MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES IN PURE AND APPLIED SCIENCES

DESIGN AND MANUFACTURING OF A LAMINATED COMPOSITE LEAF SPRING HAVING NON-LINEAR ELASTIC CHARACTERISTIC FOR AUTOMOTIVE INDUSTRY

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Osman ÖREN, a Master of Science student of Marmara University Institute for Graduate Studies in Pure and Applied Sciences, defended his thesis entitled "**Composite structure manufacturing, which will be used in suspension systems for automotive industry, by using aramid fibre reinforced laminated composite**", on August 27, 2019 and has been found to be satisfactory by the jury members.

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OTOMOTİV ENDÜSTRİSİ İÇİN DOĞRUSAL OLMAYAN ELASTİK KARAKTERİSTİK GÖSTEREN LAMİNE KOMPOZİT YAPRAK YAY TASARIMI VE ÜRETİMİ

Bu tez çalışmasında, düşük yoğunluklu, uygun rijitliğe sahip, yüksek darbe dayanımı olan, yüksek yorulma mukavemeti özelliklerine sahip ve süspansiyon sistemlerine alternatif olabilecek bir kompozit yapı geliştirilmesi amaçlanmıştır.

İki kompozit yapı bir birbine ters ve paralel olarak bir çelik çerçeveye monte edilmektedir. İç yapıda ise aramid elyaf takviyeli epoksi reçine matrisli kompozit bir yapı kullanılmıştır. Plakaların geometrisi belirli bir eğriliğe sahip olacaktır. İç kısımdaki kompozit yapının bir yaprak yay gibi görev yapması ve mevcut sistemlerden daha hafif ve daha kolay üretim prosesiyle süspansiyon alanında yeni bir ürün elde edilmesi hedeflenmiştir.

Kompozit yapıyı elde edebilmek için hedeflenen geometriye uygun olarak kalıplar hazırlanmış ve vakum infüzyon metodu (VARTM) ile kompozit imalatı sağlanmıştır. Uygun yazılımlar kullanılarak (Catia, Ansys Ls-Dyna vb.) geometrilerin optimizasyonu sağlanmıştır. Daha sonra bu optimizasyon sonuçlarına göre imal edilecek kompozit yaprak yayların eğilme test cihazı altında eğilme testleri gerçekleştirilmiştir. Sonuç olarak, deneysel verilerle simülasyon verilerinin eşleşmesi hedeflenmiştir.

ABSTRACT

COMPOSITE DESIGN AND MANUFACTURING OF A LAMINATED COMPOSITE LEAF SPRING HAVING NON-LINEAR ELASTIC CHARACTERISTIC FOR AUTOMOTIVE INDUSTRY

In this thesis study, it has been aimed to develop a composite structure which has low density, suitable rigidity, high impact strength, high fatigue strength properties as an alternative to suspension systems.

Two composite structures have been assemblied reverse and parallel to each other to steel chassis. Composite structure, reinforced with aramid fibre, has epoxy resin matrix, has been used in the internal structure. The geometry of the plates will have a certain curvature. It has been aimed the composite structure to serve as a leaf spring and this method to get a new product with its lighter and easier production process than current systems in the suspension field.

To obtain the composite structure, the suitable tools have been prepared according to the aimed geometry and the composite structure production has been made with vacuum infusion method (VARTM). The optimization of the geometries has been provided by using suitable softwares (Catia, Ansys Ls-Dyna etc.). Afterwards, the bending tests of the composite leaf springs, which has been produced according to these optimization results, have been applied under bending test machine. In conclusion, it has been aimed to meet the experimental and simulation results.

SYMBOLS

M **:** Pound (lb)

t **:** Time (s)

T **:** Temperature (°C)

µm **:** Micrometer

ρ **:** Density

P **:** Pressure (atm)

M **:** Mass (kg)

F **:** Force (N)

ABBREVIATIONS

CM : Composite material

GFRP : Glass Fiber Reinforced Polymer

CFRP : Carbon Fiber Reinforced Polymer

AFRP : Aramid Fiber Reinforced Polymer

VARTM : Vacuum-assisted Resin Transfer Molding

RCM : Reinforced Composite Materials

T_g : Glass transition temperature

MA : Middle East and Africa

CTE : **C**oefficients of thermal expansion

PAN : Polyacrylonitrile

CAD : Computer aided design

R&D : Research and development

OEM : Original Equipment Manufacturer

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1. INTRODUCTION

1.1. The Aim and Scope

This thesis study aims to investigate composite structure production which can be used in automotive industry in suspension systems in long period, right composite structure determination, inspection of effects on composite structure of composite material, lay-out and quantity.

By means of this project, it is aimed to bring a new perspective and application method into the conventioanal existing suspension systems which are used in automotive industry. One of the purposes of this study to conduct a pilot suspension system which are lighter and easier producible processes than conventional suspension systems. Engineering studies which will be conducted on leaf spring composite structure, will play a big role for increasing performance with Ls-Dyna program. [1, 2]

Fiber reinforcements in matrix material are fundamental strength elements. Fibers which have lightness, high modulus of elasticity besides low densities are also resistant to chemical corrosion. Fibers take an important place in modern composite production. Glass fiber is one of the oldest fiber types used in technology. The fiber types like boron, carbon, aramid, silisium carbide, and etc. developed in recent years, are types using in advanced composite structures.

Research and devolopment studies regarding production difficulty, multi-step process structure and high weight in existing suspension systems, have been continuing in automotive industry for long time. In this study, longer-term objectives are to get a composite structure which have low density, proper stiffness, high impact strength, high fatigue strength and may be used in alternative suspension systems to classical suspension systems. The aramid fabrics will be aligned into a special tool which produced in 3D printer, after cutting in a special form by the means of scissors. [3]

The aligned fabrics in specified quantity will be produced in this plastic tool with VARTM method by using epoxy matrix. The produced composite structures will be assemblied to a frame. The mechanism strength will be tested under the bending test machine (bending test) [4]. If successful conclusions are brought from experimental studies, these suspension system products may be used in automotive industry with its easier production process and light weight.

1.2. Composite Materials

1.2.1. Classification of Composite Materials

A composite is a new combined material which includes two or more different type materials. Composite materials are used to get a new superior material from different strong properties of composite elements. This optimisation provides composite material elements to make better their defficiencies. When composite elements are united in right technics and design, their qualities higly can be improved. Although all mechanical properties of composite materials can not be improved in same time, the desirable characteristics can be improved. [5]

Composite materials are used widely in different fields like automotive industry, infrastructure, aerospace industry, marine, architecture, sports and other engineering areas. The biggest aerospace companies in world have used largely composite materials. Some superior properties of the different materials can be provided by creating composite materials depending on their types:

- strength
- stiffness
- thermal insulation
- weight
- design flexibility
- thermal behavior
- net shape manufacture
- cost
- wear resistance
- thermal conductivity

Composite materials have been used in various fields for long years. Wood, cob, bone, leaf, bamboo, bast and seed are some of primary natural composite examples. The classification of composite materials can be done according to the reinforcement type.

<u>Composite materials based of type reinforcement in a matrix</u>

(1) Fiber reinforced composite materials

(2) Laminated reinforced composite materials

(3) Particle reinforced composite materials

(4) Combinated reinforced composite materials [5].

1.2.1.1 Fiber reinforced composite materials

Fibers have a lot of filaments which vary in different diameters from 5 micrometers to 15 micrometers. There is inverse proportion between fiber diameter and fiber rupture strength but there are some exceptions like boron fibers. They can be in different cross sections. These fibers are produced in so varius forms according to their usage areas by using special textile machines. Fibers occupy the biggest volume rate in composite material if all composite structure constituents are evaluated as volume and function. They have great importance in improvement of properties compared to traditional materials.

The right fiber type selection is one of the crucial issues in terms of proper improvements in composite materials. Fiber type, volume rate, fiber orientation, fiber length have an important role in fiber type selection. These elements affect higly characteristics of a composite material.

The most important fibers are carbon fibers, aramid fibers, glass fibers, boron fibers, ceramic fibers and some organic fibers for engineering applications. Some of them will be inspected in detailed below.

1.2.1.1.1 Glass fibers

One of the most used composite fibers is glass fiber. Glass fibers have important adavantages like low cost, high mechanical and chemical strength and high insulation level. [6]

Glass fibers are produced from molten glass at 1200 ºC which use extrusion method in its production. They have different variations according to their ingredient properties. Two variations of fiber glasses are used in a widespread manner in industry applications. These are E-glass fiber and S-glass fiber.

Glass fibers have superior physical properties that are more resisting than steel in some variations. Glass fibers are produced generally in solid circular cross section because of their wide usage area in industry. Glass fibres which are rectangular, triangular and hexagonal cross sections are also available in accordence with increasing diversity demand of industry. Because of the material costs compared to aramid and carbon fibers, glass fiber composites are the most preferred composite material. The biggest

disadvantages of glass fiber are lower modulus, higher densities and lower fatigue resistance than aramid and carbon. [7, 8]

1.2.1.1.2 Carbon fibers

Organic materials are used in production of carbon fibers, which contains PAN (polyacrylonitrile), rayon, and pitches. There are a lot of commercial carbon fibers, which have a large of strengths and modulus intervals. Carbon fibers have high stiffness, high strength, low density and coefficients of thermal expansion (CTE) in terms of reinforcement classification. Fibers have to be aligned parallel to the axis of the fibre, to get high modulus and strength layer planes of carbon. The modules of carbon fibers depend on the degree of perfection of alignment which varies considerably in the manufacturing process. [9-11]

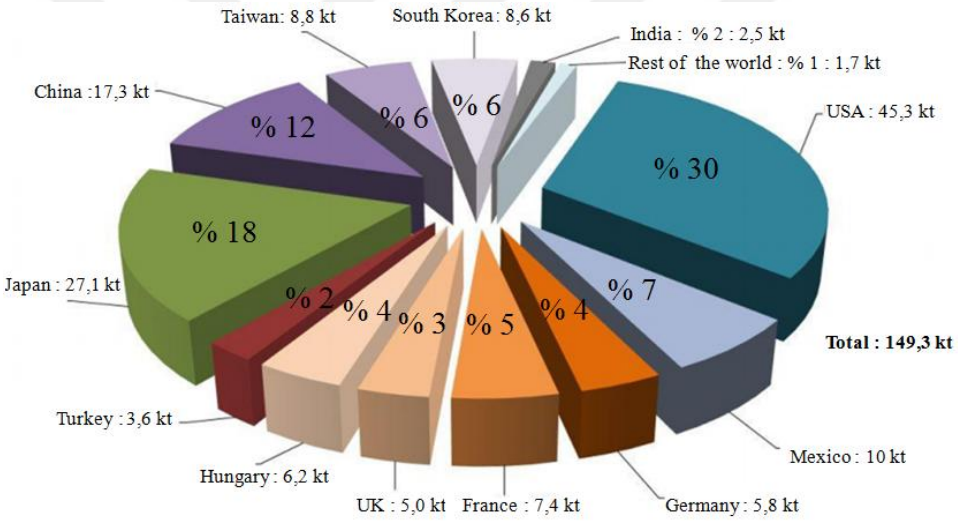


Figure 1.1 Global Carbon Fiber Demand in Thsd. Tons by region – 2018 [12]

Carbon and graphite fibers are generally used interchangeably. They are not identical but similar to each other. Despite the fact graphite has technically carbon rate bigger than 99 percent, carbon fiber has about 93 percantage. Carbon fibre is produced at 1300 ºC, while graphite fibre is produced in more 1900ºC. Galvanic corrosion can occur if it is used together with metals. To prevent this problem, an inhibitor material like glass and resin can be used.

1.2.1.1.3 Aramid fibers

Aramid fibers are high-strength, high-modulus materials which firstly were produced in the 1970s. They are particularly preferred through their outstanding strength to weight ratios. Aramid fibers are man-made high performance aromatic polyamides which are yellow organic compound. Aramid fibers, which are short for aromatic polyamides, are made of carbon, hydrogen, oxygen, and nitrogen. This type of materials is known as paraphenylene terephthalamide in chemistry.

Aramid fibers have strong hydrogen bonds. The advantages are high tensile strength, low density, low elongation up to rupture point and high resistance. They can indicate their high physical properties in low and high temperatures. Their filament diameter is approximately 12 μm and pretty flexible and ductile. These materials may commonly be processed in textile industry. However, they are not so great at compression strength. The aramid fibers are widely utilized in composites materials together with polymer matrices which include epoxies and polyesters.

These materials are used in production of bullet proof vests, insulators of cables, sporting goods, ropes, steel belting in tires and high performance applications like aircraft, automotive industry, textile and etc.. These materials have been produced by two big companies DuPont and Teijin. There are a lot of materials, which widely used in different industry areas, produced by these two companies. The some of them are kevlar 29, 49, 149, endumax, technora and twaron which have different mechanial behaviors and shapes, with their trade names. [13]

1.2.1.2 Laminated reinforced composite materials

When orientation of layer is alligned in the same direction, it is named as a lamina. When layers are alligned in different angles, the composition is identified as a laminate. Laminated materials include minumum two different ply constituents which are in contact with each other. Layers are stacked and enforced together with orientation of the high-strength direction.

The physical properties of the composite have been determined with experimental studies. The physical properties are affected from fiber direction. Therefore, it will be so useful that the majority of layers is in the main load direction. The load transmitting

ability can be balanced by layers which include a lot of different directions, like 0°, +45°, -45° and 90° directions. [5]

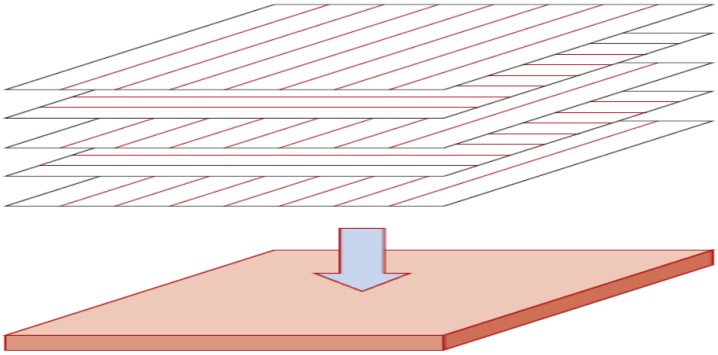


Figure 1.2 Laminated R.C.M [13]

1.2.1.3 Particle reinforced composite materials

Particle reinforced composite materials can contain a lot of hanged particles inside matrix. Particles and matrixes may be catagorized as metallic or non-metallic. Types of them are briefly mentioned below.

Nonmetallic Particles in Nonmetallic Matrix Composite Materials: One of the best known applications of this type is concrete. Concrete which includes a mixture of cement and water has sand particles and rock particles (gravel).

Metallic Particles in Nonmetallic Matrix Composite Materials: Solid-rocket propellants contain inorganic particles like aluminum powder and perchlorate oxidizers in a flexible organic binder such as polyurethane or polysulfide rubber. The particles include about 75% of the propellant leaving only 25% as a binder.

Metallic Particles in Metallic Matrix Composite Materials: A metallic particle in a metallic matrix does not dissolve on the contrary alloys. Lead particles are widely used in copper alloys and steel to improve the machinability. Lead is also a natural lubricant in bearings which are from copper alloys.

Nonmetallic Particles In Metallic Matrix Composite Materials: Nonmetallic particles such as ceramics can be suspended in a metal matrix. The final composite material is named as cermet. Two general classifications of cermets are oxide-based and carbide-based composite materials. [5]

1.2.1.4 Combinated reinforced composite materials

Combinated reinforced composite material is more than one characteristic of the various classes, fibrous, laminated, or particulate composite materials, which is obtained by using two or more different kinds of fibers in a single matrix. Combinated reinforced composite materials have better combined properties than composites contain only a single fiber type.

A variety of fiber combinations and matrix materials are used, but in the most common system, both carbon and glass fibers are incorporated into polymeric resin. The carbon fibers are strong and relatively stiff and provide a low-density reinforcement; however, they are expensive. Glass fibers are inexpensive and lack the stiffness of carbon. The glass–carbon combination is stronger and tougher, has a higher impact resistance, and may be fabricated at a lower cost than either of the comparable all-carbon or all-glass reinforced plastics. There are a lot of ways to combine the two different fibers which will highly influence the general mechanical properties.

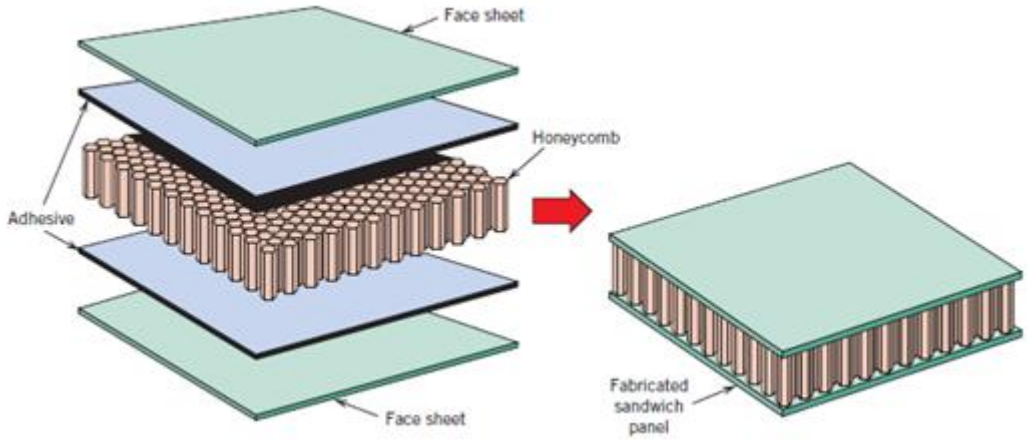


Figure 1.3 Combinated reinforced composite material [13]

For example, the fibers may be stacked and combined with one another. A structure may be occured including layers and single fiber types, alternating one with another. All combinated reinforced composite material properties are generally anisotropic. [13]

For example, reinforced concrete is both particle reinforced (because the concrete is composed of gravel in a cement-paste binder) and fiber reinforced (because of the steel reinforcement) composite materials. Laminated fiber-reinforced composite materials are

a combinated class of composite materials including fibrous composite materials, particle composite materials and lamination techniques.

1.2.2. Mechanical Behavior of Composite Materials

Composite materials have many different mechanical behavior characteristics compared to conventional industrial materials. Some characteristics are solely improvements of conventional behavior; others are completely new and require new analytical and experimental studies. The most widespread engineering materials are both homogeneous and isotropic.

A homogeneous body has uniform properties at all points of the body. An isotropic body has same material properties in every direction at a point in the body. Bodies with temperature-dependent isotropic material properties are not homogeneous when subjected to a temperature gradient, but still are isotropic. [5]

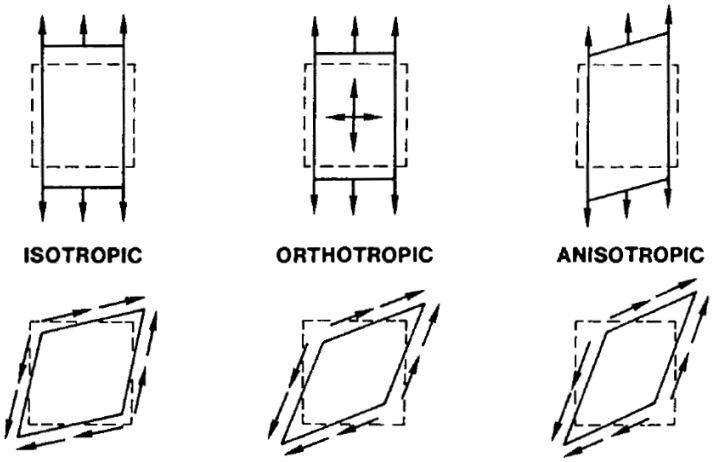


Figure 1.4 Mechanical Behavior of Composite Materials [5]

In contrast, composite materials are often both inhomogeneous and nonisotropic. Inhomogeneous materials can be named also as nonhomogeneous or heterogeneous material. Nonisotropic definition can not be used in the place of orthotropic or anisotropic words.

An inhomogeneous body has nonuniform properties at all points of the body. An orthotropic body has material properties that are different in three mutually perpendicular directions at a point in the body and, further, has three mutually perpendicular planes of material property symmetry. Thus, the properties depend on orientation at a point in the body.

An anisotropic body has material properties that are different in all directions at a point in the body. No planes of material property symmetry exist. Again, the properties depend on orientation at a point in the body.

1.2.3. Thermoset and thermoplastic composite manufacturing processes

Polymer based composite processes are classified as thermoset composite manufacturing processes and thermoplastic composite manufacturing processes. In terms of trading products, thermoset composite products pioneer in the composite industry. Thermoset resins are preferred in approximate 70% of all composite products. The thermoset composite use started firstly by using glass fiber with unsaturated polyester in 1940s, although the thermoplastic composites use started afterwards.

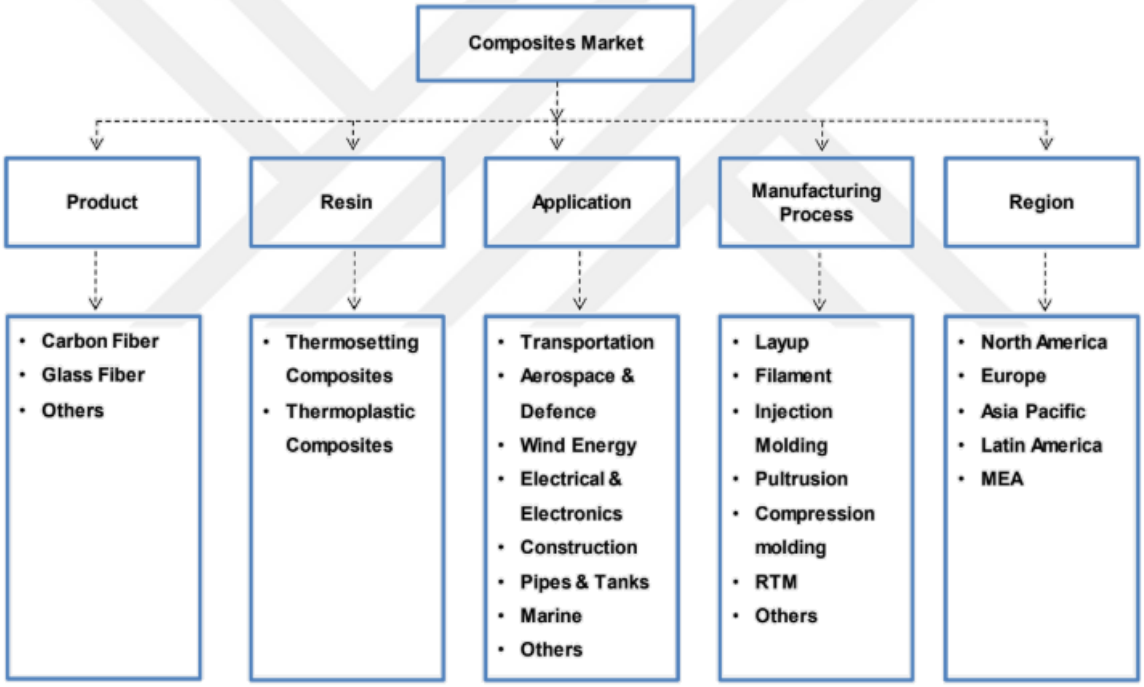


Figure 1.5 Classification of Composite Processing Techniques [14]

The thermosets pioneer in the aerospace, automotive, marine, boat, sporting goods, and consumer markets in the ratio of 70% in product applications. There are some leading production methods available on the market within this process. These are hand lay-up process, spray-up method, filament winding method, pultrusion method, RTM method, VARTM method. In this thesis, VARTM method is explained more detailed as the composite material experiment method of this study. [14]

Thermoplastic composites occupy approximate 30% place of polymer-based composites. The thermoplastic composites usage is getting more known in the automotive and aerospace industries because of their higher toughness, higher production rate, and minimal environmental concerns. The leading thermoplastic manufacturing methods are injection molding, compression molding, the autoclave/prepreg lay-up process.

Many of the manufacturing processes for thermoset composites are also available for the production of thermoplastic composite parts like filament winding and pultrusion processes, etc.. There is a big difference between thermoplastic composite process and thermoset composite process. Thermoplastic composite process takes seconds and is exactly a physical operation. As to thermosets, they take so long and are chemical reactions. In this study, some of them will be explained.

1.2.3.1. Hand Lay-Up Process

Hand lay-up process is the most common and least expensive open-molding method because it requires the least amount of equipment. Fiber reinforcements are placed by hand in a mold and resin is applied with a brush or roller. This process is used to make both large and small items, including boats, storage tanks, tubs and showers. Hand lay-up is an open molding method suitable for making a wide variety of composites products from very small to very large. Production volume per mold is low; however, it is feasible to produce substantial production quantities using multiple molds. Hand lay-up is the simplest composites molding method, offering low cost tooling, simple processing, and a wide range of part sizes. Design changes are readily made. There is a minimum investment in equipment. With skilled operators, good production rates and consistent quality are obtainable. [14]

Gel coat is first applied to the mold using a spray gun for a high quality surface. When the gel coat has cured sufficiently, roll stock fiberglass reinforcement is manually placed on the mold. The laminating resin is applied by pouring, brushing, spraying, or using a paint roller. FRP rollers, paint rollers, or squeegees are used to consolidate the laminate, thoroughly wetting the reinforcement and removing entrapped air.

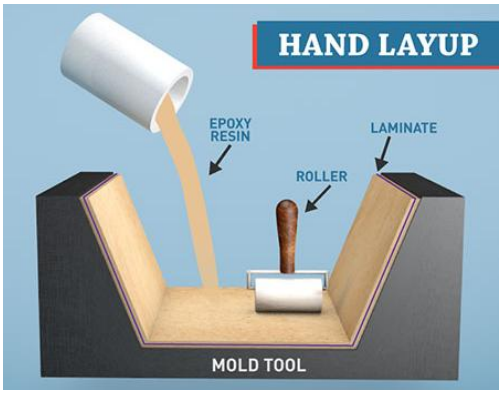


Figure 1.6 Hand-up Process [15]

Simple, single cavity molds of fiberglass composites construction are generally used. Molds can range from small to very large and are low cost in the spectrum of composites molds.

1.2.3.2. Spray-Up Process

Chopped reinforcing fibers are sprayed onto a mold and wet with resin. A yarn of reinforcing material is cut to a set length by a chopper/gun which immediately sprays them onto the mold. Resin and catalyst design must accommodate a spraying process as well. Single sided, typically composite tools are used for this process. Spray up parts normally have one visible, smooth side. A gel coat can be added during molding to produce cosmetic finished surfaces.

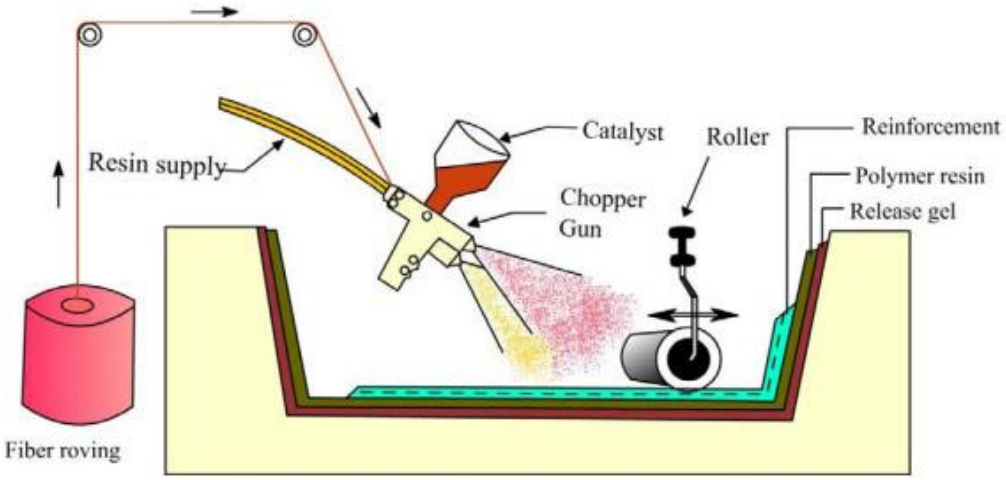


Figure 1.7 Spray-up Process [16]

This process has significant benefits. Robotic arms used for spraying can be added to automation system and variability can be decreased. Tools for this process has lower cost and this process is suitable for lower volumes. This process has also some

disadvantages. It has higher cycle times and produces only one smooth surface. It is labor dependent.

1.2.3.3. Filament Winding Process

In filament winding method, resin-saturated fibers are wound onto a rotating mandrel at the specified winding angle. Carriage unit moves back and forth and the mandrel rotates at a desired speed in a typical filament winding method. The desired fiber angle is generated. The process is very proper for making tubular parts by controlling the movement of the carriage unit and the mandrel. The process which is economically attractive, can be used for producing high-volume parts with an automation system. This method is generally preferred in cylindrical shaped structures. [14]

Filament winding is the unique production method which is proper for producing certain specialized products, like pressure vessels. The most widespread products which are manufactured with this method, are tubular structures, pressure vessels, chemical storage tanks, pipes, rocket motor casings. The modern filament winding machines and developing computer aided design systems have provided more complicated geometries to be fabricated and a lot of standard geometric limitations have been carried one step further with last research and development studies. Connecting rods, bottles, fishing rods, drive shafts (industrial and automotive), golf shafts, pressure rollers and etc. are at the present time manufactured which are using filament winding techniques. [14]

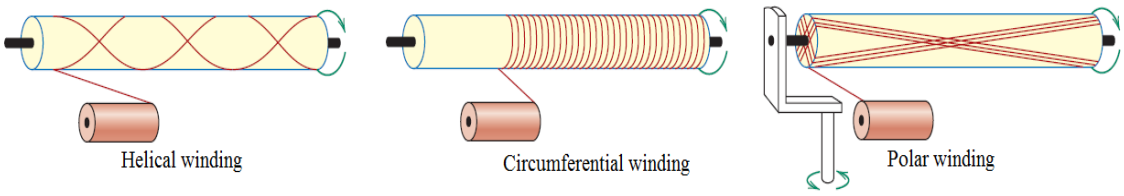


Figure 1.8 Schematic diagram showing of Winding Processes [13]

Circumferential, helical, and polar production methods are various winding patterns to occur the desired mechanical properties. Parts produced in this process have very high strength-to-weight ratios, winding standardization and easy orientation control [13]

1.2.3.4. Pultrusion Process

The pultrusion process is a cost efficient and high-volume manufacturing method in which resin-saturated fibers are pulled through a die to make the part. The process

seems like the metal extrusion process. In this process, instead of material is pushed through the die in the extrusion process, it is pulled through the pultrusion die in a pultrusion process.

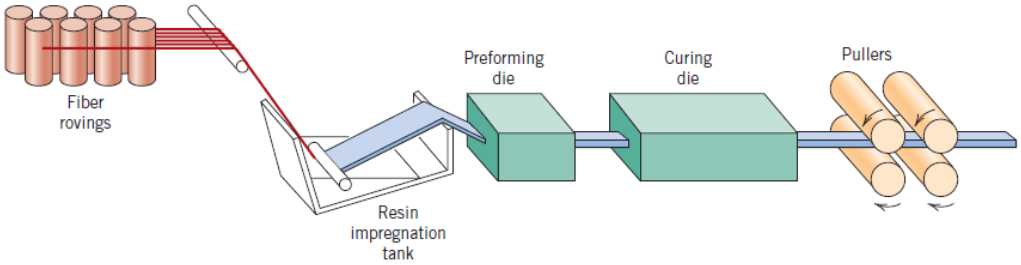


Figure 1.9 Schematic diagram showing Pultrusion Process [13]

Pultrusion creates parts of constant cross-section and continuous length. Pultrusion is a simple, low-cost, continuous, and automatic process. The figure illustrates a typical pultrusion process in which resin-saturated yarns are pulled through a heated die at constant speed. As the material passes through the heated die, it becomes partially or completely cured. Pultrusion yields smooth finished parts that usually do not require post-processing.

1.2.3.5. Resin Transfer Molding Process

The resin transfer molding (RTM) process is also named as a liquid transfer molding process. Even though injection molding and compression molding processes have became famous as high quantity production methods, their usage is largely restricted with nonstructural examples by reason of use of short fiber composites molding compounds. Contrary to these molding processes, RTM process presents low cost structural part production in medium volume quantities using low cost molding. The resin transfer molding presents the production of near-net-shape complicated structures together with specified fiber directions. [14]

RTM process uses generally continuous fibers. In the RTM process, a preform structure is inserted into the mold (tool) cavity. A counter mold half is mounted to the first half and the two sections are connected to each other with clamps properly. Afterwards, using distribution equipment, a resin mixture, a catalyst, color, filler, etc., is pumped into the mold by using entrance and exit points in the mold. After curing is completed for 6 to 30 min, depending on the cure kinetics of the mixture, the part is

then removed from the mold. Therefore, RTM studies are resulted on both sides of the composite structure in the production of structural parts with quality surface. [14, 16]

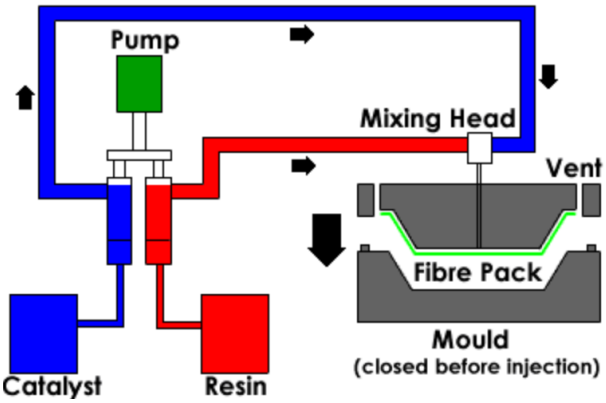


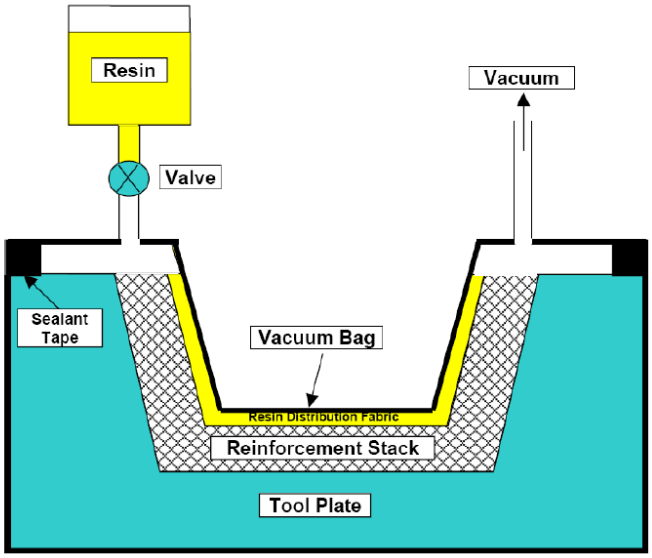
Figure 1.10 Schematic diagram showing RTM Process [17]

The RTM method presents a cost efficient tooling advantage in comparison with other tooling methods like injection and compression molding. Because the pressure needs in compression and injection molding methods are much more than the pressure using in RTM method. Thus, tooling does not require so strong and heavy. Cost efficient tooling makes a big contribution for prototype preparation and fabrication period in terms of low initial investment. The other contribution of RTM method in comparasion with other methods is that the closed manner of the RTM method occurs a more smoothly experiment environment. The RTM method molds may be generally made of steel and aluminum. Plastic and wood ones can be also preferred for special and complex prototype molds.

1.2.3.6. VARTM - A Variation of the RTM Process

The Resin Transfer Molding Processes has some kinds which is utilized in the commercial area. One of the RTM methods using in a widespread manner is VARTM. VARTM is the abbreviation of Vacuum-assisted Resin Transfer Molding. It will be explained with all details below. VARTM, is one of the RTM process variations and is low cost method in producing big structures. Tooling costs are divided to two pieces since one-sided tools are used to produce the structure in this method. Fibers are put in a one-sided mold with this infusion method and a cover is used onto the top of one-sided tool. A vacuum operation is applied to absorb the resin into closed mold thanks to mold entrance port which has various shapes. If it is compared to the wet lay-up method which using in boat hull production; this method has some superior advantages.

VARTM method applies just vacuum pressure for injection and curing. Therefore the most important property of VARTM is that the tooling is lower cost and easier to make design in comparison with RTM methods. Moreover, because of not needing an autoclave operation for curing, it has a chance to get huge composite parts thanks to VARTM method. Because VARTM needs lower pressure, lightweight foam cores may include the lay-ups. VARTM method has been applied for long years to produce fiberglass boat hulls, but it has called the attention of the aerospace industry in last decades.



1.11 Schematic diagram showing VARTM Process [18]

Because VARTM method needs only pressure for injection and curing, autoclaves are not needed and very big part dimensions can be produced. Some VARTM product suppliers prefer double vacuum bags for eleminating possible vacuum leakages in first vacuum bag. A breather layer between the two vacuum bags enhances the possibility to eject any air from leakage points. Reusable vacuum bags can also be applied to decrease the bagging cost of complicated structures.

The resins which are preferred for VARTM method should have lower viscosity than resins preferred in RTM method. It is desirable that resin viscosities are less than 100 cps to provide the needed flow for saturating the preform with solo vacuum pressure. Vacuum removal operation is frequently applied to remove the existing air from the mixture before infusion. Infusion can be applied with some resins at room temperature, although some resins need heating operation. Resin and vacuum sources should be put

about 460 mm apart. In accordance with Darcy's law, since the resin moves away from its source, resin velocity diminishes and the composite structure thickness diminishes. It is also more problematical to get high fiber volume structures in thick preforms.

As ideal fiber or fabric lay-out can not be got in preforms, an increase can occured in free volume with every layer addition. This causes less fiber volume ratio in thick parts. Because the pressure in VARTM is less than pressure RTM or autoclave methods, it is harder to get as high fiber volume percent as in the higher pressure processes. In addition, the VARTM method can't provide low dimensional tolerances as RTM method and the surface finish of bag side can not provide the tight tooled surface qua. The perform placement, the ply quantity, the fiber volume ratio and vacuum amount, which are applied to mold during the process, affect usually the structure thickness. NASA considered and tried VARTM method in the Advanced Composite Wing program. Their first wing panel structures included low fiber volume percents (<54), therefore they placed it into an autoclave for a pressurized cure. The study result included a reasonable fiber volume percent (57+). This process was named as VARTM-PB (pressure bleed) by them.

The economic and environmental advantages of VARTM process have enhanced Vacuum assisted Resin Transfer Molding application quantity. Several examples : A lot of resin types can be used with VARTM process like polyester, vinylester and epoxy. VARTM may be preferred together with many woven, stitched, knitted, braided or any fabrics. It has low cost tooling for High performance structures can be produced with lower cost, compared to other methods. Resin injection is provided to VARTM tool which is covered with vacuum bag and vacuumed. Afterwards the fabrics are saturated thanks to resin properly. Thus, resin distributes in fabrics regularly, makes fabrics harder and stronger to produce large composite structures. This technique produces parts with higher fibre content than any other process. Fabrics ratio in this method can be got much more than other methods. High fabrics ratio provides high mechanical performance. These composite structures are lighter, stronger and cheaper. Also, it has to be considered that VARTM is a nature friendly process. Simple and complex shaped productions can be obtained with this method by using regular pressure. Vacuum pressure contributes to achieve the demanded composite structure thickness. Application of vacuum removes air, excess resin and volatiles resulting in a good

uniform product. Vacuum pressure moves air and extra resin away for uniform and strong structure.

1.3. The Composite Applications in Automotive Industry

Composite materials have got a lot advantages thanks to their high properties. Fatigue life, lightness, easy-adjustable structure size, corrosion resistance, low cost assembly. The specific strength (strength/density) and specific modulus (modulus/density) of high strength fibers (especially carbon) are higher than those comparable aerospace metallic alloys. This situation contributes to get composite structures which have lightness, low cost, higher performance, fuel-efficiency.

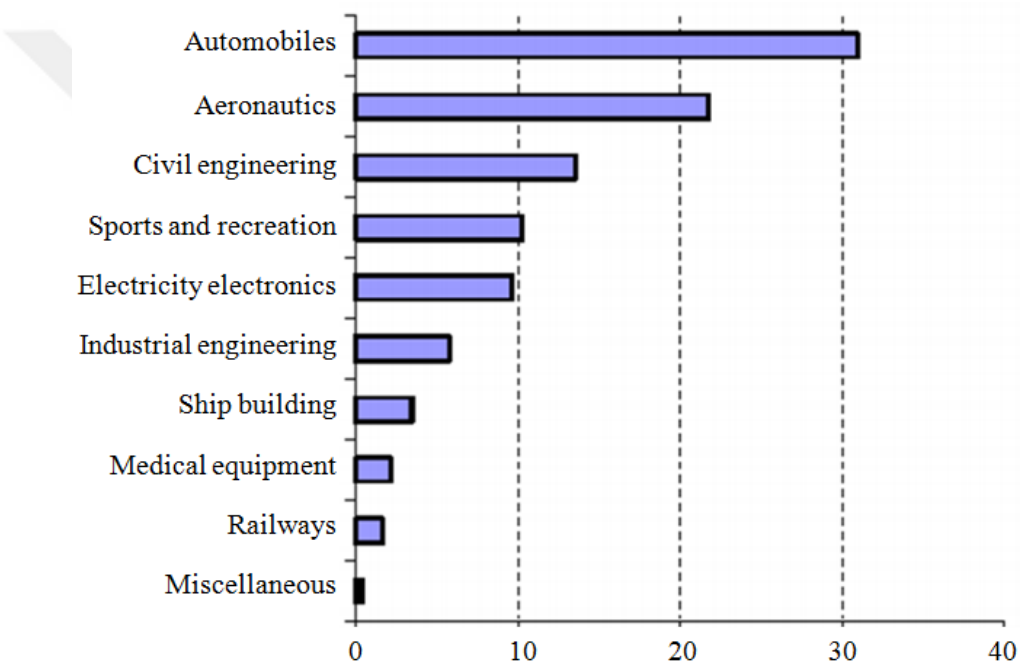


Figure 1.12 Composite material user industries in value, in % [19]

One of the higly usage reasons of composite materials by air craft companies, composite materials don't rot under difficult environmental conditions and get tired easily. Therefore, they have high fatigue resistance. Corrosion of aluminum alloys which are big solutions for centuries causes high cost maintenance problems in terms of commercial and military industries.

Low assembly costs in composite materials are another important issue. Assembly costs are able to reach to half cost of an airframe. Composite materials contribute highly to diminish detail part and fastener quantity which are used in total. Detail composite parts can obtained as a unique cured assembly by using resins, tools, etc.

Disadvantages of composite materials can be counted as high costs of raw materials and generally high production and assembly costs; negative results between moisture and temperature, weak strength outside of fiber direction. Composite materials are not so efficient for the industry areas which load directions are so various, like fittings and lugs. They are quite weak against damages and structure layer separations from matrixes. The mending of composite materials is effortful in comparison with metallic materials.

The biggest cost in composite structure production which is used in conventional hand lay up method, is labor cost in laying up the fabrics layers. Depending on composite structure design and difficulty, labor cost corresponds to 40-60 percent of the production cost on the whole.

The second biggest cost in composite structure is assembly cost which corresponds to 55 percent of the total cost. Composite materials make highly contribution to diminish detail part and fastener quantity which are used in total. This material type comes to the fore especially in terms of low assembly cost.

Temperature affects highly the mechanical properties of composite structures. Especially temperature increase affects negatively the composite structures which have a high ratio matrix in their compositions. Low temperature affects negatively the composite structures which have high ratio fibers in their compositions but low temperature effect is not as major as high temperature effect in matrixes. One of the most important issues is matrix resin selection in composite materials. Matrix resin has to be selected and designed according to proper size, proper strength and proper cured temperature in targeted application.

Composite materials are so sensitive against layer separation in period of production, mounting and maintenance. In period of composite structure production, unfamiliar materials can stay like prepreg backing paper by mistake in the lay-up. In period of composite structure mounting, non-conforming treatment or wrong mounted fasteners can induce layer seperation. In period of composite structure maintenance, low speed impact damages because of the mold drop or moving failure, etc., induce major or minor damages. Even so the damage starts with little notch effect on structure surface; it can spread inside layers and resin cracks. According to separation sizes, this situation diminishes fatigue resistance and compression buckling strength.

There is an increasing interest in weight reduction for energy savings and growing vehicle economy. Transformation in a vehicle structure material can achieve primary weight-saving. If it can be applied to widespread areas which provides smaller production plants, secondary important improvements will be in fuel savings.

The majority of automotive applications include glass-reinforced composite structures because the high cost of carbon and aramid fibers is rarely considered to be acceptable in this market. Nevertheless, the cost of glass reinforcement composite structures is generally higher than pressed steel parts. Hence, the substitution for steel parts is refused frequently in economic development projects, by freezing the energy saving issue.

Car and truck main bodies, panels and doors are presently in use, including front and rear components, bumper parts, and different trim variations. There is an intensive interest in the appliciations of controlled crush components like glass reinforcement composite structures which have high energy absorbing properties. Leaf and coil springs and truck drive shafts are another usage area. [18, 19]

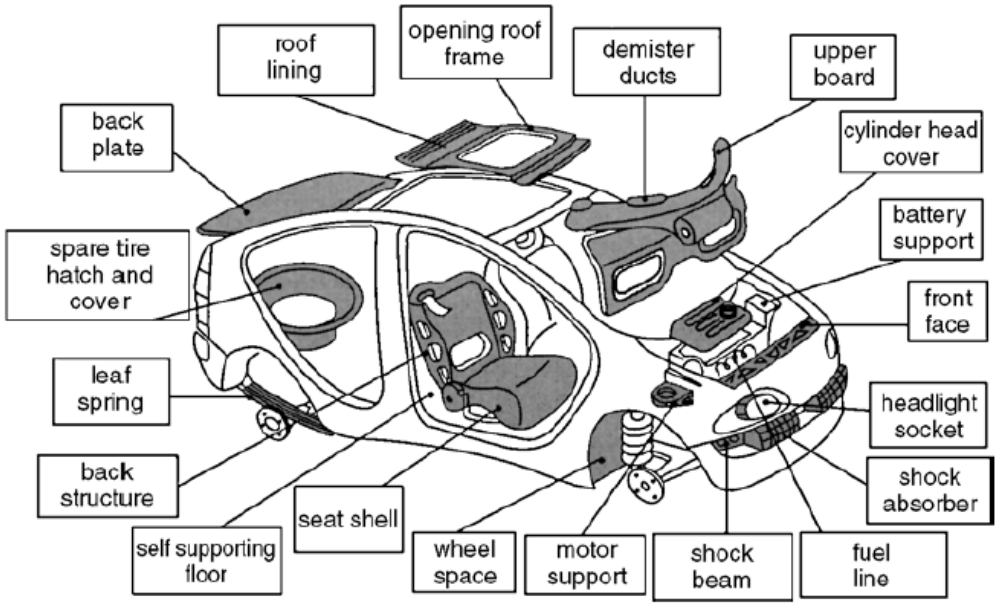


Figure 1.13 Schematic diagram showing automobile equipments [10]

Glass reinforcement inlet manifolds and wheel rims have been put into practice in industry. Also, aluminium alloy components like pistons and connecting rods are tested by means of alumina fibres regarding high temperature resistance in the long term. [20]

Composite materials have been recognised more and more in automobiles, which fibers and matrices are used basically. It is amazing to inspect the different material types in

automobiles chassis and components. Mass distributions are 75% steels, 16% polymers and 8% aluminum and 1% textile in automobiles in terms of material type use.

Although the mass of polymer-based materials are lower relatively, it has to be considered that the specific steel mass is approximate 4 times bigger than polymers. This proves much more volume percentage of the polymers than mass percentage. The plastics are in the first rank with 45% mass percentage in mass distribution among the polymers which are used in automobiles. Elastomers (rubber) are in the second rank with 40% mass percentage. Tires occupy the highest mass in elastomers with 32% percentage of polymer mass distribution. Paints and varnish follows the others with 15% mass percentage.

'Plastics' involves 'reinforced plastics' in composite materials. Reinforced plastics had an evolution with ever-growing use ratio in last decades. The importance of reinforced plastics has increased progressively in body elements, chassis parts under hood, passenger compartment, electricity, transmission&motor and suspension. [10]

Figure 1.14 Hood and door made of composite material [21]

Some dates as below are important for the start of composite parts in automobiles:

1953 : Complete body made of glass/polyester (USA-Chevrolet)

1955 : Complete roof made of glass/polyester (FRA-Citroen)

1968: Wheel rims made of glass/epoxy (FRA-Citroen)

1970: Shock absorber shields made of glass/polyester (FRA-Renault)

Unileaf E-glass fiber-reinforced epoxy springs have been used to replace multileaf steel springs with as much as 80% weight reduction. Other structural chassis components, such as drive shafts and road wheels, have been successfully tested in laboratories and

proving grounds. They have also been used in limited quantities in production vehicles. They offer opportunities for substantial weight savings, but so far they have not proven to be cost-effective over their steel counterparts. [7]

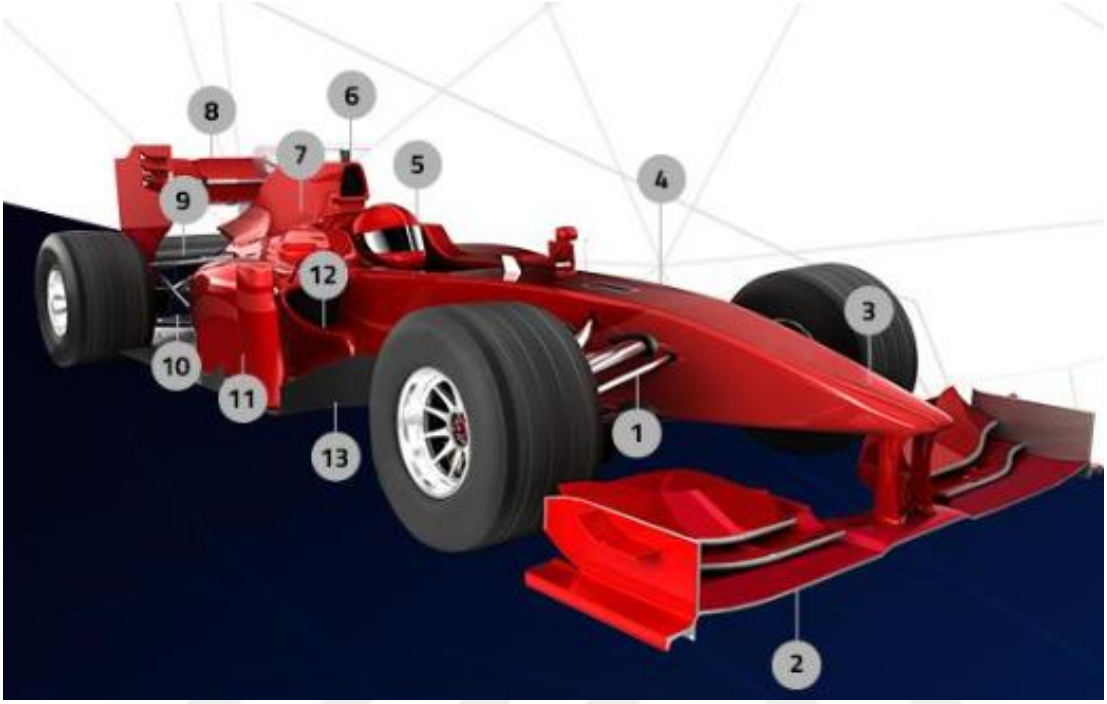


Figure 1.15 Parts constructed from composite material [21]

Table 1.1. Parts constructed from composite material [21]

No	Part name	No	Part name	No	Part name
1.	Front suspension	6.	Exhaust shielding	11.	Side impact structure
2.	Front wing	7.	Engine component	12.	Air ducts
3.	Front impact structure	8.	Rear wing	13.	Floor pan
4.	Monocoque	9.	Rear impact structure		
5.	Hans device (on driver)	10.	Rear suspension		

In the last decades, metal part use in Formula One racecars has been slowly replaced by composite materials. In this fast change, high performance composite are demanded universally by racing teams. Formula One has been replacing metal parts by lighter materials for a long time. After having been tested in the 1970s, the carbon fiber use on racecars reached a turning point in 1981, with the first monocoque entirely manufactured from carbon fiber and epoxy resin.

Carbon fiber remains the most commonly used composite material in racecars, and it's combined with epoxy resins. These carbon reinforcement composite structures have been used in the Formula One business, significantly increasing the performance and safety of racecars over the years. Large majority of Formula One teams in the world utilize these composite structures to build their cars.

Lightweighting is the major reason for choosing composite parts over metal parts when building a racecar. Composite parts get lighter every year as both material technology and design capability advance, and composite industry is constantly working to identify the best fiber-resin combinations. [22]

Composites offer other advantages as well except lightweighting. Race-car concept is a continuous prototyping process, and it's easier to make prototypes with composites. Therefore, even though the material cost is higher in production, it's more efficient to use composites than metal. Certain complex shapes are more easily achieved with composites. Certain molds used to shape the parts are made of composites themselves. Because of high costs, some composite parts like carbon reinforcement composite structures have bee used widely in luxurious vehicles like race-cars. [21]

1.4. The Composite Suspension Systems in Automotive Industry

One of the primary properties of the unidirectionals (namely like glass/resin) is their capacity to accumulate elastic energy. These properties of unidirectionals increase the importance of making composite springs. For instance, a glass/epoxy spring has an efficient storage approximate 6 times more elastic energy than a steel spring of the same mass. One of the other advantage of composite springs is nonbreakable. A small modification of the component behavior can be observed as damage. Many functions can be integrated to unique special system. They can play important role in reduction of total part quantity, decrease the occupied volumes and contribute in a function behavior. Additionally, the mass decreases highly.

Only technical feasibility is not enough for proper composite structure production. The optimization of the three issues which are product, process and production rate, must be proper. Thousand of parts may be produced daily in the automotive industry by using some new processes like compression molding, filament winding, pultrusion, and

pultrusion forming method. Thanks to current improvements, commercialization rates are increased in leaf springs and torsion beam springs.

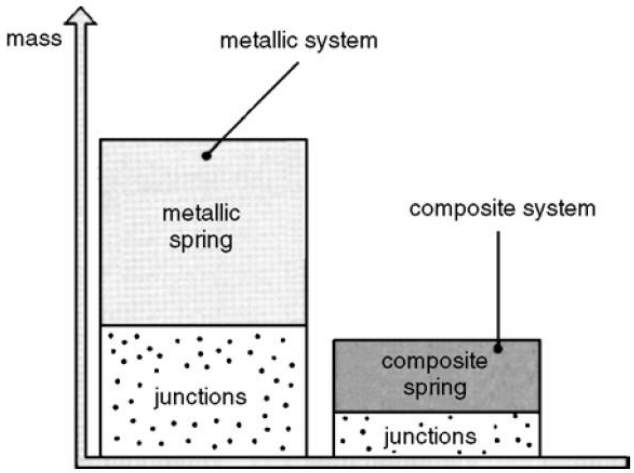


Figure 1.16 Comparation of metallic system and composite system [10]

As a result of commercialization, a metallic spring which is made of several metallic leaves is changed by a single leaf spring made of glass/epoxy composite structure.

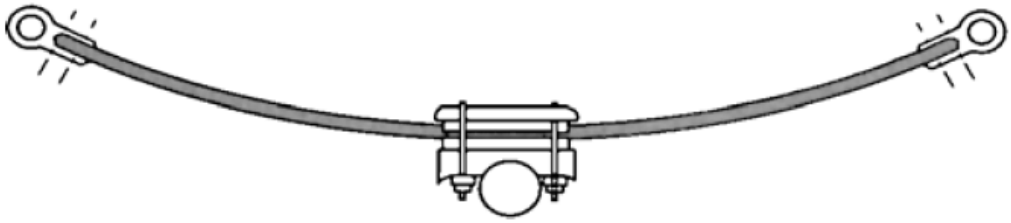


Figure 1.17 Leaf spring [10]

Its useful load is about 1300 kg in this example. The production cost is identical to conventional system. A lot of French, American and Japanese vehicles are sold with this type of spring and they are still on ways.

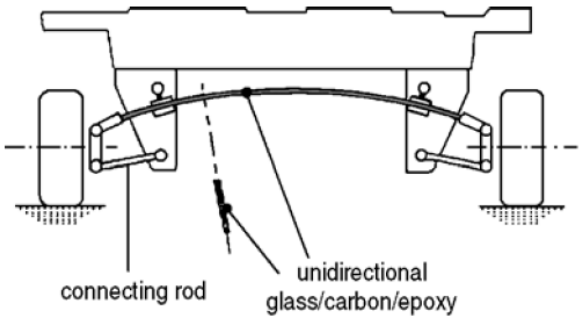


Figure 1.18 Combination of function [10]

An example of the front suspension in the vehicle shows the different combinations and properties of spring, rolling return, and wheel guide.

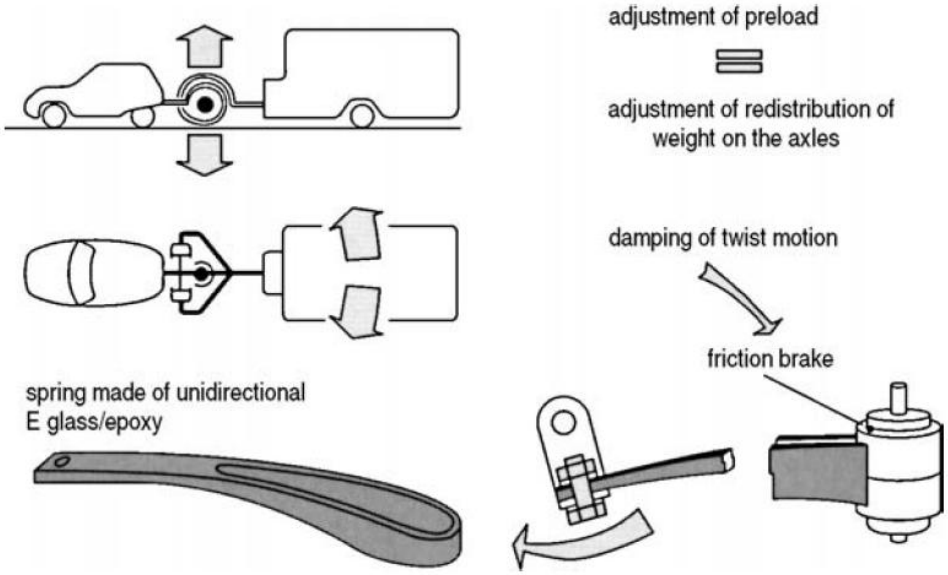


Figure 1.19 Stabilization system [10]

Stabilizing system is utilized for the junction of a vehicle and a caravan. The working principle is shown schematically in figure. The weight is divided by 4.5 compared to 'all metal' alternative. This spring is made of unidirectional E glass/epoxy composite structure. This structure has much more resistance against horizontal and vertical force and damping of twist motion in vehicle and cravan.

The automobile suspension triangle in figure are two elements which are one within the other to get a closed part in this example. First element is made of glass/epoxy composite structure (16 plies balanced fabric). The other element is made carbon/epoxy composite structure (9 plies fabric).

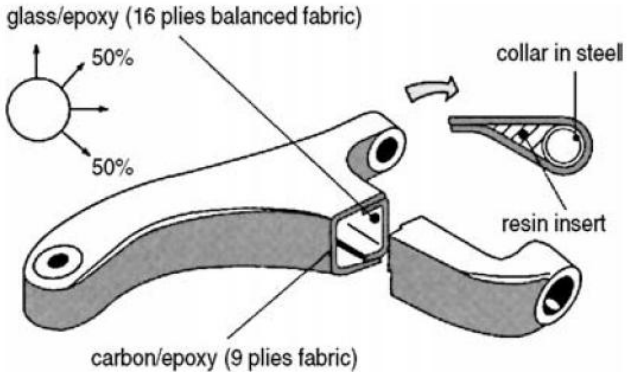


Figure 1.20 Composite suspension triangle [10]

Glass, carbon are aramid reinforced composite structures are widely used in automotive industry. The composite production costs will decrease with more widespread usage in progress of time. Especially carbon fiber reinforcement composite structures are used higly in luxurious vehicles because of high costs. It is expected that they have more widespread usage in standard vehicles. [10]

Turkmen and Koksal inspected glass fiber-reinforced composite materials produced by hand lay-up with different number of layers of glass fiber. They investigated tensile, flexural and impact fatigue strength of composite. They got the conclusions that values of tensile strength and elasticity modulus of the fiber composites increased by the number of layers and in this increase, fiber reinforcement and the thickness of the resin also have an effect. They observed that flexural strength and fracture strength values of glass fiber composites were increased depending on the number of fiber layers. [23]

Pala examined composite materials in product design and the relationship between sustainability and product design. She observed that designers didn't use so much new and advanced materials and had to inform much more about new and advanced materials like composite materials. Therefore, she proposes that the materials which have high performance properties should be introduced and encouraged much more to designers during design education. [24]

Papacz, Tertel and Kuryło examined the performance comparison of conventional and composite leaf spring. They compared the behaviours of polymeric composite leaf springs and steel springs. They observed that leaf springs made of a glass-epoxy composite have a greater ability to suppress vibrations than steel springs and composite materials provide free shape of vehicle suspension systems. Therefore, they got the conclusion that it is possible to obtain the desired stiffness, elasticity and vibration suppression in components made of composite materials and vehicle components made of glass-epoxy composites are about 5 times lighter than made of steel. [25]

Imak and friends examined the fatigue analyses of carbon and glass epoxy laminated hybrid composites experimentally. Carbon and glass composite structures in 8 different orientations were produced by using epoxy resin with handlay-up process. The highest tensile stress has been 1045 MPa in carbon unidirectional (0^o) 6 layers / Glass unidirectional (0^o) 6 layers. The lowest tensile stress has been 94 MPa in carbon

unidirectional (45^o) 6 layers / Glass unidirectional (45^o) 6 layers. The highest fatigue stress has been 710 MPa in carbon unidirectional (0^o) 6 layers / Glass unidirectional (0^o) 6. The lowest fatigue stress has been 56 MPa in carbon unidirectional (45^o) 6 layers / Glass unidirectional (45^o) 6 layers. It was observed that composite material mechanical properties showed variability depending on fiber orientation. [26]

Oztoprak and his friends investigated the developing of polymer composite-based leaf spring systems which were designed and manufactured to replace existing mono-leaf metal leaf spring in a light commercial vehicle. They obtained mechanical properties of different fiber-reinforced polymer materials and compared the results of the finite element analysis are actual size experimental prototype tests. They observed that the reinforcement type and orientation dramatically affected the spring rate. Comparison of the predicted results with the experimental test results for the manufactured prototypes showed good agreement in terms of the load-displacement response. [27]

1.5. The Involute Profile

In our thesis, composite leaf springs are assemblied to test apparatus (steel frame). This mechanism is subjected to the bending forces. During applying bending forces, an involute profile is obtained between two leaf springs as in spur gears. Therefore, the involute profile subject will be described in this section.

An involute profile is a curve traced by a point on a line as the line rolls without slipping on a circle. In involute profile, the common normal at contact level always passes through the pitch point (P) and maintains a constant inclination angle with the common tangent to two pitch circles. This angle is called pressure angle. Therefore, the pressure angle remains constant in involute tooth.

One of the most commonly used theeth forms is involute profile. This profile type is preferred in the majority of gears. Involute profile has advantages such as simplicity in design and ease of use. The involute profile satisfies the fundamental law of gearing at any centre distance. All involute gears of a given module and pressure angle are completely interchangeable and can be machined from one single tool.

In addition, the pitch point is still fixed and the law of gearing is satisfied. Therefore, the velocity ratio remains constant. When the gears are generated by involute rack cutters, this interference is eliminated because the cutting tool removes the interfering

portion of the flank. This is called undercutting. Undercutting solves interference problem.

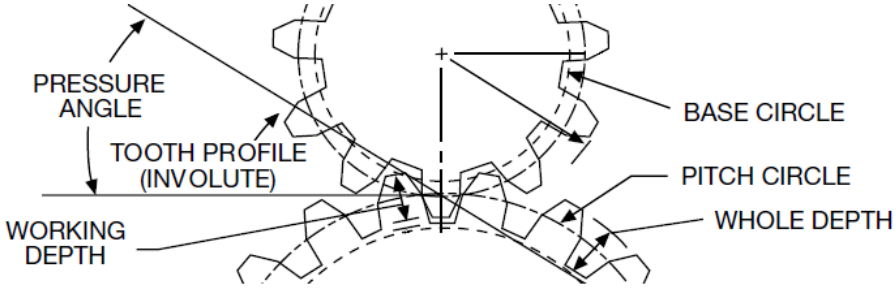


Figure 1.21 Involute profile

There are three standard systems for the shape of gear teeth. These are 14,5° full depth, 20° full depth and 20° stub depth involute systems. The minimum number of teeth is 32 for 14.5° full depth system, 17 for 20° full depth system and 14 for 20° stub system to avoid interference and undercutting. The 20° pressure angle system with full depth involute teeth is widely used in practice. It reduces interference and the risk of undercutting. It has greater length of contact. [28-31]

1.6 Spring design

Springs are flexible equipments utulized to exert a force or a torque and to store energy. Pull or push can be applied by forces or radial force can be applied. The springs may have significant duties with their functions. They may be preferred for absorbations, various suspensions, clocks and etc. They are also utilized to limit the movement or to implement a load. Thousands of examples are seen in the daily life and in the industry. There are various types of springs according to force movement method like push, pull, radial, and torsion springs. [28, 29]

Table 1.2. Types of springs [29]

Usage	Types of springs
Push	Helical compression spring, belleville spring, torsion spring flat spring, such as a cantilever or leaf spring
Pull	Helical extension spring, torsion spring, drawbar spring, flat spring, such as a cantilever or leaf spring, constant-force spring
Radial	Garter spring, elastomeric band, spring clamp
Torques	Torsion spring, power spring

One of the most preferred springs is helical compression springs. Their use ratio occupy a quite big place in automotive sector. Coiled round wire is used basically in the production. They have various cross sections like round and square etc.and various movement behaviour and pitch depending on linearity. The length of these springs are defined as free and solid length depending on unpressing or pressing, respectively. The most preferred helical compression springs are conical, hourglass, barrel, and changeable pitch types.

The helical spring has to have the necessary resistance and durability to oppose the applied forces. The spring motion behaviour has to be defined firstly. Then the size of helical spring will be so efficient in providing absorbing capacity like coil diameter, coil length and cross section size. The application area of helical spring defines the maximum and minumum size boundries during unpressing and pressing of the spring. Safety factor is generally selected about 1.5 in calculations.

Leaf springs may be manufactured from various metal, plastic and composite materials etc. The loads may be loaded from different directions in changeable amounts. In this study, composite leaf spring design which will be utilized in automotive suspension systems, will be done. Because of ride comfort request, the non-linear characteristic is selected in spring design. To get non-linearity in this springs, a special spring placement which needs 2 leaf springs have been designed. Because of the lightness requirement compared to steel products, the material has been selected composite material. The aramid reinforced composite has been preferred because of high ratio 'strength to weight' in leaf springs. All drawings and designs have been in Catia software. By specifying the suitable placements of two springs in bending test apparatus in Ls-dyna software. The necessary revisions in Catia software have been completed for best fit non-linearity design. The necessary load applied to the springs has been calculated by considering an automobile weight. The applied force in this study has been scaled to the smaller load to implement the bending test in university technical conditions. The sizes of leaf springs have been designed by considering the area around a wheel in a standard automobile. [29]

The material type is also so significant in spring function. In steel industry, there is a steel class defined as 'spring steels'. If steel will be used in spring production, medium

or high-carbon steels are preferred for material selection in springs. Except steels, a lot of various metal, plastic and composite materials are used in spring production. Low cost products are the key items, if there are no disadvantages in function and strength.

If a designer wants an extension spring to create, he has to note some properties and firstly specify the main requirements which are so critical for function. The spring behavior and force mount are the first requirements which have to be considered. Then the spring type, size and quantity are specified according to assembly motion lay-out.

Extension springs are subjected to tension from one or more directions. Tension from two directions is preferred generally in various sectors. They are not so different from compression springs. Both of them use the Hook's law as a basis. The aim of both springs is to provide first shape and create continuity.

If a designer wants to create a compression spring, he has to specify spring behavior and force mount. The design steps are generally same in the extension springs. It can be said that compression spring are the most used type in different sectors.

If a designer wants to create a torsion spring, he has to specify the torque start point and then the spring dimensions and diameter. The working direction has to be specified as right or left. If the angular motion is desired, this type can be suitable for practical use like in special hinges. [30-32]

1.7 Spring characteristics

Spring characteristic is a movement behavior which specifies the ride comfort and road handling. Linear and non-linear springs are the kinds of the spring characteristic. Driver preference specifies the determination of characteristic type. Linear springs have been widely preferred in various sectors. They have a linear line in the force vs. deplacement graph. In this type, the spring rate doesn't change during driving and it is independent from the applied force. Each spring rate remains stable to move each one milimeter distance in leaf spring.

Non linear leaf springs provide the non-linear spring rate. They have a non-linear curve in the force vs. deplacement graph. The compression in suspension changes the spring rate. Therefore, the rate values vary from first suspension to the other ones. While first spring rate is 50 N to act one milimeter in spring, the othere spring rate can become 80

N in next steps. Non linear springs can be classified degressive and progressive. Progressive springs are used more widespread in automotive suspension industry thanks to their increasing load values. [33]

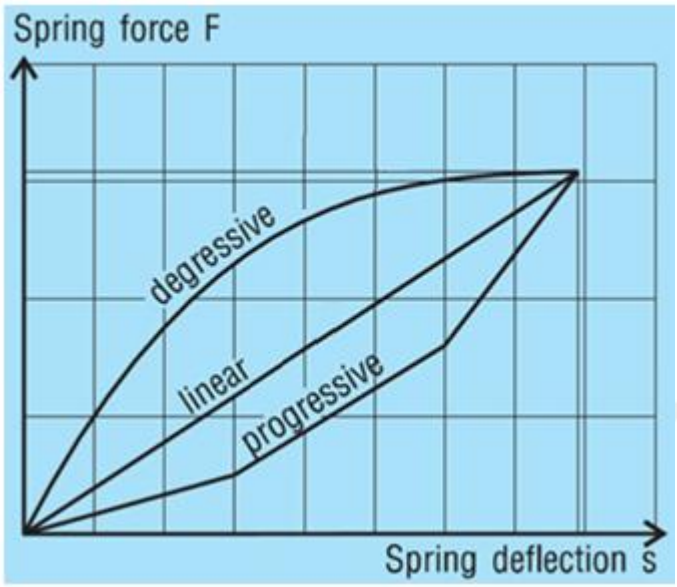


Figure 1.22 Spring characteristic graph (Force vs. deflection) [34]

Helical springs have linear and non-linear characteristic. Linear helical springs are the most commonly type of spring used. The linear spring is most times uniform in shape and has equal distance between each spring coil. In function, the linear spring is a great choice for its reliability, consistency, and predictability. The linear spring is a good choice for performance drivers and racers for its predictable nature. The linear spring retains the same spring rate regardless of how much it is compressed. If it is assumed that the spring rate is 250 N per mm, the spring rate with 250 N per mm takes 250 N of pressure/force to compress it the first measured mm and then every following mm also takes 250 N of pressure/force. [33]

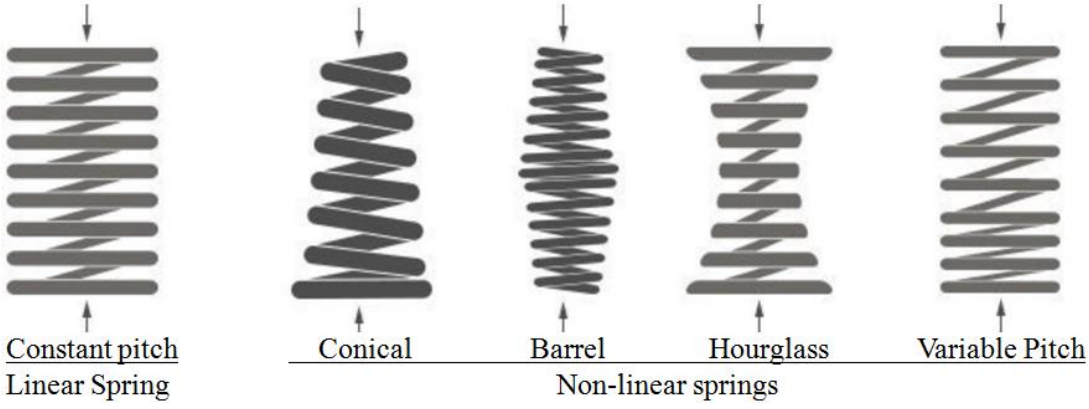


Figure 1.23 Helical springs: Linear and non-linear spring types [34]

This is ideal for those interested in setting up an all-out performance vehicle or a race car. This non-variable spring rate will allow the driver to better predict the car through the suspension and have positive feedback through a high-speed turn on a race track. When set up correctly with the other components, a linear spring can still be a very comfortable and useful spring for the street as well.

The non-linear progressive spring can differ quite a bit from a linear spring in both shape and function. Progressive spring has not a uniform shape. In function, the progressive spring is often unmatched in its ability to provide equal measures of performance and comfort. Most vehicle manufacturers use a progressive spring for their new vehicles for this balance. A progressive spring effectively get stiffer and increase in rate the further it is compressed. This is why it is often seen that aftermarket suspension manufacturers list a spring a 'progressive' instead of listing it by a specific numerical number. It often doesn't accurately describe the spring by giving it one numerical number. If a progressive spring has a 250 N per mm rate at the first measured mm, it could very well have a 350 N per mm second mm, 500 N per mm third mm, and maybe a 675 N per mm four mm.

This style of spring is ideal for street vehicles where it is important to have good balance between comfort as well as performance. A progressive spring is able to handle road conditions often much better than a linear spring could. This doesn't mean that you can't get performance out of a progressive spring. In some cases, due to its nature, a progressive spring can often provide a higher spring rate in hard corners to keep the car flatter and very stable. Besides, it can not be said that this characteristic is better than the other. The main issue is more suited for a specific vehicle and customer demand.

Disc springs are used widely in different sectors because of their different properties. They are conical and round rings and have round hole inside. They have different forms when depressing onto disc springs with a force. Disc springs have linear and non-linear characteristic. The cone height and ring thickness are the most significant sizes in disc springs. These sizes, cone height with 'h_o' and thickness with 't' are indicated in the figure.

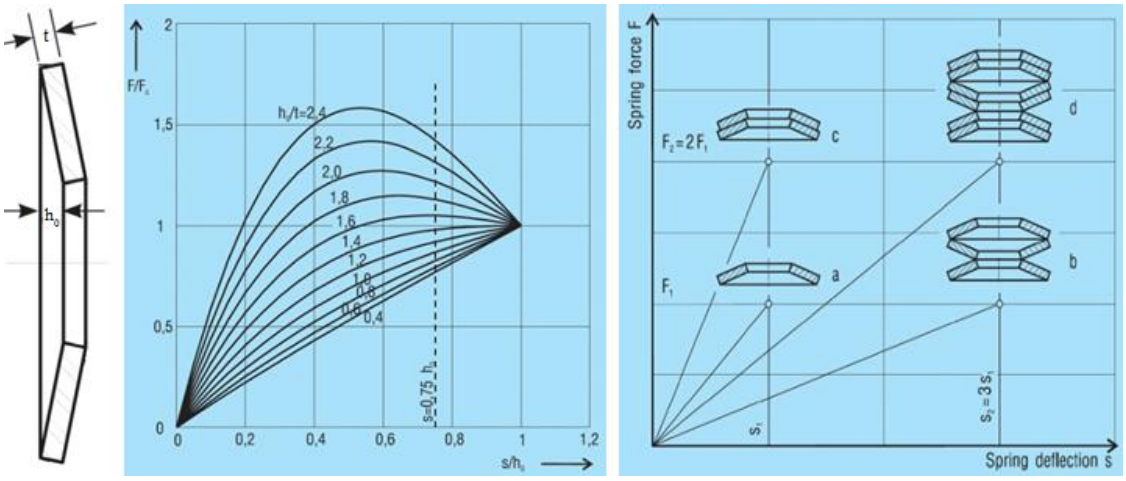


Figure 1.24 Disc springs : Linear and non-linear degressive spring characteristic [34]

According to the h_o/t rate, the dics spring changes its form. When this rate is under 0.4, it is assumed that the disc shows linear behavior which has a flat line. After this rate is exceeds 0.4, the line is getting rounder curve shape. Until the rate 1.5, this progressive characteristic can be obtained because the curve has a straight line in this value. After this value until the rate 2, the disc spring shows degressive behaviour. After the rate 2, disc spring may change suspension direction. These springs can be placed in various forms as indicated in the figure. (a:single arrangement, b:serial arrangement, c:parallel arrangement, d:combined arrangement)

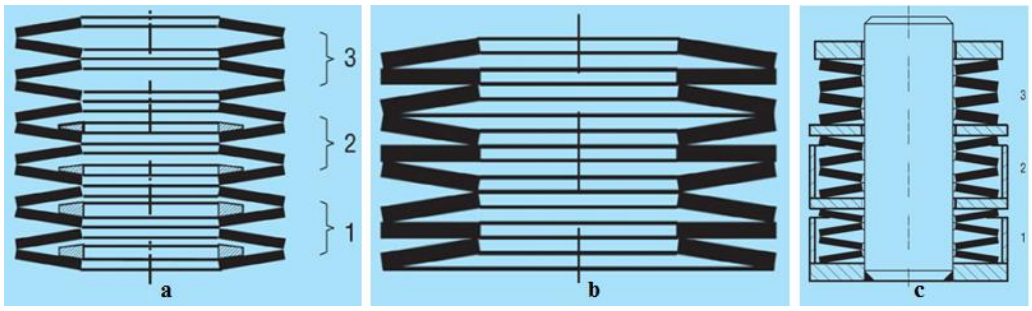


Figure 1.25 Disc springs: Non-linear progressive spring characteristic [34]

Also, the non-linear behaviour can be got with additional items like smaller rings. Progressive characteristic examples are shown in disc springs in Figure 1.25. The additional rings are putting among disc springs; the working stroke is adjusted and specified the size boundries suitable to the ring thickness. All thicknesses in rings and disc springs can be various from each other to get the suitable spring behaviour and the spring rate. [34]

Figure 1.26 Leaf spring : Linear spring characteristic

Leaf springs have linear and non-linear characteristic. Conventional leaf springs provide the linear spring rate. They have a linear line in the force vs. deplacement graph. In this type, the spring rate doesn't change during driving and it is independent from the applied force. Each spring rate remains stable to move each one milimeter distance in leaf spring. For instance, when the initial spring rate is 40 N, the other spring rate for same distance is additionally 40N. Thus, 80 N move the springs two milimeters in total. Thereafter, spring rate will become 40 N for each mm.

Linear springs indicate the identical reactions whatever circumstances may come because of constant spring rate. Therefore, linear springs have better and more predictable handling in suspension compared to non-linear springs.The driver has much more informations about road handling of the vehicle. Linear springs show better performance in consistent roads like racing track which has perfect and smooth track surface.

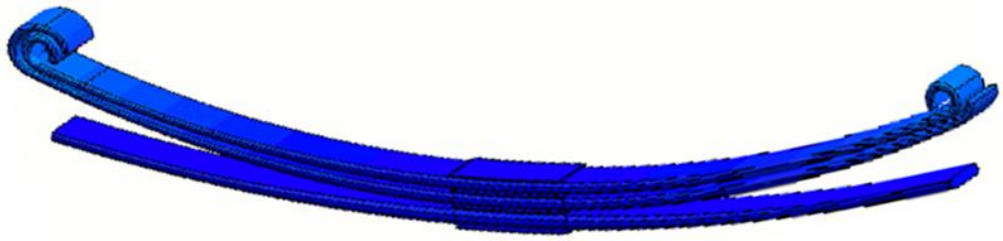


Figure 1.27 Leaf spring : Non-linear spring characteristic

Non linear leaf springs provide the non-linear spring rate. They have a non-linear line in the force vs. deplacement graph. The compression in suspension changes the spring rate. Therefore, the rate values vary from first suspension to the other ones. While first spring rate is 50 N to act one milimeter in spring, the other spring rate can become 80 N in next steps. [35]

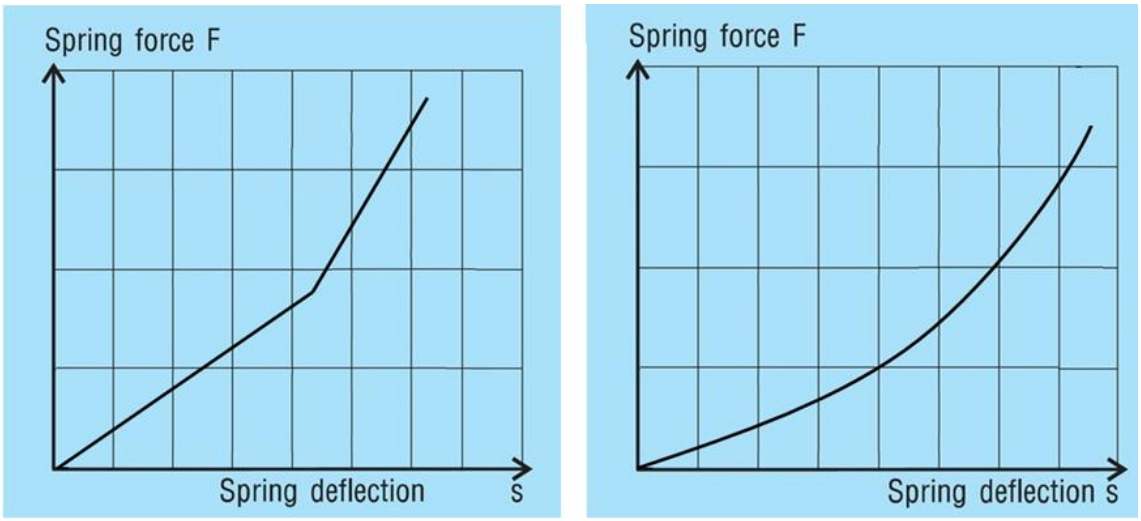


Figure 1.28 Leaf spring : Non-linear progressive spring characteristics [35]

Soft ride is one of the significant aims of the sole progressive leaf springs. This type springs can be the first choice together with developing stiff handling instead of linear systems. There is a inverse relationship between ride comfort and handling. If one is made better, the other characteristic is getting worse. Track roads dont have rough surfaces, therefore non-linear spring choice which have superior properties in rough roads, will not be the right solution. [36, 37]

1.8. The importance of non-linear elastic characteristic in suspension systems

Linear and non-linear elastic characteristics are higly utilized for vehicle suspensions. It will not right to define for them that one is better than the other one, but which is more suitable to the riding type you prefer. The most important objective and contribution of non-linear elastic characteristic in suspension systems is ride comfort. More conformity is obtained in non-linear springs for the suspension of rough surfaces and non-linearity presents low initial spring rates in the beginning but fastly enhance while the spring is compressed. Therefore, vehicles can travel smoothly over bumps and road hollows and provide ride comfort.

The suspension system designs usually need a common way for the conflict between ride comfort and handling requirements. A soft suspension is necessary for better ride comfort and a stiff suspension is necessary for better handling. It is quite difficult to provide both of them in same spring characteristic. Reasons for preference of non-linear springs: In comparison to linear springs, non-linear springs offer a smoother, more enjoyable ride in terms of better ride quality. If the vehicle driver is a daily driver and

constantly in the driver's seat, non-linear spring use will right solution in order not to have a rough ride over bumps and road hollows. These springs provide better results against variations in road surfaces, road conditions and riding loads. [38]

Linear springs indicate the identical reactions whatever circumstances may come because of constant spring rate. Therefore, linear springs have better and more predictable handling in suspension compared to non-linear springs. Linear springs show better performance in consistent roads like racing track which has perfect and smooth track surface. [39]

Non-linear spring use is getting more in automotive industry every passing year. Some OEMs (Original Equipment Manufacturers) produce directly the suspension systems with non-linear springs. Non-linear springs are used widely not only in suspension sytems but also in vehicle seats. The aim is the ride comfort for both usage areas. [40]

2. MATERIALS AND METHOD

2.1 Material Selection

Thousands of products have been used in part design and production from thousands of material at the present time. Because the characteristics and superior properties are interested in material type, the importance of material selection has been grown day by day. The best fit material selection for necessary application provides the most suitable function and maximum benefit. Part design, price, quality are determined suitable to the selected material. Although there are thousands of materials in the world; the developing and growing industry requirements need new material alternatives. Today, the some materials which are so significant in the past, are demanded so limited.

Cost, lightweight materials, energy efficiency and function are key issues in material selection in vehicle sector. In this study, alternative composite structures will be inspected in detailed in stead of conventional steel suspension systems in automotive industry. Composite materials have a lot of different types which vary in their mechanical properties, costs, functions and weights. When the commonly used fiber reinforcements are considered in general automotive applications, it will be seen that glass fibers, aramid fibers and carbon fibers are highly preferred in this industry thanks to their some superior behaviors. These fibers have different mechanical behaviours which may be used in various applications and industries with various combinations. In

our thesis, it will be studied on composite structure manufacturing, which will be used in suspension systems for automotive industry, by using aramid fibre reinforced laminated composite. The material selection will be one of the crucial topics. Firstly, it will be discussed which reinforcement material will be optimum type for suspension system. One of the most important properties for suspension is fatigue resistance. It is expected that this system also has high fatigue resistance. Aramid fibers possess excellent vibration damping resistance compared to carbon and glass fibers. The comparison of these commonly used fiber properties are shown in Table 1.3.

The automotive industry emphasizes lightweight and energy efficient materials. This interest in lightweight and energy efficient parts has opened a significant door to generalize these items and to use in new sectors.When composite material types are considered by means of weight in automotive sector, aramid fibre reinforced laminated composite weights take attention with their low densities. Compared to glass and carbon reinforced laminated composites, the aramid reinforced structures have low densities. At the present time which energy demand increased and energy sources decreased, fuel consumption for automotive industry has had a particular importance. Fuel consumption is decreased by less lightweight vehicles. This situation is required to decrease the automotive part weights. Therefore, proper alternative lightweight material investigations have been continuing. As a solution, composite materials have been enhancing day by day their usage ratio in automotive industry. Automotive part durability plays an important role beside their lightness. Hence, material tensile strength to weight is the main criterian by considering fatigue resistance and cost requirement for composite suspension structure in material selection. The comparison of these commonly used fiber properties are indicated in Table 1.3.

Table 1.3. Comparison of fiber properties

Fiber type	Density (g/cm^3)	Tensile Strength (Mpa)	Strength to Weight	Fatigue Resistance	Price Factor (Approx.)
Glass fiber (E)	2,58	2500	Poor	Fair	1
Aramid fiber	1,44	3000	Excellent	Excellent	4
Carbon fiber	1,80	3200	Excellent	Good	6-8

For the weight reduction, carbon and aramid mixture can be preferred instead of sole glass fibers; if there is no cost concern. If high strength is asked for, aramid fiber reinforced laminated composites can be preferred. If high rigidity is asked for, carbon fiber reinforced laminated composites are preferred. Besides, composite fiber costs will be play an important role in material selection. Carbon reinforced composites are more expensive than aramid and glass, relatively. Carbon reinforced parts are utilized widely in automotive sector. Usage ratio increases progressively in more luxurious automotive concept thanks to their high stiffness, lightness and high strength.

High cost of these materials restricts their wide usage area in standard, regular cars. In low price oriented vehicles, aramid reinforement composite parts may be used in stead of carbon reinforement composite parts, if their usage areas are proper.

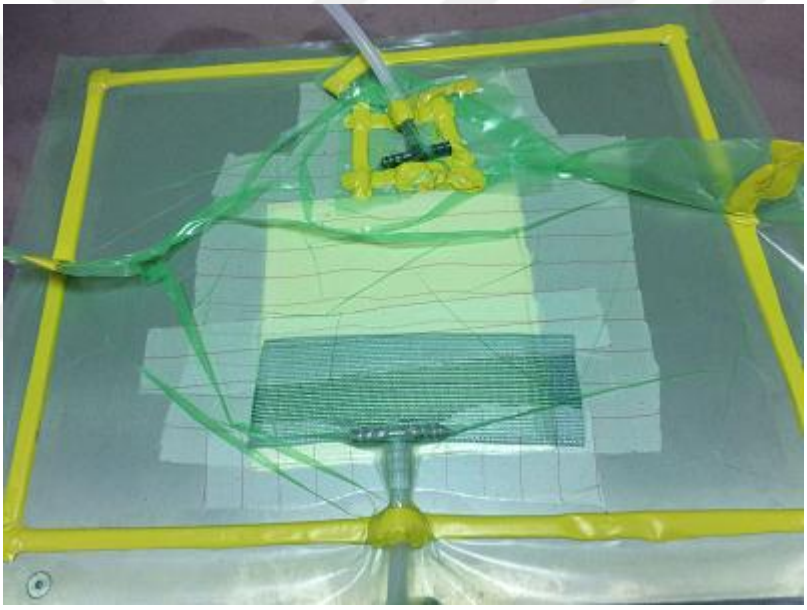


Figure 2.1 Test specimen production

Composite materials have not constant and defined mechanical properties. They can not be obtained directly from material mechanical property libraries in literature and analysis softwares. Their mechancial properties vary according to composite constituent material type, material usage rate, size, production method, etc.. To specify the physical characteristics of aramid reinforcement laminated structure; some physical tests are applied to composite specimens. These tests are pulling, compression and shear tests. All mechanical tests are applied in Shimadzu AGS-X Series Universal Electromechanical test device (50 kN table top model) in Marmara University. This device can apply pulling, compression, shear, bending and fatigue tests etc..

Aramid reinforcement laminated composite specimen production was made for mechanical tests. Composite specimens were produced with VARTM method (Vacuum Assisted Resin Transfer Molding). 16 pieces aramid fabric layers and epoxy were used for each aramid composite test specimen. All composite material production steps will be explained in detailed in next chapters. The test specimen plates are cut suitable to the specified test specification (American Society for testing and materials - ASTM). [41]

In tensile test, tensile test fixture is firstly assemblied to test machine and then test specimen is assemblied to tensile test fixture. Tensile test is applied to composite test specimen according to ASTM tensile test standard. (D3039/D3039M − 17) Test specimen has constant rectangular cross-section. This test is one of the most significant tests to specify the material mechanical properties.16 pcs aramid layers were used in each test specimen. The test specimen thickness which is 3,8 mm in all mechanical tests, is same with original composite leaf thickness. The specimen width and length were specified suitable to standards ASTM. Specimen wideness and length are 25 mm and 250 mm in the tensile test. [42]

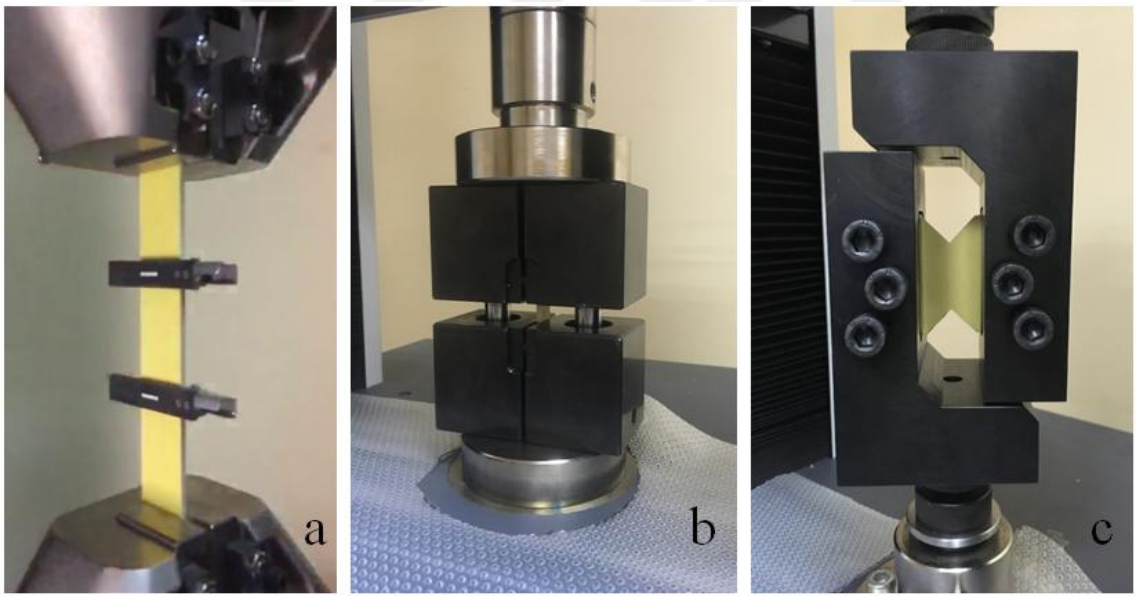


Figure 2.2 Mechanical tests for aramid reinforcement laminated composite material:
a) Tensile test b) Compression test c) Shear test

In compression test, tensile test fixture is firstly assemblied to test machine and test specimen is assemblied to compression test fixture. Compression test is applied to composite test specimen according to ASTM compression test standard. (D6641/D6641M − 16) The flat composite specimen has rectangular cross section. The test material thickness is same with original composite leaf thickness. The specimen

width and length were specified suitable to standards ASTM. Specimen wideness and length are 13 mm and 140 mm in the compression test. [43]

In shear test, shear test fixture is firstly assemblied to test machine and then test specimen is assemblied to the test fixture. Shear test is applied to composite test specimen according to ASTM shear test standard. (D7078/D7078M − 12) The test specimen has a flat rectangle section with symmetrical centered V-notches. The test specimen thickness is same with original composite leaf thickness. The specimen width and length were specified suitable to standards ASTM. Specimen width and length are 56 mm and 76 mm in the shear test. [44]

Table 1.4. Composite material properties

Composite material properties, unit	**Value**
Longitudinal tensile strength a-axis, Mpa	577
Transverse tensile strength b-axis, Mpa	577
Normal tensile strength c-axis, Mpa	345
Longitudinal compression strength a-axis, Mpa	110
Transverse compression strength b-axis, Mpa	110
Normal compression strength c-axis, Mpa	66
In plane shear strength, Mpa	130
Transverse shear strength, Mpa	78
Transverse shear strength, Mpa	78
Young’s modulus - longitudinal direction (Ea), Mpa	10130
Young’s modulus - transverse direction (Eb), Mpa	10130
Young’s modulus - normal direction (Ec), Mpa	6066
Shear modulus (Gab), Mpa	1530
Shear modulus (Gbc), Mpa	916
Shear modulus (Gca), Mpa	916
Poisson ratio along XY-direction (Vba)	0,154
Poisson ratio along YZ-direction (Vca)	0,092
Poisson ratio along ZX-direction (Vcb)	0,092
Mass density of the material, kg/mm3	1,14E-8

According to results which are obtained in tension, compression and shear test, the mechanical properties are obtained in the composite material. These physical

characteristics will be used for the comparison of experimental results under bending test machine and numerical results in Ansys Ls-Dyna software. [45]

2.2 Aramid Reinforcement Laminated Composite Structure Production Method

Aramid Reinforcement Laminated Composite Structure will be produced by using aramid fabric, resin and hardener with VARTM method. VARTM method is required one sided tool, vacuum pump, vacuum tank and vacuum infusion equipments like aramid fabric, epoxy, vacuum bag, perforated film, peel ply fabric, distribution media and vacuum hose. Tool surface form will specify aramid reinforcement laminated composite structure surface form and 3 pieces tools will be produced for try-out studies. After composite structure production, they will be assemblied onto steel frame. 2 pieces composite structures on steel frame will be used in each bending test under bending load test machine. It is aimed that this mechanism works as a suspension system in automotive industry. Bending tests will be applied in Marmara University, Mechanical Engineering Department laboratory. The bending test results will be compared with Ls-Dyna program analysis results. [46]

2.2.1 VARTM Method

Aramid reinforcement laminated composite structure will be manufactured with VARTM method (Vacuum Assisted Resin Transfer Molding). VARTM is required one sided tool, vacuum pump, vacuum tank and vacuum infusion equipments like aramid fabric, epoxy, vacuum bag, nylon film, perforated film, peel ply fabric, distribution media, hardener and vacuum hose. Firstly, one sided tool is produced from bioplastic filament material by means of 3D printer by considering composite structure sizes and requirements. The aramid fabrics are cut in specified sizes with fabric cutting machine. The layer quantity is specified according to the studies which obtained from strength analyses in LS-Dyna program. Accordingly, the aramid fabrics are aligned each on the top of the other as 16 layers. The materials are put into the tool in the alignment order, vacuum bag, aramid fabrics (16 layers), perforated film, peel ply fabric and distribution media respectively. Sealent tape is applied into edges of upper surface of VARTM tool. Then, vacuum hoses are assemblied into the epoxy entrance and exit points. Vacuum hose entrance and exit ends must be assemblied properly with sealent mastic tape. Tape papers are removed from mastic tape and vacuum bag is adhered carefully to tool

surface.

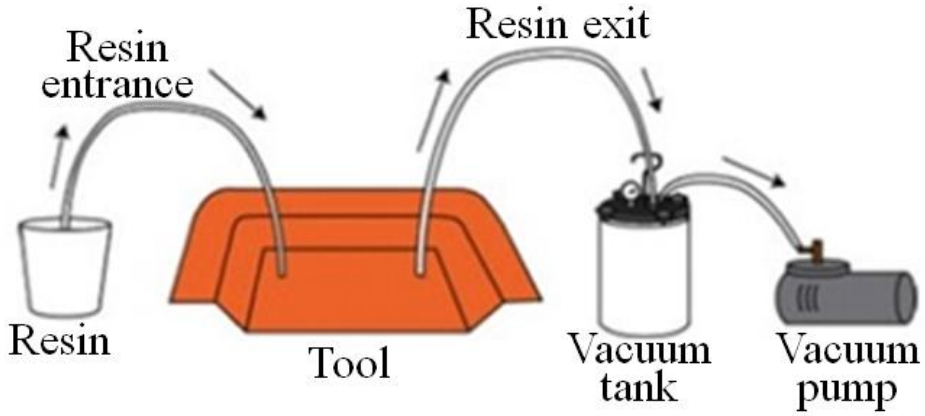


Figure 2.3 Schematic diagram showing VARTM Process [46]

Tool equipments are completed precisely.Three vacuum hose connections are completed for system installation in figure. Then, epoxy preparation operation can start. Resin and hardener are mixed until they seem like one element. One hose end is connected to epoxy resin tube. Infusion process is started after lay-out installation. Vacuum pump is worked 5 minutes long and the preform is leaved to curing 24 hours long at room temperature. [47]

2.2.2 Tool production

A classical Vacuum Assisted Resin Transfer Molding method includes single sided tool and a vacum bag. Tools can be made of steel, aluminum or plastics etc.. Various kinds of tool production techniques may be used for one sided tool. The other side will be covered another material like plastic vacum bag.

Tool design is so important for accurate composite structure and resin (epoxy) flow. A special attention has to be paid for resin entrance and exit points inside of tool. It will provide highly the sealing of resin during vacuming by vacum pump.

The composite structure gaps have to be planned in detailed during tool design. According to the composite structure thickness, tool depth has to be adjusted. Tool materials can be made of steel, aluminum and plastics, etc. according to composite structure design complexity and composite structure production quantity.

In this thesis, tool material was preferred from bioplastic because of low composite structure production quantity by considering low tool abrasion. 3D printer method has

advantages in terms of design development, easy and fast production, cheap cost compared to classic production methods. This tool was produced by 3D printer (Ultimaker 2 extended). The tool was made of PLA grey material by using filaments in diameter 2,85 mm. Before production, tool design is created by a 3D CAD software program and nozzle path is specified in 3D printer program. Then, this cad-design data is read to 3D printer by SD card. The production takes about 11 hours.

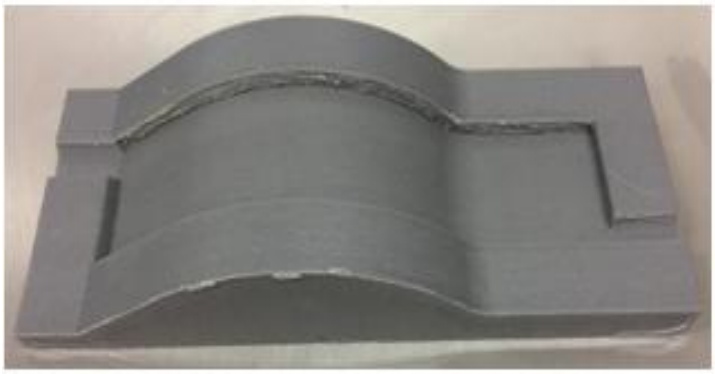


Figure 2.4 VARTM tool

Figure 2.5 3D printer [48]

It may be also produced by CNC machining. In this study, 4 pieces tools were produced for multi parts production.These tools were produced identical to each other in 3D printer.

2.2.3 Aramid Reinforcement Laminated Composite Structure Production

In this thesis, woven aramid fabric is used for the reinforcement of laminated composite structure. The aramid fabric type is Twaron CT-709 which is 200 g/m^2 fabric, and has a good cost to performance ratio. These fabrics are produced by Teijin Company and widely used in ballistic protections and armours. [49]

These aramid fabrics have excellent strength to weight ratio and high dimensional stability which has very low creep and small negative thermal expansion coefficient. They have excellent thermal stability which are usable across a wide temperature range, have no melting point, high heat stability and low heat conductivity. High modulus and high cut resistance, good chemical resistance, low flammability, electrically non – conductivity and long life time are its strong aspects.

Figure 2.6 Aramid fabric cutting (Twaron CT 709 - 200 g / m^2)

Aramid fabrics are cut meticulously in sizes of 200x40 mm (1 layer: 1,6 gr) as in figure above by the help of fabric cutting machine (scissors). Before cutting operating, it would be so helpful to mark fabric cutting lines with any pencil. Because rectangular small fabrics will be used more than one and equally to each other, cutting operation in same sizes will be so important for proper composite structure. According to Ls-Dyna Analysis, 16 pieces aramid fabric layers will be used for each aramid reinforcement laminated composite structure. In our study, since 10 pieces aramid reinforcement composite structures will be produced in total, 160 pieces rectangular small fabrics cutting will be necessary in total.

Figure 2.7 Rectangular aramid fabrics (Twaron CT 709 - 200 g / m^2)

After cutting operation is completed, 16 pieces rectangular small aramid fabrics are aligned each on the top of the other as shown in figure. The aligned fabrics are ready to be used in tool with VARTM method. For composite structure production, epoxy and hardener mix was applied onto the aramid fabric surface with of VARTM method. [50]c

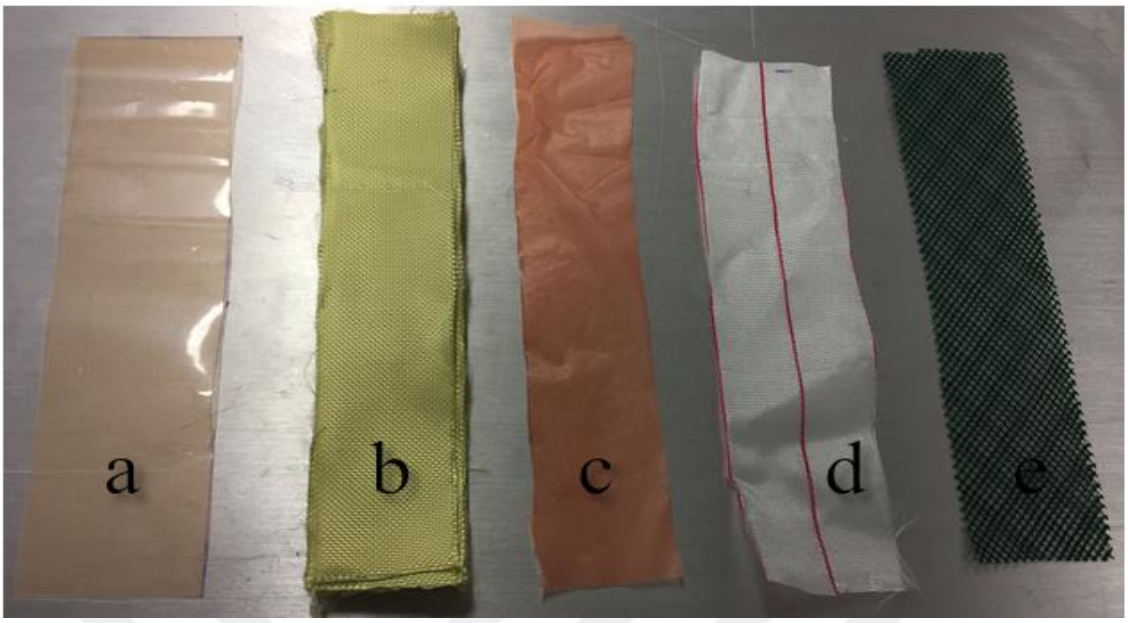


Figure 2.8 VARTM equipments : a) nylon film b) aramid fabrics c) perforated film d) peel ply fabric e) distribution media

This mixture ratio is 3:1 for epoxy and hardener. These elements have be to mixed properly until getting an exact mixture. This mixture must not be waited so long time against hardening and must be prepared after all necessary elements are ready. In VARTM method, the main subject is vacuum assisted resin transfer. In this sytem, air vacuum and epoxy flow must be applied properly. Air sealing is the most improtant issue for proper resin transport in this system.

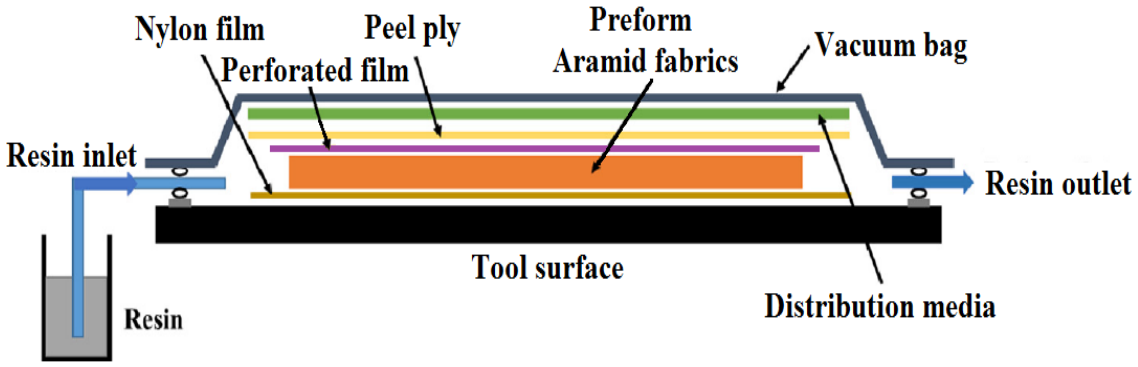


Figure 2.9 VARTM equipment placement [8]

Hence, the additional materials are used for better resin flow in figure. A plastic separator nylon film is placed onto lowest surface of tool as shown in figure.

This separator will provide the resin not to adhesive to tool and tool will be able to be used properly in next vacuum operations. [51, 52]

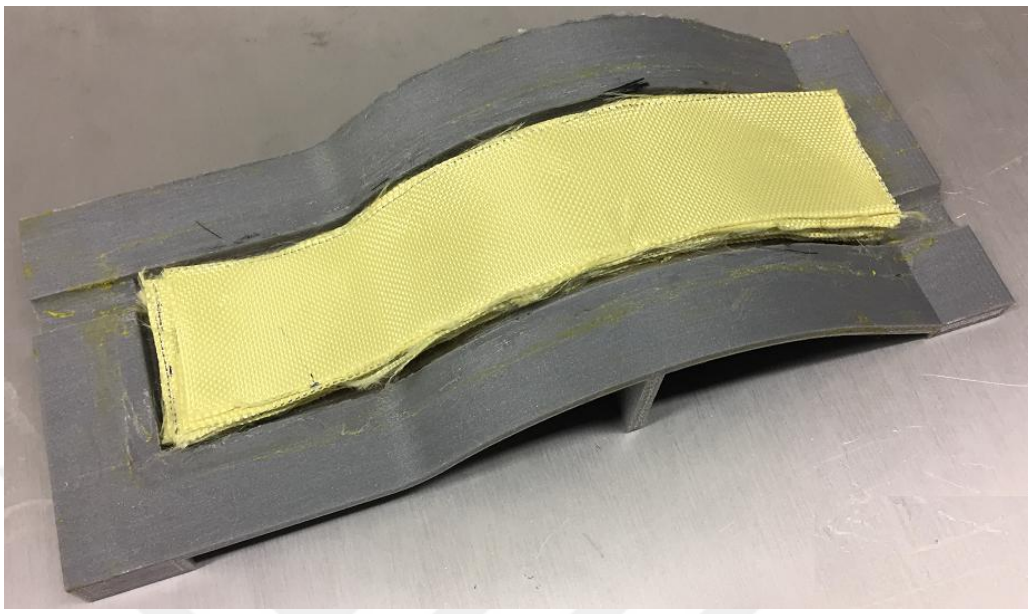


Figure 2.10 Composite tool and nylon film against adhesive to tool

16 pieces rectangular small aramid fabrics are placed onto tool surface as shown in figure .Tool dept, entrance and exit must be proper to aramid structure thickness. Aramid fabrics must be cut according to tool internal sizes. Fabric thickness must not exceed composite tool depth and fabric must not prevent resin flow in tool entrance and exit. Tool entrance and exit must be considered in tool design phase.

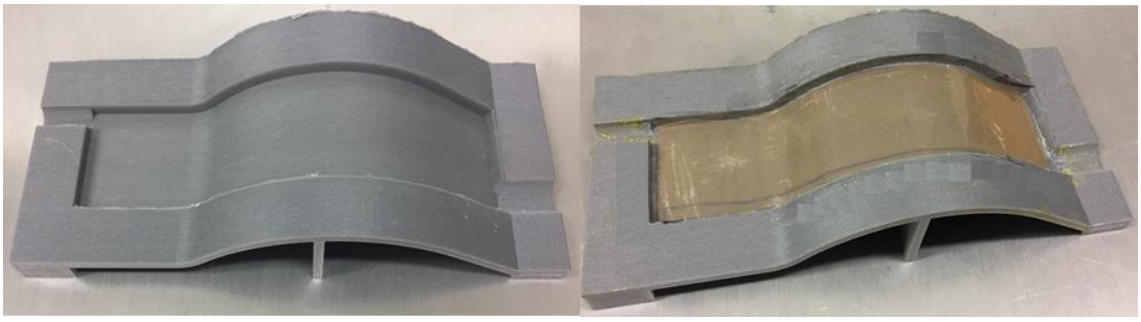


Figure 2.11 16 pieces aramid fabrics inside composite tool

Tools must be made of leak proof material against air leakage. After 16 pieces aramid fabrics are cut in specified sizes, they are weighed with a lweighing device. These values are noted into notebook. Epoxy, which will be applied into composite structure, will be used according to total aramid fabric weight.

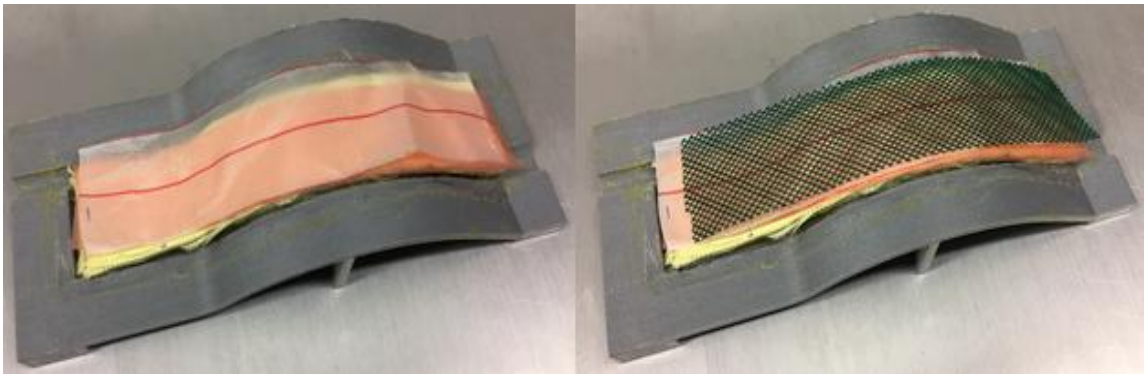


Figure 2.12 Perforated film, peel ply fabric and green distribution media

The other materials, which provide better resin flow and prevents adhesive onto tool, are perforated film, peel ply and green distribution media. These materials provide accurate composite structure production. A perforated film is utilized in connection of release fabric. This perforated film provides to keep the resin inside perform. Perforated films have the various holes according to pump pressure and resin viscosity. Peel ply which is also known as release fabric and release film, is a durable woven polyester fabric. It is used to separate the distribution media and the preform so that resin doesn't adhesive to preform. Excessive resin is filtered through the peel ply and can be removed from preform after curing. It provides a smooth surface and resin passing control. Green distribution media which is a light polyester cover, provides slight air pass between preform and vacuum bag. Distribution media absorbs excessive resin.

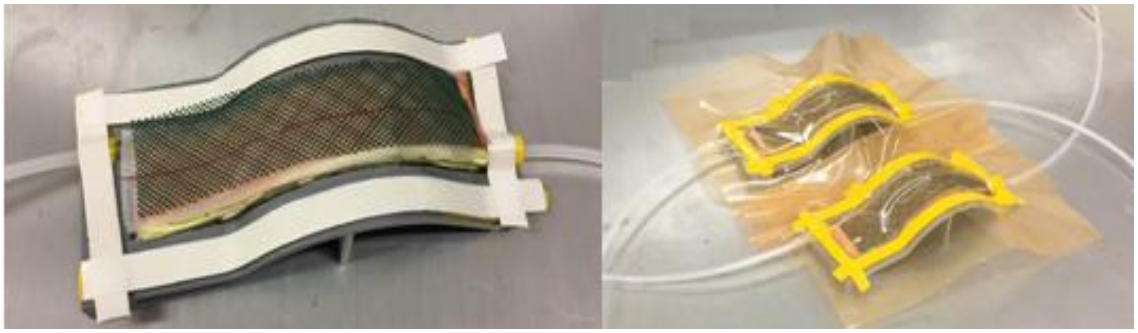


Figure 2.13 Sealent tape, hose and vacuum bag usage on tool

In VARTM method, a lower tool and vacuum bag are required for vacuuming. Sealent tape is applied for connection of tool and vacuum bag. This type yellow tape will be effective for air vacuum sealing. Firstly the sealent tape is applied onto tool upper surface, then paper on sealent tape is removed. The air hose is assemblied into tool entrance and exit points. The air hose ends must not be inserted so much into the fabrics in order not to prevent proper epoxy flow. Thus, the accurate resin transfer can be

provided in this method. A perforated film can be used together with peel ply fabric. This film gives support epoxy to hold in the structure.

Tape corner connections are applied carrefully, because air leakage occurs higly from these corners.Afterward, the vacuum bag is connected onto tool by starting from one edge.To avoid possible air leakages, each connected edge is checked by touching and pressing by means of finger if they have still air leakages.The most important subject will be sealing in composite structure production success with VARTM method.

After tool equipments are completed precisely, VARTM method lay-out can be occured together with vacuum pump, vacuum tank and epoxy resin. Three vacuum hoses are needed for system installation. One of the first hose ends is assemblied to epoxy resin, the other end of the hose is assemblied to tool entrance point. One of second hose ends is assemblied to tool exit point, the other end of the hose is assemblied to vacuum tank. One of third hose ends is assemblied to vacuum tank, the other end of the hose is assemblied to vacuum pump. Thus, system installation is completed.

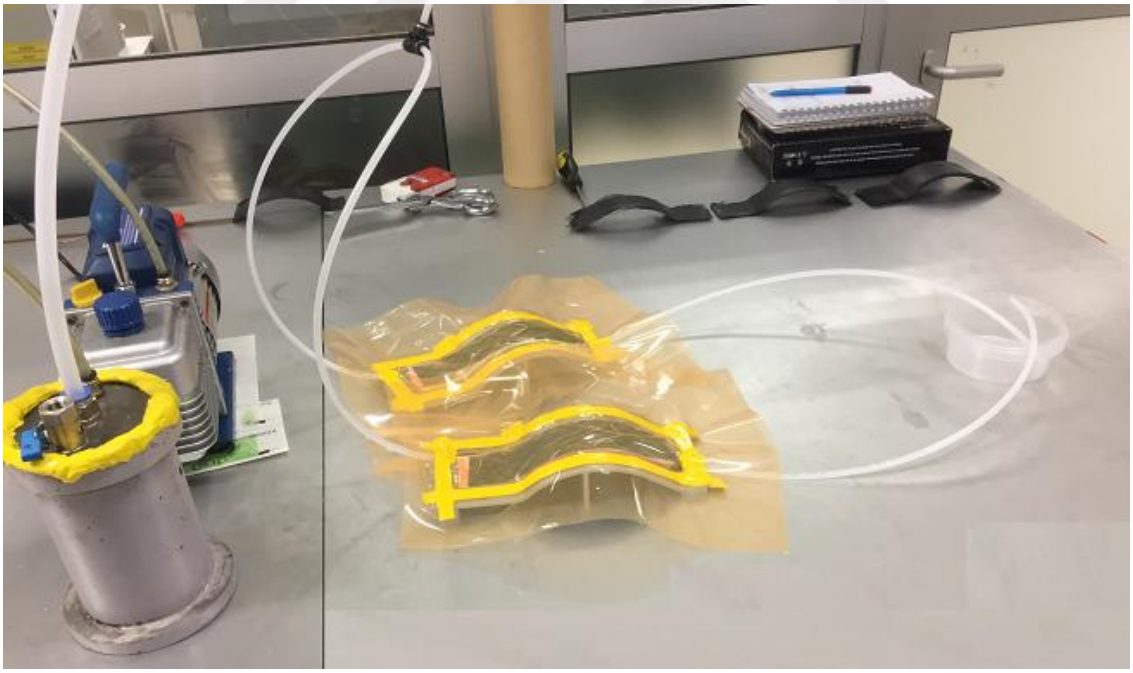


Figure 2.14 VARTM experiment lay-out

Then, epoxy preparation operation can start. The epoxy mixture consists resin and hardener. The mixing of resin and hardener together occurs a chemical reaction . This operation transforms them from liquid state into solid state. The mixture rate and reaction duration is important for propercuring. 100 gr resin is used for each 34 gr

hardener, in this study. The used resin type is Araldite ly1564 which is a product of Huntsman Company. The used hardener type is Aradur 3487 which is a product of Huntsman Company. These elements are mixing properly until they seem like unique material. Before hardening of the mixture, the hose has to be connected to epoxy resin. Then, VARTM operation can be started.

Firstly, the air is removed from the composite preform by operating vacuum pump. After the system is balanced and air leakages are eliminated, the resin can be flowed into the preform (16 pieces aramid fabrics). A pressure in 1 atm can be used to inject the resin into tool. Distribution media is getting easier the resin to flow in fabric preform under the vacuum bag layer, by injecting low pressure in 1 atm. The fast epoxy pass within the preform is obtained with distribution medium. Thus, the epoxy can act easily in the distribution medium and fills the gaps and dry points inside the preform. The distribution medium is also getting lower the process duration.

Before resin injection, the air gaps can be degassed in preform for 30 seconds and the leakages can be eliminated. Then resin tube is connected to hose coming from tool entrance. After the lay-out is ensured, the infusion process is started.

The air is completely absorbed from preform until composite structure are gelled exactly and then hose ends in resin side and vacuum tank side are closed and vacuum pump is turned off. The preform structure is cured 24 hours long about at 25 °C prior to demounting from the tool. [47] The 16 aramid fabric layers in a composite spring weigh 25,6 gr (16 pcs x 1,6 gr). A composite spring weight is 42 gr.Aramid fabric ratio is %61.

Figure 2.15 Aramid reinforcement laminated composite structure (Leaf spring)

A steel frame test apparatus will be required for simulating the automotive suspensions systems. This test apparatus serves in mechanism like a vehicle chasis. It is the part which composite structures are mounted. In automotive industry, the suspension systems are connected to the main chasis.Aramid reinforcement laminated composite structures will be tested under bending test machine. Two pieces composite structures are required to obtain the mechanism.

Firstly, the composite structure assembly concept must be determined in vehicles. In this study, composite structures will play in role of leaf spring.They will be aligned to each other in reverse direction. The flat sides of composite structures will be mounted into the steel frame. The flat sides of composite springs have to aligned into the middle of steel assembly holes. Because the test apparatus is flexible dimensionally, this steel frame can be used for different experimental studies, as well.

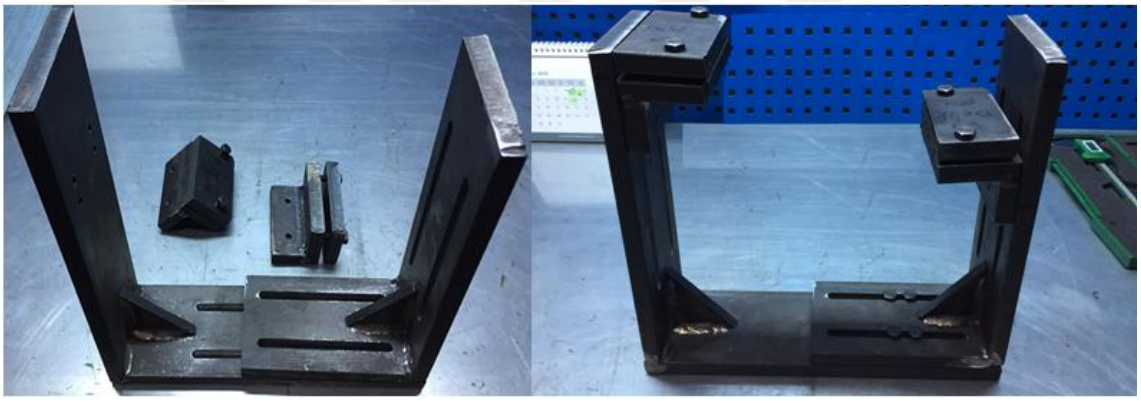


Figure 2.16 Steel frame (Bending test apparatus)

The steel frame is made of steel CK45E - 1.1191 material. This steel type is used generally for tools. Flat steels in 15 mm thick and 100 mm width are bought in steel industry as standard steel type .This flat steel is cut in length of 1500 mm by saw machine. Thus, a flat steel is obtained in size of 15x100x1500 mm.

Steel is divided to 9 different parts and the necessary holes are pierced by laser cutting machine.Some holes are used for bolts and some holes are used for assembly. Bolt threads are opened to frame assembly points by threader apparatus in order not to use nut.After these operations, steel parts are welded to each other as shown in figure with arc welding. Two pieces triangle small parts are welded to corner edges for better strength support.

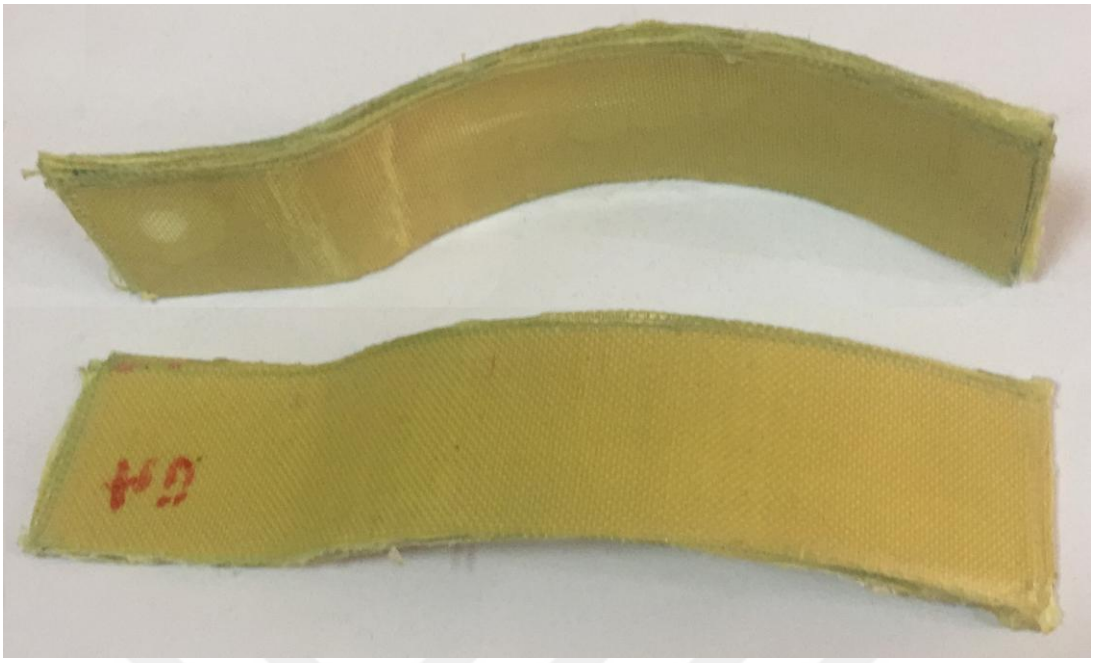


Figure 2.17 Leaf springs

It is planned that frame is adjustable in horizontal and vertical axis, in case the composite structures in different sizes and designs can be used in same frame. 12 pieces M6x20 mm bolts are assemblied to the frame. Then the frame is painted completely into black color with sprey paint. Frame connection edges are adjusted according to vertical and horizontal distances which obtained from LS-Dyna analyses. The two pieces composite structures are assemblied to frame by means of M6 bolts . The bolts are screwed properly. If the frame is wanted to carry by a person, it can divided to two parts from the middle assembly bolts because of high weight.

In leaf spring lay-out, the involute profile in spur gears was taken as reference. Two leaf springs mesh like spur gears and support each other for better strength. After they complete the gap between two leaf springs, they get in touch with each other and drive each other for suspension start. They work in range of lower and upper movement limits under bending loading. The composite structure vertical and horizontal distances have to be adjusted properly. Otherwise, the required strength and bending loading results can not be obtained under bending test machine.

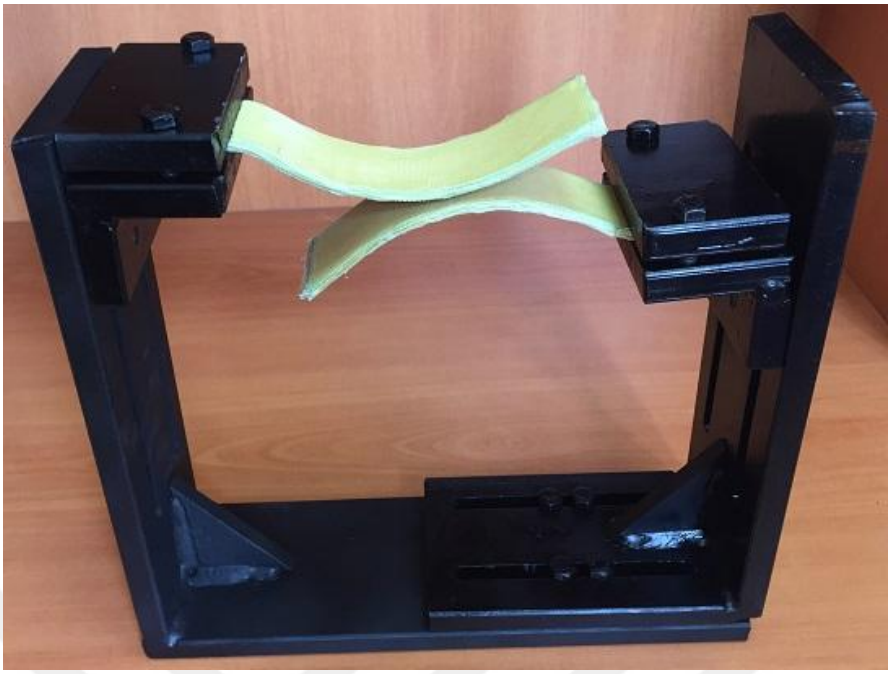


Figure 2.18 Leaf spring assembly on test apparatus

The spring design is one of the most important issues to get linearity characteristics. To get optimum spring characteristic is to creat optimum spring design. The subjects below have to be specified for the optimum spring design. Spring quantity has to be specified in mechanism. Spring connection to body has to be determined. The force load applied and spring raw material have to be specified. It has to be determined how the spring will be formed to provide safety under the load and ambient conditions. These criteria will be helped determine the spring design.

Springs are one of the principle mechanical elements which provide the basis of many mechanical systems. A spring can be described as an elastic component which applys resisting force when its body is compressed. The force is applied to spring from one side and the other side is keeped as fixed. The general spring length is reduced during force application. The change amount in length of spring is defined as displacement. There is a non-linear behaviour between force and displacement in the non-linear springs. In order to understand whether a spring is linear or non-linear , the datas regarding force and displacement are collected and a graph is obtained thanks to these datas. According to linearity in the obtained graph, it is determined whether the system is linear or non-linear. The applied forces are determined according to limits of spring usage area. [37]

2.3 Bending test

The bending tests are usually utilized to specify the material bending strength. The bending strength is the force amount which a material can act and change shape without rupture. The bending strength is a force per unit area. Bending test is also used as a mechanical property for some materials and described as the ability to resist deformation under load, as well. [52]

Bending tests have become an important test method in materials science and R&D studies together with ever increasing demand for high strength materials. Young's modulus and bending stres are the characteristics which have significant duties for the bending durability of test sample.

Various technological devices or objects which are subjected different effects such as tensile, compression, bending and fatigue forces, etc., are used often at the present time. Some tests like tensile test, bending test and compression test etc. are applied to these products to see effects of these forces.

In this study, bending test will be applied to test specimen. The bending test simulates the working concept in test specimens which are subjected to many bending cycles in daily usage. One of the commonly used bending types is cantilever bending, this bending type is preferred because of simplicity in investigations. Another type is three point bending test; this test is used often to obtain mechnaical values, as well. Lastly four point flexural test is also preferred not only in non-composite materials but also in composite materials. In this thesis, cantilever bending system will be used in bending tests. Not only one but also two cantilever bending systems which are aramid fiber reinforced laminated composite structure, are mounted to test apparatus. These composite structures together resist to bending loading under bending test machine.

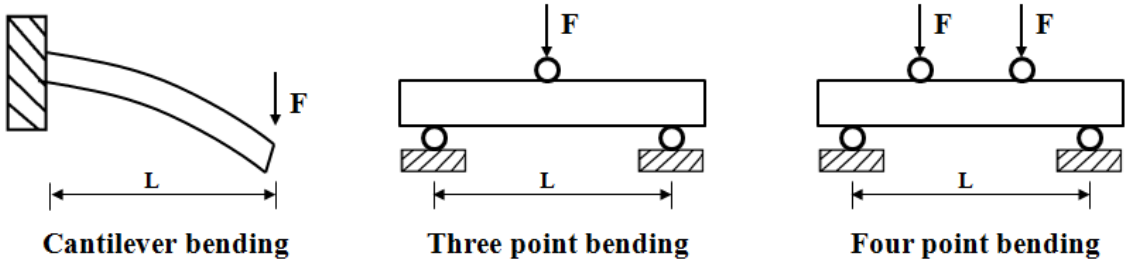


Figure 2.19 The some of the commonly used bending types

The desirable bending forces are applied to the top of the composite structure in various strokes. Two composite structures have to be assemblied reverse and parallel to each other into test apparatus in this mechanism. It is aimed that the lower second composite structure supports the first composite structure during bending loading.

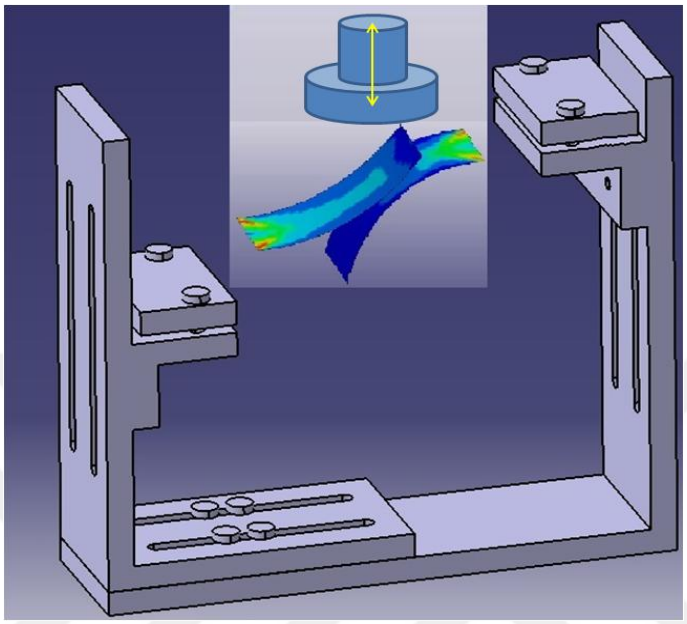


Figure 2.20 Bending test experiment lay-out

The first composite structure is subjected to the bending until first contact with bending machine. After first stroke is completed between first and second composite structure; both of composite structures are subjected to bending load ing. This stroke and composite structure lay-out have to be adjusted accordingly. If they are not carried out correctly, the compsite structures can not support each other and they damage.

Analysis studies have been simulated for the most suitable material, the most suitable composite structure sizes and the best fit mechanism lay-out in ANSYS LS-DYNA program. This program is mostly preferred to simulate explicit studies. Each direction of the the equation can be checked with its some constituents, contact modules, structure models and more functions to see the virtual reactions of complex issues. [53, 54]

3 RESULTS AND DISCUSSION

The bending tests were applied on two aramid fiber-reinforced composite leaf springs. Composite spring lay-out and force position were investigated according to cantilever bending concept. In this thesis, the experimental results under bending test machine were compared with numerical results which were obtained in ANSYS LS-DYNA

software. A mechanism which contains two composite leaf springs, was obtained. It was aimed that these springs have a high damping force and non-linear elastic characteristic and to get an alternative system in suspension systems. This mechanism was experimented under bending test machine. The bending load vs. time was recorded corresponding displacements in size 15mm, 20 mm, 30 mm. The experiment was completed until the maximum applied load had a sharp drop in the peak value of the force. Initiation of the first cracking at the outer tensile surface of the leaf spring was detected during peak forces. This cracking in leaf springs was easily observed by monitoring the progress of the recorded bending load.

In order to generate a solution to multi-physics subjects like solid mechanics, fluid dynamics and heat transfer, LS-DYNA program is utilized. In this study, it will be used to solve the composite bending operation which is a solid mechanics. The model geometry and material parameters are defined in Ansys Ls-Dyna program. The boundary conditions are also defined. There are a lot of different material models for metals, plastics, glasses, composites and etc. in LS-Dyna. The some of the available material models for composites are indicated in the below chart. Some constituent models give more accurate results in case of solid or shell material. Because the spring thickness is not so thin, the shell module can not be applied. In solid module, the results can be obtained also in thickness direction. In this study, MAT 22, MAT 54/55 and MAT 59 models which have solid model for composite materials, were tried and it was observed that MAT 59 model is best fit with experimental values. [55, 57]

MAT 59 model is based on Hashin's criteria. Because of it its uncomplicated interface and usage easiness, this method is widely used within structural investigations for composites. Because this criteria does not become suitable with experimental outcomes so good everytime, base hypotheses which Hashin proposed, are re-investigated currently. This method used in the tension fiber and tension matrix mode is modified relying on physical evaluations and in this study, the modified Hashin criteria will be used. [58]

Because it is aimed to observe the composite failure of springs and the material is solid, the material model is selected as Material 59. The selected material model specifies material behaviour in the simulation. This model determines also the mechanical behaviour method in failure initiation. [59]

Material Model	Element	Failure factor	Comment
MAT_022: COMPOSITE_DAMAGE	Shell, Tshell, Solid	Chang-Chang	No fibre compression failure Simple brittle model. No crash front algorithm
MAT_054/55: ENHANCED_COMPOSITE_ DAMAGE	Shell, Tshell Solid	54: Chang-Chang 55: Tsai-Wu	Enhanced versions of MAT_022 Crash front algorithm
MAT_058: LAMINATED_COMPOSITE_ FABRIC	Shell, Tshell (1,2)	Modified Hashin	Smooth stress-strain relation Non-linear shear behaviour Minimum stress limit factor Exponential softening
MAT_059: COMPOSITE_FAILURE_ MODEL (Plasticity Based)	Shell, Tshell, Solid, SPH	Modified Hashin	Similar to MAT_054 Crash front algorithm Minimum stress limit factor
MAT_158: RATE_SENSITIVE_ COMPOSITE_FABRIC	Shell, Tshell	Modified Hashin	Same as MAT_058 Rate sensitive
MAT_261: LAMINATED_FRACTURE_ DAIMLER_PINHO	Shell, Tshell, Solid	Pinho	Physical based failure criteria Continuum damage model Linear softening evolution based on fracture toughness
MAT_262: LAMINATED_FRACTURE_ DAIMLER_CAMANHO	Shell, Tshell, Solid	Camanho	Physical based failure criteria Continuum damage model Bi-linear/linear softening evolution based on fracture toughness

Figure 3.1 Available material models for composite materials [58]

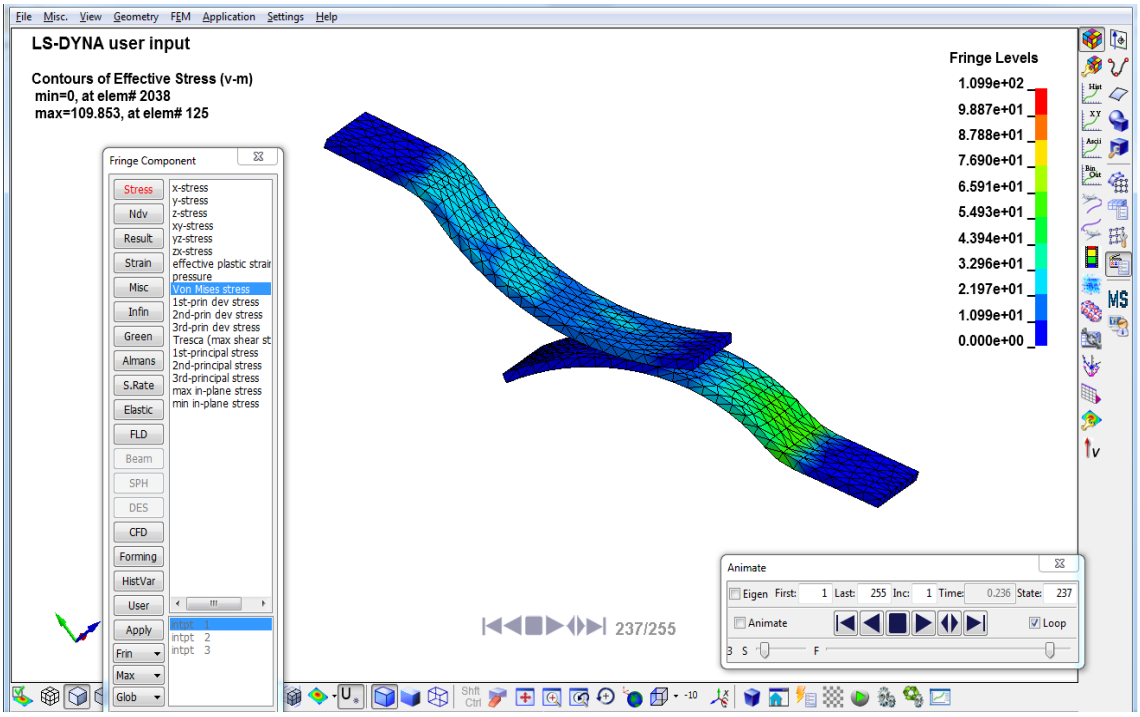


Figure 3.2 Bending test in LS-Dyna program

All mechanical properties of the composite material were defined in experimental mechanical tests (tension, compression, shear test). These parameters are entered into material card of the program. The geometry of springs and boundary conditions are defined in program. It is aimed to observe the displacement vs. time in this simulation and compare with the results in experimental bending results. The main objective of these investigations is to obtain non-linear elastic characteristic in composite leaf springs.

For the preliminary numerical results, aramid fiber reinforced laminated composite structure properties are investigated in LS-Dyna software. Accordingly, the composite structure geometry and the position of springs are determined by considering the optimum bending analysis results. After some wrong try-outs in Ls-Dyna, the optimum non-linear elastic characteristic was obtained in the program.

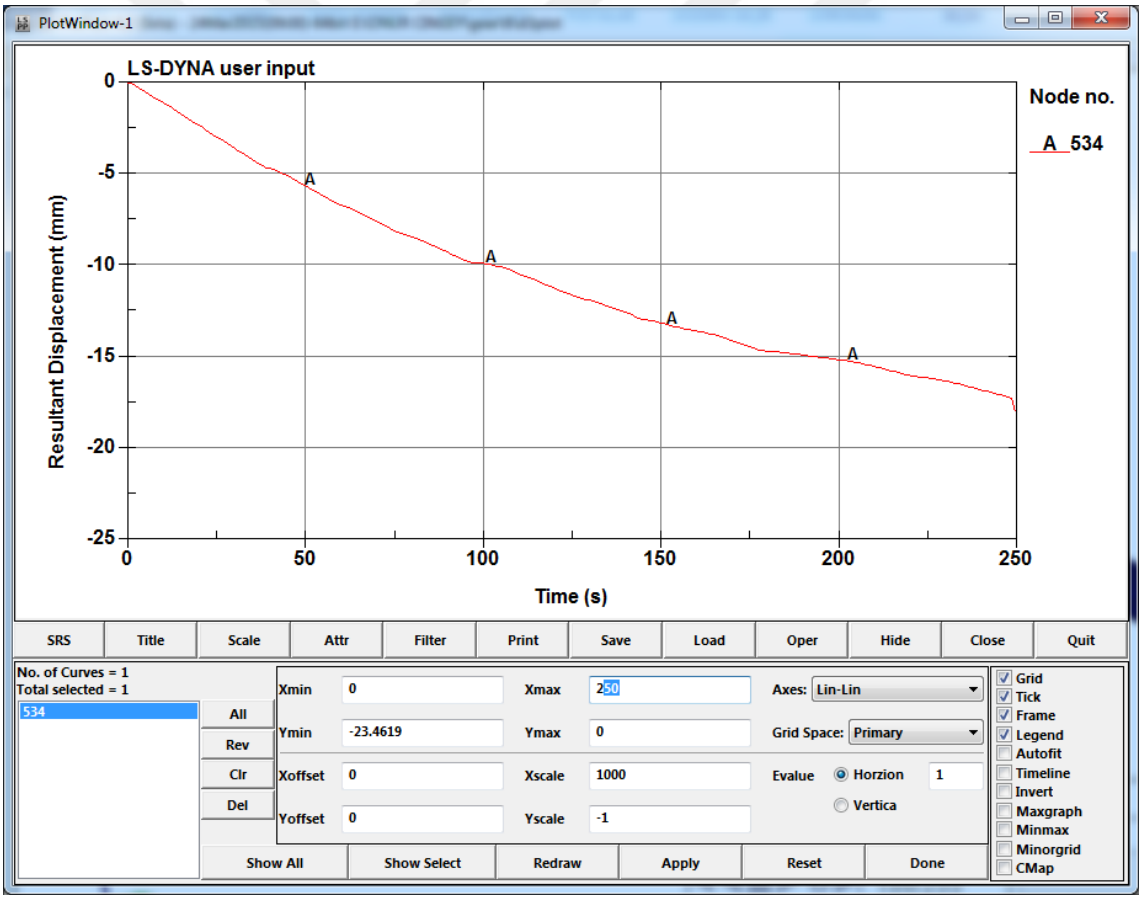


Figure 3.3 Displacement – time graph in LS-Dyna software

The positions of two composite structures to each other and assembly methods are defined according to analysis results. The fixed and free edges and surfaces are defined in the program. The each composite structure has to be carefully fixed at one end

(assemblied side to test apparatus) and the other end will be left free for applying the normal loading. In test concept, the cantilever bending test concept is taken as an example.

In necessary test forces, a standard automobile weight is considered to calculate about test bending loads in one of the four suspension systems. If a standard automobile weight is thought as one ton, the weight in one wheel suspension system can be calculated as 250 kg. This thesis study aims to get a start point in suspension area on a small scale. The test forces in these range of 0 - 400 N are applied and numerical results are obtained. These analyses are performed in three stroke lengths which are 10 mm, 20 mm and 30 mm long, respectively.

Figure 3.4 Bending test machine

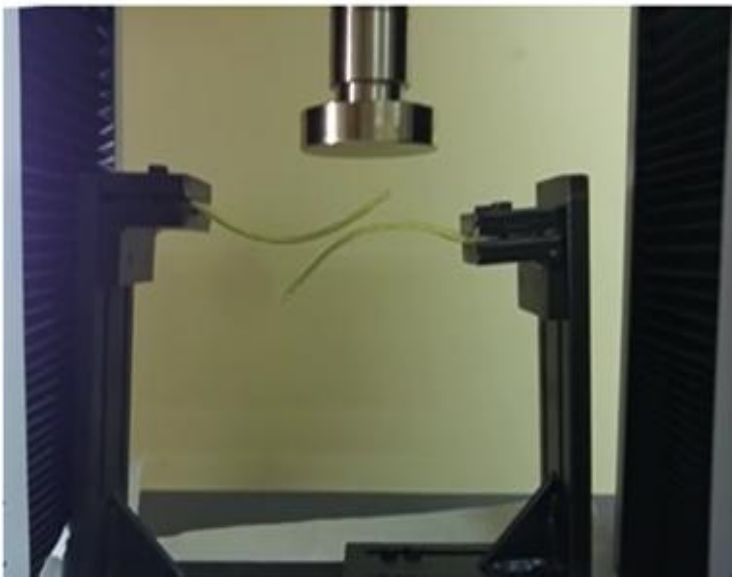


Figure 3.5 Bending test experiment lay-out

The necessary forces are determined depending on time and shown in the graph. This graph shows that this composite mechanism has a non-linear elastic characteristic. For the bending test experiment, the specimens which are composite structures (leaf springs) are clamped to test apparatus. The specimens are placed horizontally into steel frame test apparatus. Composite leaf spring assembly into test apparatus was described in detailed in previous section. Afterwards test apparatus is laid into the bending test machine. [60-64] The bending test machine is Shimadzu AGS-X Series Universal Electromechanical test device. (50 kN table top model)

The bending test machine is operated hydraulically. The punch load and punch velocity are adjusted in the bending machine. The forces which are seen in LS-Dyna are applied

to inspect if the composite structure mechanism has a non-linear behavior.The test method has to become suitable with the device software which can control the experiment and the measurements.

All forces are shown in the diagram. It is aimed that the forces between 0 – 400 N are applied into specimens. All cantilever bending tests are applied in the Shimadzu test machine in Marmara University, Engineering Department.

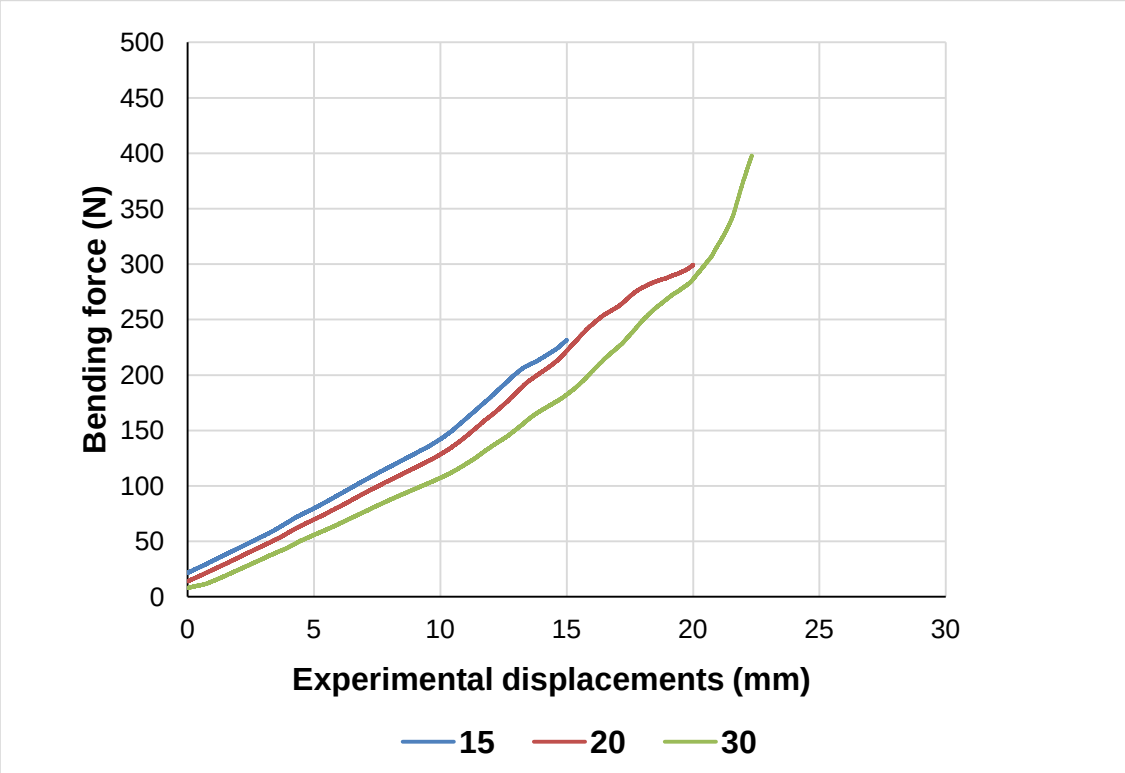


Figure 3.6 Force – displacement graph obtained under bending test machine

Non-linear elastic characteristic was inspected on composite material leaf springs. It was aimed to obtain a non-linear composite suspension system. Therefore force vs. displacement curve was observed in stiffness graph of aramid reinforced composite leaf spring above. In this experiment, non-linear spring rate was observed in non-linear leaf springs. Non-linear springs allow different spring rates. These analyses were performed in three stroke lengths which are 10 mm, 20 mm and 30 mm long. The forces were performed onto leaf springs betweeen 0 and 400 N. In three phases, the same non-linear spring characteristics were obtained and this non-linear curve showed progressive characteristic.[35-37]

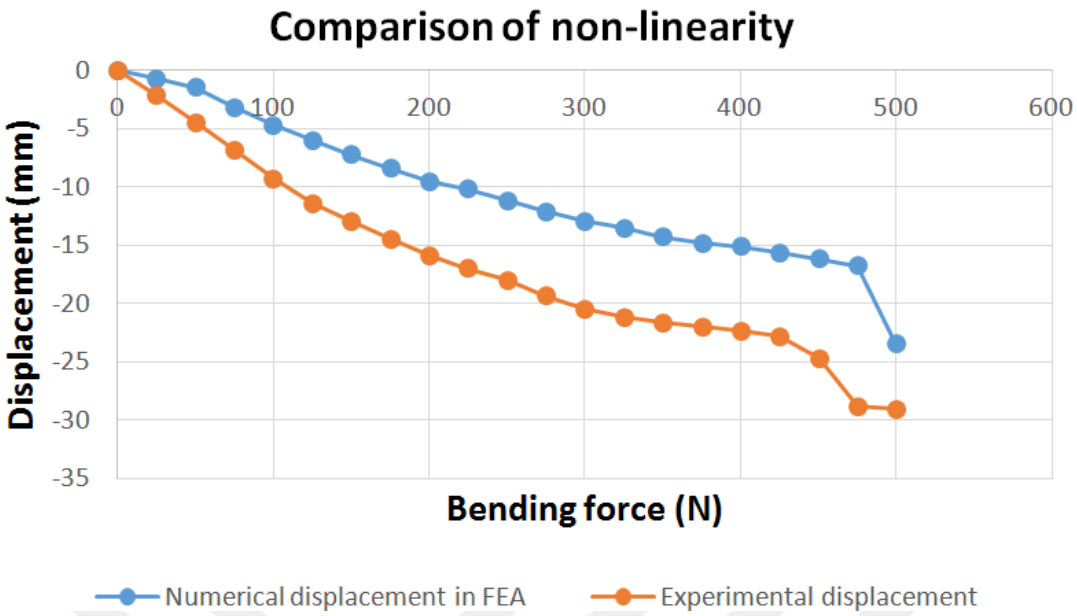


Figure 3.7 Comparison of non-linearity

After the numerical studies in Ansys Ls-Dyna and experimental studies under bending machine are completed, the main graphs of these studies are combined on the same graph and axes. Thus, the non-linear characteristics are compared in the same graph for displacement vs. bending force. The force-displacement curves and slopes are nearly identical to each other. Both of studies show that the leaf springs are damaged in about 500 Newton and in displacements between 24 mm and 29 mm .

4. CONCLUSIONS

In this study, design and manufacturing of a laminated composite spring having non-linear elastic characteristic was done for automotive industry. The experimental results under bending test machine were compared with numerical results which were obtained in Ansys LS-Dyna software.

It was observed that the force-displacement curves drawn with the numerical method, are nearly identical to the curves in the experimental technique. Both of these methods demonstrated that laminated composite leaf springs have non-linear characteristic.

We have proposed a method for designing and manufacturing of non-linear elastic leaf springs. The use of composite leaf spring, which will be used in suspension systems for automotive industry, by using aramid fibre reinforced laminated composite, is available according to requested sizes.

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