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Design and Manufacture of Hybrid Composite Leaf Spring

A Thesis Submitted to the Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

By

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بسم الله الرحمن الرحيم

نرفع درجات من نشاء وفوق كل ذي علم عليم

صدق الله العظيم

(يوسف:76)

DEDICATION

THIS WORK IS DEDICATION WITH

ALL MY LOVE AND RESPECT TP MY:

DEAR FATHER

DEAR MOTHER

BELOVER HUSBAND

LOVELY BROTHERS

LOVELY Dr. EKHLAS EDAN KADER

LOVELY FRIENDS

Acknowledgment

Many thanks and praise to my creator first and above all. His Almighty ALLAH, most beneficent, most gracious, and all most merciful, who gave me the ability and the desire to complete this work despite all the hurdles and constraints in the way of its completion.

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The researcher

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ABSTRACT

In order to have best performance of leaf spring, a study was conducted to replace the conventional steel leaf spring that used in vehicle by composite materials. This thesis focused on describe about design and analysis of hybrid composite leaf spring. A rear leaf spring for a "Toyota" is regarded for this purpose, and three materials are employed to fabricate the leaf springs. The matrix material was epoxy, while the reinforced materials were E-glass and carbon. Composite materials have a good corrosion resistance, a high strength to weight ratio, and high elastic strain energy storage capacity. So aim of this research is to investigate the structural properties of a hybrid leaf spring which made of (95% Epoxy with 5% carbon), (95% Epoxy with 5%glass fiber), and (95% Epoxy with 5% of hybrid composite 2.5% of carbon and 2.5% of glass fiber). In this study, Hand Lay-up technique was used in the fabrication of leaf spring due to its advantages (low cost tooling and simplest method) over the other methods. The effectiveness of the proposed composite leaf spring was evaluated by implementing the mechanical tests, which were Tensile, Impact, Hardness, Fatigue, Damping and Flexural. The experimental results recorded an improvement in the mechanical properties when the reinforcing fibers are used as well as the best results were obtained by hybrid reinforcement.

Finite Element method was employed based on ANSYS software to simulate the leaf spring part. The linear isotropic model was chosen to determine stresses, deformations, and fatigue life when an internal static load is applied.

Finally, the results proved that the hybrid composite materials have the ability to carry the load-applied leaf spring without failure and with minimum deflection and long fatigue life

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Symbol	Term	Units
σT	Tensile Strength	MPa
E	Young's Modulus	Gpa
ρ	Density of Material	g/cm3
V_c	Volume Fraction of Composite	-
V_m	Volume Fraction of Matrix	-
V_r	Volume Fraction of Reinforcement	-
W_c	Weight Fraction of Composite	-
W_m	Weight Fraction of Matrix	-
W_r	Weight Fraction of Reinforcement	-
w_m	Weight of Matrix	Kg
w_r	Weight of Reinforcement	Kg
w_c	Weight of Composite	Kg
ρ_c	Density of Composite	g/cm^3
ρ_m	Density of Matrix	g/cm^3
ρ_r	Density of Reinforcement	g/cm^3
v_m	Volume of Matrix	cm^3
v_r	Volume of Reinforcement	cm^3
v_c	Volume of Composite	cm^3

V_m/V_c	The matrix volume fraction	-
V_f/V_c	The fibers volume fraction	-
L	Length of leaf	
b	Width of leaf	
t	Thickness of leaf	
W	The force effective at middle of leaf	
σ	Tensile Strength	Mpa
W	The Applied Load	N
A	Cross- sectional Area	m^2
ϵ	Strain	-
δ	Deflection	mm
δ_l	Change in the Length	mm
v	Poisson Ratio	-
δ_d	Change in Width	mm
G	Shear Modulus	Gpa
I.S	Impact Strength	$\frac{KJ}{m^2}$
U	Impact Energy	Joule
I.T	Impact Toughness	$10^{-4}\frac{J}{mm^3}$
V	Volume of Sample	mm^3
σ_F	Flexural Strength	Mpa

M	Internal Bending Moment	N.m
Y	Perpendicular Distance from the Neutral Axis	mm
I	Moment of Inertia of Beam	mm^4
E_F	Flexural Modulus	Mpa
τ	Shear Stress	Mpa
σ	Applied Stress	Mpa
b	Width of Sample	mm
t	Thickness of Sample	mm
ζ	Damping Ratio	-
δ	Logarithmic Decrement	-
$x_n + x_{n+1}$	Vibration Amplitude	-
S_1, S_2, S_3	Equivalent Stress	Mpa
U_x, U_y, U_z	Component of Deformation	mm

CHAPTER ONE

Introduction

1.1 Introduction

A leaf spring is a basic type of spring that is widely used for vehicle suspension. Springs are critical suspension components in automobiles that used to reduce vertical vibrations, impacts, and bumps caused by road disturbances to provide a comfortable ride. Leaf springs are long slender and plates that connect to the trailer frame and rest above or below the trailer's axle. It also serves as a frame in order to support vertical loading that caused by the vehicle's and payload's weight [1].

1.2 Functions of the Leaf Spring

The primary function of leaf spring is to deform when loaded and return to its original form when extracted. A leaf spring is a kind of spring that has an elastic body, which absorbs the vehicle's vibration, shock, and bump load. The potential energy is contained in the leaf spring and then eventually released. The ability to retain and absorb more strain energy provides a comfortable suspension structure [2]. The leaf spring is mounted on the car's frame, and the entire load is supported by it. The spring's front end is attached to the frame by a plain pin joint, and the spring's back end is connected by a shackle. The shackle is a versatile connection that links the rear eye of the leaf spring to the frame. When the leaf spring is deflected, the upper side of each leaf tip slips or ribs towards the lower sides of the leaf above it, dampening and diminishing spring friction and producing a squeaking sound [3]. Figure (1.1) shows the leaf spring of the vehicle.

Figure (1.1). Leaf Spring of the vehicle [4].

1.3 Kinds of Leaf Springs

Leaf springs existed in the form of three main classifications [5].

1.3.1 Single Leaf Spring (mono leaf spring)

The single leaf spring is used in the construction of emerging technology for small car suspension systems, which can be shaped as an iron sheet fixed on both ends. This spring is made of a single sheet of chromium steel alloy. The thickness of this layer varies as the thickness increases in the middle and decreases towards the ends. Figure (1.2) shows the single leaf spring.

Figure (1.2). Single Leaf Spring

1.3.2 Laminated or Multi Leaf Spring

This type of leaf spring is frequently employed in vehicle suspension systems, and it is a series of iron sheets graduated in length that fixed on top of each other. When a screw in the middle and a central screw are joined with each other, the long and equal width leaf is called the (master leaf), and two ends of the main paper form a circle shape for the purpose of linking to the car's bodywork. Figure (1.3) shows multi-leaf spring.

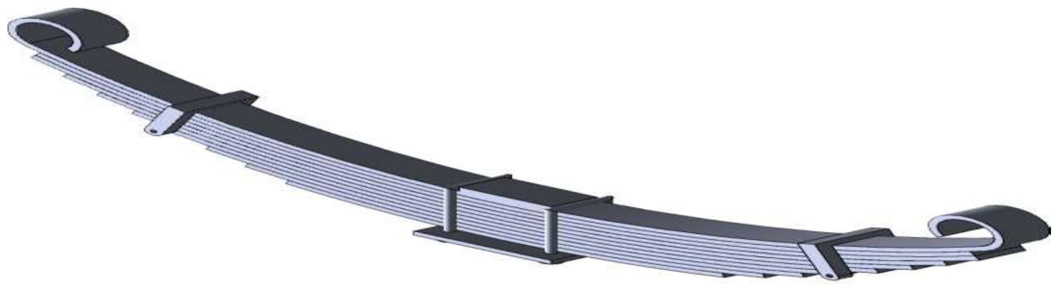

Figure (1.3). Multi Leaf Spring

1.3.3 Tapered Leaf Spring

This spring is frequently utilized in large vehicles and its primary purpose is to withstand the heavy force that influences it. The tapered leaf spring combines the benefits of multi-leaf and single-leaf springs. Spring is constructed from multiple sheets of varying thicknesses, with the paper tapering at the ends to separate the sheets. The spring is from the middle using rubber pieces has the advantage of securing the papers on top of each other and fixing the papers and paper fasteners with a central screw. Both papers are equal in thickness, except the first sheet's ends are rounded to hold the spring to the car's chassis. Figure (1.4) shows the tapered leaf spring.

Figure (1.4). Tapered Leaf Spring

1.4 Material of Leaf Spring

Springs differ from other machine structure elements in that they bend greatly when loaded, allowing to storing mechanical energy that can be retrieved easily. If a wheel meets an obstacle in a vehicle suspension, the spring allows the wheel to pass over the obstacle and then returns the wheel to its usual location. A tension bar is the shortest spring, since all of the elements are stressed in the same manner, this is an effective energy store, but its deformation is negligible as it is made of metal. The leaf spring is stressed almost continuously over its length. Unlike the constant cross-section beam, since the linear increase in bending moment from any basic support is balanced by the expansion of the beam. As longitudinal weight loss has been the prime goal of car producers in order to save the natural resources and electricity. The reduction in weight can be accomplished mainly by the use of better fabrics, optimization of design and better production processes. One of the possible things for vehicle weight reduction is the suspension leaf spring, as it accounts for ten to twenty percent of the unsprang weight. This assists in the development of a vehicle with better riding characteristics [6].

Many researchers try to use new materials to develop the leaf spring that materials should have the following [7].

1- The material must have high modulus of elasticity.

2- Must have high ultimate strength.

3- High strength to weight ratio.

4- Good corrosion and wear resistance.

5- More elastic strain energy storage capacity.

6- Fatigue resistance and natural frequency.

7- The economic aspects of material.

8- Toughness is often greater too.

9- Vibration damping.

10-Acoustical insulation.

11-Electrical and thermal conductivity.

12- Low maintenance.

1.5 Composite Materials

A composite material is described as a material made up of two or more materials that has better properties than the individual components when used alone. Unlike metallic alloys, each material retains its distinct chemical, physical, and mechanical properties. Based on the form of matrix material, composite structures can be divided into three types. Polymer matrix composite (PMC) is a term that is used to describe a material that is made up of many different polymers. Metal matrix composite (MMC) and ceramic matrix composite (CMC). Each composite material has its own set of applications. Since polymer matrix composites have poorer strength and hardness than ceramics and metals, they are the most widely used [8].

1.6 Hybrid Composite Materials

Hybrid composite materials are becoming increasingly being used in many engineering applications due to their superior properties and benefits over conventional composite materials. The goal is to achieve a synergistic effect of reinforcing properties on composite total properties. In hybrid composite materials, more than one type of reinforcement is used in a single matrix. It may be possible to gain greater control over the properties of hybrid composites, and also to achieve a better balance between the advantages and disadvantages of any composite material [9].

1.7 Matrix Material

It is also known as (the continuous phase), and it is regarded as a fundamental material in the development of the structure of composite materials. A binder known as matrix holds fibers together. The fibers cannot transmit load in the composite and their small cross- section area and cannot directly loaded. Therefore, the matrix transfers loads and stresses within the composite structure to protect the composite from effect of external environment such us humidity and chemicals, the matrix providing the composite with impact and abrasion [10].

1.8 Polymer

Polymers are large molecules consisting of a large number of molecules. These large molecules consist of a broad variety of small molecules connected together by covalent or chemical bonds forming long Chains. It can be categorized into linear polymers, branched polymers, cross-linked polymer or net polymers, as shown in figure (1.5). They are bounded by monomer-bound. In fact, a monomer is a small molecule with a basic chemical structure and a low molecular weight that is bound together by the polymerization mechanism. Polymerization is defined as the mechanism of converting small molecules with low molecular weight (monomers) into materials of high molecular weight without altering the molecules' basic structure. The number of repetitive units inside the long chain, known as the degree of polymerization. It is used to measure the length of the polymer chain. Polymers with a high degree of polymerization are referred to as polymers with a high degree of polymerization [11].

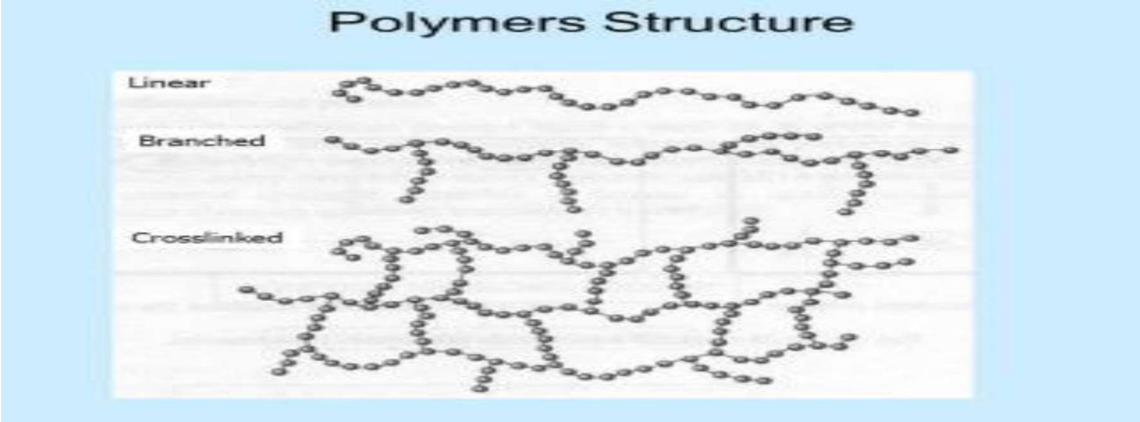

Figure (1.5). Polymer Chains [11].

1.9 Types of Polymers

Polymers can be divided into three classes based on structural properties and functional applications:

1.9.1Thermosetting Polymers

Thermoset is a polymer that is cured by heat or chemical reaction and transforms into a substance that is infusible and soluble. Thermoset polymers have an irreversible polymerization per moment. Heat helps to take the final casting in unique mold consistently. During heating the polymer became harder because the chemical changes that, occur during heating process. Chains transform the polymer tangle to non-fusion polymers and are not resolved in common solvents, which contribute to low thermal ability and electricity [11]. Thermal bonding has a cross-connected molecular structure and is formed by polymerization in two phases. A polymer with linear chains is the first step. The second polymerization stage leads to a final cross-related structure. The final may be flexible or rigid. Polymerizing is regulated so that short chain for hard products is strongly interconnected and long chain links are slightly interconnected with soft and flexible products. Polymer have low density and strength with high stiffness. Examples of these types are Epoxy, Polyester, Urea, Melamine, Silicon and Phenolic resins [12].

1.9.2 Thermoplastic Polymers

Thermoplastic is a material that melt when heated and hardens when cooled in a reversible manner. A high molecular weight polymer is not cross-linked structured material. It can be either a linear structure or a branch structure. There are three types of thermoplastics crystalline, amorphous and semi- crystalline. Crystalline polymers have high melting point and the molecular chains have a regular arrangement having high impact resistance. Such as Polyethylene. In amorphous thermoplastic, the melting point is diffused and the molecular are randomly arrange [13].

1.9.3 Elastomer Polymers

A Unique polymer that are very elastic called elastomers (rubbers), with a glass transition temperature far below room temperature, they are lightly cross-linked and amorphous. They can be considered as a very large macroscopic molecule. The intermolecular forces are very weak between the polymer chains [14].

1.10 Epoxy Resin

Epoxy resins are the most commonly used matrices for advanced composites. Epoxy resin belongs to the group of thermosetting resins. due to the formation of long polymeric chains intertwined with each other, which is called crosslinking. These resins are distinguished by the inability to reform them by heat after turning into a solid. There are two or three sets of epoxide groups in the epoxy resin, consisting of one oxygen atom bounded to two carbon atoms. To form a three-dimensional network that is cross-linked in the curing process. Epoxy group is chemically associated with other molecules. Epoxy resins have various unique chemical and physical characteristics. Having excellent chemical resistance, excellent adhesion, good heat and electrical resistance, low shrinkage, and good mechanical properties, such as high strength and toughness are the most important in

These features resulted using Epoxies in large industries such as, packaging, aerospace and construction [15].

1.11 Curing of Epoxy Resins

The mechanisms of the cured epoxy resins control their mechanical and complex mechanical properties. The most important element deciding the composition of the cured resin is the curing process of an epoxy resin or the form of operating group of a hardener. Polyamines, acid anhydrides, and polymerization catalysts are well-known hardeners. Amines are the most stable at both room and elevated curing temperatures. The processes of amine curing and the properties of amine cured epoxy resins have been thoroughly researched, and systems of epoxy resins with amine hardeners are widely used [16].

1.12 Reinforcement Materials

Reinforcing material is one of the composite material components, which is applied to the matrix material to enhance its strength, where load on the matrix material is passed to the reinforcing material through the interface; reinforcements are called a secondary stage or a reinforcement process. Composite polymers are categorized into three types based on the geometry of reinforcement: particulate-reinforced, fiber-reinforced, and structurally reinforced composites [17].

1.12.1 Particle Reinforced Composite

A particle reinforcement composed of a matrix of one substance and scattered particles of another material. Particles may be any size or form, but they are usually rectangular, ellipsoidal, polyhedral, or irregular in shape. The particles can be applied directly to a liquid matrix, and then solidifies, or they can be squeezed together and then inter diffused into a powder phase. Ceramics, glasses, and metals such as aluminum, as well as amorphous compounds are used as reinforcing particles. Particle composites have excellent tensile, compressive, and shear strength. Figure (1.6) shows a schematic of particles reinforced composite [18].

Figure (1.6). Example of Particle Reinforced Composite [18]

1.12.2 Structural Composite

The constituents and geometrical geometry of structural composites are the primary properties on which they depend. Laminar and sandwich panels are the two types of structural composites based on this classification. The laminar composite is made up of two-dimensional sheets or plies with a chosen high strength direction. Each composite panel is made up of layers that are layered on top of each other and cured together such that the orientation of the high strength direction changes with each successive layer. Figure (1.7) shows the different type of structural composites [19].

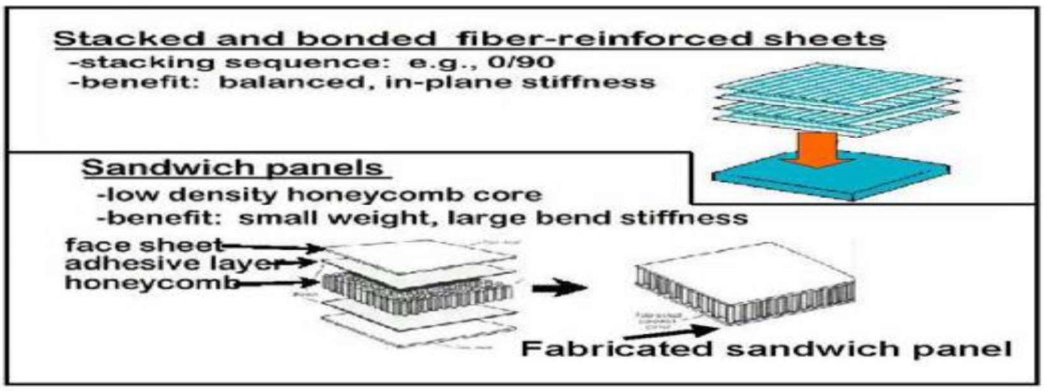

Figure (1.7). Example of Structural Composite [19]

1.12.3. Fibers Reinforced Composites

Reinforcing fibers act as load-bearing members in fiber reinforced composites. This gives the composite the necessary strength. The matrix holds the fibers together and distributes loads that protects them from extreme environmental conditions such as humidity and moisture. Depending on the application, the fibers in these composites may be short or long. They have a high modulus and need a lot of force to break due to the strong covalent bond in the fiber length direction. Fiber reinforced composites have a very high strength-to-weight ratio. As compared to metals, these blends have many advantages, including non-corrosiveness, good bonding power, and ease of repair. The fiber structure has different properties in different directions. Figure (1.8) shows fibers forms. Depending on the using, these fibers may be continuous and aligned, discontinuous and aligned, or discontinuous and randomly focused, however this composite is become widely used in a variety of applications [20].

Figure (1.8). Example of Fiber Reinforced Composite [20]

1.13 Glass Fiber

Glass fibers are by far the most widely used fibers due to their low cost, corrosion resistance, and sometimes-efficient processing potential. Glass fibers have a low density, a high elongation, and a strength-to-weight ratio. Glass fibers are less costly to manufacture than other fibers. These fibers are commonly used in corrosion-resistant applications such as plumbing in the chemical industry and marine applications. Glass fibers' fabrics degrade easily when exposed to moisture. A liquid mixture of silica and other oxides is drawn through small holes in a platinum-alloy bush to create glass fibers. Since glass is an amorphous material, drawing it does not resulted in the ideal microstructure orientation. As a consequence, glass fibers are naturally isotropic. Machining of glass fibers reinforced composites is difficult due to the abrasive nature of glass [21].

1.14 Carbon Fiber

Carbon fibers are fibers between 5-10 micrometers in diameter and mainly made up of carbon atoms. Like high rigidity, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. Carbon fibers are widely found in engineered composites in aerospace and industrial applications. Carbon fibers are low in density but high in strength and stiffness. These fibers have both a high stiffness to weight ratio and a high strength to weight ratio. Carbon fibers are available in a number of grades, depending on the production method. Fibers are classified into three types: high modulus fibers, intermediate modulus fibers, and high strength fibers. Carbon and graphite are created using chemical precursor products such as rayon, pitch, and PAN (polyacrylonitrile). Carbon fibers are anisotropic, and their properties are determined by the degree of orientation of graphite layers with respect to the fiber axis. A higher graphitization temperature allows for more graphite layer orientations in the fiber direction, resulting in a high tensile modulus [22].

1.15 Lamination of Composite Material

Composite lamina is a single ply or lay-up with all layers or plies lined in the same direction. Since the plies are stacked at various angles, the lay-Up is called a laminate. In continuous-fiber composites, specific layers, plies, or laminates are typically oriented in ways that maximize the power in the primary load direction. As shown in figure (1.9) Unidirectional (0°) lamina are very stable and stiff in the 0° direction. They are, however, very small since the load must be carried by a much weaker polymeric matrix in the 90° direction.

The longitudinal stress and compression loads are carried by the fibers, the matrix distributes the loads between the fibers in tension and stabilizes and prevents buckling in compression. The matrix is also the primary load carrier in interlinear shear. Since fiber orientation has a direct impact on mechanical properties, it seems logical to have as many layers as possible aligned in the load-carrying direction. Although this approach may work for certain systems, it is usually necessary to match the load-carrying potential in many directions, including 0°, +45°, -45°, and 90°. Figure (1.9) shows a photomicrograph of a cross-plied continuous carbon fiber/epoxy laminate. A balanced laminate with comparable numbers of plies in the 0°, +45°, –45°, and 90° directions is called a quasi-isotropic laminate since it carries identical loads in all four directions [23].

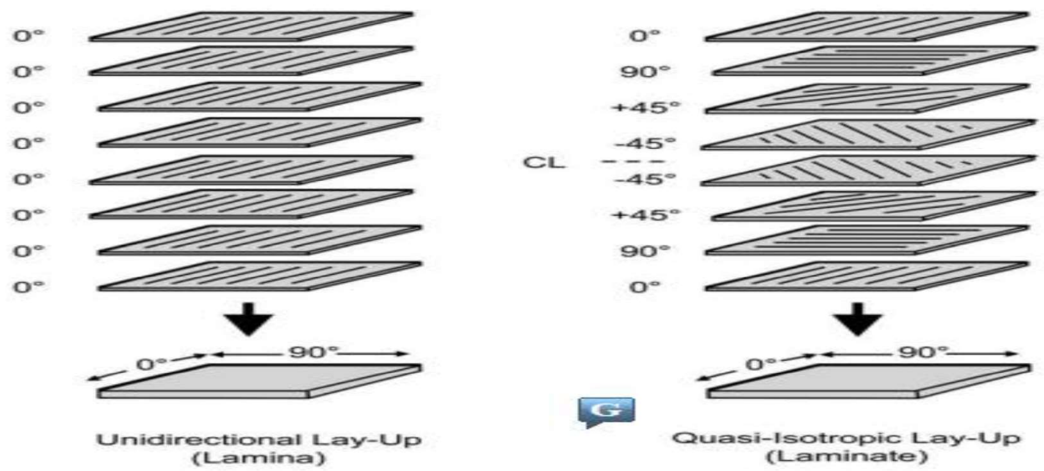

Figure (1.9). Shows the Direction of Composite [23]

1.16 Thesis Objective

The thesis goals are as follows:

1. Designing, manufacturing and improve a techniques improvement of composite leaf spring system for automotive.
2. Studying the performance of replacing the steel leaf spring with composite material by preferring mechanical tests.
3. Studying the introduced composite leaf spring weight reduction and comfort riding.
4. Studying the validation and the suggested leaf spring by using FEA.
5. Studying the possibility of applying the composite leaf spring into automotive industry.
6. Find the total deformation, von-misses stress, fatigue life and vibration analysis.

1.17 Thesis Layout

This thesis is divided in to six chapters as follows:

1. Chapter One includes an introduction to hybrid composite materials, as well as a chapter's history, purpose, problem statement, drawbacks, and methodology.
2. Chapter Two include a study of literature, including magazines, papers and thesis-related publications.
3. Chapter Three includes the theoretical aspect take into account composites.
4. Chapter Four Includes the experimental of work including composite production process and mechanical tests.
5. Chapter Five Includes the find tests results and the discussion of hybrid composite experimental work.
6. Chapter Six summarize the main conclusion drawn from this work, also there are some recommendation for farther work.