleum residues to appropriate temperatures. Fibers may be 7 to 8 microns in diameter and are more that 90% carbonized.

These fibers are the stiffest and strongest reinforcing fibers for polymer composites, the most used after glass fibers. Made of pure carbon in form of graphite, they have low density and a negative coefficient of longitudinal thermal expansion. Carbon fibers are very expensive and can give galvanic corrosion in contact with metals. They are generally used together with epoxy, where high strength and stiffness are required, i.e. race cars, automotive and space applications, sport equipment. Depending on the orientation of the fiber, the carbon fiber composite can be stronger in a certain direction or equally strong in all directions. A small piece can withstand an impact of many tons and still deform mainly. The complex inter UD nature of the fiber makes it very difficult to break. [8]


Figure 3.2: UD and chopped high modules carbon fiber

Generally the overall property composite materials can be summarized as follow

Table 3.1: Advantage and disadvantage of composite materials

Fiber	Advantage	Dis advantage	Remark
E glass	High strength	Low stiffness	
	Low cost	Short fatigue life	
		High temperature sensitivity	

Kevlar	High tensile strength	Low compressive strength	
	Low density	High moisture absorption	
Boron	High stiffness	High cost	
	High compressive strength		
Carbon (AS4,T300,C600)	High strength to weight ratio	Relatively high cost	Recommended for helical coiled spring
	High stiffness		
	Low density		
Graphite (GY-70,pitch)	Very high stiffness	Low strength	
		High cost	
Ceramic (silicon carbide, alumina)	High stiffness	High cost	
	High use temperature	Low strength	

3.1.3. Epoxy Resin and its Hardener

Among main group of the matrix materials, thermoset resins is the major one which includes polyesters, phenolic, melamine, silicones, polyurethanes and epoxies. The resin used for this study is Epoxy Resin with brand name of SYSTEM #2000 EPOXY RESIN, which is manufactured by Fiber Glast Development Corporation Company It has superior flexural strength, tensile strength, bond strength, adhesive characteristics and fatigue resistance than other types of resins. In general, epoxy resins have the following advantage over the other resin types

- Better adhesive properties (the ability to bond to the reinforcement or core)
- Superior mechanical properties (particularly strength and stiffness)
- Improved resistance to fatigue and micro cracking
- Reduced degradation from water ingress (diminution of properties due to water penetration)
- Increased resistance to osmosis (surface degradation due to water permeability) Quantity of resin required

Hardener (Catalyst) Epoxy resin is cured by adding a catalyst, which causes a chemical reaction without changing its own composition. The catalyst initiates the chemical reaction of the epoxy resin and monomer ingredient from liquid to a solid state. The curing agent applied in this work for the liquid epoxy resin is hardener with brand name of SYSTEM #2060 HARDNER Manufactured by Fiber Glast

Development Corporation Company. Here, in #2060, the number 60 indicates that the mixture of epoxy and hardener will change from liquid to solid state after 60 minutes if it used as an impregnation. The ratio of epoxy resin to hardener used for this study was based on their masses. In general ratio is calculated based on manufacturer guide lines and that was 27% hardener for 100% epoxy. According to manufacturer guide lines, better mechanical properties of composites after curing process are attained if & only if the above mentioned ratio is correctly applied irrespective of any environmentally determined conditions. Finally, these proper amount of epoxy & hardener is mixed and stirred for few minutes using deep stick material. [5]

3.2. Analytical Methods and Condition

3.2.1. Design Analysis of Conventional Helical Coiled Spring

The design of the new helical coiled spring made of carbon reinforced composite material is starting from design of the profile of conventional helical coiled spring made of structural steel at the static condition using loading condition, modeling of the system, design the new helical coil spring by developing a new composition of matrix and fiber and finally preparing the recommended manufacturing system of the spring including the overall prototype of the spring.

3D modeling of helical coiled spring for light vehicle

Using **Solid works 2015** we can model the helical coiled spring made of carbon reinforced composite material and conventional steel as follow.

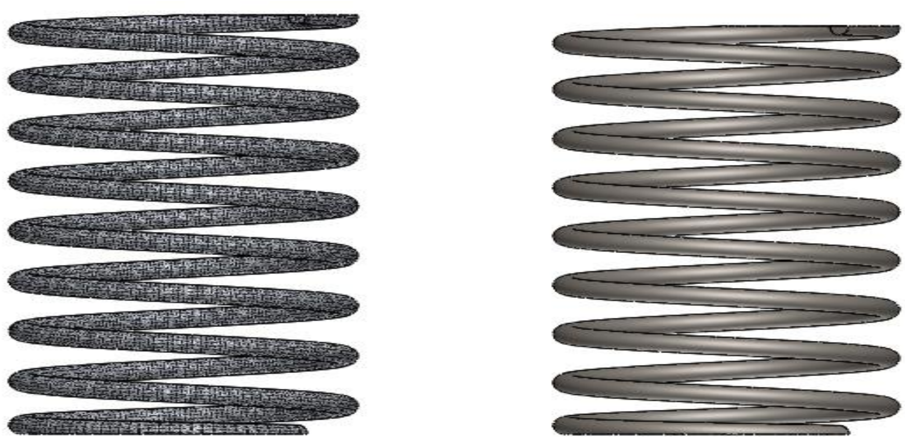


Figure 3:3D modeling of the HCS made of CRC material and structural steel respectively

The design of the profile of helical coiled spring can be carried out from loading condition of the standard lightweight vehicle at the specified dynamic condition as shown it table 3.2 below.

Through searching different literates and by investigation some local spring which are mainly used for light weight vehicle we can select a coil and closed end type of spring for our design of helical coiled spring.

According some loading condition and research we have three loading condition in which the total self-load of the spring and weight of the passenger should consider to develop the profile of the spring as follow.

Table 3.2: Loading condition of light weight vehicle [34]

Case	Dynamic condition	Weight of the vehicle resting on the springs(N)	Average weight of passenger (N)	Total resting on the springs(N)
1	At static condition(neglecting the weight of the passenger)	273	0	273
2	At static condition(considering the weight of the passenger)	273	900	1173
3	During dynamic condition(considering vibrational load)	273	930	1202

In this case the loading condition of the spring material can be considered the dynamic condition by considering both weight of the vehicle resting on the spring and average weight of the passenger using structural steel. This helps to develop the final profile of the spring that satisfy the dynamic condition of the spring.

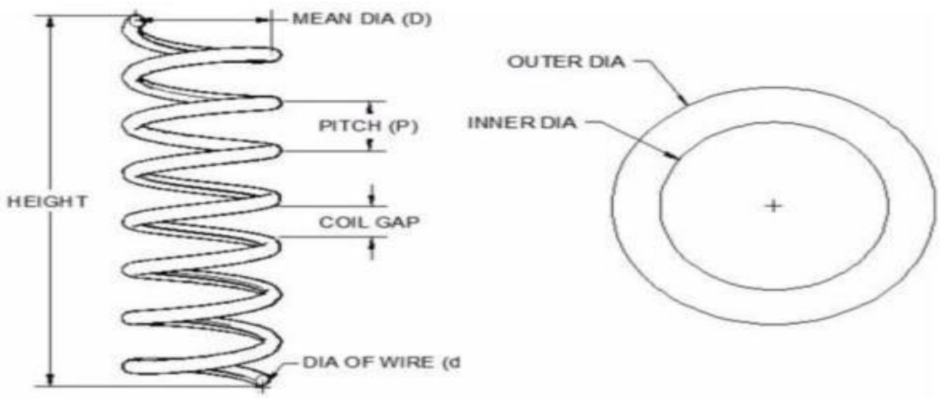


Figure 3.4: Over all profile of helical coiled spring

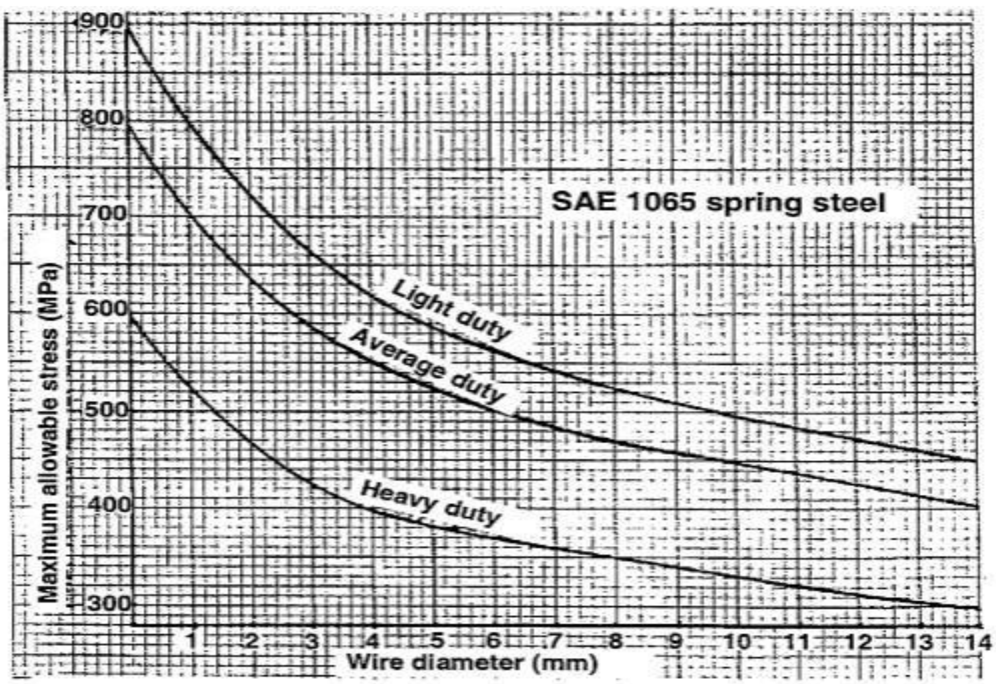


Figure 3.5: Maximum allowable stress of spring [17]

One of the important variables of a spring is the spring index C which is defined as the ration of the mean diameter to the wire diameter. In this case springs used in engineering have a spring constant that lies in the range 4 to 15.a rule of –thumb increase as the size of the spring increase in accordance with the following table. [17]

Table 3.3: spring index value of different spring

Size of spring	**D (mm)**	**d (mm)**	**C**	**Remark**

Small	<8	<1	4-8	
Medium	8-24	1-4	8-12	
Large	>24	>4	12-15	Recommended

From this we can consider the size of the spring as a large from the principle of the standard size of spring for automobile and some current literates. From this we can select a spring index factor as 12. [14]

$$i.e\ C = \frac{D}{d} \qquad (3.1)$$

From iteration principle we can find out the allowable stress of the helical spring in accordance the spring index of 12 as 515 MPa due to a wire diameter of 10 mm and the mean coil diameter as 120 mm. This is true that the maximum stress of the steel is less than the allowable stress of the steel which lies between (75%-85%).i.e. the maximum torsional stress of the spring is 459 MPa

Bending stress are present but can be ignored except when the pitch angle is greater than 15^0 and deflection of each coil greater than D/4.under elastic condition, torsional stress is not uniform around the wire cross section due to coil curvature and a direct shear load.

The maximum allowable shear stress in the spring under design or maximum load conditions depends up on the following factors such as wire material property, diameter of the wire and service condition or duty which depends primarily upon the number of cycles required in the life of the spring and the amount of shock associated with the load. For continence three service condition can be identified as listed in the following table. [17]

Table 3.4: Spring service condition

Load type	**Number of cycles**	**Types of load**	**Remark**
Light	$<10^4$	Static or gradually applied	
Average(medium)	10^4-10^6	Gradually applied-light shock	Recommended
Heavy	$>10^6$	Light-heavy shock	

In addition to this the maximum stress occurs at the inner surface of the spring and is computed using stress correction factor. The most widely used stress correction factor K_{W1} is attributed to wahl.it is shown below. [17]

$$Kw = \frac{4C-1}{4C-4} + \frac{0.615}{C} \quad (3.2)$$

$$Kw = \frac{4*12-1}{4*12C-4} + \frac{0.615}{12}$$

Kw=1.25

From this the maximum shear stress will be

$$\text{Max } shear(\tau) = \frac{8 \times 1202N \times 120mm \times 1.25}{\pi(10mm)^3} \quad (3.3)$$

Max shear stress (τ) =459.36 MPa

From this we can cheek the corresponding allowable stress of the spring material from fig 3.5 with corresponding diameter of the spring as 10 mm as 515 which is 83.3% of the max shear stress. So the selection of the diameter of the wire according the given standard allowable stress of the spring in fig 3.5 will be possible.

Table 3.5: Loading condition at midsize base line of suspension component and weight of passenger [33]:

d(mm)	C	D	d^3	π	W	Kw	Constant	8*Kw*D*W	π *d^3	Max Shear	σ max
5.6	12	67.2	175.61	3.14	1202	1.25	8	807744	551.4154	1464.85	610
6.3	12	75.6	250.04	3.14	1202	1.25	8	908712	785.1256	1157.40	570
7.1	12	85.2	357.91	3.14	1202	1.25	8	1024104	1123.837	911.25	560
8.6	12	103.2	636.05	3.14	1202	1.25	8	1240464	1997.197	621.10	540
9	12	108	729	3.14	1202	1.25	8	1298160	2289.06	567.11	520
10	12	120	1000	3.14	1202	1.25	8	1442400	3140	459.36	515
11.2	12	134.4	1404.9	3.14	1202	1.25	8	1615488	4411.386	366.20	500
12.5	12	150	1953.1	3.14	1202	1.25	8	1803000	6132.734	293.99	480

From this lets select the spring index (C) =12

$$C = \frac{D}{C}$$

In addition to this the mean coil diameter D and outer diameter of the spring can be calculated as follow.

From this D=12d

The deflection of the helical compression spring for circular cross-section is calculated by the formula. [14]

$$\delta = \frac{8WD^3n}{Gd^4} \; or \; \frac{8WC^3n}{Gd} \qquad (3.4)$$

$$\delta = \frac{8WC^3n}{Gd} = \frac{8 \times 1202 \times 12^3 \times 9}{78.6 \times 1000 \times 10}$$

δ =190.26mm

In addition to this from the above design parameters we can also calculate the stiffness of the spring material deflection as follow.

$$K = W / \delta \qquad (3.5)$$

i.e. the stiffness of the spring at 1202N will be 6.3N/mm, [14]

The solid height of the spring can also calculate as

$$L_s = d \times Na + 2 \times d \qquad (3.6)$$

$$L_s = (10 \times 7 + 2 \times 10)$$

L_s=90mm

The free length of a compression spring were compressed solid length would be [14]

$$L_f = d \times Na + \delta \qquad (3.7)$$

Where δ is the total deflection from the zero load position. However it is undesirable to have a compression spring shock under load so a clash allowance Ca should be included when determine the free length of the spring.in this case the clash allowance is the amount by which the design deflection is increased to eliminate the possibility of chocking under load. The clash allowance is usually at least 10%, however a check of the ASP spring catalog reveals that their spring usually have a clash allowance of between 10% and 20%.[14]

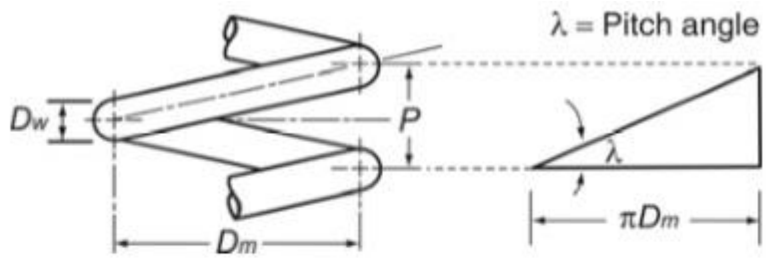
$$L_f = d \times Na + \delta\,(1 + Ca) \qquad (3.8)$$

From this by considering the clash allowance as 13% we can calculate the free length at respective load as follow.by considering the crash allowance as 13%

$$L_f\,(at\ 300N) = 10 \times 7 + 190.2(1 + 13\%)$$

L_f=284.9mm

In addition to this the pitch which is the distance between the distances between consecutive coils of spring can be calculated using the equation.



$$P=\frac{Lf-2d}{Na} \tag{3.9}$$

$$P=\frac{284.9mm-2*10}{9}$$

P=29.5mm

The length of wire needed to make the spring is found from,

$$Lw = \frac{\pi\times D(Na+2)}{\cos(\theta)} \tag{3.10}$$

Where θ is the helix angle which can be calculated as,

$$\text{Pitch angle } (\theta) = \tan^{-1}(\frac{\text{coil pitch}}{\pi D} \tag{3.11}$$

$$\text{Pitch angle } (\theta) = - (0.0.076)$$

$$\text{Pitch angle } (\theta) = 4.2^0$$

From this the total length of the wire for manufacturing of the above helical coiled spring is obtained using the above expression as

$$Lw\ at\ 1202\text{N} = \frac{\pi\times D(Na+2)}{\cos(\theta)}$$

$$Lw\ at\ 1202\text{N} = \frac{\pi\times 120mm(7+2)}{\cos(4.2)}$$

$$L_w\ (1202N) = 3402.05mm$$

Finally we can also calculate the mass of spring from calculating the volume of the spring as

$$V=(\pi r^2)(2\pi nR) \tag{3.12}$$

Where R is the distance from the center of the tube to the center of the helix and r is the radius of the wire .From this volume of the spring at dynamic condition three will be 0.00027m^3 which can get the mass of the spring as 2.61kg by corresponding with the density of the structural steel

In addition to the design of the spring as the free length of the spring increase in proportion to its diameter (that's the spring becomes more slider) the spring can buckle under loads in similar manner for column.

Since if L/d >10 the spring will most likely buckle under any load or deflection

If L/d<10 the likelihood of buckling depends upon the maximum load or deflection and can be determined by reference to the graph 3.3 below. [17]

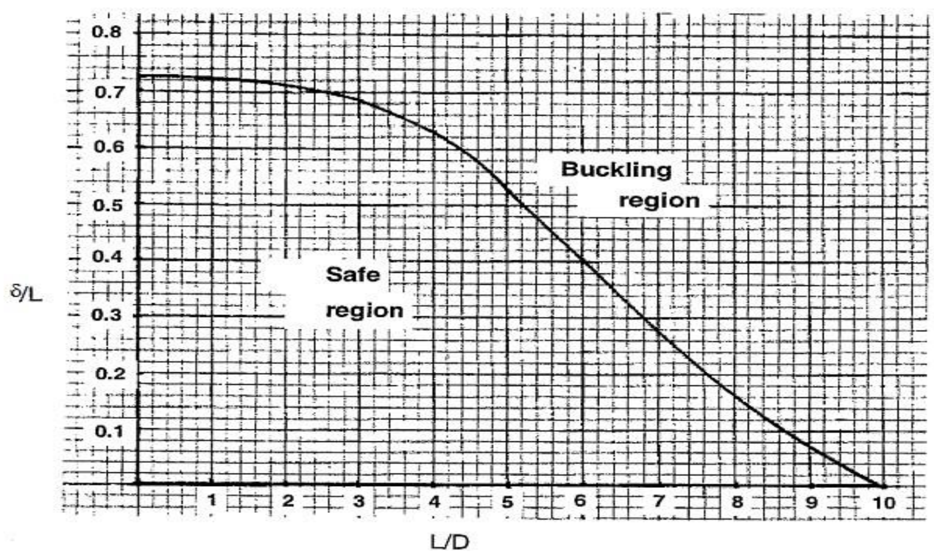


Figure 3.6: Maximum L/D ratio for buckling

From this using the above design result and parameters lets first determine the ratio of L/D

i.e. L/D=$284mm/120mm$=2.3, then using fig 3.3 the corresponding value will be

0.7(maximum for buckling) δ_{max}=$0.7 \times 284mm$=198.8mm

Since the deflection for the spring is 198.8mm, buckling is unlikely and no support is needed.

In addition to tis this by considering the modules of elasticity of the material and the maximum stress caused on the spring we can calculate the strain energy stored by the spring as

$$U = \frac{\sigma^2}{\rho * E} \qquad (3.13)$$

Since by considering the maximum shear stress induced on the spring and by considering the modules of elasticity and density of the material we can get the maximum energy stored by the spring as 610 mJ.

3.2.2. Fiber and Matrix Volume Content of the Composite

In design, fabrication and analysis of composite materials, the first and critical task is the determination of ingredient percentages such as fiber and matrix (resin) fraction presence in both chopped carbon and glass composite material. These components are microstructural elements of the composite in which composites strength and properties are determined and limited by these values. In generals, result obtained from the equations presented below are mandatory for:

Composite chopped carbon and glass fiber preparation

- ✓ In order to use ASTM standard. To determine weight of composite that meets the ASTM requirements prior to composite fabrication, these values are necessary.
- ✓ Finite element analysis purpose. Even though it didn't in this study, but, if anyone who want do this task in future it is possible to take these values as a primary data for analysis.
- ✓ The improvement of fabricated sample test for the future by varying these values.
- ✓ These values can be used as a design manual in collaboration of composite sets such as composite sample different experimental results which are fabricated by these content [18], etc.

In this case we have two approach that helps for determine the basic property of the composite material according

1. Advanced rule of mixture through different volume fraction ration composition ratio of fiber and matrix.
2. Using UTS (Universal tensile testing machine) by preparing a specimen with different composition of fiber and matrix and accounting some assumptions
3. Analyzing the error and selecting the appropriate value

Using advanced rule of mixture the mechanical property of the composite material such as modules of elasticity and shear modules by considering the passions ratio for chopped fiber orientation can be calculated as follow.

Assumption

Assume that the fiber is randomly oriented which can be considered as a homogenous structure [21]

$$E = \eta o\, \eta L\, Ef\, Vf + Em\,(1 - Vf) \qquad (3.14)$$

η_L is a length correction factor. Typically, η_L approximately 1 for fibre longer than about 10 mm.

η_O corrects for non-unidirectional reinforcement:

Table 3.6: ηo corrects for non-unidirectional reinforcement:

Position of fiber	η_O
Unidirectional	1
Biaxial	0.5
Biaxial @±45	0.25
Random in plane	0.375
Random 3D	0.2

And the theoretical length correction factor will be calculated as

$$\eta_L = 1 - \frac{\tan h(\beta L/2)}{(\beta L/2)} \quad \text{and} \quad \beta = \sqrt{\frac{8Gm}{EfD^2 \ln(\frac{2R}{D})}}$$

Ply thikness the ply thikness is defined as the number of gram of mass of fiber m_{of} per m^2 of area if we assume the ply thikness as b such that

$$b \times 1(m^2) = \text{total volume} = \frac{total\ volume \times mof}{fiber\ volume \times density\ of\ fiber}$$

$$\text{that is } b = \frac{mof}{vf\rho f}$$

$$b = m_{of}\left[\frac{1}{\rho f} + \frac{1}{\rho m}\left(\frac{1-mf}{mf}\right)\right]$$

In short fibre-reinforced thermosetting polymer composites, it is reasonable to assume that the fibre are always well above their critical length, and that the elastic properties are determined primarily by orientation effects.

From this we can calculate the overall result property of the composite as follow.

Table 3.7: Analytical result of modules of elasticity different chopped composite at different volume fraction

Vm	Vf	E glass	E fiber	E resin	η L	ηO	E of chopped carbon fiber	E of chopped glass fiber	Reference
0.4	0.6	72	228	4.5	1	0.2	138.6	45	ROM
0.5	0.5	72	228	4.5	1	0.2	116.25	38.25	ROM
0.6	0.4	72	228	4.5	1	0.2	93.9	31.5	ROM

Following the same procedure for determine the density and poisons ratio of the composite of both fibers as

Table 3.8: Analytical result of Poisson's ratio different composite at different volume fraction

Volume fraction of matrix and fiber respectively		Poisson's ratio of glass fiber	Poisson's ratio of glass fiber	Poisson's ratio of resin	Density of carbon fiber	Density of Glass fiber	Density of epoxy resin	Poisson's ratio of carbon fiber after mixing	Passion's ratio of glass fiber after mixing	Density of carbon fiber after mixing	Density of glass fiber after mixing
0.4	0.6	0.53	0.22	0.35	1.8	2.58	1.2	0.476	0.259	1.56	2.028
0.5	0.5	0.53	0.22	0.35	1.8	2.58	1.2	0.422	0.298	1.5	1.89
0.6	0.4	0.53	0.22	0.35	1.8	2.58	1.2	0.458	0.272	1.44	1.752

Table 3.9: Analytical result of shear modules of different composite at different volume fraction

Vm	Vf	E of chopped carbon fiber (GPa)	E of chopped glass fiber(GPa)	V of chopped and UD glass fiber	V of chopped and UD carbon fiber	G of chopped glass fiber(GPa)	G of chopped carbon fiber(GPa)	Reference(equation)
0.4	0.6	138.6	10.44	0.25	0.47	9.64	30.64	3.22

0.5	0.5	116.25	9.45	0.29	0.42	8.3	25.8	3.25
0.6	0.4	93.9	8.46	0.27	0.45	6.96	20.96	3.25

3.3. Experimental Methods and Condition

3.3.1. Fiber and Matrix Volume Content of the Composite

Preparation of Test pieces

The mechanical property of composite materials with varying composition of fiber and matrix can be carried out for chopped and random orientation using lab experiment by preparing standard specimen as shown in figure 3.7.

The preparation of test pieces of composite material for analyzing the mechanical property such as modules of elasticity and shear modules using tensile testing machine can be carried out by considering the standard profile of the tensile testing machine.

The overall manufacturing technique of composite material made of chopped glass and carbon fiber with the specified weight and volume composition of the fiber and matrix is carried out as follow.

1. Preparing a mold which has a rectangular shape and dimensions according **(ASTM DI-CP/V2B)** the mold for preparing a sample can be considered as a rectangular structure with a dimension shown below.

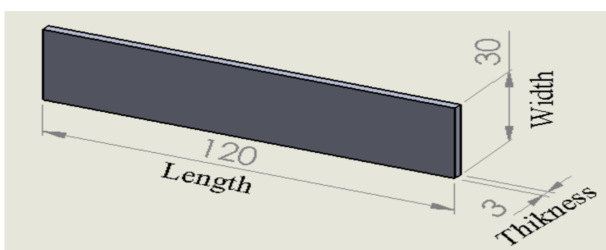


Figure 3.7: Standard size of specimen for testing

2. Analyzing the weight fraction relative with the volume fraction of the fiber and the matrix

By considering the volume of the mold and density of the composite material after manufacturing using rule of mixture we can get the respective weight of the individual composite material as follow.

3. Preparing the weight composition of the mold for manufacturing aspects

Table 3.10: Composition of chopped glass and carbon fiber for mold preparation

Profile type	**Number of specimens**	**Fiber orientation**	**Total volume**	**Volume fraction**		**Total density of the rectangular plate**	**Total weight(g)**	**Weight fraction**	
				Matrix	**Fiber**			**Matrix**	**Fiber**
120*30*3	3	Chopped	10.8cm^3	0.4	0.6	1.924	20.77	8.176	12.462
120*30*3	3	Chopped	10.8cm^3	0.5	0.5	1.76	19.008	9.5	9.5
120*30*3	3	Chopped	10.8cm^3	0.6	0.4	1.596	17.23	10.33	
120*30*3	3	Chopped CF	10.8cm^3	0.4	0.6	1.45	15.66	6.26	9.39

4. Preparing the mold element for respective composite composition
5. Preparing the specimen mold for molding purpose for the condition that removing of the work piece from mold will be easy
6. Mixing of both fiber and resin including hardener for each type of composite material by considering the weight fraction of the resin and the matrix
7. Relating with the analytical determine value of the composite material for the mechanical property of the material

3.3.2. Design Analysis of New Helical Coil Spring Made of Composite Materials

Table 3.11: Overall profile of the spring

Standard Profile of Spring	**Numerical Input Result**				
	Profile of Helical Coiled Spring	Mechanical property			
		Chopped Carbon Fiber		Chopped Glass Fiber	
Wire diameter of spring (d)	10mm	Density (Kg m^{-3})	1450	Density (Kg m^{-3})	1924

Active loops number(N)	7	v ratio	0.45	v ratio	0.25
Total number of coils (N_t)	9	Shear modules	33.2(GPa)	Shear modules	3.8(GPa)
Mean coil diameter (D)	120mm	Modules of elasticity	130(GPa)	Modules of elasticity	9.6(GPa)
Pitch (P)	29.71mm				

The design parameter of the helical coil spring made of composite material consists of analyzing the spring rate, deflection of spring relative with the effect of load at the static condition and overall weight of the spring using lab experiment result.

From this using lab experiment result of the property of the composite material with the desired composition such as the modules of elasticity and shear modules we can obtain the design result of the spring as follow.

The maximum deflection of spring at a maximum load of 900N

$$\delta = \frac{8WC^3n}{Gd} = \frac{8 \times 1202 \times 12^3 \times 9}{78.6 \times 1000 \times 10}$$

$\delta = 190mm$ From this the spring rate will be 6.10N/mm *(equation 3.5)*

Following the same procedure we can also obtained the deflection and spring rate of the remain springs from the lab experiment data obtained.

In addition to this the total weight of the spring can be calculated from the overall volume of the spring as

$$V=(\pi r^2)(2\pi nR)$$

$$V=0.00027m^3$$

And the weight of spring made of carbon fiber composite material will be

$$m = \rho \times V$$

From this the mass of the spring composed of carbon fiber will be 391.5g and the weight of the spring made of glass fiber will be 519.48g relative with 2610 g weight of conventional helical coiled spring made of structural steel.

3.4. Analyzing Cost of the spring

The overall cost of helical coil spring made of conventional structural steel, chopped glass fiber and carbon fiber is listed as follow.

Table 3.12: Overall cost breakdown of spring

Type of spring	Material cost/birr				Manufacturing cost/birr		
Glass fiber spring	Material	Resin (lit)	Hardener(lit)	Glass fiber(Kg)	Labor cost /hr.	Machine cost	Total cost/birr
	Total amount	2.3	0.25	1.2	2	-----	569.5
	Unit cost /litter (birr)	100	13	82	110	------	
	Total cost (birr)	230	20.5	98.4	220		
Carbon fiber spring	Material cost/birr				Manufacturing cost/birr		
	Material	Resin(lit)	Hardener(lit)	Carbon fiber (Kg)	Labor cost /hr.	Machine cost	Total cost/birr
	Total amount	2.3	0.25	0.82	2	1.3	821.5
	Unit cost /litter	100	13	325	110	65	
	Total cost	230	20.5	266.5	220	84.5	
Conventional spring							413

3.5. Manufacturing of Helical Coil Spring Using Composite Materials

We may have different manufacturing system of helical coiled spring but among those different types of manufacturing processes resin transfer molding processes is the most and widely used for manufacturing of different spares which have more truncated shape such as coil spring.

In this case for specific type of the material which is the helical coiled spring made of composite material such as carbon and glass fiber composite materials with the specified fiber and matrix structure we can manufacture and prepare the helical coiled spring through the following two alternatives.

Type 1. Prearing a cylindrical mold of a liquid which have a profile of inner diameter of the mold as ± outer diameter of the helical coiled spring. From this the profile of the spring is obtained through machining from the center of the mold up to the inner diameter of the spring and further machining process which can be considered as a surface finish.

In this case the fiber position is always oriented as randomly plus the fiber length is short and discontinuous.

i.e. preparing final profile of spring made of any material which have elastic property

↓

Preparing a liquid mold of composite material

↓

Molding to any cylindrical shape

↓

Inserting the profile of the spring to cylindrical mold

↓

Waiting until the liquid is solidified to somehow a solid state

↓

Removing the profile of the spring

↓

Machining the mold structure

↓

Machining and further surface finish of the profile of the spring until we get the final profile of the spring

Type 2. The second type of manufacturing processes of helical coiled spring which can be categorized under resin transfer molding process is similar with the above type of manufacturing processes except that the type of fiber can be a continuous fiber. In this case the type of loading with the fiber position can vary. This processes can be simply summarized as follow.

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. Mandrel is prepared with aluminum or any other metal that can be easily machining. This mandrel having the shape of the spring profile is fixed between the centers of the filament winding machine. A mould release agent such as wax is applied on the mandrel for minimizing friction between the contact surfaces. 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 diameter 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 an hours according the volume ratio of the hardener. After curing the spring is removed from the mandrel. The cured spring has the dimension of as the result of the design.

Generally we can evaluate and select the type of manufacturing of the spring as follow.

Table 3.13: Evaluation of manufacturing processes of HCS using composite materials

No	**Evaluation criteria**	**Weight (%)**	**Type 1 (%)**	**Type 2 (%)**
1	Easy for Manufacturing	30	20	22
2	Simplicity for Mass Production	30	22	25
3	Manufacturing Cost	15	13	12
4	Material Wastage	15	10	14
5	Accuracy of Final Product	10	5	10
	Total	**100%**	**70%**	**83%**

Since by considering the above different evaluation criteria's we can select the first type of manufacturing processes of helical coiled spring **(Type 1)** due to the specific application and type of fiber orientation From this we can manufacture and test the helical coiled spring for the sake of testing some mechanical property such as spring rate, deformation and weight of the spring as follow.

The method used for the production of the springs is a variation of the RTM (Resin Transfer Molding) 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 first stage in filament winding machine is preparation of the mold from aluminum solid bar with the specified number of coil and profile of spring including helix angle as follow; In this case a solid which is helical coiled spring composite is going to be produced, so a solid Perspex mould from aluminum is used. Preparing a mold.

Figure 3.8: Preparing of spring mold from solid aluminum

The mould surface is cleaned with wax and then a release agent such as jelcot is applied to the mould surface. This will help the removal of the composite part after curing.

Figure 3.9: Wax release agent such as jelcot

Next the fiber reinforcement is cut out to the desired shape and fiber orientation from the roll.

Figure 3.10: Twintex comingled UD fabric of carbon and glass fiber

If the material being used is not a comingled resin and fiber weave, now would be the time to mix the resin with the relevant hardener in the desired ratio. (For our general purpose resin that will be used on the final composite of the spring, this ratio is 0.4:0.6 by weight as shown in our design composition the material used in this filament winding process is a fabric called glass fiber and has a commingled weave consisting of glass fiber fibers and general purpose resin as from the other side or tanker, shown in Figures.

Once this is done the composite making can now be started, first resin is applied to the surface of the mould (making sure to leave enough room for the vacuum bagging apparatus) and the first layer of the fibers is laid down. Then more resin is applied and the next layer is put down in the correct orientation, this continues until the desired composite profile is achieved as shown in Figure and.

Winding the chopped fiber as mat form by considering the critical length with the specified resin type according the specified volume of the fiber and the resin as specified in the above table

Figure 3.11: Final manufacturing of HCS made of composite material

CHAPTER –4: ANALYTICAL AND EXPERIMENTAL RESULT AND DISCUSSION

4.1. Tensile Test Result

The mechanical property of composite material such as modules of elasticity is derived from tensile test with varying the composition of the composite content. In this case the composition of the composite material with chopped fiber orientation on carbon fiber (0.4:0.6) and chopped glass fiber with (0.4:0.6, 0.5:0.5, 0.6:0.4) is investigated using tensile testing machine **(ASTM DI-CP/V2B serial number 12M9993)** is shown is figure below.

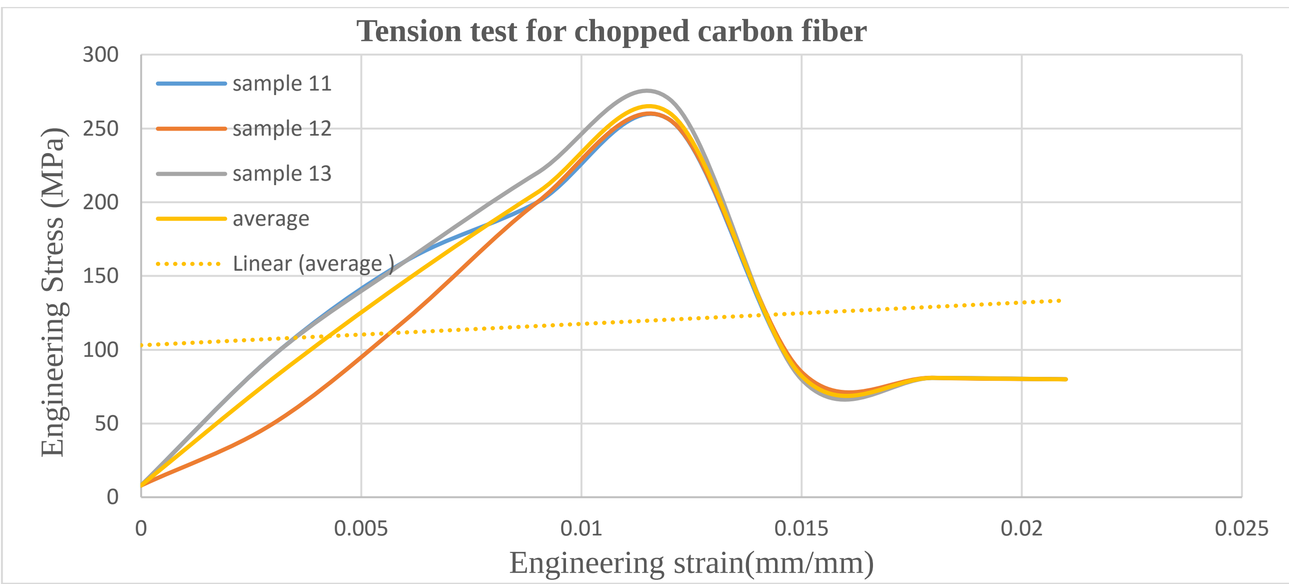


Figure 4.1: Engineering stress vs engineering strain for chopped carbon fiber

Engineering stress/strain are laboratory stress/strain that obtain by taking load & elongation of a given specimen as primary output from the experiment that defined the curve of stress-strain.

Following the same procedure we can conduct an experiment on analyzing the property of chopped carbon fiber as follow. From this the slop under thee graph y=ax+b where the value x will be the modules of elasticity. In addition to this the shear modules or modules of elasticity will be calculated using equation. Where the possion’s ratio is obtained from analytical result using advanced rule of mixture. Following the same procedure we can also find out the modules of elasticity for chopped glass fiber with random fiber orientation as follow.

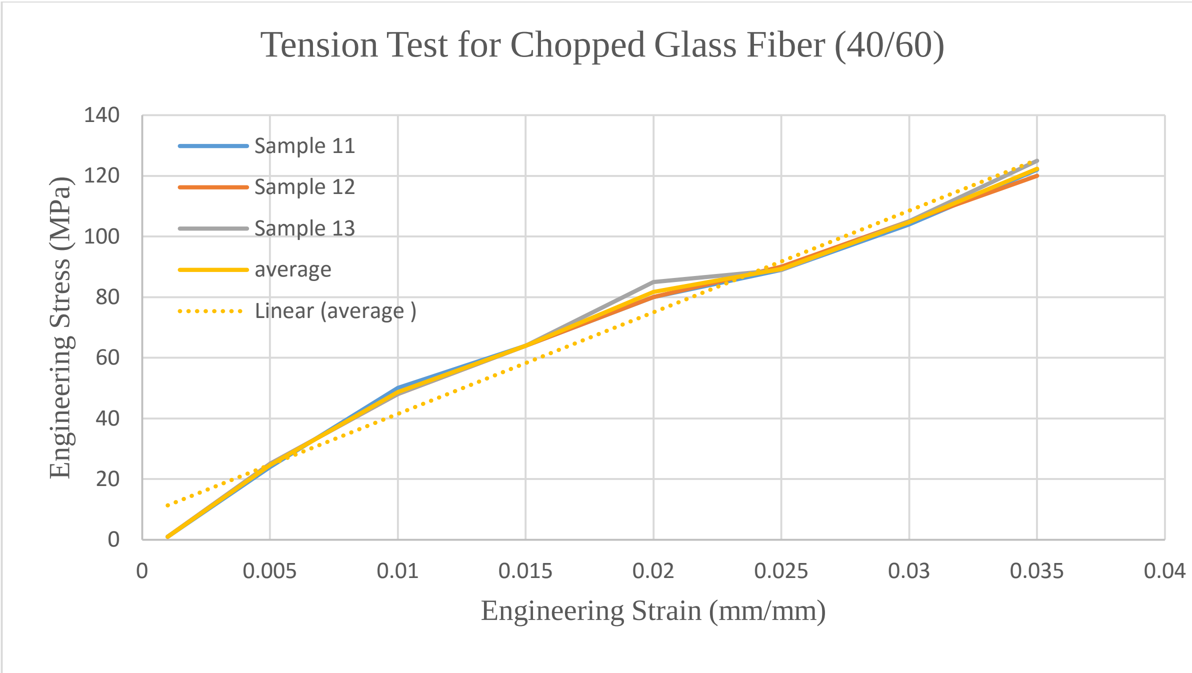


Figure 4.2: Engineering stress vs engineering strain for chopped glass fiber

Table 3.11: Overall Experimental Result

Vm	Vf	E of chopped carbon fiber (GPa)	E of chopped glass fiber(GPa)	V of chopped glass fiber	V of chopped carbon fiber	G of chopped glass fiber(GPa)	G of chopped carbon fiber(GPa)	Reference(equation)
0.4	0.6	130	9.6	0.25	0.47	3.8	33.2	
0.5	0.5		9	0.29	0.42	9	24.6	
0.6	0.4		8.6	0.27	0.45	9	22.6	

4.2. Analytical Result

4.2.1. Loading Condition Design Result of New Helical Coil Spring

The design result on the profile of helical coiled spring using conventional structural steel for further design and development of new helical coil spring made of composite material is listed in table (4.1) below. In this case the effect of self-load of the total load setting on the spring and load of passenger which yields 1202 N at the static condition yields the full profile of spring as shown in table below.

Table 4.1: Loading condition result of helical coiled spring in different load condition

Design Profile of spring	Dimension of spring	Remark
Wire diameter of spring (d)	10mm	
Solid height(h)	90mm	
Maximum load possible	1202N	
Total length of the wire(L)	3402.13	
Free length (L_f)	284.9mm	
Spring constant (K)	6.3N/mm	
Maximum displacement	34mm	
Active loops number(N_a)	7	
Total number of coils(N_t)	9	
Mean coil diameter (D)	120mm	
Pitch (P)	29.5mm	
Coil outer diameter (Do)	130mm	
Rise angle of coil	4.2^0	
Deflection of spring	142mm	
Maximum deflection for buckling	198.8mm	
Critical length of fiber	100mm	
Mass of spring	2.09Kg	

The final design of helical coiled spring for the specified load is listed in table (4.1).since the geometry of the spring which is developed using loading condition will be used for analyzing the spring stress and design analysis.

4.3. Analytical and Experimental Result on Composition of the Composite Material

4.3.1. Analytical and Experimental Result on Mechanical Property of Composite Material

The fiber volume fractions of both the composite type with different fiber composition is given in table appendix C1. The overall result on the mechanical property of the composite material such as modules of elasticity and shear modules is obtained both analytically and lab experiment. The slop under the graph stress-strain yields the modules of elasticity (Appendix B). In addition to this from the above modules of elasticity and passion's ratio we can find out the shear modules. It is evident from the results that the variation of volume fraction of the fiber and the matrix has a positive variation of mechanical property of the material relative with the analytical result. The overall analytical and experimental result shows the final composition of the composite material for design and development of the spring should be 0.6:0.4 (where 0.6 volume fraction of fiber and 0.4 volume fraction of matrix) as sown from the final mechanical property of the composite material listed below. However due to manufacturing difficulties and variation in the fabrication process the exact fiber volume fraction could not be achieved. The exact fiber volume fraction can be achieved by precisely controlling the manufacturing variables. Since the maximum variation in the fiber volume fraction is less than 5%, the results obtained are not much affected.

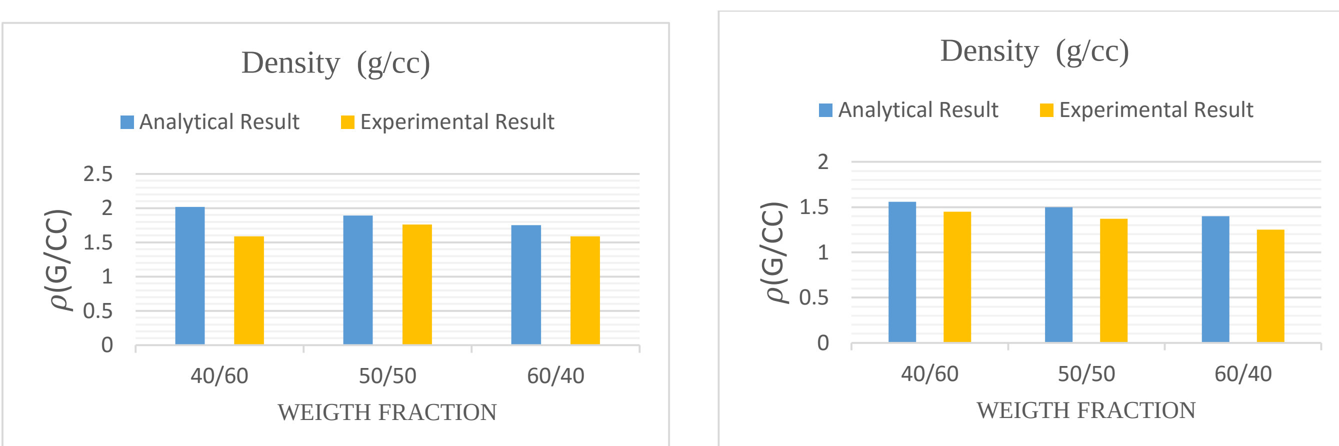


Figure 4.3: Comparison of density of glass and carbon fiber composite material respectively

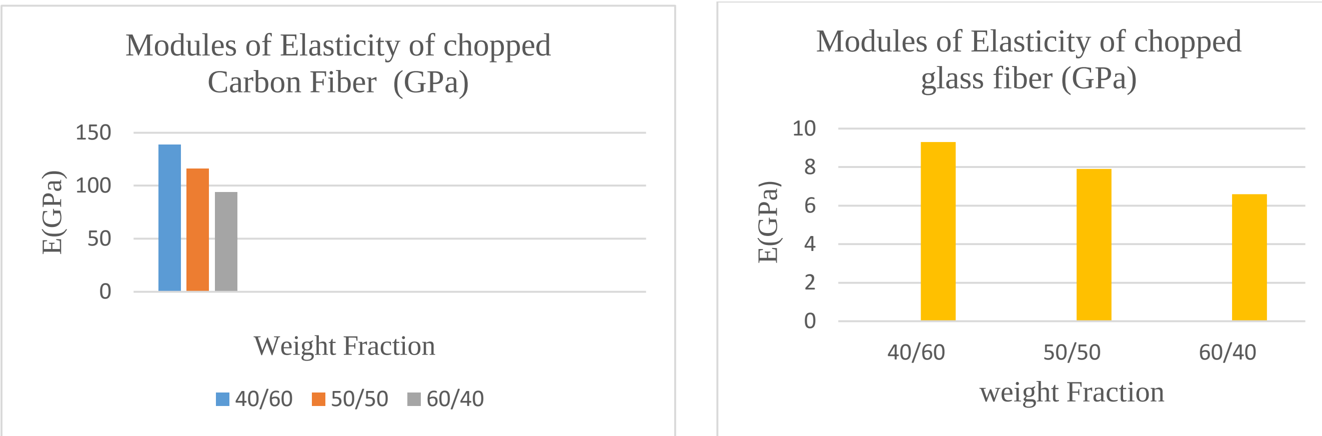


Figure 4.4 Comparison of modules of elasticity of chopped carbon and glass fiber

4.3.2. Weight of the spring

The weight of steel spring is 2.6 kg but after replacing the material property of the spring model to the composite materials the weight of the composite helical spring was drastically reduced. For carbon fiber reinforced composite material we c have the weight is 0.391 kg and for the glass fiber composite material the weight is 0.519 kg obtained from lab experiment. The numerical result from the experimental result of the mechanical property such as density in all spring with the same profile of spring and volume of spring shows helical coil spring made of carbon reinforced composite material is 84.96% more lighter than conventional helical coil spring and 24.66% than glass fiber reinforced composite material.

In addition to this the reduction of weight of coil spring have an effect on reducing the total weight of the vehicle in 0.385% relative with carbon fiber and 0.09% relative with glass fibre with the current light weight vehicle that have around 1150-1500Kg total weight.

Corresponding with the research are on replacing metal coil spring by composite materials [1,18,] with rectangular profile for the wire of spring and [2,3,22] with circular profile of wire of the spring shows a good arguments on lowering the weight of spring.

This drastic reduction of weight in helical spring can lead to very good stiffness to weight ratio which is the concluding factor in this project. The volume of the spring remains the same.

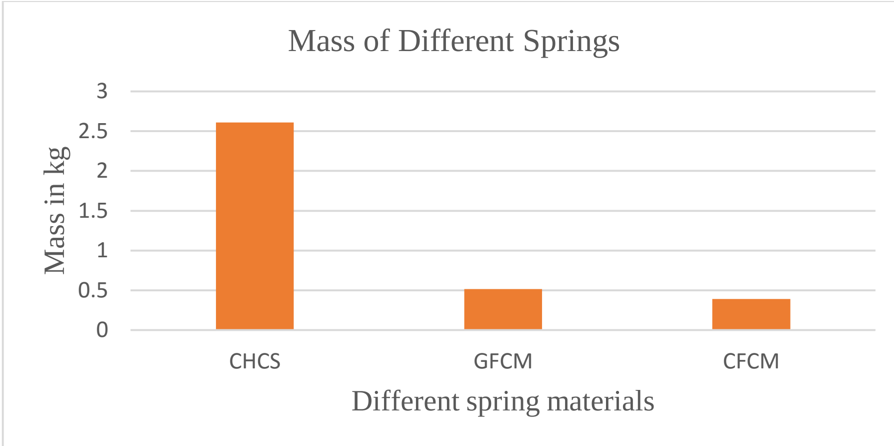


Figure 4.5: Comparison weight of spring

4.3.3. Load vs Deflection

The average values of the load deflections of the composite material which is obtained the property of the composite material from the lab experiment including the conventional helical coiled spring made of structural steel, carbon fiber and glass fiber composite spring shown in fig below. As it is evident from the results that the carbon fiber springs with stand more load than the glass fiber types of springs but lower than structural steel. That is 34.44% more than that of glass fiber and 56.01% lower than that of conventional helical coil spring.

Research's on analyzing deflection of spring using experimental set by ASTM D3171 [1] is also similar with spring that made from the composite material. Linear variation of deflection of spring has investigated due to the composition of the fiber and finally due to the variation of shear modules of the composite material.

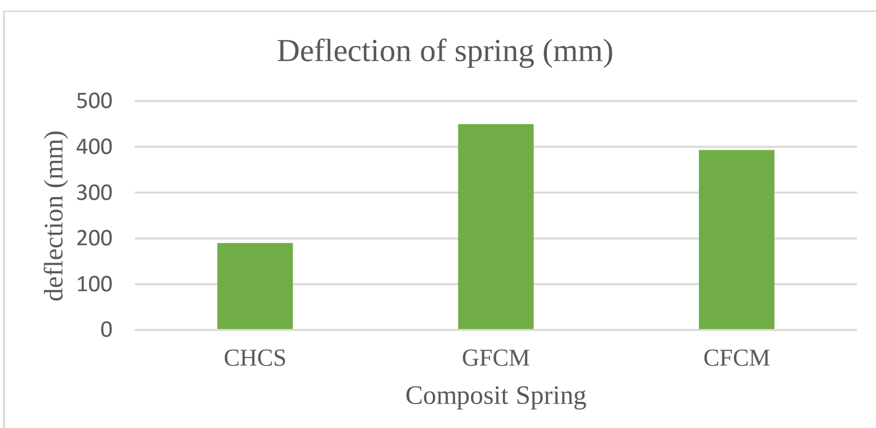


Figure 4.6: Comparison of deflection of spring

4.3.4. Load Vs Spring Rate

The spring rate which is the stiffness of the spring is the force required to compress a spring by unit length. Spring rates depend on the rigidity modulus, number of coils, shape and dimensions of the spring. Rigidity modulus plays a major role in the spring rates. The spring rates were determined from the load deflection curves and are evidently very stable and almost constant for the same load and spring profile but vary with different composite spring due to the nature of property of the material as shown in figure below.

Carbon fiber springs with chopped and random fiber orientation gives more stiffness due to its superior mechanical properties and higher rigidity modulus. The next highest spring rates are obtained with the springs made using conventional structural steel. Springs develop using chopped glass fiber yields less spring rates compared to other two orientations.

The spring rates of carbon fiber springs is 41.30% more than glass fiber helical coil spring and 54.78% lower than conventional helical coil spring made of structural steel. Spring rates were calculated analytically by using deflection of spring using rigidity modulus obtained from lab experiment with the same spring profile and the same load effect.

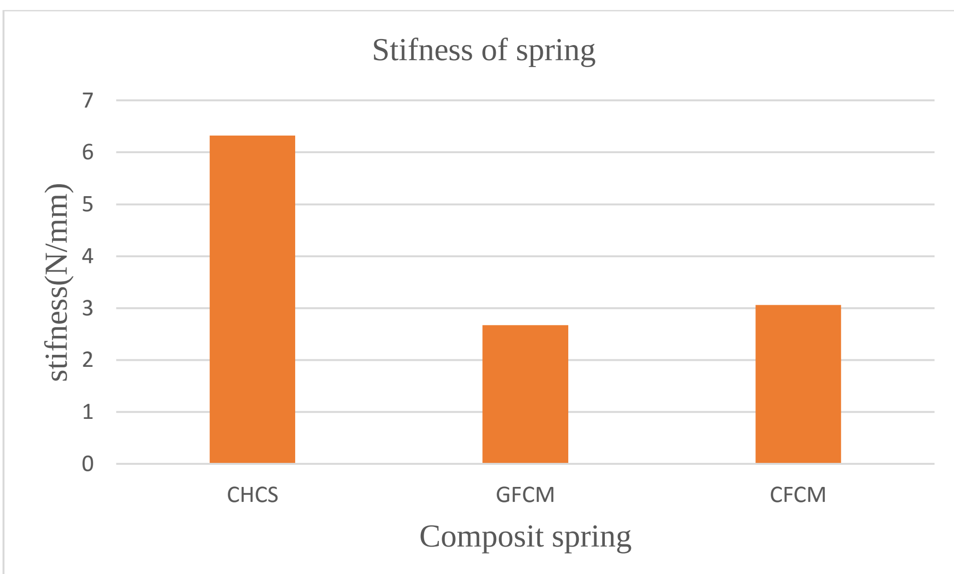


Figure 4.7: Comparison of spring rate of the springs

4.3.5. Specific Strain energy of the spring

The main factor to be consider in the design of a spring is the strain energy of the material. In this case by considering the density and modules of elasticity of the conventional steel and the new lab experimental result for our composite material with the corresponding constant value of the shear stress of the spring we get the following estimated value of strain energy (mJ).

The result shows that specific strain energy of the spring made from carbon fiber reinforced composite material is 79.35% higher than that of conventional helical coil spring and 11.39% lower than glass fiber as shown in fig below.

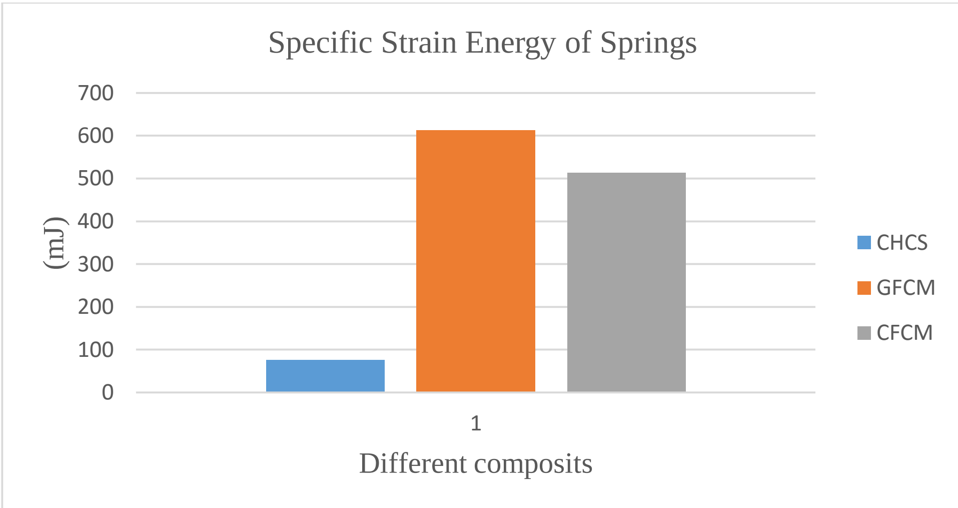


Figure 4.8: Comparison of specific strain energy of springs

4.3.6. Strength to weight ratio of spring

As our main objective on achieving a "high strength to weight" ratio of composite material we can obtain the overall stiffness of the spring (figure 4.8) as the measure of strength and the weight of the spring from figure (4.6).So by considering both basic design result data we can get the following result as shown in figure below.

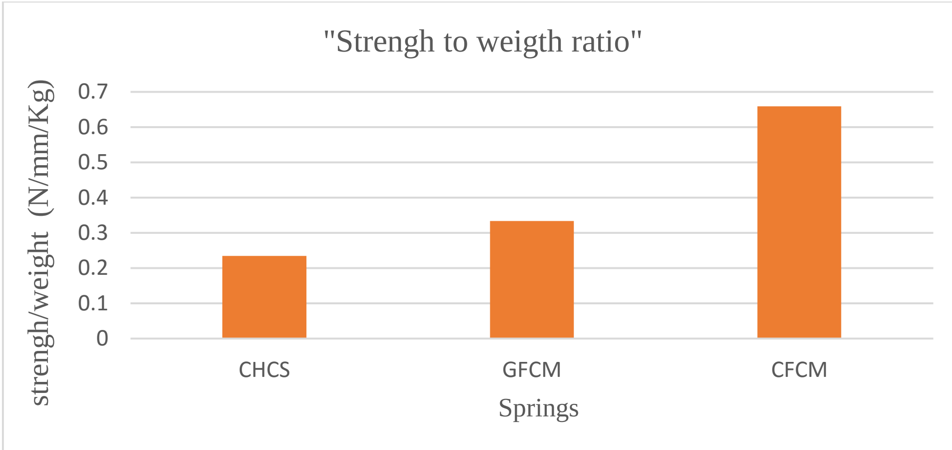


Figure 4.9: Strength to weight ratio of composite material

The result tells us the ratio of strength to weight of a coil spring made of carbon fiber reinforced composite material is almost 58.61% more than conventional and 51.6% than that of glass fibre coil spring. This Shows that the achievement of basic characteristic of composite materials in terms of their high strength to weight ratio for specific application.

4.3.7. Cost break down of spring

The overall cost of spring as a product using the dimension of the spring obtained from the loading condition analysis and the composition of the composite material obtained from lab result is obtained as follow.

Since the figure below shows the same volume fraction of the resin and fiber with the same manufacturing technology and cost of manufacturing the helical coil spring made of carbon fiber reinforced composite material is high relative with that of conventional helical coil spring and the spring made of chopped glass fiber.

Generally cost of helical coil spring made of CFRC material is 50.06% more expensive than conventional helical coil spring and 27.94% than glass fiber composite material. But by modernizing the manufacturing technology of the spring using filament winding machine we can minimize the cost of manufacturing of the spring with all the desired property of the spring.

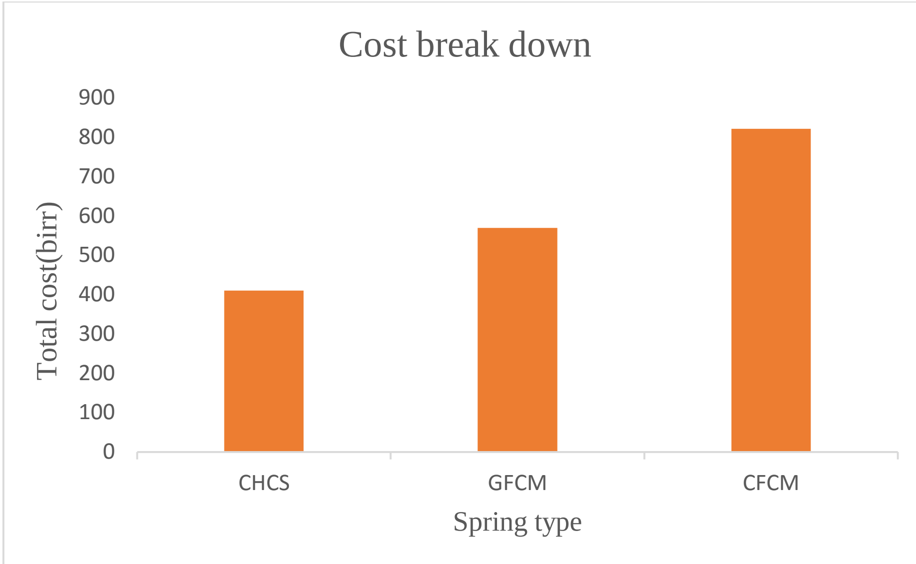


Figure 4.10: Overall cost of spring

4.4. Ansys Result

4.3.1 Final 3D model of HCS

The basic solution result in ansys software such as strain energy and maximum stress are calculated by considering the property of the composite material obtained from the lab experiment. (Appendix C1 and D)

Table 4.2: Final Dimension of the spring

Material	**Conventional steel**	**Chopped glass fiber**	**Chopped carbon fiber**	**Remark**
Wire diameter(mm)	10	10	10	
Mean coil diameter(mm)	120	120	120	
Pitch	27.71	27.71	27.71	
Maximum height of spring(mm)	231	231	231	
Coil inner diameter (mm)	110	110	110	
Active Number of coils	9	9	9	

Mesh Detail of the Model

Table 4.3: Mesh Detail of the Model

Mesh Parameter	Conventional steel	Chopped glass fiber	UD carbon fiber	Remark
Mesh size(mm)	2	2	2	Optimized mesh size
Node	15214	15214	15214	
Element size	7012	7012	7012	

Analyzing of Helical Coiled Spring Made of structural steel

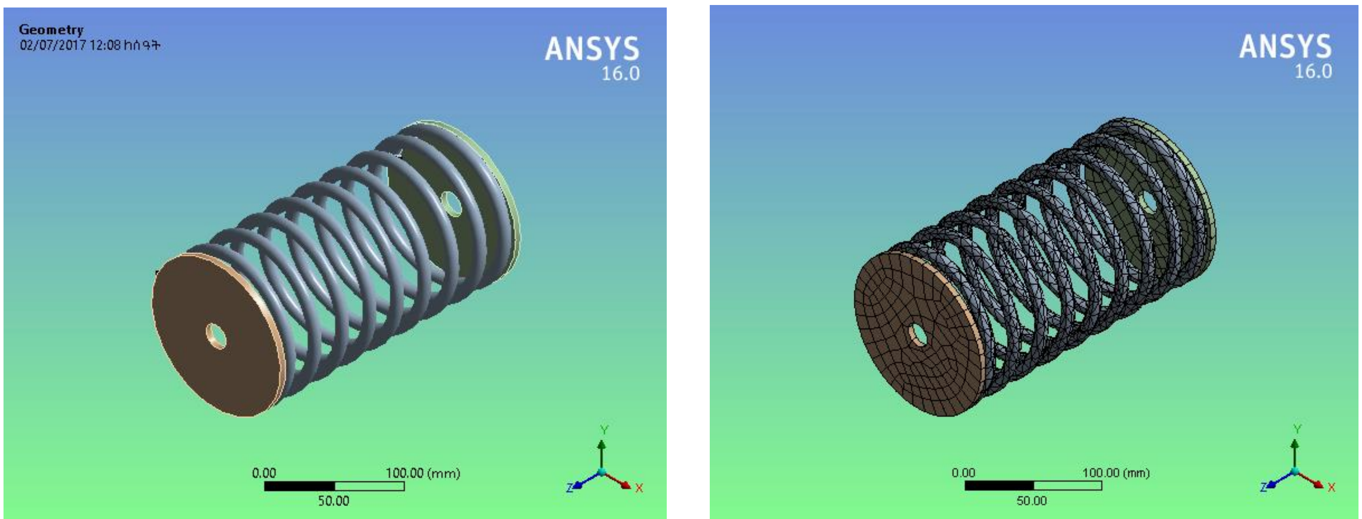


Figure 4.11: Mechanical and mesh size of HCS using Mechanical work bench

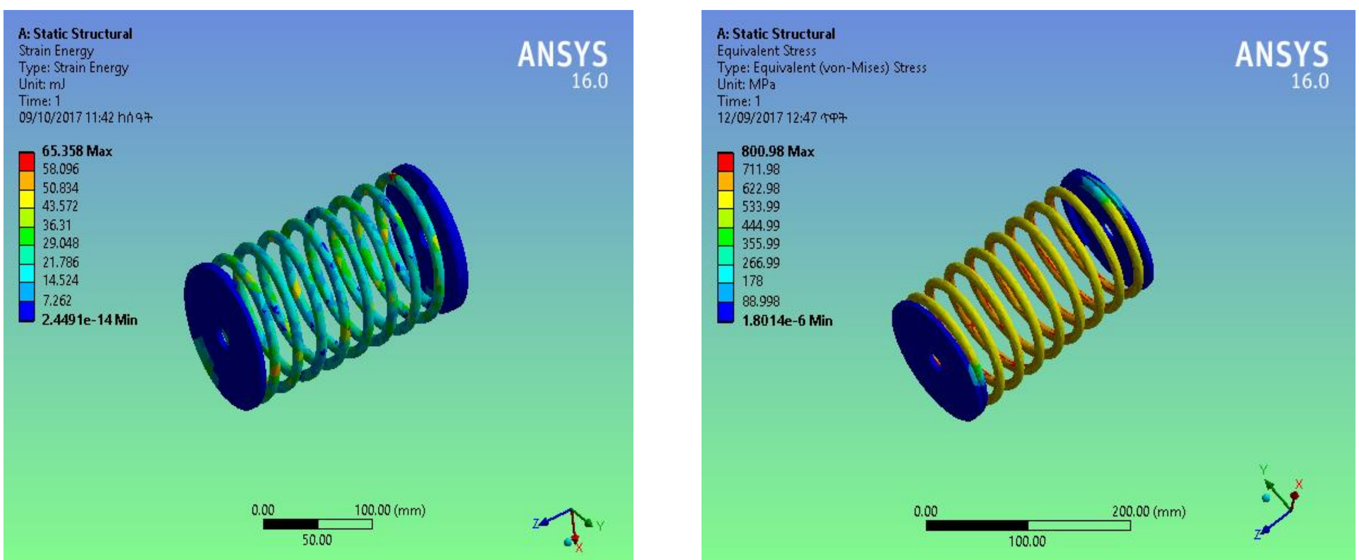


Figure 4.12: Elastic strain and equvalent stress of HCS using structural steeel

Analyzing of Helical Coiled Spring Made of carbon fiber composite material

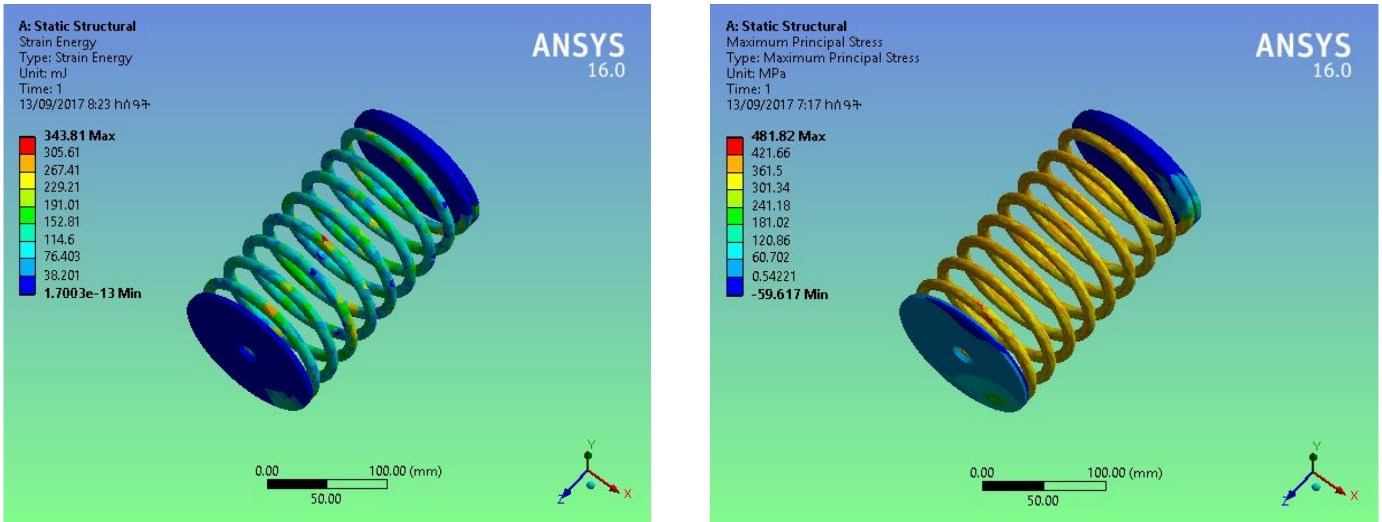


Figure 4.13: Elastic strain and equvalent stress of HCS usign choped glass fiber

Analyzing of Helical Coiled Spring Made of carbon Fiber Reinforced Composite Material

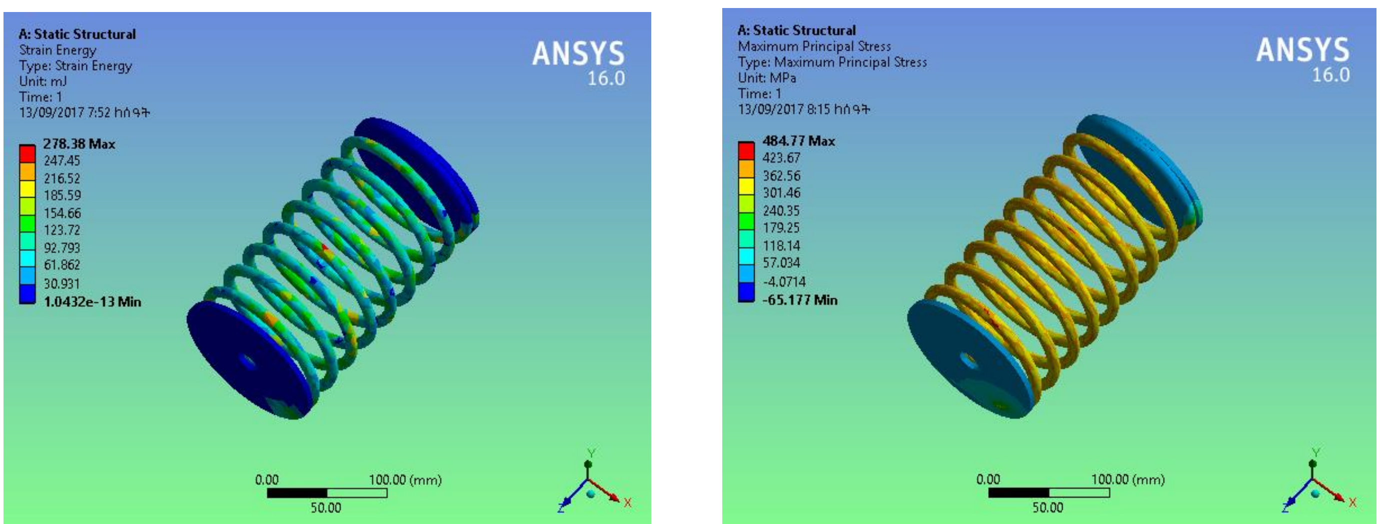


Figure 4.14: Elastic strain and equvalent stress of HCS usign carbon fiber

The overall stress and strain energy of the spring for respective spring can be summarized as

Design parameter	Steel	Glass	Carbon
Stress(MPa)	800	481	484
Energy(mJ)	65	342	278

As tabulated results shown in table above. The Total strain energy for helical coil spring made of structural steel is 65 mJ, that of chopped E-glass Epoxy 342 is mJ and that of carbon fiber is 278 mJ. In the same manner as, the equivalent stress for helical coil spring made of steel is 800 MPa that of chopped E-glass Epoxy is 481 MPa and that of helical coil spring made of carbon fiber is 484 MPa through ANSYS Simulation Workbench 2016.

Hence the development of helical coil spring by considering loading condition and FEA have been achieved through varying the mechanical property of the spring material which obtained from the lab experiment which is applicable for light weight vehicle. From ansys workbench result equivalent strain of chopped E glass epoxy material, carbon material and structural steel are in permissible range for the ideal spring material compared to the theoretical calculations. A carbon fiber has the maximum total strain energy when compared to the existing conventional structural steel material. Hence, it is concluded that carbon fiber with chopped and random fiber orientation as a better spring character than conventional structural steel, and chopped glass fiber with random fiber orientation. Carbon fiber with another best performance relative to chopped glass fiber and structural steel is its lower weight relative with the strength or stiffness of the spring the ration of the strength to weight yields a maximum value. The objective of this thesis is using materials having high strength to weight ratio. Since as shown the weight proportion of the composite material by considering the weight fraction of the fiber and matrix a carbon fiber has a maximum strength to weight ratio than the existing and chopped glass fiber which consequently have advantage on replacing the conventional helical coil spring

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The feasibility of producing composite coil springs is discussed. The basic mechanical property of the spring have been developed in both analytical and lab experiment in order to get an accurate weight composition of both the fiber and matrix element.

Due to the variation of composition of the composite material with different volume and weight composition there will be different property of the composite material such as density, shear modules and modules of elasticity. In this case the exact weight composition of the composite material that yields the required property of the system is obtained using laboratory test. Using a tensile testing machine the required mechanical property of the spring are obtained in the weight fraction of 0.6 fiber and 0.4 epoxy resin for the carbon fiber. Not only this the composition of chopped glass fiber with a variation of 0.4:0.6,0.5:0.5,0.6:0.6 ,the desired property of the spring is obtained in the composition of 0.6 weight fraction of fiber and 0.4 weight fraction of epoxy resin.

By considering the overall lab experiment result on the composition of the glass fiber and carbon fiber composite material spring using glass fiber and carbon fiber exhibits a satisfactory result relative with the conventional helical coil spring starting from weight reduction to the overall strength to weight ratio of the spring. Helical coil spring made of carbon reinforced composite material is 84.96% more lighter than conventional helical coil spring and 24.66% than glass fiber reinforced composite material. That is the weight of spring made of structural steel is 2.6Kg and spring made of chopped glass fiber as 0.51Kg and that of chopped carbon fiber as 0.391Kg. The result tells us the ratio of strength to weight of a coil spring made of carbon fiber reinforced composite material is almost 63.02% more than conventional and 49.6% than that of glass fibre coil spring. This will have an advantage on maximizing the strength of the composite material with lowering the weight of the component of the spring material then finally utilize the fuel consumption of the vehicle.

The simulation result on the von miss stress for all chopped glass and carbon fiber with conventional structural steel corresponding with the ultimate compressive strength of the structural steel and carbon fiber is a good validation.

5.2.Recommendation

The feasibility of replacing helical coil spring using composite material for any type of loads according loading condition has been investigated in this paper. The approximate result using analytical and lab experiment shows the helical coil spring using composite material can be used for replacing the conventional structural steel in terms achieving high strength to weight ratio of spring.

The profile of helical coil spring developed using carbon fiber reinforced composite material is open end due to the manufacturing difficulty of the mold. But using advanced manufacturing system of the mold such as CNC machine and developing the mold will help to obtain a closed end profile of the spring which finally obtain an equalized stress distribution throughout the spring.

The basic factor on the strength of the spring material is the shear modules which is derived from modules of elasticity is minimum in both chopped glass fiber and carbon fiber. Not only this the von miss stress induced in the spring using chopped glass fiber is also high relative with compressive strength of the composite material .In this case the uniform effect of load including the same profile and dimension of spring and Experimental set up on the formation of unnecessary resin which finally develop brittle character have their own factor .So developing a new profile of spring and removing un necessary epoxy using rotary vacuum pump to get a maximum and appropriate von miss stress with corresponding compressive strength of spring.

5.3. Future Work

From different aspects, working on composite materials can replace different automobile spare parts due to their advantage on achieving "high strength to weight ratio" with easy manufacturing systems. Since to achieve those the following areas are recommended for future work.

- Dynamic analysis of helical coil spring using composite material.
- Analyzing the effect of epoxy on brittle characteristic of composite materials.
- Effect of different manufacturing technique of helical coil spring using composite material.

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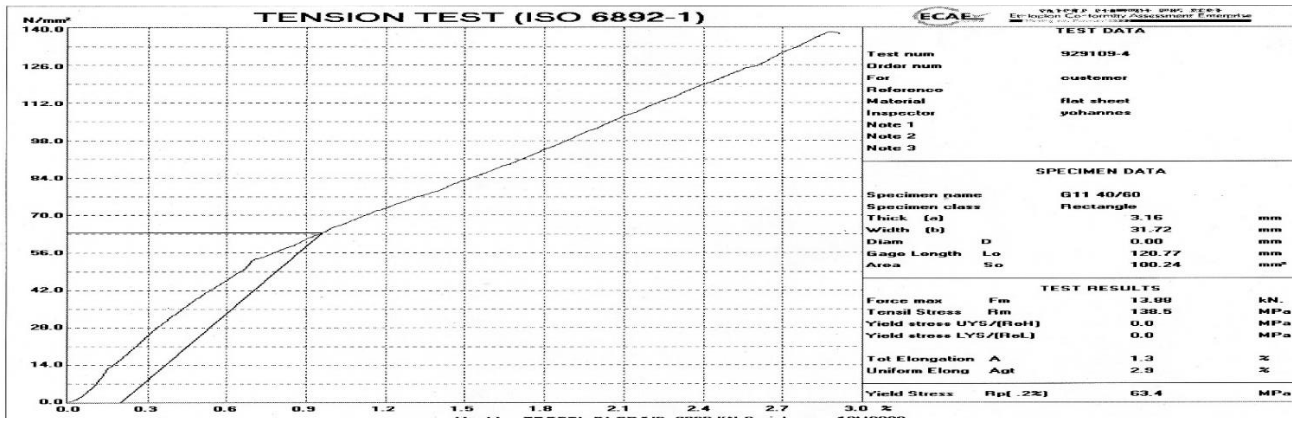
APPENDIX A: Mechanical and physical property of composite material

Table A. 1 Different mechanical property of fiber and matrix of composite materials relative structural steel [22, 27, 31.]

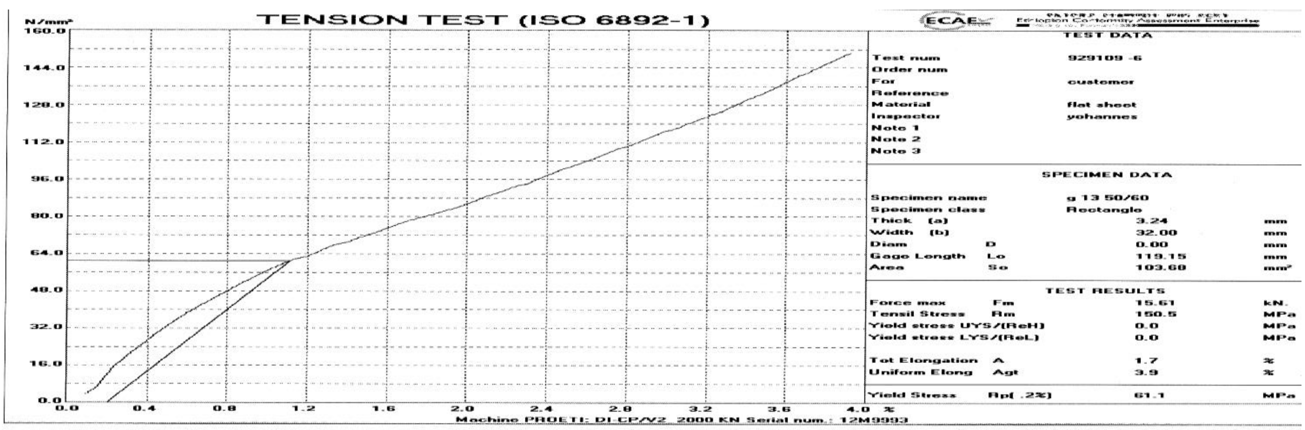
Mechanical and physical Property	**Carbon fiber**	**E Glass fiber**	**Epoxy resin**	**Conventional structural steel**
Density ρ ($g.cm^{-3}$)	1.8	2.58	1.2	7.80
Ultimate Compressive strength (MPa)	570	425		990
Shear modules(GPa)	50	15	1.6	78.6
Elongation at break (%)	1.6	1.3	4	1.8
Fiber strength(GPa)	4.5	3.45		
Poisson's ratio	0.22	0.35	0.3	0.32
Modules of Elasticity (GPa)	228	72	2.4	200

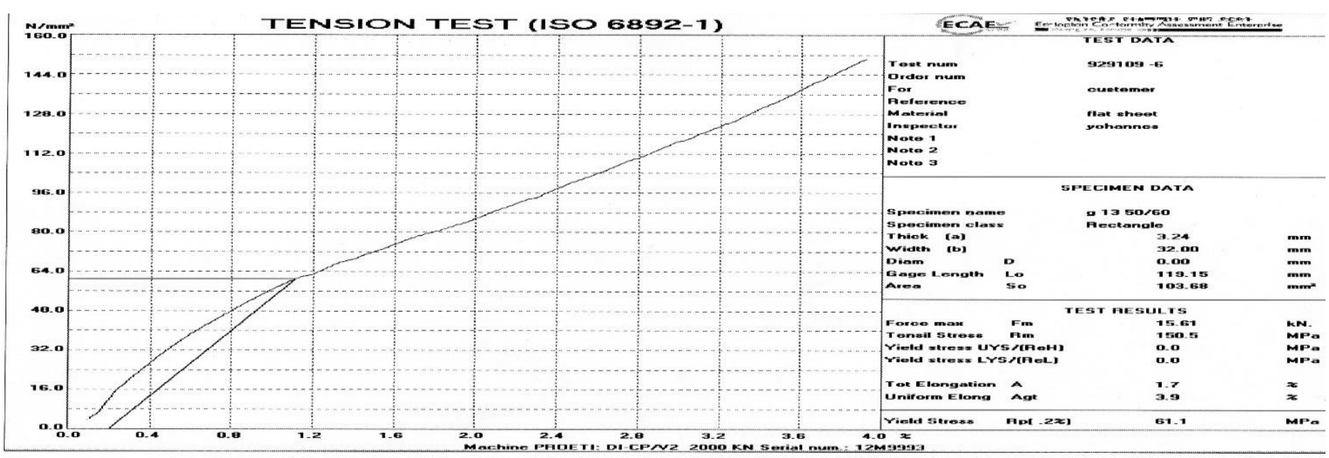
APPENDIX B: Sample lab Result

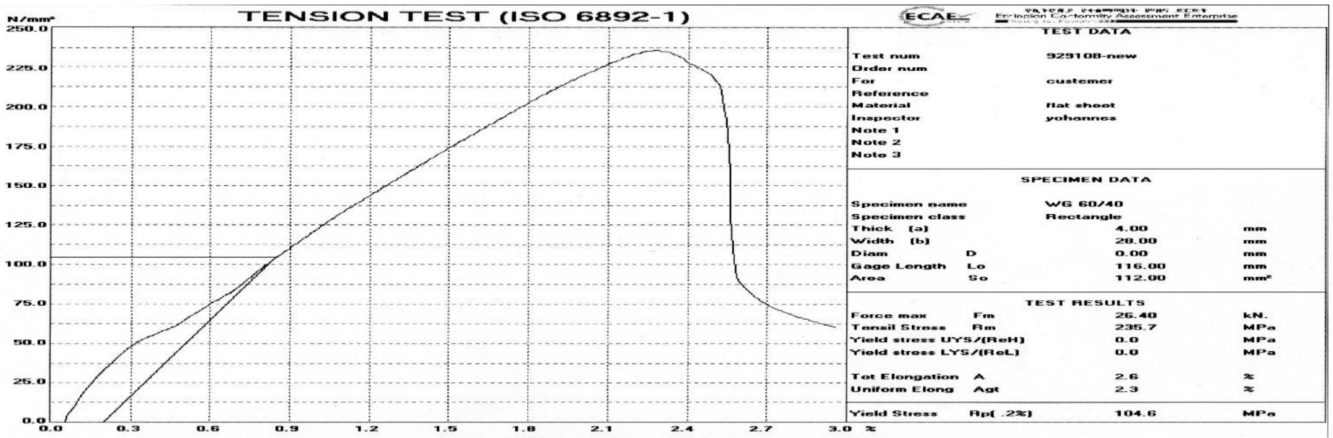
Table B. 1 Sample test result using UTM


TENSION TEST (ISO 6892-1)
ECAE
TEST DATA
Test num 929109-4
Order num
For customer
Reference
Material flat sheet
Inspector yohannes
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name G11 40/60
Specimen class Rectangle
Thick (a) 3.16 mm
Width (b) 31.72 mm
Diam D 0.00 mm
Gage Length Lo 120.77 mm
Area So 100.24 mm²
TEST RESULTS
Force max Fm 13.88 kN.
Tensil Stress Rm 138.5 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.3 %
Uniform Elong Agt 2.9 %
Yield Stress Rp(.2%) 63.4 MPa
N/mm²
%


TENSION TEST (ISO 6892-1)
ECAE
TEST DATA
Test num 929109-new
Order num
For customer
Reference
Material flat sheet
Inspector yohannes
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name WG 60/40
Specimen class Rectangle
Thick (a) 4.00 mm
Width (b) 28.00 mm
Diam D 0.00 mm
Gage Length Lo 116.00 mm
Area So 112.00 mm²
TEST RESULTS
Force max Fm 26.40 kN.
Tensil Stress Rm 235.7 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 2.6 %
Uniform Elong Agt 2.3 %
Yield Stress Rp(.2%) 104.6 MPa
N/mm²
%


TENSION TEST (ISO 6892-1)
ECAE
TEST DATA
Test num 929109 -6
Order num
For customer
Reference
Material flat sheet
Inspector yohannes
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name g 13 50/60
Specimen class Rectangle
Thick (a) 3.24 mm
Width (b) 32.00 mm
Diam D 0.00 mm
Gage Length Lo 119.15 mm
Area So 103.68 mm²
TEST RESULTS
Force max Fm 15.61 kN.
Tensil Stress Rm 150.5 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.7 %
Uniform Elong Agt 3.9 %
Yield Stress Rp(.2%) 61.1 MPa
N/mm²
%
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993


TENSION TEST (ISO 6892-1)
ECAE
TEST DATA
Test num 929109 -6
Order num
For customer
Reference
Material flat sheet
Inspector yohannes
Note 1
Note 2
Note 3
SPECIMEN DATA
Specimen name g 13 50/60
Specimen class Rectangle
Thick (a) 3.24 mm
Width (b) 32.00 mm
Diam D 0.00 mm
Gage Length Lo 119.15 mm
Area So 103.68 mm²
TEST RESULTS
Force max Fm 15.61 kN.
Tensil Stress Rm 150.5 MPa
Yield stress UYS/(ReH) 0.0 MPa
Yield stress LYS/(ReL) 0.0 MPa
Tot Elongation A 1.7 %
Uniform Elong Agt 3.9 %
Yield Stress Rp(.2%) 61.1 MPa
N/mm²
%
Machine PROETI: DI-CP/V2 2000 KN Serial num.: 12M9993

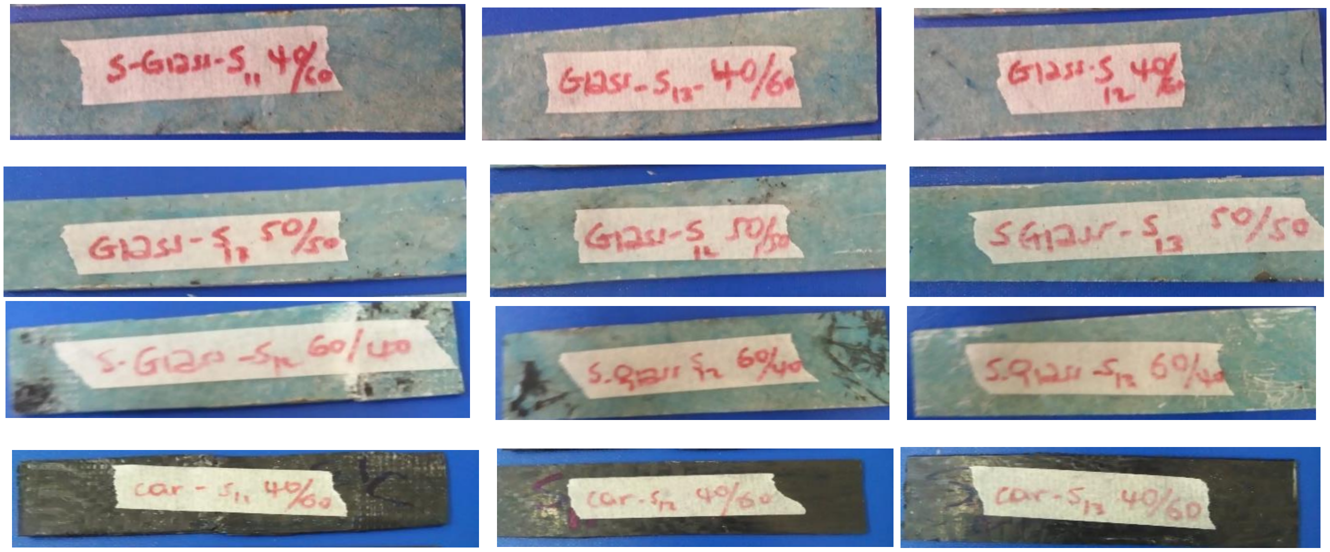


APPENDIX C: Overall analytical and experimental result on mechanical property of composite material

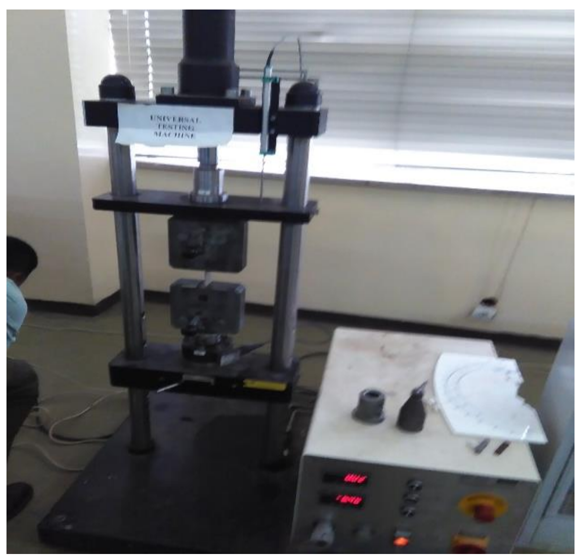
Table C. 1:.Effect of weight of components of light weight vehicle [34]

			Average /kg	Standard deviation /kg	Lightness part in comparison /kg	Remark
Vehicle			1477.4	97.2	1403.0	
Suspension +steering +breaks			285.1	18.5	267.3	
	Average weight on spring		27.3	4.9	22.1	
		Front	15.29	3.36	11.36	
		Rear	11.83	2.37	9.68	
	Axles		103.1	9.4	89.5	
		Front	43.39	10.75	32.43	
		Rear	59.72	3.90	55.38	
	Wheels incls.caps		84.4	5.3	75.6	
		Wheels	83.35	9.8	74.78	
Steering system			23.8	1.6	21.6	
	Rack and pinion steering		23.77	1.59	21.55	
Breaking system			46.5	3.9	41.577	
	Front break and		29.01	2.71	25.03	
	Rear break		17.50	4.30	10.91	

APPENDIX D: Chopped glass and carbon fiber sample test (before and after testing)



1. Testing using different testing machine such as **tensile testing machine (DI-CP/V2 50KN serial number 12M9993),** weight balancing machine.



Over all mechanical lab result property of structural and composite material

Properties of Outline Row 8: chopped Glass fiber

	A	B	C
1	Property	Value	Unit
2	Density	1460	kg m^-3
3	Isotropic Secant Coefficient of Thermal Expansion		
4	Coefficient of Thermal Expansion	1.2E-05	C^-1
5	Reference Temperature	22	C
6	Isotropic Elasticity		
7	Derive from	Young's Modulus and Poi...	
8	Young's Modulus	9.6E+09	Pa
9	Poisson's Ratio	0.25	
10	Bulk Modulus	6.4E+09	Pa
11	Shear Modulus	3.84E+09	Pa
12	Field Variables		
16	Alternating Stress Mean Stress	Tabular	
20	Strain-Life Parameters		
28	Tensile Yield Strength	425	MPa
29	Compressive Yield Strength	425	MPa
30	Tensile Ultimate Strength	460	MPa

Properties of Outline Row 5: choppped carbon fiber

	A	B	C
1	Property	Value	Unit
2	Density	1425	kg m^-3
3	Isotropic Secant Coefficient of Thermal Expansion		
4	Coefficient of Thermal Expansion	1.2E-05	C^-1
5	Reference Temperature	22	C
6	Isotropic Elasticity		
7	Derive from	Young's Modulus and Poi...	
8	Young's Modulus	1.3E+11	Pa
9	Poisson's Ratio	0.32	
10	Bulk Modulus	1.2037E+11	Pa
11	Shear Modulus	4.9242E+10	Pa
12	Field Variables		
16	Alternating Stress Mean Stress	Tabular	
20	Strain-Life Parameters		
28	Tensile Yield Strength	600	MPa
29	Compressive Yield Strength	570	MPa
30	Tensile Ultimate Strength	600	MPa
31	Compressive Ultimate Strength	570	MPa

Properties of Outline Row 4: Structural Steel

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	7850	kg m^-3		
3	Isotropic Secant Coefficient of Thermal Expansion				
6	Isotropic Elasticity				
7	Derive from	Young...			
8	Young's Modulus	2E+11	Pa		
9	Poisson's Ratio	0.3			
10	Bulk Modulus	1.6667E+11	Pa		
11	Shear Modulus	7.6923E+10	Pa		
12	Field Variables				
16	Alternating Stress Mean Stress	Tabular			
20	Strain-Life Parameters				
28	Tensile Yield Strength	460	MPa		
29	Compressive Yield Strength	460	MPa		
30	Tensile Ultimate Strength	990	MPa		
31	Compressive Ultimate Strength	0	MPa		