ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

Berkay KARAÇOR

THE USAGE OF NATURAL FIBER REINFORCED HYBRID COMPOSITE MATERIALS AS AN ALTERNATIVE TO AUTOMOBILE INTERIOR PLASTICS

DEPARTMENT OF AUTOMOTIVE ENGINEERING

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ABSTRACT

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THE USAGE OF NATURAL FIBER REINFORCED HYBRID COMPOSITE MATERIALS AS AN ALTERNATIVE TO AUTOMOBILE INTERIOR PLASTICS

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Material selection has recently started to play an important role in the engineering design of a successful sustainable product. Today, the purpose of turning unsustainable products into sustainable ones has emerged in many sectors. In this context, the importance given to natural fiber reinforced composite materials is rapidly increasing in terms of both application areas and unique properties. In this study, composite material was produced by using vacuum-supported resin transfer method (VARTM) with linen material reinforced epoxy matrix from natural fibers. Experimental studies were conducted to evaluate the application of natural fiber reinforced composite materials as an alternative to plastics used in the vehicle interior. The composites produced by using vacuum infusion method have been applied thermogravimetric analysis, differential scanning calorimetric analysis, water absorption, hardness and impact test, and the basic mechanical properties and thermal stability of the materials have been determined. When the results were evaluated, it was found that adding glass fiber of different weights per square meter to the natural fiber significantly increased the properties of the composites.

Keywords: Natural fiber composites; Flax fiber; Vacuum assisted resin transfer method; Thermal properties; Mechanical properties

ÖZ

YÜKSEK LİSANS TEZİ

OTOMOBİL İÇ MEKÂN PLASTİKLERİNDE ALTERNATİF OLARAK DOĞAL FİBER TAKVİYELİ HİBRİT KOMPOZİT MALZEMELERİN KULLANIMI

Berkay KARAÇOR

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Son zamanlarda malzeme seçimi başarılı sürdürülebilir bir ürünün mühendislik tasarımında önemli bir rol oynamaya başlamıştır. Bugün, sürdürülebilir olmayan ürünleri sürdürülebilir ürünlere dönüştürme amacı birçok sektörde ortaya çıkmıştır. Bu bağlamda, doğal elyaf takviyeli kompozit malzemelere verilen önem hem uygulama alanları hem de benzersiz özellikleri bakımından hızla artmaktadır. Bu çalışmada, doğal liflerden keten malzeme takviyeli epoksi matrisi ile vakum destekli reçine transfer yöntemi (VARTM) kullanılarak kompozit malzeme üretilmiştir. Taşıtın iç kısmında kullanılan plastiklere alternatif olarak doğal elyaf takviyeli kompozit malzemelerin uygulanmasını değerlendirmek için deneysel çalışmalar yapılmıştır. Vakum infüzyon yöntemi kullanılarak üretilen kompozitlere termogravimetrik analiz, diferansiyel taramalı kalorimetrik analiz, su emme, sertlik ve darbe testi uygulanmış, malzemelerin temel mekanik özellikleri ve termal kararlılığı belirlenmiştir. Sonuçlar değerlendirildiğinde, doğal fibere metrekare başına farklı ağırlıklarda cam elyaf ilave edilmesinin kompozitlerin özelliklerini önemli ölçüde arttırdığı bulunmuştur.

Anahtar Kelimeler: Doğal fiber kompozitler, Keten fiber, Vakum infüzyon yöntemi, Termal özellikler; Mekanik özellikler

GENİŞLETİLMİŞ ÖZET

Hızla gelişen teknoloji ve mühendislik uygulamalarında ve günlük yaşamda artan rekabet, yüksek performanslı, düşük yoğunluklu, hafif, korozyona dayanıklı ve yüksek mukavemetli ürünlerin tasarımını gerektirmektedir. Kompozitler de savunma sanayi, havacılık sanayi, uzay teknolojileri, otomotiv sanayi gibi birçok alanda mevcut malzemelere alternatif olarak araştırılan bu ürünlerden biridir.

Kompozitler, en az iki farklı malzemenin, birbirlerinde çözülmeyecek şekilde birleştirilerek, bileşenlerin her birinde mevcut olmayan özellikleri geliştiren malzemelerdir. Kompozitler, matris adı verilen bir temel malzemeden ve takviye elemanı adı verilen dayanıklı bir malzemeden oluşur. Kompozitler sınıflandırılırken, matris malzeme tipi, matris takviye elemanı tipi, takviye elemanının şekli ve yer değiştirmesi kullanılır. Bu çalışmada kullanılan hibrid kompozitler sınıfı, parçacıklı kompozitler, katmanlı kompozitler, fiber takviyeli kompozitler gibi takviye elemanının şeklin ve yerleşiminin alt sınıfıdır. Kompozit malzemeler üretmek için iç yapılarına göre farklı üretim yöntemleri bulunmaktadır; el yatırması, püskürtme, pres kalıplama, güçlendirilmiş termoplastik levha kalıplama, reçine transfer kalıplama, pultrüzyon, lif sarma, santrifüj kalıplama, sürekli tabaka, ekstrüzyon, enjeksiyon kalıplama, vakum kalıplama, otoklav, vakum infüzyonu gibi.

Modern elyaf takviyeli polimerlere geçiş sentetik polimerin gelişmesiyle 20. yüzyılın başlarında olmasına rağmen, insanlık eski zamanlardan beri saman takviyeli çamurdan kompozit yaylara kadar birçok kompozit malzeme örneği yapmıştır.

Kompozit malzemelerin kullanıldığı ilk alan inşaat endüstrisi olarak bilinir. Diğer kompozit örneklere de insanların evlerinde bambu ile güçlendirilmiş çamur duvarlarında, dövme kılıçlarda katmanlı metallerde rastlanabilinir. Yirminci

yüzyılın ortalarından itibaren ise, otomotiv endüstrisindeki araç karoserleri için kompozit malzeme uygulamaları kullanılmaya başlanmıştır.

İlerleyen yıllarda, kompozit malzemelerin çelik ve alüminyumun yerine kullanıldıklarında geleneksel yapılardan daha iyi sonuç vermesiyle yapısal uygulamalarda kullanımı hızlı bir şekilde artış göstermiş ve günümüzde de mühendislik alanlarının çoğunda uygulama alanı her geçen gün artmakta olup, bunların sonucunda büyük miktarda enerji tasarrufu sağlandığı görülmüştür.

Dünyada çevre ve sürdürülebilirlik konularında artan hassasiyet artık elyaf takviyeli malzemelerin kullanımındaki gelişmelerin öncüsüdür. Bazen şirketlerin çevre bilinci ve zaman zaman da devletler tarafından yürürlüğe konulan yasal düzenlemeler, birçok mevcut materyalin değiştirilmesine veya yeni materyallerin geliştirilmesine yol açmıştır.

Bu noktada, malzeme seçimi için en uygun alan elyaf takviyeli kompozit malzemelerdir. Elyaf takviyeli polimer matris kompozitlerin önemi, otomotiv endüstrisi de dahil olmak üzere birçok sektörde giderek artmaktadır. Çelik gibi diğer yaygın malzemelerden daha büyük miktarlarda, daha dayanıklı ve daha hafif olarak üretilebilmeleri onları tercih sebebi kılmaktadır.

Kompozit takviye için kullanılan iki tip lif vardır: doğal ve sentetik lifler. Sentetik elyaflar kompozit malzeme üretiminde yaygın olarak kullanılırken, doğal elyaflar kompozit takviyeler olarak yapısal uygulamalar için birincil tercih değildir. Bu nedenle, matriste birden fazla elyaf türüyle hibridizasyon adı verilen yöntem kullanılarak hem doğal hem de sentetik elyafların en zayıf yönlerini azaltılırken, aynı zamanda onları çevre dostu malzeme haline getirmiş darbe enerjisi emilimini ve yük taşıma kapasitelerini de geliştirmiştir.

Bu çalışmada kullanılan doğal elyafların mevcut kullanılan malzemeler ile değiştirmek için mühendislik çalışmalarına artan bir ilgi vardır. Darbe direnci, tokluk ve esneklik gibi özelliklere sahip olan doğal liflerin, geleneksel malzemelere kıyasla avantajlı olduğu durumlar vardır. Ayrıca doğal fiberler düşük maliyet, düşük yoğunluk, yüksek titreşim direnci gibi istenen özelliklere de sahiptir.

Bunların yanı sıra, doğal liflerin bulunabilirliği, minimum sağlık riskleri ve iyi aşınma direnci de tercih nedenleri arasındadır. Diğer açıdan, doğal elyaf takviyeli kompozitlerin dezavantajları da vardır; düşük sertlik, düşük mukavemet ve hızlı bozulma gibi.

Önceki çalışmalar incelendiğinde özellikle jüt, keten, sisal, kenevir gibi doğal liflerle yapılan hibrit kompozitlerin yaygın kullanıldığı görülmüştür. Bu tür malzemelerin kullanımı aynı zamanda çevre dostu, sürdürülebilir ham maddelere olan ilgiyi de arttırmıştır. Buna göre otomotiv şirketleri, araç ağırlıklarını düşürerek emisyonları azaltmak için yüksek mukavemet ve yüksek mukavemet / düşük ağırlık oranlarına sahip doğal liflerin kullanımına yönelmiştir. Yenilenebilir ve doğal kaynaklı malzemelerin gelecekte yeni nesil yapısal malzemeler olarak otomotiv endüstrisinde geniş kullanım alanı bulacağı açıktır. Bu tür malzemelerin, mevcut elektrikli ve hibrid araçlar için de kullanılıyor olması iyi bir örnektir.

Bu çalışmada, geliştirilmiş mekanik özelliklere sahip yeni nesil bir hibrit kompozit yapının araç iç mekanına alternatif bir malzeme olarak geliştirilip kullanılması araştırılmıştır. Metrekare başına farklı ağırlıklara sahip cam fiberlerin, keten takviyeli doğal fiberle oluşturacağı birleşim incelenmiş, üretilen bu ürünlerin termal ve mekanik özellikleri analiz edilip, araştırılarak karşılaştırması yapılmıştır.

Tezde ilk olarak geri dönüştürülebilen, çevre dostu malzemelerin otomotiv ile diğer sektörlerde kullanımı, mevcut malzemelere alternatifi olarak hangi malzemelerin araştırılıp uygulamada kullanıldığından bahsedilmiştir. Küresel iklim değişiklikleriyle artan çevre sorunları şirketleri kısa sürede doğada çözünebilen çevreye zarar vermeyecek malzemelerin üretimine zorladığı görülmektedir. Bunların bir sonucu olarak da kompozit malzemelere, bunların doğal fiberlerle takviye edilerek üretimine mühendislik uygulamalarında büyük bir ilgi ortaya çıktığı anlaşılmıştır.

Bu çalışmada 49 gr/m²,86gr/m²,100gr/m² ağırlığında olan cam fiber kumaş ile %100 saflıkta keten kumaş, matris elemanı olarak epoksi reçine kullanılarak vakum infüzyon tekniğiyle on iki farklı kompozit örneği üretilmiştir. Doğal

fiberlerin dezavantajlı özellikleri sentetik fiberin avantajlı olduğu yönlerden dengelenerek malzeme özellikleri geliştirilmek istenmiştir.

Tüm kompozit yapıların uygulanacak test standartlarına göre farklı katman sayısı ve dizilimleriyle üretimi yapılmıştır. Üretilen on iki farklı kompozit yapının; mekanik özelliği için Charpy darbe testi ve sertlik testi; termal özellikleri için termogravimetrik analiz ve diferansiyel tarama kalorimetri analizi, su emilimini ölçmek için de numuneler belirli sürelerde su dolu kaplarda bekletilerek analizleri yapılmıştır. Üretilen kompozit numunelerin araç iç mekânında kullanımı incelendiğinden, mekanik test dışındaki termal analizlerin ve su emilimi analizinin de bu malzemeler için uygun olduğu sonucuna varılmıştır. Bu analizler, otomobillerin kullanıldıkları sürede iç parçaların sıcaklığındaki veya nemdeki artışın malzemenin yapısını ve termo-mekanik özelliklerini nasıl etkilediğini gözlemek için yapılmıştır.

Ham kumaşların termogravimetrik analizi sonucunda, keten kumaş yapısının yaklaşık 68 ° C ve 332 ° C'de iki bozunma aşamasından geçtiğini, cam fiber kumaşların ise 600 ° C'ye kadar hiç bozunma göstermediğini ortaya koydu. Ham keten fiber takviyeli ve cam fiber takviyeli kompozitlerde ise 344 ° C ile 352° C aralığında bozunma tespit edildi. Ham keten kumaş malzemesinin ve keten ile cam fiber takviyeli kompozit malzemelerin DSC analizinde, keten içeren numunelerin, keten kumaşın yapısındaki kimyasal bileşenler nedeniyle yaklaşık 150° C de ekzotermik, yaklaşık 350 ° C'de ise endotermik bir reaksiyon oluştuğunu gösterdi. Yapılan su emilimi deneyinin sonucunda cam elyafların aralarındaki kimyasal bağlanmadan dolayı saf ketenle karşılaştırıldığında hibrit kompozitlerin su emme kabiliyeti azalmıştır. Deneyler sonucunda Charpy çentik darbe deneyinde 100 gr/m² cam elyaf takviyeli kompozitlerin en yüksek darbe enerjisine ulaşan malzemeler olduğu saptanmıştır. Darbe dirençleri incelendiğinde, saf keten kompoziti ile 49 gr/m² ve 86 gr/m²'lik cam fiber ile takviye edilmiş hibrit kompozitlerin değerleri birbirine çok yakın çıkmıştır ve 100 gr/m² cam elyaf takviyeli kompozitle aralarındaki fark ise yaklaşık %21 olarak hesaplanmıştır. Sertlik testi sonuçlarına bakıldığında en yüksek değerin 25,24 HV ile keten ve 100 gr/m² cam elyaf takviyeli kompozite ait olduğu tespit edilmiştir.

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LIST OF ABBREVIATIONS AND NOMENCLATURE

20th	:	Twentieth
Kg	:	Kilogram
%	:	Percentage
CO_2	:	Carbon Dioxide
g/km	:	Grams per kilometer
CFRP	:	Carbon fiber reinforced plastics
HP-RTM	:	High-pressure resin transfer molding
etc	:	Et cetera
OEMs	:	Original equipment manufacturers
EOL	:	End of life
USA	:	United States of America
IP	:	Instrument panels
GFRP	:	Glass-fiber reinforced plastic
BIW	:	Body in White
FRPs	:	Fiber reinforced polymers
WF	:	Wood flour
PP	:	Polypropylene
DEFRA	:	Environmental, Food and Rural Affairs
US	:	United States
ABS	:	Acrylonitrile butadiene styrene
R&D	:	Research and Development
CFRM	:	Continuous Filament Random Mat
FE	:	Finite Element
PTP	:	Polymer material made oftriglycerides and polycarbon acid anhydrides
SMC	:	Sheet molding compound

FST	:	Fire, Smoke and Toxicity
PE	:	Polyethylene
NFC	:	Natural Fiber Composite
EMA	:	Experimental modal analysis
FRF	:	Frequecy Response Function
PES	:	Polyester
NFRCs	:	Natural fiber-reinforced composites
VBRTM	:	Vacuum bag resin transfer molding
MH	:	Magnesium hydroxide
MH-NFRC	:	Magnesium hydroxide impregnated natural fiber reinforced composites
GF-SMC	:	Glass-fiber sheet molding compound
3R	:	Reduction, reuse and recycling
PVC	:	Polyvinyl chloride
PC	:	Polycarbonate
DFD	:	Design for dismantling
PLA	:	Polylactic acid
GWP	:	Global warming potential
PA	:	Polyamide
C	:	Celsius
MPa	:	Megapascal
GPa	:	Gigapascal
LCA	:	Life Cycle Assessment
EOL	:	End-of-life
psi	:	Pounds Per Square Inch
WS	:	Wheat straw
LiCl	:	Lithium chloride salt
N-BBSA	:	N-Butyl benzene Sulfone amide

PMCs	:	Polymer-matrix composites
PEEK	:	Polyetheretherketone
PPS	:	Poly (phenylene sulfur)
PEI	:	Polyetherimide
PMMA	:	Polymethyl methacrylate
T_m	:	Melting point temperature
T_g	:	Glass transition temperature
PET	:	Polyethylene terephthalate
PBT	:	Polybutylene terephthalate
g/cm³	:	Gram per cubic centimeter
mm	:	Millimeter
$/kg	:	Dollars per kilogram
UV	:	Ultraviolet
KF	:	Kenaf fiber
PPTA	:	P-phenylene terephthalamide
GRP	:	Glass-reinforced plastic
RTM	:	Resin transfer molding
VARTM	:	Vacuum-assisted resin transfer molding
mPas	:	Millipascal second
mgr	:	Milligram
KOH	:	Potassium hydroxide
gr/m²	:	Gram per square meter
FL	:	Flax
G49	:	Glass Fiber (49 gr/m²)
G86	:	Glass Fiber (86 gr/m²)
G100	:	Glass Fiber (100 gr/m²)
FLG49	:	Flax/Glass Fiber (49 gr/m²)
FLG86	:	Flax/Glass Fiber (86 gr/m²)

FLG100	:	Flax/Glass Fiber (100 gr/m²)
gf	:	Gram force
kgf	:	Kilogram force
TGA	:	Thermogravimetric Analysis
DSC	:	Differential scanning calorimetry
CUMERLAB	:	Cukurova University Central Research Laboratory
TG	:	Thermogravimetry
ASTM	:	American Society for Testing and Materials
mJ	:	Millijoule
J	:	Joule
kJ	:	Kilojoule
HV	:	Vickers Hardness Number

1. INTRODUCTION

The automotive sector is developing day after day as it is becoming one of the milestones of the country's economy. Directly, as well as vehicle production, auxiliary industry and spare parts production are of great importance in the industry of the world countries. Regarding recent developments in automotive production, improvements in material technologies have made it feasible to produce high value-added products in the automotive industry in global. Rising productivity in vehicles, reduction of fuel consumption and minimalizing of exhaust emission are the essential topics that the automotive industry and searchers work to a high degree.

It is the historical process and development of the transport system that gives us an idea of how the world's scientific, technological, social and economic parameters alter the environment. The economic growth in the early 20th century is closely related to the development in the automotive sector. Vehicles occupy an important place in people's lives, both individually and in groups, and in the transport of goods.

The very high increase in the production of these cars causes significant expenditures in the continuity of the transportation network, which is of critical importance in the country's economy, and in the building of the required infrastructure. Taking into consideration that an average of 1500 kg of material is required for a car, this sector consumes 70 million tons of material annually. It is understood that this amount should be manufactured, used and eventually recovered or made away with at the end of its operable life. When developing new or alternative materials, it is aimed at cost-effective, fuel-efficient materials that reduce emissions, enhance safety and are usually capable of being recycled or biodegradable in the future (Kamath et al,. 2018).

Reducing vehicle fuel consumption and exhaust emission is likely on condition that vehicles are produced from lighter materials. Nevertheless, conventionally many parts of vehicles are made of metal materials. In recent years, these parts have begun to be produced from composite materials, allowing the production of much lighter parts with similar mechanical properties. When the parameters such as strength/density of composite materials are viewed, they have great advantages in comparison with metal materials. On the other hand, materials produced with carbon reinforcing materials specially have high costs. Furthermore, the way of producing composite materials is dissimilar to conventional production methods and thus engendering huge investment costs.

Global composite industry - about 90% currently based on glass fiber - now worth 80 billion worth and has become the largest sector of automotive and transportation for the last five years. Yet, composites still correspond with only 1.5% of global materials in the market where steel, wood, plastic and aluminum dominate. Obviously, it is the ultimate goal of the composite industry to replace this percentage with any of the other materials.

It is a glass-like, undirected, discontinuous or continuous low-cost fiber familiar in the current situation in the automotive industry, and a composite thermoplastic such as polypropylene or a thermoset matrix like polyester. Production times for these materials are very fast, but the cost is low. However, carbon fiber composites have many useful properties, such as high strength and durableness, but the automotive industry's emphasis is on being 50% lighter than steel.

The reduction in weight from replacing steel body parts with carbon fiber composites revealed that the truck industry will both provide low fuel consumption and achieve much higher payloads. It will also cause safety enhancements in collision behavior, as shown by Formula 1 racing cars for years (Adrian Wilson, 2017).

The methods developed and presented with new materials and optimized construction methods; solved the problems of the global competitive environment in commercial acceptance, cost reduction and meeting the legal requirements of motor vehicles. The desire to reduce total costs and ensure ecological protection promotes the use of new materials. Future vehicle systems need to be synchronized with a significant reduction in emissions of automobile pollutants - especially CO_2 - to enhance ecological protection. There is an initiative to deal with the problem by implementing lightweight design, constitutive and also light material measurements. Hence, with the advent of new developments, the industry uses aluminum alloys and magnesium alloys as well as light materials, along with traditional materials such as steel (Adam, 1997).

One of the increasingly important issues today is the fuel saving and the environmental problem. The energy use of transport at a global level constitutes roughly 23% of greenhouse gas emissions. A new legislative proposal aimed at reducing CO_2 emissions from light vehicles was adopted by the European Commission and the European Association of Automobile Manufacturers. In the newly published legislation, the rules are made more stringent; 65% of new vehicles sold in 2012, 75% of 2013, 80% of 2014, and 100% of 2015 should encounter exhaust emissions. The long-time objective for the year 2020 was 95 g/km. Using hybrid vehicles and decreasing the weight of the vehicles are among the ways to achieve the goal. This is a functional and promotive resolution for manufacturers (Park et al., 2013).

There are different global applications such as making materials from lighter materials to reduce vehicle weight, improving the functionality of existing parts and applying these novelties in vehicle design. The most unmediated and influential method for reduction of weight is the use of latest lightweight materials like composites, aluminum alloys and high tensile steel. Especially in German cars, Carbon Fiber Reinforced Plastic quantity production automotive bodies are used in widely. Carbon fiber reinforced plastics (CFRP), the basic technical parts of

modern industries, have recently been exerted to a broad diversity of engineering fields. In terms of potential implementation targets, the use of CFRP applications in automotive structures may be expected to increase rapidly over the next two decades. German technology is based on a high-pressure resin transfer mold (HP-RTM) that uses carbon fiber textile products and fast-drying epoxy resins when applying CFRP to mass-produced automotive bodies. Nonetheless, in this technology, there are many disadvantages. These are the complexities that arise at a much higher production rate, the wastes for cutting carbon textiles and the operation of slow adhesion currently required for joining the enwrapping components (Ishikawa et al., 2018).

Especially when the last thirty years have been examined, the utilization of composite materials has become an integral part of society. The striking rise of this rapid development coincided with what is often called green movement. As a result of this rising environmental consciousness, it became clear that the industry should be more involved in the development of waste disposal strategies than ever before. This is particularly important for the composite material industry in the increased number of composite parts that reach their end of life. Conventional methods make substantially focused on disposal at landfills. This option, which has become increasingly unpopular, is limited in extent and laws are take into promote the use of environmentally more reasonable options, such as recycling (Buggy et al., 1995).

Recently, the application of composites to automotive parts has been continuing regularly and this growth is expected to continue in the future. Although composites have some important property advantages such as reduced weight, freedom of design, etc., and the application volume has increased in the industry, it may not be seen to be of great use in structural components in high-volume automotive at present. This is not only a matter of minimum cost and manufacturing, there are many reasons for this.

Cost-effective manufacturing was the key to composites that were considered important when significant lead-ups were made in major non-structural and semi-structural applications. In sectors that use new materials such as composites and automotive components, it is anticipated that significant developments will be achieved when material and production costs are prioritized during the design phase. It should also be taken into account that when designing a composite part in the automotive industry, there are several different determinants. In some respects, the specific material used, the combination of material as well as the function of the part are related to these effects (Brooks, 2004).

High security, light, low emission, high maneuverability, high quality and low-cost vehicle production in parallel with technological developments is directly related to research in material technologies. Green composites are good examples for stating these developments. Green composites that emerge from renewable sources provide a great potential and promising future to the end customers, the natural surrounding and firms in view of the decrease in oil resources. The transition to sustained structures in the automotive sector is to provide a more applicable environment and cost effectiveness, as well as to meet the requirements of a European regulation (Koronis et al.,2013).

Sustainability is one of the most important problems in material technologies. Declining underground sources indicate that prices in metallurgy will gradually increase. For this reason, developing renewable and sustainable material technologies is of great importance for any country's industry and economy. Recycling is one of the sustainable working topics that are inactive and allow for the reuse of waste materials, which are the disposal costs and the economic damage.

Worldwide environmental concerns arise from the use of non-renewable resources such as petroleum, but the use of renewable resource-based materials is becoming increasingly important. Emissions of carbon dioxide, a subject of constant debate in the scientific community, stem from human activities. In the last

years, the need to adapt to eco- friendly production technologies and products has been recognized in various fabrication sectors.

Various industrial applications and innovative material studies are done to minimize environmental concerns of end users. Comprehensive research and laboratory experiments have been applied to composite materials relying on renewable resources with a broad variety of uses and technologies; economic, environmental and technical usefulness are demonstrated in many ways (Misra et al,. 2015).

Increasing the number of vehicles as shown in Figure 1.1 around the world, it will lead to increase in fuel demand, material demand and emissions from vehicles on a global scale.

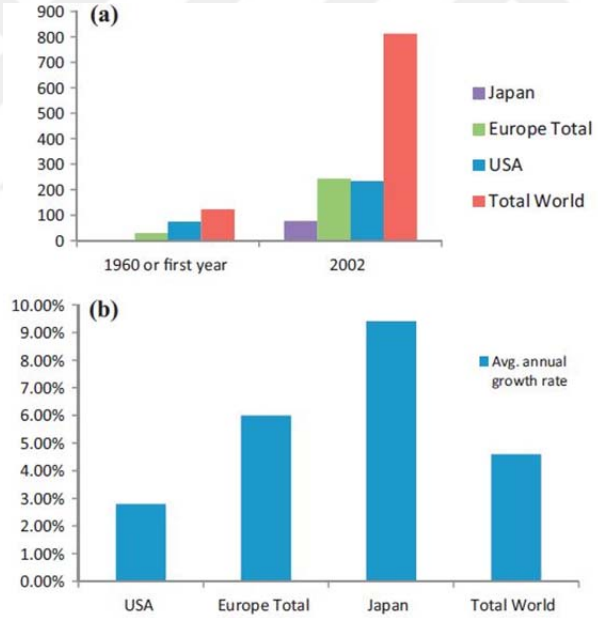


Figure 1.1. (a) Historical vehicle ownership (millions), 1960–2002; and (b) average annual growth rate between 1960 and 2002 (Adapted from Mayyas et al., 2012)

Eventually, sustainability is the most important factor motivating the automotive industry and aims to minimize the environmental damage of vehicles and to be seen as environmentally friendly products. Nonetheless, it is this trend that puts more pressure on original equipment manufacturers (OEMs). It is the responsibility of both the efficient methods of processing the resources and using them in a way that minimizes the environmental impact (Mayyas et al., 2012).

In this point, recycling occupies an important place in sustainability. It will make contribution to the continuity and sustained improvement of industrial processing by making the recycling of engineering materials. Today, recyclable materials include metals, glass, thermoplastics and many other engineering materials. But researchers have not been able to properly recycle composite materials, a specific category of engineering materials. Due to its heterogeneous construction and matrix reinforcement, the recyclability of composite materials, especially thermoset-based composite materials, is low. Products such as cars and planes containing all engineering materials require appropriate recovery and recycling of products at the end of their lifetime (EOL) with the applicable legislation. The resources and energy savings required to produce reinforcement and matrix materials will be provided by recycling (Y. Yang et al., 2012).

Increasing with environmental awareness and public interest, unsustainable oil consumption and novel environmental ordinance leads to the usage of friendly materials for environmentally. Natural fibers are seen as environmentally friendly materials with better features than synthetic fibers. Considered simply, natural fibers are non-synthetic or man-made fibers. They are available from animals and plants. Using natural fibers to produce composite materials from renewable and non-renewable sources such as linen, jute, sisal and palm has gained great importance for the last ten years.

Fiber reinforced polymer matrix has attracted great interest in many implementations due to its good features such as low-priced, fairly low weight, minimal damage to processing equipment and unsurpassed advantages of natural

fibers compared to synthetic fibers. The huge variety of natural fiber polymer composites is rapidly expanding innumerable engineering fields. Many automotive companies such as the German automotive companies, the Proton company, the national automobile manufacturer in Malaysia, and the Cambridge industry, which is in the automobile industry in the USA, have attached great importance to the usage of various natural fiber-reinforced polymer composites in various automotive applications. Apart from the automobile industry, sports fields, building and construction industries, aviation and others, such as flooring, panels, window frames and bicycle frames, have also been the field of application of natural fiber composites (Mohammed et al., 2015).

Significant changes have been seen in the types of materials used in modern car manufacturing from the past to the present. Cars, which had a metallic frame in the 1950s, are an area where alternating light materials are widely used today.

The goal of this remarkable change from past to present is to meet the escalating request to decrease weight of vehicle, thereby enhancing fuel economy and fulfilling legislation and legal requirements. Studies by car manufacturers investigating various methods include efforts to achieve legal objectives, including lightweight cars. This is because a 10% drop in car weightiness can have a 6-8% positive effect on fuel efficiency.

With optimized design, material change and parts integration, vehicles can be made lighter. These operations involve the exchange of materials made of plastic, which provides lightweight, easy-to-use and highly corrosion-resistant parts, especially in the automotive industry.

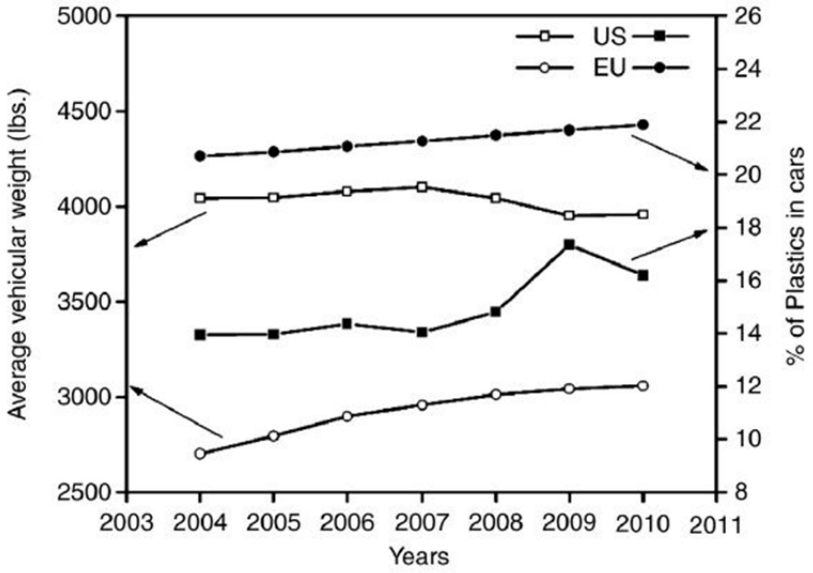


Figure 1.2. Trend of plastic content in European and American cars (Pradeep et al., 2016)

It is stated that it is necessary to take a look at the 1900s for the history of plastics in the automotive industry. However, the most obvious use of these materials was that in 1941, Henry Ford introduced a plastic body car made from hemp, sisal and cellulose-backed plastics. Figure 1.2 shows the tendency to use plastic content in vehicles in the European and American automotive industries between 2003-2011. Conventionally, thermoplastics and elastomers are operating in tires, gaskets, seats, belts, instrument panels (IP) and sealing adhesives. Besides, more and more thermoset composites such as glass-fiber-reinforced plastic (GFRP) and carbon-fiber-reinforced plastic (CFRP) are being applied to the constructional components of a car, like leaf spring, impact box , columns A and B and a white body (BIW) (Pradeep et al., 2016).

Glass and mineral fillers in many interior parts are being replaced by light, strong and low-cost bio fibers. For many centuries, bio-fibers have been used in baskets, garments, hold-all, hawser and carpet. They were even smoked. Plant-

based bio fibers in automobile components today; jute, banana, cannabis, linen, sisal, hemp as well as wood fiber are used.

The growing interest in researching biofibers is that it has properties comparable to glass fibers, especially from composite materials. It has been stated that the use of these composite materials is most demanded and the area of increasing use is predominantly interior applications in vehicles. In the studies conducted, it is expected that the use of biofibers will increase 54% annually in automotive parts. During the past ten years, European car manufacturers have adopted the application of bio-fiber reinforced polymer composites, door panels, backrests, headboards, package trays, dashboards and luggage liners (Bledzki et al., 2006).

Composites, which have the potential for weight reduction when compared to existing designs and materials, are used in automotive interior door panels, front mudguard, tailgate, roofs and public transport systems such as buses. With the weight decreasing operation, emissions can be diminished, fuel savings can be achieved and cost of overhaul (tires and brakes) can be cut down, thus contributing to the environmental and economic benefits of public transport. Nevertheless, it is known that when designing and operating these alternative materials, it is possible to meet safety requirements at an affordable cost, as well as need to noteworthy alteration in construction (Vaidya et al., 2004).

Fiber-reinforced polymers (FRPs) are applied in several practice of engineering, but particularly when using conventional FRP composites is a problem when high strength and stiffness are necessary. These problems are often caused by biodegradable fibers and matrices, as they cause problems with recycling at the end of their lifetime or their reuse. This was the reason for the advancement of natural fibers and green composites of biodegradable rosin.

Owing to the limited presence of the fossil sources, major oil shock occurs and the amount of toxic gas released into the atmosphere has gone up due to the burning of fossil sources and the raise in the volume of composite waste. For

various reasons, a new social consciousness of green compounds has emerged. In the 1980s, the improvement of partial biodegradable composites shape into cellulosic fibers based on thermoset resin began. It was stated in the 1990s that composite reinforced with wood flour (WF) was produced using thermoplastic resin (Bajpai et al., 2014).

Research on product development, recycling, and the use of biodegradable ingredients has increased dramatically recently. Automotive parts containing conventional matter like manufactured fibers and foams and glass, which are now hard to recycle at the present time, revealing the need for biodegradable nonwoven fabrics for about 40 automotive internal parts.

Non-woven products used in the automotive sector for various goals are preferred because of their light weight, sound absorption capacity, litheness, versatility and easy adaptability. At the same time, it has an interesting expense / performance rate with its ability to be molded, recyclable, low process and material expenditure.

The reason for enhanced attention in kenaf and ramie fiber nonwoven fabric applications is due to their great strength and regenerable nature, so they are a viable option for making automotive interiors. Nonwovens have found wide use in the automotive industry, from luggage coverings to carpets, including cabin air filters, molded seat coverings and upholstery. The application areas of new materials continue to increase due to their use techniques and applications, expense, productivity and reduction in weight (Thilagavathi et al., 2010).

Decreasing the weight of the vehicle provides many possibilities, such as the further reduction of gases released into the environment, including the usage of natural fiber-based nonwoven fabrics from thermoplastic composites. The tool used to produce natural fiber / polypropylene (PP) resin composites is 20% cheaper than injection molding options and provides, for example, 25% to 30% weight reduction in door panels. It also ensures that there are no pointed corners during sidewise

impact. Injected inserts were inserted into the tool prior to compression, resulting in a 35% weight saving in small, flax / PP construction dashboards.

Particularly impressive, the wood fiber materials formerly applied in the 1994/5 Mercedes-Benz E-Class door panels were switched with linen/sisal fiber mat embed in an epoxy resin matrix. From that time, the usage of this type of natural fiber substrates has found a widespread use network in European cars, as shown in Figure 1.3 (A. Wilson, 2016).

Manufacturer	Models	Applications
Audi	A2, A3, A4, Avant, A8, Roadster, Coupé	Seat backs, side and back door panels, boot lining, hat rack, spare tire lining
BMW	3, 5, 7 Series and others	Door panels, headliner panel, boot lining, seat backs
Daimler/Mercedes	A, C, E and S Series	Door panels, windshield/dashboard, business table, pillar cover panel
Fiat	Punto, Brava, Marea, Alfa Romeo 146, 156	Various
Ford	Mondeo CD 162, Focus	Door panels, B-pillar, boot liner
Lotus	Eco Elise	Sisal carpets, hemp class A panels
Mercedes-Benz trucks	Various	Internal engine cover, engine insulation, sun visor, interior insulation, bumper, wheel box, roof cover
Peugeot	New model 406	Seat backs, parcel shelf
Renault	Clio	Rear parcel shelf
Rover	Rover 2000 and others	Insulation, rear storage shelf/panel
Saab	Various	Door panels
Seat	Various	Door panels, seat backs
Toyota	Brevis, Harrier	Door panels, seat backs
Vauxhall	Astra, Vectra, Zafira	Headliner panel, door panels, pillar cover panel, instrument panel
Volkswagen	Golf, Passat, Bora, Fox	Door panel, seat back, boot lid finish, boot liner
Volvo	C70, V70	Seat fillings, cargo floor tray

Figure 1.3. Examples of established natural fiber automotive components, Europe (ADAS)

Today, there are many samples of the usage of vegetable fibers something like reinforcements of thermoset and thermoplastic polymers like epoxy, polyethylene, polypropylene and polyester to fabricate so-called friendly composites. Over the last decade, natural fibers have not only substituted glass fibers, but also have increased attention in their usage as consolidation in composite materials. One of the most voluntary sectors for using natural composite materials is the automotive industry, which uses them in interior practice as door panels and luggage coverings. When the DEFRA (Environment, Food and Rural Affairs) report is examined, an increase of approximately 54% per year is observed in the use of natural fibers in automotive parts by European and American car manufacturers to succeed the Environmental Directives. Natural materials are utilizing by automotive companies in the US: plant fibers just as jute, hemp, kenaf are present in about 1.5 million vehicles in any case as reinforcing of thermoplastic and thermoset polymers (Alves et al., 2010).

The 1950s are when the first use of natural plant fiber composites in the automotive industry. As a characteristic example of the implementation of native vegetable fibers buried in the polyester matrix (cotton), the body of the East German car "Trabant" in the 1950s and 1990s is given. In recent years, it has been observed that a completely new market place has developed for textile fibers (leaf and bast fibers) in order to strengthen composite products. In the automotive market, plant fibers were used in interior lining before the 1970s. In the 1970s and 1980s, for interior cabin panels, these fibers were superseded by petrochemical polymers such as non-reinforced acrylonitrile butadiene styrene (ABS) plastics, which have faster production processes and easy-to-optimize properties.

As an important alternate to these plastics, usage of natural fiber-reinforced composites was expected in the mid-1980s due to the technical, economic and ecological benefits as well as the social turmoil in the global food supply. There were promising developments in R&D (Research and Development) during this period, but even in the mid-1990s in the automobile industry there were only a few

examples where the first bast fiber (jute) reinforced plastic door panels were included in the German-made 1996 Mercedes-Benz model E class.

In 2000, distinct option made of green composites was introduced to the market. The A2, mid-range vehicle, using a mixed sisal mat / linen reinforced polyurethane on the door trim panels was introduced by Audi. In the automotive sector, attention in natural fibers rather than glass fibers has been raising from that beginning of the new millennium. Nonetheless, over the last two decades, the application of these materials to the automotive field has been limited to interior parts, such as flooring applications, rear shelves, instrument panels and interior trims for door panels. In addition to the low priced of natural fibers, these implementations are mainly related with thermal isolation and great acoustic features. Meanwhile, some of these practices have discovered an eco- friendly view and the usage of materials from regenerable resources to take part in marketing policies (Loureiro and Esteves, 2018).

In this research thesis, the main goal is to investigate the usability of hybrid composite materials made with natural fibers and glass fiber fabrics of different weights as an alternative to vehicle interior plastics. In composite structures produced with this study, two different fabrics, reinforcement material linen and glass fiber, were preferred, epoxy resin was chosen as the matrix material, and the products were produced by vacuum supported resin transfer molding method. By analyzing the mechanical, thermal properties, microscopic-macroscopic structure of these structures, it was examined whether their use in the automotive industry is more suitable for our ecosystem. Thus, the share of materials that are environmentally friendly, cost-effective, renewable and less harmful to living health in the automotive industry will be increased by such studies. In the light of these studies, it is thought that the results will give an idea about the future studies on fabric and natural fiber reinforced polymer composite materials.

2. PRELIMINARY WORK

2.1. Interior Applications Literature Review

At the beginning of 1930s it was Henry Ford, who studied various inartificial materials such as melons, carrots, corncobs, onions to look for potential materials to make an organic car bodywork. At that time, since the economic restrictions did not allow, the vehicle could not be mass-produced, but a cannabis-based prototype was developed. The emergence of other high-strength materials, as metals, reduced relevancy for natural materials, and the return to natural fibers did not begin until the 1940s (Suddell, Bc and Rosemaund, 2008). Composite materials have attracted interest since that time and their applications are also seen in many industries. It is possible to examine diverse composite material applications in studies. Nevertheless, these applications include high efficiency, low cost, high security, sustainability and environmentally friendly works. When considered from this point of view many researchers have studied applications of composite materials into automotive parts such as door trim panels, roof liner, center console trim, seat cushions, etc. and the parameters that affects this practice.

Long and Rudd (1994) investigated models for indiscriminate and oriented reinforcement deformation. In this study while random reinforcements were modeled by applying a modified plastic theory, directional reinforcements were simulated using pin jointed deformation model. A pattern was developed using the finite difference method to imitate the CFRM (Continuous Filament Random Mat) exerted to hemispherical stress. This can then be implemented in an appropriate FE (Finite Element) area to model complex three-dimensional formatting process. The directional simulation applied to a general three-dimensional face comprise bilinear patches was dependent on the needle joint fabric deformation model. The applied process provided an excessive value of the fiber orientation degree induced during deformation, while supplying stint to the deformation process. If the locking angle

required to fully cover the component can be estimated, it can thereby remove clipping and thus produce waste-free preforms for composites.

Komus and Beley (2018) presented the effect of composite material usage for ground transportation industry. In today's technology, how the properties of the materiel are affected when different kinds of reinforcements just as glass and carbon are used; advantages and disadvantages of these applications compared to thermoplastics were also investigated. It is stated how cost, performance and weight saving concepts come into prominence with composite parts. Also manufacturing process like infusion, hand-lay-up, pultrusion questioned and it had been shown that a selection is made depending on the factors in the industry. A 3-wheel vehicle was designed to demonstrate the application of composite parts. The existing design was replaced with new composite parts and the effect on the vehicle production process and weight was observed. Thus, it was shown a roughly 13% reduction in fuel consumption, while number of parts used dropped to 8 while 19, and the time required for production was reduced by almost 30%. A bus door was designed to investigate how its thermal performance changes with composite materials.

Davoodi et. al. (2011) researched application of natural fiber composites and their hybridizations with other reinforcement or matrices,furthermore the importance of geometric optimization. Different buffer concepts that are exposed to low impact tests are designed in the simulation program to choose the best geometric beam theme. Six different criteria such as easy manufacturing,mass,deflection,cost,strain energy and the rib possibility were examined. The results showed that the impact character of the advanced hardened hybrid biocomposite was not fully met by the common buffer beam. At this point, although the material is a fixed factor, it is thought that choosing the appropriate concept plays a critical part in structural strength. In addition, it is concluded that when structural optimization is made in bio-based composite materials, it can be used in automotive constructional parts. It is concluded that it is appropriate to use

epoxy matrix hybrid glass fiber / kenaf reinforced composite in compact type automobile buffer beam.

Müssig et. al. (2006) represent a study that the production of a plant-based thermoset resin with sheet molding compound technology (SMC) in the production of PTP (polymer material and polymer material made of triglycerides and polycarbonic acid anhydrides), which is a natural fiber-based bus body part. Until now, production of glass fiber reinforced polyester resin has been made for conventional components, in this study it has been optimized in production by choosing hemp fibers as the material and developing a technically mature PTP-SMC variant. The component was then tested daily for convenience in a practical application test. The produced parts were evaluated in terms of properties such as density, shrinkage, charpy effect, burning, water absorption, and the results were compared. The results showed that a homogeneous compound can be produced with hemp / PTP prepregs, with a favorable flow capacity in natural fibers with high surface quality and excellent combustion properties. It is stated that the implementation of renewable resources meets the recycling procedures that are specific to SMC and that this will be economically considerable in the future. Compared to the polyester system, the life cycle evaluation of PTP polymer materiel has been found to give more positive worth in almost all ecological aspects.

Petrone et.al. (2014) presented the consequences of the study on two sandwich panels that are ecologically compatible. Made of natural or plastic fibers, the face layers of which contain recyclable resin, all discovered panels offer a recyclable core. To examine the replacement of glass fibers with flax fibers, the two panel core materials were produced using the same but the face layer with different materials. Although the core used has excellent FST (Fire, Smoke and Toxicity) properties, good mechanical and processing properties, this core is a recyclable, pre-made compatible foam core (DIAB Divinycell F90). The first type of face plates were made up of five Plytron layers having a sequence of

0/90/0/90/0. Plytron consists of 35% volumetric unidirectional glass fiber in a polypropylene (PP) matrix as a commercially available pioneer material.The other types of face layers were made up of five layers of linen / PE (polyethylene) of the order 0/90/0/90/0. Linen is a natural fiber that has recently been available in trading grades for use in NFCs(Natural Fiber Composite). A recyclable three-layer composite was created from sandwich panels (compatible foam core and two face layers made of linen-PE for panel A, glass-PP for panel B). The two panels had equal plane size (400mm x 200mm) but the core had different thickness. When the core thickness of panel A is 26mm, the core thickness of panel B is 20mm.

Experimental modal analysis (EMA) called wick hammer technique was used to determine the dynamic properties in sandwich panels. It is the FRF (Frequency Response Function) analysis that gives modal parameters in terms of natural frequency, mode shape and mode damping. As a result of experimental and numerical analysis of two sandwich panel classes, the lower values of the elastic modules of the layers in natural fibers shift the natural frequencies to lower values, however, the total thickness of the sandwich panel contained therein has a slightly higher and lower weight. In addition to the natural frequencies, the main conclusion about the damping values of these panels examined is twice that of other sandwich panels (in almost the entire frequency range). These analyzes show that the high functional capacity of the panel made of natural fibers, in terms of damping, can also be highlighted according to the analysis of natural frequencies, average values of mechanical properties and low weight.

Parikh et. al. (2006) investigated that how to prevent undesired sound in the passenger section of motor vehicles. There were many methods to decrease noise and their sources using sound-absorber materiels connected to diversified parts like ceiling tiles,door panels, package trays,body liners and floor coverings. The most suitable for the automobile industry is renewable and biodegradable natural fibers. In this study, low-priced, biodegradable, environmentally-friendly natural fibers (cotton, linen,jute and kenaf), polyester (PES) and polypropylene

(PP)blends were produced qua potency sound-absorber materials. To measure the sound energy absorption abilities of these materials, tests were performed by ASTM E-1050-98 standard test method, alone or by using a combination of soft cotton underpads and rebonded PU (polyurethane) underpads. When the analysis results from two underpads are examined, the PU underpad, which has a high density and thickness, was more influential in decreasing noise.It has been shown in this study that natural fiber-essential non-woven composites (floor coverings) could be fabricated with sound-absorber features convenient for use as automobile sound reduction parts.

Wu et. al. (2018) investigated to substitute the glass fiber sheet molding compound (GF-SMC) in the automotive industry using natural fiber reinforced composites (NFRCs). The production of composites was used to increase the mechanical properties and water resistance studies of NFRCs and vacuum bag resin transfer molding (VBRTM) technology, which uses magnesium hydroxide (MH) to absorb fibers. It was observed that the tensile strength and modulus of the rupture of the modified composites increased by 73.9% and 54.6% compared to normal NFRCs. Compared with the regular NFRC, swelling and 24-hour water absorption of the MH-NFRC thickness impregnated with MH decreased by 84.2% and 83.9% , in sequence. In addition to the mechanical properties, the benefits of replacing the GF-SMC with MH-NFRC have been seen in environmental impact and energy consumption reduction. When the results were examined, the use of kenaf fibers showed a 22.8% reduction in the environmental loads of composites. Newly developed NFRC has been found to be a significant chance of substituting GF-SMC in vehicle parts, in terms of low energy consumption and environmental impact.

2.2. Applications of Composites in Interior

The reason for the rising in the ratio of ends of life vehicles (ELV) is associated with the increase in the number of cars produced. The traditional ELV

processing approach includes assembly, shredding and waste disposal. The principle of "3R" (i.e. reduction, reuse and recycling) is progressively used in the processing of ELVs, especially ELV parts, to support sustained improvement. This approachment can guide the design stage of automotive products. For example, it can give an idea about the optimization of the materials used in a dashboard design. The dashboard was one of the unique parts of a vehicle, which included many functional features that affect the interior quality for an interior. The dashboard ensured drivers with safety, functionality, comfort and aesthetics and is settled in front of the driver.

The composition of the dashboard epidermis was mainly polyvinyl chloride (PVC), which also includes foam padding. The frame composed of polycarbonate (PC), acrylonitrile butadiene styrene copolymers (ABS) and polypropylene (PP). At this point, single polymer principle in terms of automotive parts design had some advantages. By decreasing the number of incompatible polymers, a cut down on the difficulty of removing and recycling internal and external coatings and the improvement of a range of green design guidelines for automotive parts could be achieved. Pyrolysis and DFD (design for dismantling) methods can significantly increase the recycling rate of the material (Tian and Chen, 2014).

Specific requirements are more difficult for bio-based material applications in the automotive sector than medical or disposable implementation. One of the important researches in bio-based materials is to improve production procedures, additives, catalysts and different formulations to enhance their inherent durability impact and thermal properties. It was desirable to meet some criteria like cost, material properties, production methodology, continuous supply, before bio-based materials substitute the traditional non-renewable materials in the automotive sector. In this study, the environmental impact of PLA (polylactic acid resin) + flax fiber composites and then PLA + flax fiber composites compared to PP + wood powder composites used in the internal components of the currently produced

FIAT cars were evaluated. For PLA + flax components, flax short fiber production, Ingeo (PLA) production, extrusion compound, pellet drying and injection molding processes environmental impact potentials have also been evaluated in terms of production processes. In terms of global warming potential (GWP), the new PLA + flax bio composite performs its current PP + wood powder composite task, but there may be differences in terms of local environmental performance. As the production methods progress and the material properties improve, bio-based composites such as PLA + flax may be a suitable choice (Tseng, 2013).

During recent years, different composite application methods have been commonly used in the automotive industry determination of manufacturing of automobiles. In this respect, either natural fibers or eco design material may be applied to various types of manufacturing and designs of automobiles' exterior, interior, trim parts.

Leao et.al. (1998) researched and compared the application areas of natural fibers in terms of many different parameters in the automotive industry. Various natural fibers like coconut, ramie, jute, sisal and curaua were examined in this study. The combine of the three components, such as viscose-jute-polypropylene, was examined for different density (0.59 to 0.95), thickness (1.75 up to 2.95). The fiber ingredients were stirred on a dry weight base and blended by hand before the collector, dividing the fibers by 5 cm to provide more blending. It was concluded that curaua was found to be the finest natural fiber for the use of composite implementation under tested terms. Others showed a similar situation, saying that price and availability would be essential. The results also showed that the tested natural fibers can compete well with traditional materials, mostly glass fiber and wood-based composites. The implementations of composites in the tests carried out had optimal properties such as tension strength and tension modulus for many parts in the automotive industry.

Buchenauer (2016) conducted the study to investigate the usage of natural wood fibers qua filler in polyamide composites. Polyamide is a good example of its

usage in relatively high temperature applications, such as a vehicle engine, as its melting temperature is high. Thus, it has been found how to improve the sustainability and environment friendly of a polyamide composite for usage in automotive execution. Two sources of natural wood fibers were regarded: eucalyptus pulp, Woodforce fiber. Three sorts of polyamide were designed. These involved recycled PA 6, PA 6,10 and PA 10,10. The properties of the fibers such as thermal gravimetric, melting and crystallization temperatures were compared before compounding. 20 percent by weight filler was combined to peruse how the fibers affected mechanical properties just as the impact and bending properties, following examined the thermal behavior of the wood fibers separately.

It has been observed in the study results that the eucalyptus pulp fiber has the highest progression in mechanical properties when combined with each polyamide, thermally and mechanically. The 20% cellulose level provided the optimal combination of characteristics. The use of PA 6,10 is favorable in terms of sustainability due to its biological content, but it has been found that it needs to be offset at supplement cost. It was recommended that the development of the fiber pre-treatment method for easy bonding with polyamide. It has been concluded that the usage of natural fiber composites instead of glass fibers is possible in constituent that does not need wholly fiberglass material properties.

Rwawiire et. al. (2015) examined natural cellulose fabric reinforced green epoxy composites for execution to automotive dashboards. The chemical composition of bark cloth included hemicellulose, lignin, α-cellulose. Natural cellulose fabrics were subjected to 5% alkaline dispersion in one hour at room temperature conditions. Afterward processing, the fibers were rinsed out with running water and dried in the oven at 80 ° C. Composite samples were prepared by hand lay-up method. The curing of the composites was implemented using a hot air oven for 45 minutes. Surface structures, mechanical and thermal properties of the material were examined. In the analyzes, it was obtained that the tensile strength of alkali-treated bio composites was 33 MPa and its modulus was

approximately 4 GPa. Bending strength in the material was found 207 MPa. It turned out that the glass transition temperature in bio composites ranged from 163 ° C to 185 ° C, based on the frequency. Advanced bio composites had an equivalent value of 33 MPa, which was higher than the 25 MPa lower-limit force required for dashboard panels or automobile parts. Thus, it was understood that green epoxy composites with bark cloth reinforcement became an alternating material for automotive interior panels.

Luz et. al. (2010) searched environmental benefits of polypropylene composites when sugarcane bagasse reinforced polypropylene replacing for talc-filled polypropylene. With this study, the comparison of sugar cane bagasse-PP composites with that of talc-PP composites for automotive parts applications was made from an environmental impact point of view. A comprehensive Life Cycle Assessment (LCA) was used in this comparison. Life Cycle Assessment (LCA) was utilized in this study because it is the most proper access to determine material flows, energy and their ecological influence throughout the life cycle from crude extraction to end-of-life (EOL). Due to the different specific weights for the equal dimensions and resembling mechanical features, 25 kg PP talc-filled composites were conceived, compared with 20 kg for sugar cane bagasse-based composites to carry out the identical function, and a 50% recycling rate was also assumed for the composite parts. The results were assessed in the way of environmental impact categories, energy consumption, global warming effects and the suitability of different EOL strategies. There was evidence that the sugarcane bagasse-reinforced composites were environmental supreme to those filled with talc. It was seen that sugarcane bagasse fiber production leads to low environmental effect, composites reinforced with sugarcane bagasse were slighter and had equal performance when used in the aesthetic coating of the inside of the car. Besides, during the cultivation phase, sugar cane used up carbon as the carbon grows, which promoted to carbon credits, and the economic redispose of the EOL material composite seems to be the ideal alternate to reduce ecological effect.

Ozen et. al. (2013) undertaken engineered thermoplastic composites prepared from nylon 6 filled with natural fiber blend, in order to create and optimize a production process suitable for automotive applications. The natural fiber blend was obtained by blending the kenaf, flax and hemp fibers, and was added to nylon 6 to produce the composite pellet using the melt blend. In the study, there are natural fiber / nylon 6 compounds containing 5% to 20% by weight natural fiber with different concentrations prepared by injection molding. The natural fiber mixture, Nylon 6 and homogeneous fibers were dried for 16 hours using an oven at 1058 ° C to have a moisture content of less than 1%. The Nylon 6, matrix polymer was mixed with uniform fiber and natural fiber blend. All materials were molded by injection using an injection pressure of 2500 psi, a barrel temperature of 250 ° C, at a mold temperature of 250 ° C. The thermogravimetric, melt flow index and density of the produced composites were tested. It has been observed that adding 20% of the natural fiber mixture can be compared to 20% addition of homogeneous fibers or exhibit higher mechanical properties. With the addition of natural fibers, the elastic modulus of a composite and the viscosity of the composite melt suspension increase, while reducing the viscosity of nylon 6. In addition, the densities of the composites are gradually rising with the content of the natural fiber mixture. It is believed that the application of natural fibers will enhance in many areas when surface modifications for natural fibers are developed, new joining techniques are used, and with new engineering thermoplastics with melt temperatures higher than nylon 6.

Amintowlieh (2010) has researched improving a formulation using wheat straw (WS) as a reinforcing fiber for Nylon-6. The subject investigated in this study is what effect the additive will have to drop the melting point or reduce the viscosity of Nylon-6. It is a lithium chloride salt (LiCl) and N-Butyl benzene Sulfone amide plasticizer (N-BBSA), which is used as processing additives to cut down the melting point, lower the process temperature and time. The effect of various additions of these two additives on the thermal, physical, mechanical

properties and machinability of the composites was investigated. The results showed that making an addition in 15% by weight to the wheat straw to Nylon-6 reduces strength by 9.9% while increasing the module by 26.9%. It was found that the 4% LiCl supplement reduced the melting point from 222 ° C to 191 ° C, which enhanced the module by 14% compared to Nylon-6 / wheat straw (15%). With the addition of 4% plasticizer (N-BBSA), the increase in modulus and strength was only 2.6% and 3%, in sequence, compared to Nylon-6 / wheat straw (15% by weight) composites. Samples containing 2% LiCl and 2% NBBSA by weight had 29.3% higher tensile modulus than smooth Nylon-6, while the strength was almost identical to that of Nylon-6, but 6.3% higher than Nylon-6 / WS (% by weight 15).

Magurno (1999) investigated the usage of vegetable fiber / plastic composite materials in interior auto parts and the technologies required to apply them. At the same time, with the development of composite materials in the automotive industry, research lines on various vegetable fibers (linen, jute, kenaf, eucalyptus) to be applied to semi-finished products are also expressed, extruded sheets for thermoform (short and long vegetable fiber) and granules for injection molding (short vegetable fiber). The majority of the use of vegetable supplements was made to use as binding material in thermoset polymer. Among the families of thermoplastic materials and different thermoplastic polymeric materials, thermoplastic polyolefins were preferred because they are most versatile. As it has reinforcing activities, vegetable fiber plastic composites were made use of producing the structural part of the interior upholstery. In this study FIBRIT, Wood Fibre/phenolic resin, polywood process, Fibroflax, Fibropour fibres, COIXIL technology were researched. Besides, short vegetable fibre and long vegetable fibres were analyzed in the way of mechanical properties and aesthetixil. Then, COFIBER composite material was compared with short vegetable fiber in density, toughness, stiffness, impact strength, energy absorption, flammability and recycling. Lightweight, stronger and low-priced composite was the main aim of composite manufacturers. It was observed in this study that vegetable long fiber

reinforced composites were considered to be a very suitable choice for standard formulations in extrusion operation, whereas natural short fibers were seen to be a better supplement for the injection molding operation.

3. MATERIAL AND METHOD

3.1. Composites

3.1.1. Composite Structures

Composites that are a heterogeneous compound of two or more supplements, matrix and material, giving the material fully different superior chemical, physical and mechanical features (Anuradha, 2019).Figure 3.1 shows the classification of these structures.

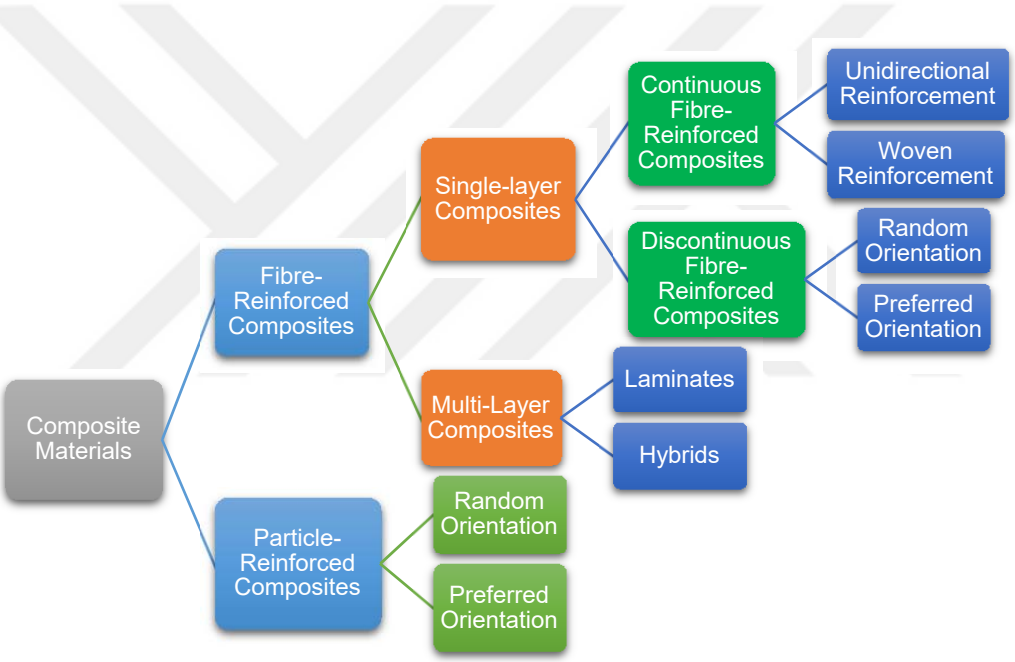


Figure 3.1. Classification of composite materials (Techapaitoon, 2015)

3.1.2. Hybrid Composites

Composite materials can be exposed to unusual loading states, which are sometimes compels researchers to use different types of reinforcing materials in the composite structure. Such composites reinforced with two or more types of materials are known as hybrid composites.

Hybrid composites are separated into two categories. These are; interply and intraply composites. Interply hybrid composites have one type of fiber per fabric layer, while intraply hybrid composites have two or more fiber types per fabric layer (Sezgin H., 2018).

Hybrid composite materials are designed for special task applications. The properties of the composites can be improved by careful design of the hybrid configuration. Two or more fibers and fillers are mixed together to take advantage of the mechanical, thermal and tribological properties of both of the fiber / fillers. A possible cause of the improved properties is that the fibers and fillers of certain properties are mixed in a particular pattern to provide the desired properties which cannot be achieved by mixing individual fibers in the matrix (Agarwal et.al., 2014).

The strength of the hybrid composites based on the properties of the fiber, the aspect ratio of the fiber content, the length of the individual fibers, the orientation of the fibers, the degree of the intertwining of the fibers, the bonding of the fiber to the matrix interface, and failure strain of both the fiber and the individual fibers. Maximum hybrid results are obtained when the fibers are highly tensile compatible (M. Jawaid and Abdul Khalil, 2011).

Hybrid composites generally consist of fibers; a high modulus fiber, low elongation high cost, e.g. carbon, boron and other fibers are generally low modulus, high elongation low cost examples; E-glass, Kevlar. High modulus, low elongation fiber (carbon) hybridizes the hybrid and provides high load carrying capability. On the other hand, low modulus, high elongation low cost fiber (E glass) makes the hybrid more ductile and damage tolerant and keeps the material cost low (Ikbal et. al., 2017).

3.1.3. Polymer Matrix Composites

Polymer-matrix composites (PMCs) are formed from a polymer resin as a matrix and fibers as a reinforcing medium. These materials are used in the largest variety of composite applications and in the largest quantities, in light of room temperature properties, ease of production and cost. The matrix generally determines the maximum service temperature because it normally softens, melts or decomposes at a temperature much lower than the fiber reinforcement.

The most widely used and cheapest polymer resins are polyesters and vinyl esters, which are mainly used for glass fiber reinforced composites. Numerous resin formulations provide a wide variety of properties for these polymers. Epoxies are costlier and are widely used in PMCs for aerospace applications together with commercial applications; they have better mechanical properties and moisture resistance than polyesters and vinyl resins. Polyimide resins are used for high temperature applications; for continuous use, the upper temperature limit is about 230° C. Finally, high temperature thermoplastic resins offer the potential to be used in future aerospace applications; these materials include a polyetheretherketone (PEEK), poly (phenylene sulfur) (PPS) and polyetherimide (PEI) (Callister, 2007).

Polymer matrix composites have been finding increasing use in high technology and traditional applications in the last two decades. Designers are looking for high specific stiffness, high specific strength, improved dimensional stability, energy absorption, corrosive resistance and low cost when selecting material systems for typical applications. Various fiber and resin systems are available for designers (Pandya et al., 2011).

Polymer composites consist of resin and reinforcement selected according to the desired mechanical properties and application. Thermoset resin polyester, epoxy, phenolic, silicone and polyamide resins are widely used in many structural and engineering applications (Gujjala et al.,2014).

3.1.3.1. Matrix Material

The task of the matrix is to combine the fibers regularly and protect them from the environs. In addition to transferring loads to the fibers, the matrix plays a critical role in intercepting premature defects caused by fiber micro bending in compression loading. The matrix also provides the compound with impact, wear resistance, damage tolerance and toughness. Thermal and oxidative stability, maximum operating temperature, resistance to liquids and moisture are determined from the properties of the matrix. Polymeric matrices for advanced composites are categorized as thermoplastics and thermosets (Campbell, 2010).

Polymers commonly used in structural materials for use at relatively low temperatures are fiber-reinforced polymers. In general, polymers with lower strength and modulus than metals or ceramics are more resistant to chemical attack than metals. Figures 3.2 show a schematic comparing the strength properties of elastomers, polymers, metals and ceramics (Asthana et al., 2006).

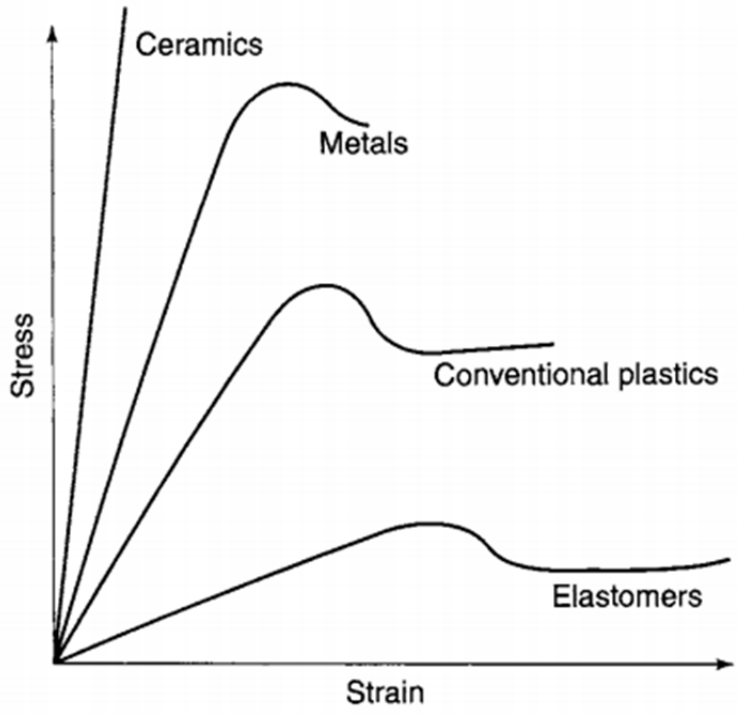


Figure 3.2. Comparison of idealized stress-strain diagrams for metals, amorphous polymers, and elastomers (Asthana et al., 2006)

3.1.3.1.1. Properties of Matrix Material

Huge, macromolecules with carbon atoms or chain-like molecules, connected with a covalent bond as the basic of the chain, are called polymers. Monomers are known as small chain organic molecules with low molecular weightiness, they are combined with the polymerization process that turns monomers into polymers. Generally, polymers consisting of a long chain of atoms with wrapped or twisted bonded side groups are called linear polymers. Examples of these are polyvinyl chloride, polyethylene, polymethyl methacrylate or PMMA. Those formed from the lateral branching from atomic chains are called branched polymers. Cross-linked polymers are known to form cross-linking molecules of one chain with molecules of another, thereby making a three-dimensional netting.

Polymers, in contradistinction to pure metals that smelt at a constant temperature, indicate a temperature interspace in which crystallinity is lost during heating. In cooling, polymer fluids shrink like metals. In amorphous polymers, this shrinkage goes on under the melting point (T_m) of the crystalline polymer to the temperature T_g, called the glass transition temperature, where the supercooled liquid polymer becomes highly hard due to the excessively high viscosity. Changes in specific volume in a polymer are indicated in Figure 3.3 as a function of temperature.

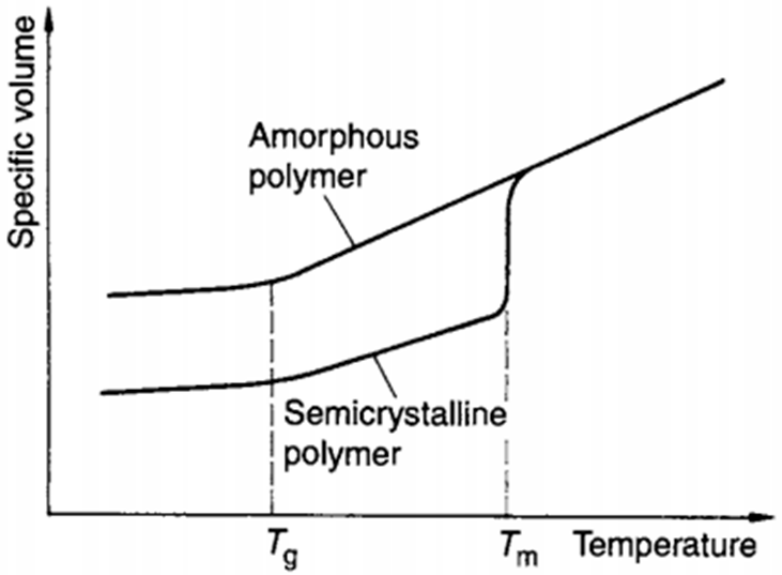


Figure 3.3. Specific volume versus temperature relationship for amorphous and semi crystalline polymers (Tg, glass transition temperature; Tm, melting temperature) (Asthana et al., 2006)

Many physical properties like heat capacity, viscosity, thermal expansion and modulus suddenly change in Tg. As an example, changing the natural logarithm of the elastic module is shown in Figure 3.4 as a function of temperature;

the discontinuity of the module is accompanied by the transition from glassy rubber to the liquid state (Asthana et al., 2006).

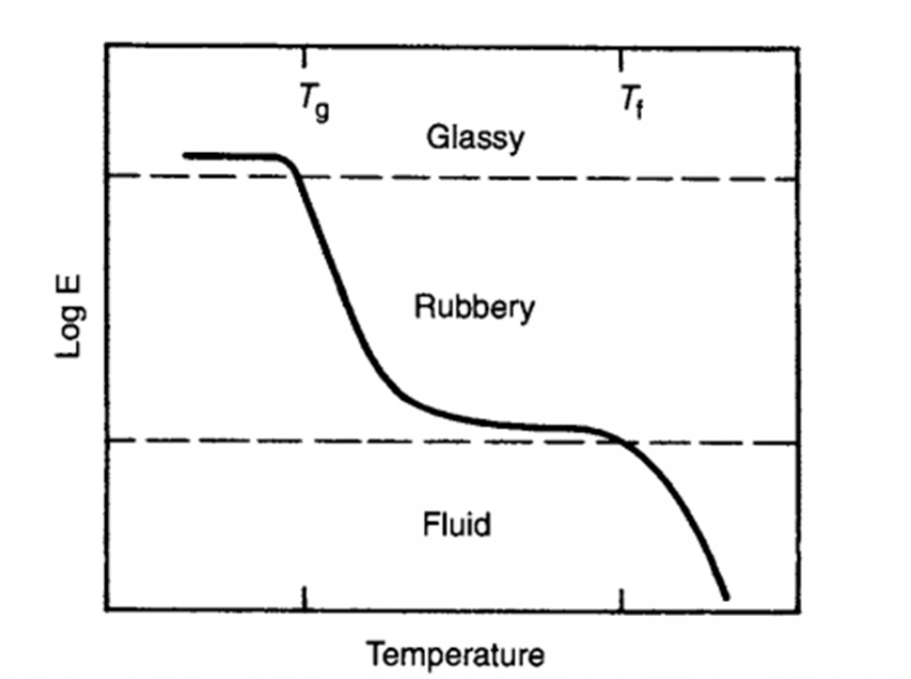


Figure 3.4. Variation of modulus of an amorphous polymer with temperature (Asthana et al., 2006)

3.1.3.1.2. Thermoset Resins

Thermoset resins are the most common matrix system for composite materials because they have low melt viscosity, good fiber impregnation and very low process temperatures. They are also less costly than thermoplastic resins (Lee and Suh, 2006).

Thermoset composite matrices include polyesters, vinyl esters, epoxies, bismaleimides, cyanate esters, polyimides and phenolics (Table 3.1).

Table 3.1. Properties of some thermoset resins (Campbell, 2010)

Resin Types	**Characteristics**
Polyester	High processing flexibility Can be used for both continuous and discontinuous composites Inexpensive
Epoxy	Relatively expensive Higher temperature resistance than polyester and vinyl ester resins.
Polyimide	Not easy to process High temperature resistance
Phenolic	High fire resistance Not easy to process
Vinyl ester	Relatively inexpensive Tougher than polyester resin
Cyanate ester	High-temperature resin matrices for use in the temperature range of 135–176,7 °C with epoxy like processing. Requires elevated-temperature postcure.
Bismaleimides	High-temperature resin matrices for use in the temperature range of 135–176,7 °C with epoxy like processing. Requires elevated-temperature postcure.

Thermosetting polymers or thermosets are resins which are readily cross-linked during curing. Curing involves the addition of heat and pressure, ultraviolet radiation or a catalyst known as a stiffener or hardener.

Thermosets are brittle at room temperature and cannot be reshaped by reheating due to cross-links. Thermosets decompose during reheating and in some

cases may burn, but are not soft enough for reshaping. However, because the weak van der Waals bond between the polymer chains is replaced by strong crosslinks, the stiffness increases. Furthermore, thermosets can be used at higher temperatures because they have higher softening temperatures and better creep properties than thermoplastics.

They are more resistant to chemical attack than most thermoplastics (Lee and Suh, 2006).

3.1.3.1.3. Thermoplastic Resins

Thermoplastic materials are generally flexible and relatively soft; they are heated becomes softer and more flexible. Thermoplastics are linear or branched-chain polymers. Thermosets and elastomers are cross-linked polymers. Polyethylene linear molecular chains and the like is a thermoplastic material. It is easily stretched and not rigid. Because the chains are independent of each other, they can easily pass through each other, and therefore the material has a relatively low melting point, no energy is needed to break the bonds between the chains. The absence of ties between the chains also means that the removal of heat allows the material to return to its initial hard state, as none of them break when heated.

Since linear chains do not have side branches or cross-links with other chains, they can easily cross each other. The presence of side branches reduces the ease of crossing the chains so that the material is harder and has higher strength. The side branched thermoplastics are thus stiffer than the linear chain thermoplastics. Polypropylene is such a material, harder and harder than polyethylene. Another consequence of a material having branched chains is that the material will generally have a lower density than the linear chain material, since they are not so easily packaged as linear chains in the material (Bolton, 1993).

In general, short fibers are used as reinforcements with thermoplastics due to the high viscosity of thermoplastics, but some continuous fiber reinforced thermoplastics are also produced. Thermoplastics well known for composites

include nylon (polyamide), acrylic, polypropylene, polystyrene, thermoplastic polyesters (e.g. polybutylene terephthalate: PBT, polyethylene terephthalate: PET) and polycarbonates. Certain of the novel high temperature matrix materials include polyarylsulfone, polyetherether ketone (PEEK), polyamidimide and polyphenylene sulfide (PPS) (Lee and Suh, 2006).

The structural distinction between thermosets and thermoplastics gives an idea of the potential vantages of thermoplastics. Since thermoplastics are not cross-linked, they are naturally much harder than thermosets. Thus, they have a much higher tolerance than uncured thermoset resins that have been used for a certain time in the past and are resistant to low impact damage.

Other advantages of thermoplastic composites include safety and health, since these materials react completely, low-molecular weight unreacted resin components are not dangerous to the worker. Moreover, thermoplastic composite prepregs do not need cooling like thermoset prepregs. Any other potential advantages of thermoplastics include low moisture absorption capacity. Cured thermoset composite parts reduce the high temperature performance of the material by absorbing moisture from the atmosphere (Campbell, 2010).

3.1.4. Reinforcement

The reinforcements are the ones that assume the essential role of providing strength and stiffness mainly in composite materials. Today, a wide variety of supplements, usually in fiber form, are available on the market. It is a high aspect ratio (length / diameter) of the fibers, which allows the load to be transferred to the fibers very efficiently through the matrix and makes the fibers a very effective and attractive reinforcing material.

The main reinforcements used in polymer matrix composites are glass, carbon and aramid fibers. Due to its low cost, E-glass fibers are the most important reinforcement fibers. Carbon, graphite and aramid fibres are excepted owing to

their high stiffness. Parts used to reinforce metal and ceramic matrices are ceramic fibers, whiskers. Natural fibers are now progressively used in composites.

The orientation of the reinforcement affects the isotropy of the composite. Coaxial, uniformly dispersed particles or randomly oriented short fibers form isotropic composites which are independent of their properties. The hemp fibers used in this study were in the form of a nonwoven randomly oriented mat and therefore the composites made from them were expected to have isotropic properties. The use of continuous fibers in composites usually ends up anisotropic material whose properties diversify different directions in the material, but they are optimal in the fiber direction.

Since the direction of the fibers in the composite can be adjusted to work with the loading direction, anisotropy is one of the main advantages of using composite materials (Shahzad, 2009).

3.1.4.1. Natural Reinforcement

Natural fibers are those obtained directly from natural sources such as plants and animals. Natural fibers are renewable and cheaper (Table 3.2) than synthetic materials. With the increasing costs of synthetic materials, the usage rate of the natural fiber composite industry is expected to increase in the current and future years. These factors promote the development of oil-based fiber alternatives, natural fibers.

Table 3.2. Price comparison between natural and synthetic fibers (Liu Xueyuan, 2015)

Fiber	Carbon	Steel	Glass	Sisal	Jute	Coir
Cost (USD $/kg)	200	30	3.25	0.36	0.30	0.25
Modulus Cost (GPa kg/$)	2.0	6.7	21.5	41.7	43.3	20.0

Another reason for the increase in usage rate is strict environmental regulations, so the use of NFRC increases significantly. Developed countries are implementing more stringent laws on greenhouse gas emissions, particularly in the automobile industry. Vehicle manufacturers that exceed vehicle emission limits face serious fines. So, automotive companies seek to reduce gas emissions. Another reason is environmental awareness, changing the industry through the people's desire for green life, laws and media control (Liu Xueyuan, 2015).

Natural fibers can be classified into three main categories according to their origin, plant, animal and mineral resources as shown in Figure 3.5.

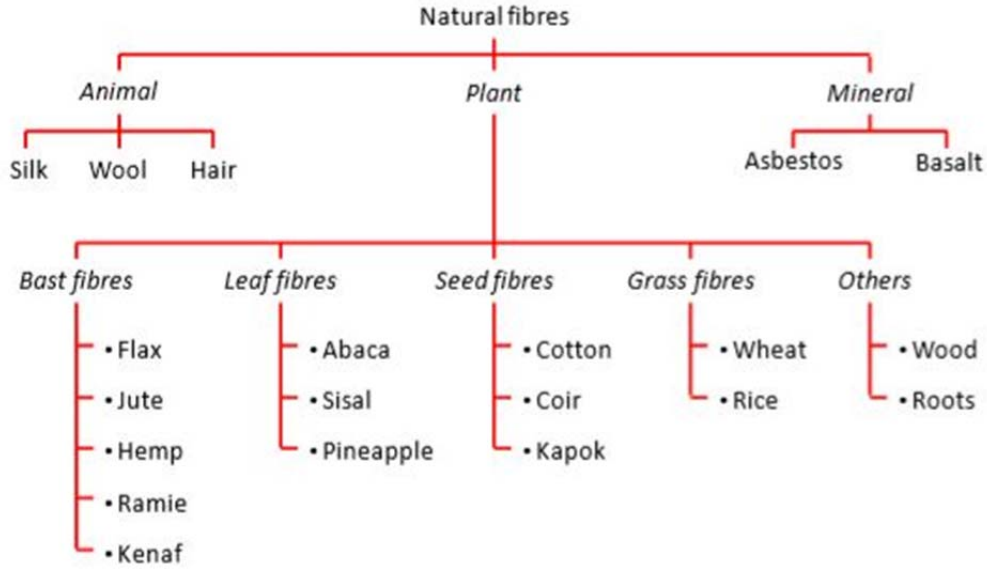


Figure 3.5. Types of natural fibers classified by source of their origin (Pornwannachai, 2015)

The physical and mechanical properties of these fibers reported in the literature are given in Table 3.3.

Table 3.3. Properties of several natural fibers and E-glass (Koronis et al., 2013)

Fibers	Density (g/cm^3)	Diameter (mm)	Tensile Strength (MPa)	Young Modulus (GPa)	Elongation at brake (%)	Price ($/kg)
Flax	1,5	40 – 600	345-1500	27 – 39	2,7 – 3,2	3,11
Hemp	1,47	25 – 250	550-900	38 – 70	1,6 – 4	1,55
Jute	1,3-1,49	25 – 250	393-800	13 – 26,5	1,16 – 1,5	0,925
Kenaf	1,5-1,6	2,6 – 4	350-930	40 – 53	1,6	0,378
Ramie	1,5-1,6	0,049	400-938	61,4 – 128	1,2 – 3,8	2
Sisal	1,45	50 – 200	468-700	9,4 – 22	3 – 7	0,65
Curaua	1,4	7 – 10	500-1100	11,8 – 30	3,7 – 4,3	0,45
Abaca	1,5	10 – 30	430-813	31,1-33,6	2,9	0,345
E-Glass	2,55	15 – 25	2000-3500	70 – 73	2,5 – 3,7	2

Jute: The most commonly used natural fiber as a reinforcing element in green composites is jute, a kind of bast fiber. In addition to being one of the low-cost natural fibers, it is the bast fiber which is stated to have maximum production volume at present. Although jute fibers are less resistant to moisture, acid and UV light, their thin structures, heat and fire resistances have found wide applications in industries such as textiles, construction and automotive. As a single or hybrid fiber, jute is a lightweight and eco- friendly natural fiber and rewarding as a reinforcing material for sustained and environmentally friendly applications (Singh et al., 2018).

Ramie: Ramie fiber is a typical type of natural fiber, tensile strength is lower than that of glass fiber, however, the ramie fiber shows the value that is

comparable or better than the glass fiber, especially considering the particular module. Moreover, China is the largest ramie fiber manufacturer in the world. Therefore, the ramie fiber composite is not only low cost, low density, renewable, natural and less abrasive during the process, but is also easy to obtain. It is a potential green material to be used in many fields such as automotive, packaging and construction industry (Leı et al., 2006)

Besides as a reinforcing material in the polymer composite for bulletproof panels or impact resistant and safer structures, ramie has on average higher mechanical properties than others. The abundance of natural resources makes the length of the ramie constantly available and this physical property can be used for reinforcing fiber polymer composite in continuous form for the panel (Marsyahyo et al., 2009).

Hemp: Industrial hemp fiber can be grown for kernel or as a dual purpose product. This fiber is flax, kenaf and a jute-like bast or long-fiber plant. Industrial hemp is accord to the temperate region and could grow up in a wide variety of environmental circumstances. The potential industry for hemp fiber involves molded car parts, glass fiber substitutes and composites. Even some automobile companies have researched the use of non-wood fibers such as hemp and cannabis in the manufacture of molded auto parts because they are lighter and easier to recycle than existing raw materials. Some BMW models include body linings and die-cast airbag components using hemp fibers. However, to gain in these markets, hemp will have to compete with other non-wood fiber sources and will need to be supplied in sufficient quantities throughout the year. Hemp fiber is desirable in this market due to its length and durability. Some companies produce non-structural chipboard and wicker boards, and hemp can be a potential raw material with a sufficiently low price in the production process (Fortenbery and Bennett, 2001).

Kenaf: Kenaf fiber (KF) from Hibiscus cannabinus is remarkable by combining its fibers with thermoplastics as a method for developing new composite species. In addition to its low cost, KF is also low density, non-abrasive

and biodegradable and has very good mechanical properties. KF from renewable sources is suitable for use in automotive applications, buildings, devices, etc. However, the development of these applications is limited to some important disadvantages that need to be considered during blending, including lower process temperature, high moisture uptake, and mismatch between hydrophilic fibers and hydrophobic thermoplastic matrices (Anuar et al., 2008).

Among the lignocellulosic fibers, the most efficient lignocellulosic additives are long natural fibers such as kenaf. The ratio of specific Young modulus and specific bending modulus, composite modulus to composite specific gravity of composites, with natural fibers such as kenaf is significantly higher than that possible with wood fibers. It is noted that kenaf fibers are a viable alternative to inorganic / mineral based reinforcing fibers as long as the correct processing conditions and auxiliaries are used and lignocellulosic based fiber composite is not critical for higher water absorption (Rowell et al., 1999).

Sisal: Among the several natural fiber types, sisal is one of the attracted plants grown in Thailand for local use for a long time. The fiber obtained from sisal leaves is also used because of its good strength, durability and flexibility in various applications such as rope, twine, carpet and handicraft; and affinity for certain dyestuffs (Suppakarn and Jarukumjorn, 2009).

One of the most widely used natural fibers is sisal fiber and can be easily cultivated. It has short renewal times and grows wild on field fences and railroad tracks. Using sisal fiber as reinforcement in composites attracted great interest among material scientists and engineers and increased expectations. Especially recently, the properties investigated verbosely of sisal fiber are dielectric, thermal and mechanical. The effects of processing methods, fiber length, fiber direction, fiber volume and fiber surface treatment on the mechanical and physical properties of sisal fiber reinforced composites were examined.

Compared to synthetic fibers, the price of sisal fibers is very low. This is about one-fourth of glass fiber and one-fifth of carbon fiber. The tensile properties

of the sisal fiber are not the same throughout their length. The stem or bottom has low tensile strength and modulus, but has high fracture strain. Although sisal fiber is one of the most used natural fibers, most of this economic and renewable resource is still under-utilized. At present, sisal fibers are mainly used as ropes for the marine and agricultural industries, but work is continuing for other areas (Li et al., 2000).

Flax: Flax is one of the fibers with potentially best mechanical properties. Flax can be grown in temperate climatic regions of Europe and the USA, for example. Unlike man-made fibers, flax fiber is not a continuous fiber, but is actually a compound in itself (Bos et al., 2002).

Flax fibers originating from renewable sources are an interesting alternative to mineral fibers. Low densities, high specific stiffness and low cost together with recycling are the main incentives for their use in composites. However, to optimize their performance, physicochemical properties and mechanical behavior must be known (Baley, 2002).

Flax is an annual product where fibers have been used to make linen fabrics since ancient times. However, since linen fiber is a relatively strong, stiff and lightweight fiber, its recent use as a reinforcing agent in polymeric composites has attracted much attention (Bos and Donald, 1999).

Flax is a product of great antiquity that has been transformed into the finest of yarns for thousands of years and is hard-wearing, absorbent, comfortable-wearing, and obtains a strong and versatile natural fiber that touches the material it works skillfully.

Nowadays linen is predominantly in the fashion market in Western Europe, but while home textiles still matter, the relatively large linen area in Eastern Europe predominantly meets the domestic demand for lower grade short fibers for coarse fabrics, sacking and upholstery production.

Flax fiber is different from many other types of agricultural products, because the yield, quality and value of the main product depends heavily on the

management of the post-harvest product, not pre-harvest. The flax crop yields two main fiber fractions which can be broadly classified as long fibers and short fibers or tows having a value of about half of the long fibers. Flax plants also have a much higher proportion of long fibers which are thinner and therefore suitable for textile uses (Easson and Molloy, 1996).

Flax has been supplying fibers for textiles for thousands of years. New technology and separation techniques in terms of using more homogeneously color, strength, length and fineness to reduce fiber production costs and thus make it more suitable for composites. Environmental legislation in Germany recyclable or biodegradable forced to use parts. At this point since 1995, Daimler-Benz has produced the flax fiber door panels in the Mercedes G class. Automobiles manufactured by BMW, Volkswagen, Rover, Opel and Audi contain composite panels made of flax fiber. These fibers back up to decrease the weight of the vehicle.

According to the researchers, their low weight does not produce low quality mechanical parts, but it absorbs sound well and provides safety features because they do not leave splinters or sharp corners under impact. The low weight and high strength of the flax fibers make them economical substitutes for other composite fibers. Companies such as BASF, Bayer, Krauss-Maffei and Cannon have advanced the technology to produce natural fiber composites for use in the automotive sector (Foulk et.al. , 2000).

3.1.4.2. Synthetic Reinforcements

Carbon fibers: Carbon fibers are a new type of high strength materials made from graphitic and non-crystalline regions. Among of all reinforcing fibers, carbon fibers are the ones that offer the highest specific modulus and strength. Carbon fibers also offer high electrical and thermal conductivities with a relatively low coefficient of thermal expansion (Prashanth et al., 2017).

Carbon fibers are resistant to many chemical solutions that do not absorb water. They are perfectly resistant to fatigue, do not cause corrosion, do not show any relaxation. They show less relaxation than low slackening high tension prestressed steel strips. Carbon fiber is electrically conductive and can therefore cause galvanic corrosion in direct contact with steel (Carolin, 2003).

The two main sectors of carbon fiber applications are high-tech sectors including aviation, nuclear engineering; and general engineering and transport, including automobile bodies, engineering components. However, the requirements of the two sectors are fundamentally different. Large scale use of carbon fiber airplanes and aviation in terms of maximum performance and fuel efficiency are crucial, while the cost factor and production requirements are not critical. The use of carbon fibers in general engineering and transportation is dominated by cost constraints, high throughput requirements and generally less critical performance requirements (Chand, 2000).

Kevlar Fibers: Kevlar fibers poly (p-phenylene terephthalamide) (PPTA), 31 is the simplest form of AABB (The polymers formed by the condensation of diacids and diamines) para-oriented polyamide. The properties of aramid fibers depend on specific spinning and finishing conditions. Aramid fibers have unique properties that distinguish them from other fibers. The tensile strength and modulus of the aramid fiber is significantly higher and the fiber elongation is lower than the previous organic fibers. Aramid fibers can be woven on fabric looms more easily than brittle fibers such as glass, carbon or ceramic.

The mechanical properties of aramid materials form the basis of important commercial uses in many areas. For example, the as-twisted Kevlar aramid fibre shows over twice the tensile strength and nine times the modulus of high strength nylon. It is stronger than steel wire on weight basis and harder than glass. Both coefficients of creep and linear thermal expansion are low and thermal stability is high. The favorable strength / weight ratio for Kevlar and its composites

has enabled them to be used in flooring, spaceships and radomes for airplanes (Hearle, 2001).

Glass Fiber: Glass fibers are known as the world's major considerable sustained inorganic composite reinforcing fiber. These fibers are sold more than continuous ceramic fibers, boron fibers and carbon fibers. The characteristic overall and private purpose fiber components involve more than 50% silica. General or commercial purpose E-glass fibers are reinforcing fibers covering the majority of today's market. Figure 3.6 shows several general commercial applications of fiberglass reinforced composites (Wallenberger, 1999).

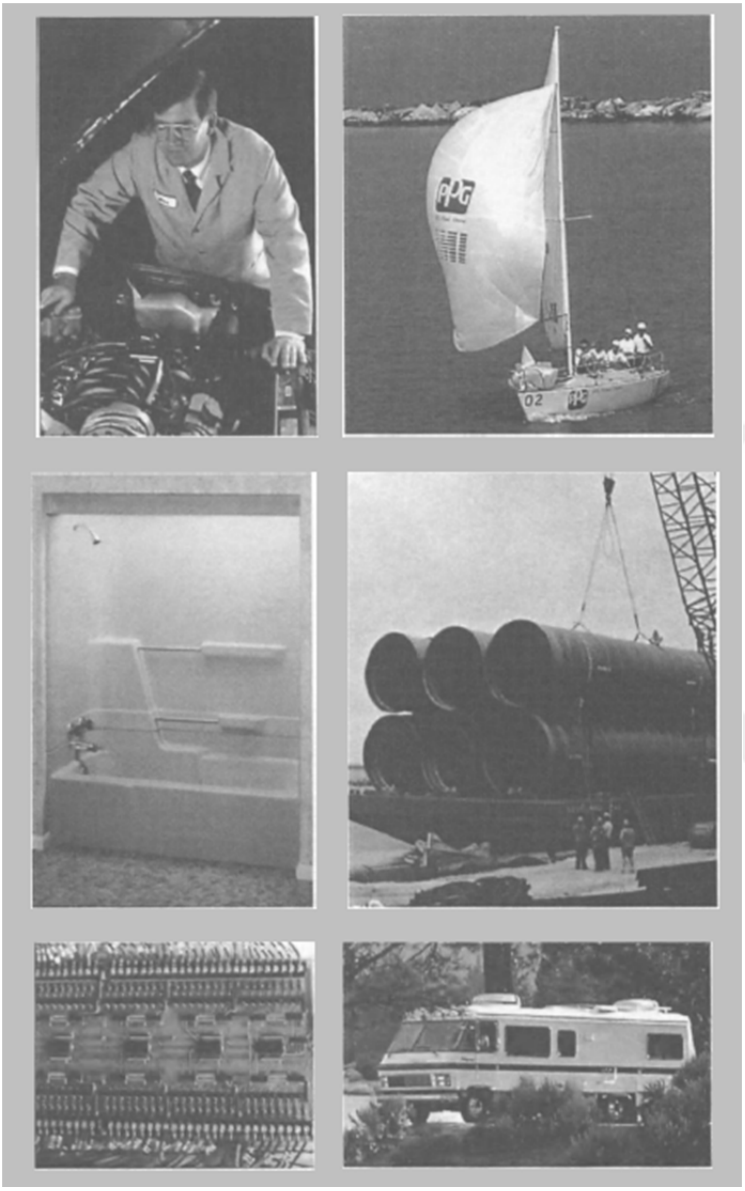


Figure 3.6. Commercial applications of fiberglass reinforced polymer matrix composite structures. Manifold intake (top, left): shower and tub unit (center, left); printed wiring board (bottom, left); boat hull (top, right): pipes (center, right); recreation vehicle body (bottom, right) (Wallenberger, 1999)

In old industrial plants, there are not many glass fibers produced straight from freshly melted glass. In place of, the molten glass is at first converted into marble, which, after examination, is melted in the bushes. In new plants, glass fiber can be produced directly by drawing. Some forms of glass fiber that are commercially available are shown in Figure 3.7.

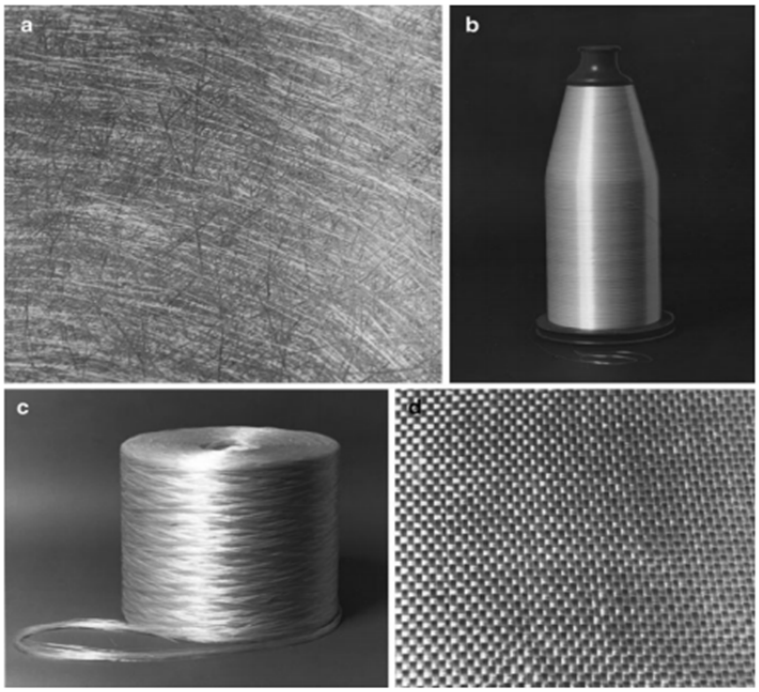


Figure 3.7. Glass fiber is available in a variety of forms: (a) chopped strand, (b) continuous yarn, (c) roving, (d) fabric (Chawla, 2012)

A range of alumina and silica-alumina fibers from metal alkoxide solutions called Nextel fiber is produced by a company. Figure 3.8 shows an example (cut from a continuous fiber reel) of drawn silica fibers procured by way of the sol-gel technique.

Figure 3.8. Continuous glass fibers (cut from a spool) obtained by the sol–gel technique (Chawla, 2012)

While the density of the e-glass is very low, its strength is rather high; nevertheless, Young's module is not very high. Therefore, although the strength-weight rate of glass fibers is fairly high, the module-weight rate is just moderate. Since the modulus-to-weight rate is merely moderate, the aviation industry is directed towards other advanced fibers (boron, carbon etc.). The use of glass fibers continues to strengthen epoxy, phenolic and polyester resins. It is fairly inexpensive and present in various forms. Glass fiber reinforced resins have found widespread use in the construction and building industries. In these sectors, it is generally referred to as glass-reinforced plastic or GRP. Other important users of GRP include the road and rail transport industry and the aviation industry (Chawla, 2012).

3.1.5. Some Manufacturing Methods of Composites

The chemical and physical nature of the matrix (i.e. thermoset or thermoplastic, metal, ceramic) significantly determines the selection of a composite production process. The temperature required to form, melt or harden the matrix is

also important. However, the process chosen for an industrial application should allow the user to take full advantage of the unique features or capabilities that the user has. If these opportunities are not provided, the alternative technologies can offer a more cost-effective production process (Lee and Suh, 2006). Figure 3.9 presents composite processing techniques in accordance with reinforcement and matrix materials.

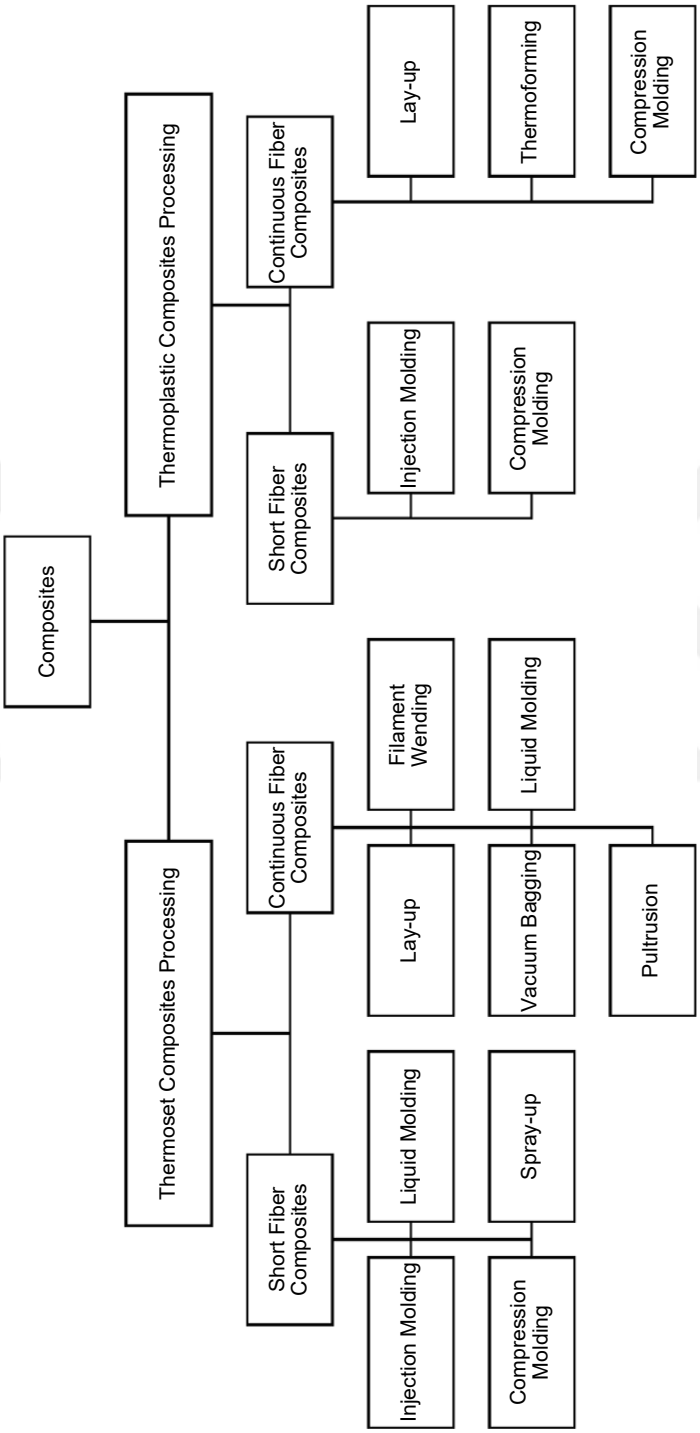


Figure 3.9. Composite Processing techniques (Campbell, 2010)

The composite manufacturing industry confirms that the importance of initial material forms and the processing of them is always important for part performance. Advances in material chemistry, the introduction of compatible fabrics into the industry, and more scientific-based processing from the trial production approach to reduce production cost improved the composite production processes (Advani and Hsiao, 2012).

There are many composite production methods, such as resin transfer molding, autoclave vacuum bag degassing, vacuum assisted resin transfer molding, pultrusion, filament winding, compression molding etc.

3.1.6. Manufacturing Techniques of Composites

3.1.6.1. Lay-up Process

Lay-up processes are ideal for low volume, medium size manufacturing big pieces. However, there is an intense effort in manual lay-up operations and part quality largely based on worker skill. Three lay-up operations are mentioned: prepreg lay-up, wet lay-up and vacuum bag prepreg / low temperature curing layup.

Prepreg lay-up and autoclave curing is the dominant manufacturing method used to make carbon / epoxy parts in the aerospace industry. Wet lay-up is widely used in commercial industries for the production of polyester / fiberglass parts. The third lay-up process, vacuum bag curing / low temperature prepreg, was first improved to make carbon / epoxy tools. Nevertheless, owing to material and process improvements, it is considered an alternative to autoclave curing when the expense of autoclavable tools is very high and the number of parts is low. Figure 3.10 depicts the basics of the wet lay-up process schematically (Campbell, 2010).

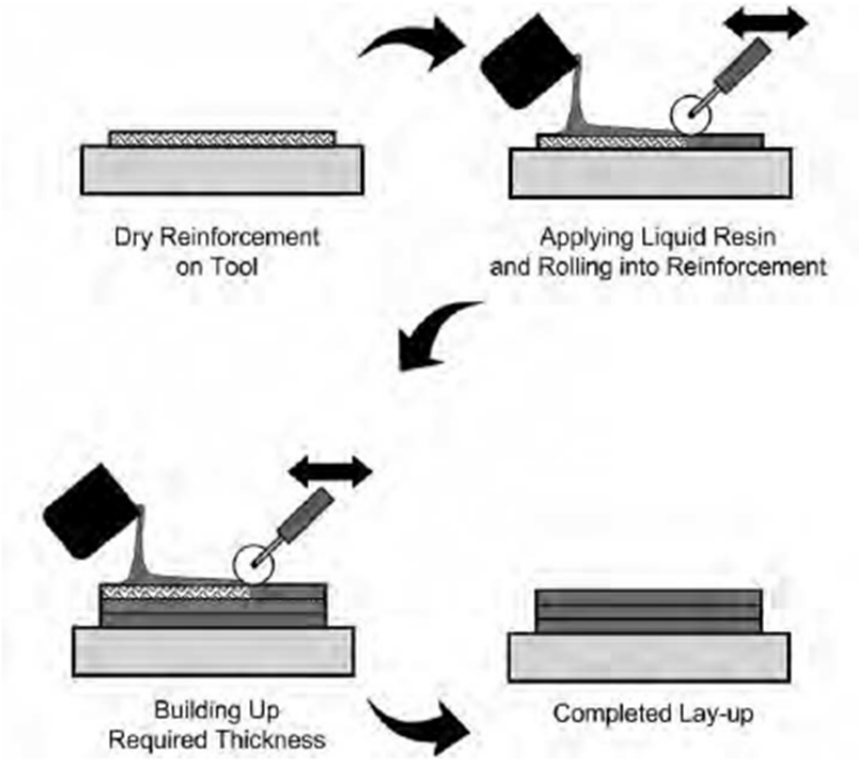


Figure 3.10. Typical wet lay-up operation (Campbell, 2010)

3.1.6.2. Filament Winding

A schematic drawing of a filament winding process is shown in Figure 3.11. One of the techniques used in the production of revolution surfaces such as pipes, tubes, cylinders and spheres is the filament winding (Lee and Suh, 2006).

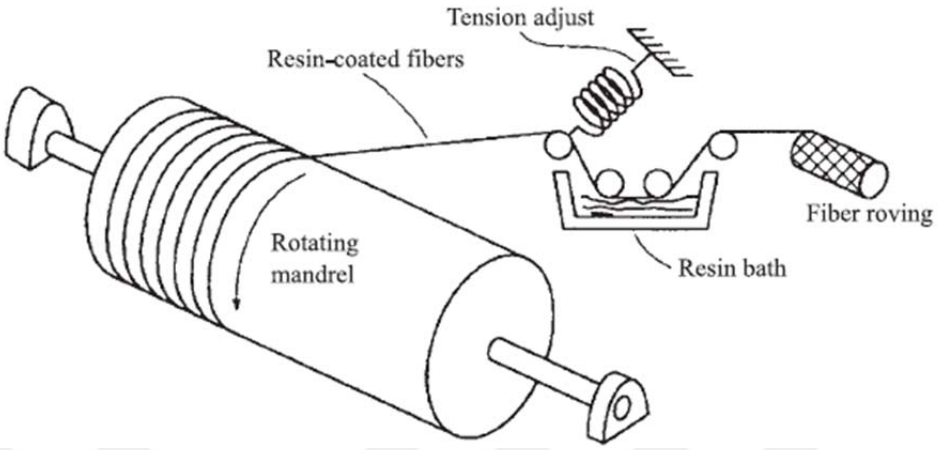


Figure 3.11. Schematic drawing of filament winding operation (Lee and Suh, 2006)

There are several winding methods, such as wet winding, prepreg winding and post-impregnation, where the fibers can be impregnated with resin. In the filament winding, two basic winding types are used in the winding pattern: helical and polar (Figure 3.12) (Groover, 2010).

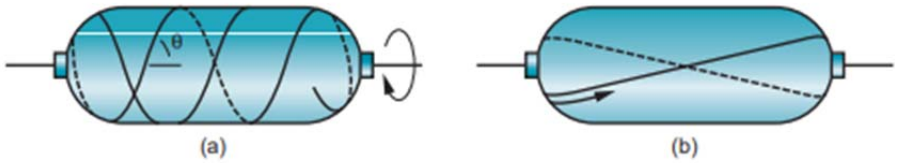


Figure 3.12. Two basic winding patterns in filament winding:(a) helical and (b) polar (Groover, 2010)

3.1.6.3. Vacuum Bagging

It is stated that the vacuum bagging process is mainly used in the aviation and space industry, where composite part performance is important, not high production speed.

A typical bagging scheme is shown in Figure 3.13. Initially the material is normally a prepreg, but wet placement laminates can also be molded with a vacuum bag (Lee and Suh, 2006).

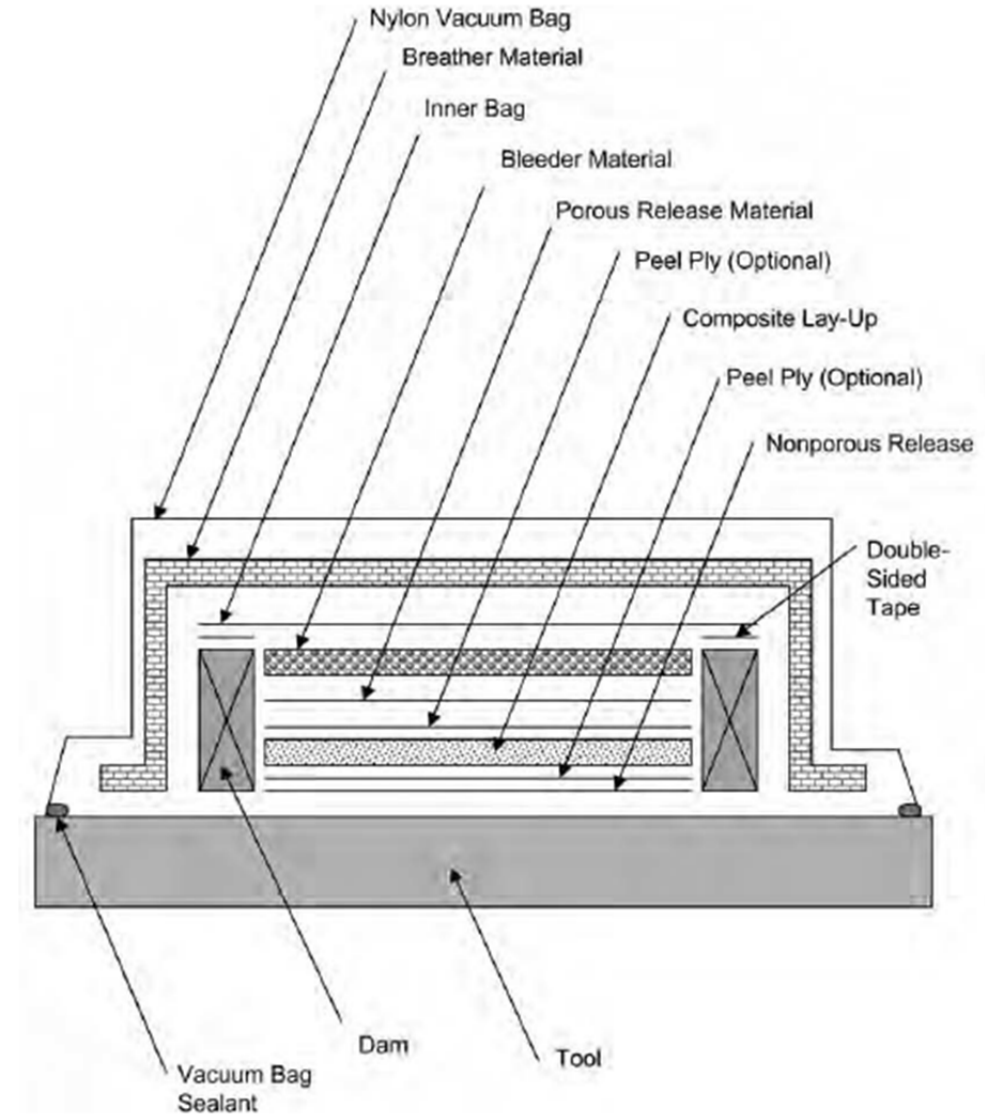


Figure 3.13. Typical Vacuum Bagging Schematic (Campbell, 2010)

3.1.6.4. Pultrusion

The pultrusion method is a process similar to extrusion by immersing continuous fiber wicks in a resin bath and pulling from a forming die where the impregnated resin hardens. Resins commonly used in pultrusion are unsaturated

polyesters, epoxies and silicones and all thermosetting polymers. Figure 3.14 illustrates the section of the method showing that the cured product is cut into long, flat sections (Groover, 2010).

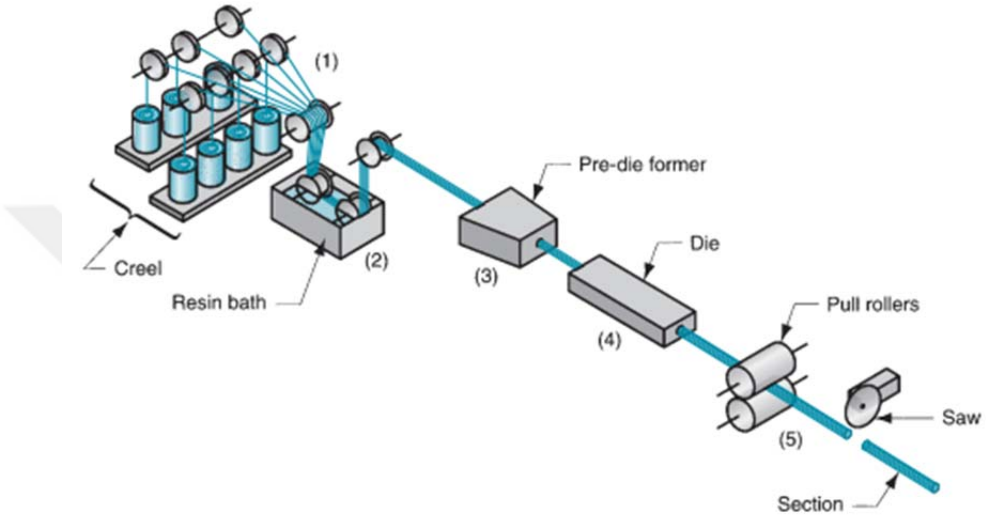


Figure 3.14. Pultrusion process (Groover, 2010)

In the pultrusion process, there are several variables and processing parameters that can affect the quality of a pultruded product. These process control parameters are: pull speed, fiber volume fraction, viscosity, preform plate size, mold taper geometry, and fiber diameter (Raper et al., 1999).

3.1.6.5. Thermoforming

Thermoforming is a process that has been used in the manufacture of thin-walled plastic containers for a long time and enables the manufacture of commercial products such as yoghurt containers and blister packaging. This method allows the rapid conversion of semi-finished raw materials to the desired design form with the combined effect of heat and pressure. The process can be

described in terms of physical deformation and thermal history of the cavity during the entire process shown in Figure 3.15 (McCool et al., 2012).

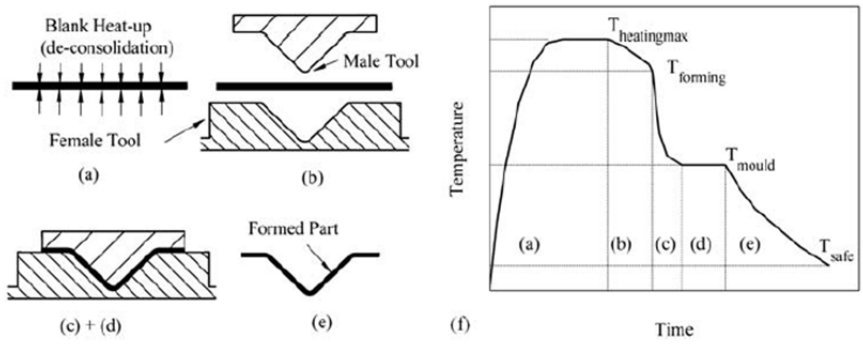


Figure 3.15. Key stages in the thermoforming process for reinforced thermoplastic composites, including thermal history (McCool et al., 2012)

The most commonly used reinforcement fabrics in this method are woven carbon or glass fibers. The matrix resin is usually chosen taking into account the mechanical requirements in the final stage and is often replaced with additives to increase usability in a production process. Polypropylene (PP), polyamide (PA), Polyphenylene-sulfite (PPS) or Polyetheretherketone (PEEK) are some examples widely used in the automotive and aerospace industry due to their high thermal performance (Fleischer et al., 2018).

3.1.6.6. Resin Transfer Molding

The resin transfer molding (RTM) process has been admitted as a composite production method in the high-volume production of net shaped structural parts using low viscosity thermoset resins and continuous fibers. Injection and compression molding of discontinuous fibers can manufacture clear shape structures in high volumes, but structural performance cannot be achieved with short fibers. In the mid-1980s, resin transfer molding (RTM) was adopted for composite production. The reason for its emergence was the automotive industries

that wanted the production of high-volume net-shaped structural parts. Figure 3.16 shows a diagram of the various stages of the RTM process (Advani and Hsiao, 2012).

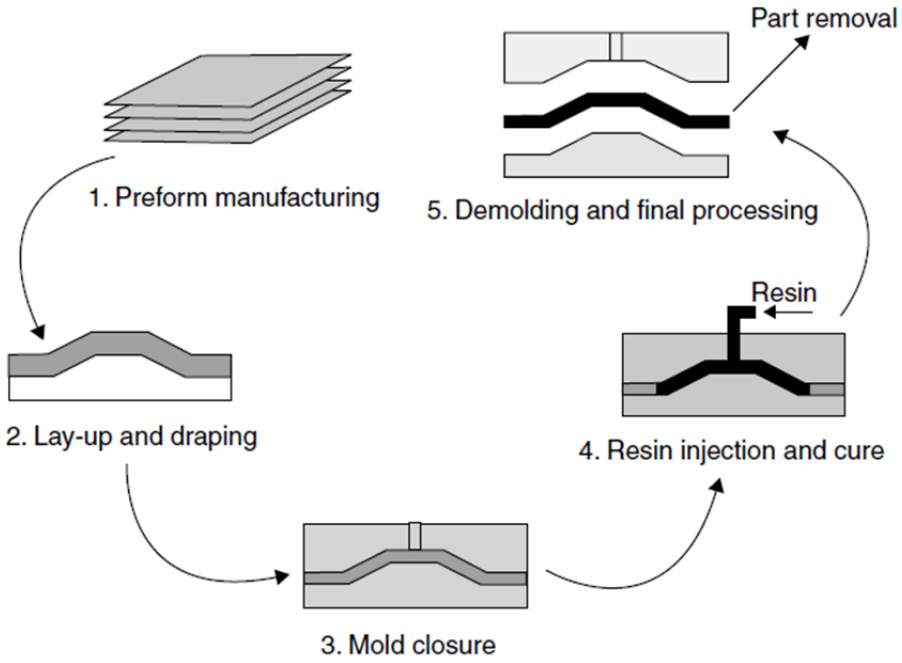


Figure 3.16. RTM process (Advani and Hsiao, 2012)

Resin transfer molding is a reactive polymer processing method in which liquid reactants harden into a mold containing fiber reinforcements to produce a composite part. In RTM, the resins were mixed with a static mixer at low pressure and pumped into the mold. Mold filling pressure is generally less than 0.7 MPa for RTM and the force required to compress the mold is also low (Lee and Suh, 2006).

3.1.6.7. Vacuum Assisted Resin Transfer Molding

Vacuum-assisted resin transfer molding (VARTM) process is called a closed mold process that can produce high performance and large-scale parts with low tool cost. It is stated that the VARTM process plays an important role in improving the quality, cost and part complexity of large closed mold FRP

composite structures (Advani and Hsiao, 2012). VARTM uses only vacuum pressure for injection and curing, one of the great advantages of VARTM is that its design is much simpler and less expensive than traditional RTM processes. Although VARTM-type processes have been used for many years to build fiberglass hulls, they have recently attracted the aviation industry's attention (Campbell, 2010).

In general, the VARTM process consists of five stages: pattern preparation and fabric placement; sealing forming the mold and a vacuum; resin preparation and getter; resin impregnation and fabricated curing panels (A. Subagia et al., 2014). A typical VARTM process is shown in Figure 3. 17.

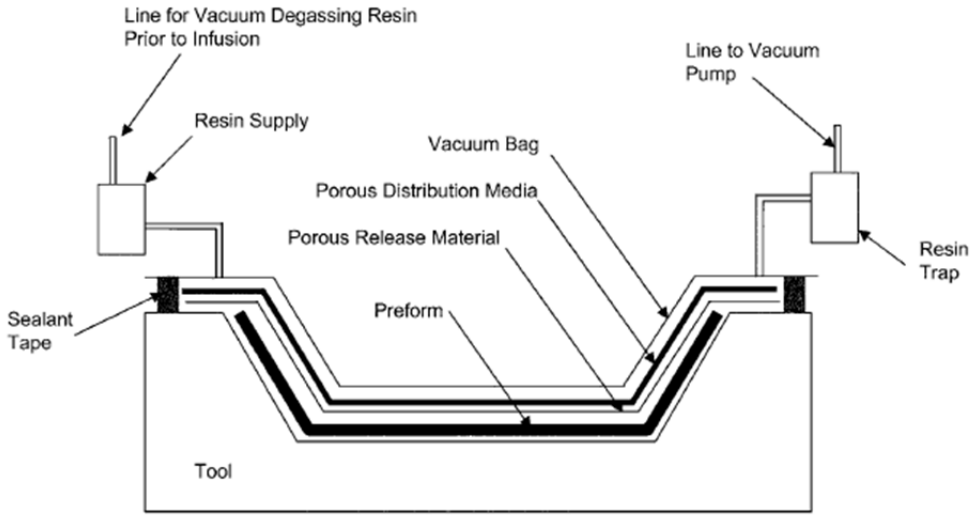


Figure 3.17. Typical Vacuum Assisted resin transfer molding (VARTM) process (Campbell, 2010)

In the VARTM process, the resin is injected into the mold with vacuum pressure. It should be noted that the resin passes quickly through the flow distribution medium layer and is gradually infused into the preform in the direction of the thickness. When the resin reaches ventilation, mix a few extra resins for a few more minutes to remove small air bubbles from the resin flow front. After the

resin is completely dry on the solid phase, the vacuum can be closed and the composite piece can be removed from the mold (Advani and Hsiao, 2012).

The VARTM method has many advantages. Some of those;

- Flexibility in mold tool design and choice of mold materials
- To be able to produce high quality and complex composite parts
- It can be easily changed for the production of different part geometries, having a mold similar to the open mold of a hand placement process
- Possibility of storing the resin and catalyst separately and mixing them right before the infusion of the resin.
- With a transparent plastic vacuum bag, the possibility of removing air by pulling out the air with the help of a vacuum needle in a visible dry spot that occurs during the resin infusion process (Advani and Hsiao, 2012).

The VARTM process also has some disadvantages;

- Vacuum pressure is much less compared to the pressure applied during a typical RTM process or an autoclave / vacuum bagging process and is limited by air gap compressibility.
- There is a high probability of air leakage and greatly affects the quality of the process. A leak can be initiated at any time if a careful and frequent inspection for air leakage is not performed before the resin infusion, during the infusion resin, and during the curing cycle. All three processing steps disrupt composite part production.
- Vacuum equipment (peeling, vacuum bag, tubes etc.) cannot be reused. It is necessary to re-prepare these materials whenever a VARTM operation is to be performed (Advani and Hsiao, 2012; Hande SEZGİN, 2018).

3.2. Material

3.2.1. Reinforcement Materials

In this study, flax (country of origin: Istanbul, Turkey) and three different types of weight glass fibers (country of origin: Istanbul, Turkey) were used as a reinforcement material. Reinforcement properties were shown in Table 3.4 (Kompozitshop, n.d.; Kumascı.com, n.d.).

Table 3.4. Fabric Properties

Fabric	Weave	Weight(gr/m²)	Thickness of Fabric(mm)	Warp	Weft
Flax	Plain	280	0,5	–	–
Glass Fiber	Plain	49	0,02	11x1	24x19
Glass Fiber	Plain	86	0,06	34x1	12x12,5
Glass Fiber	Plain	100	0,08	22x1	24x22,8

Fabric samples used in the study can be seen in Figure 3.18.

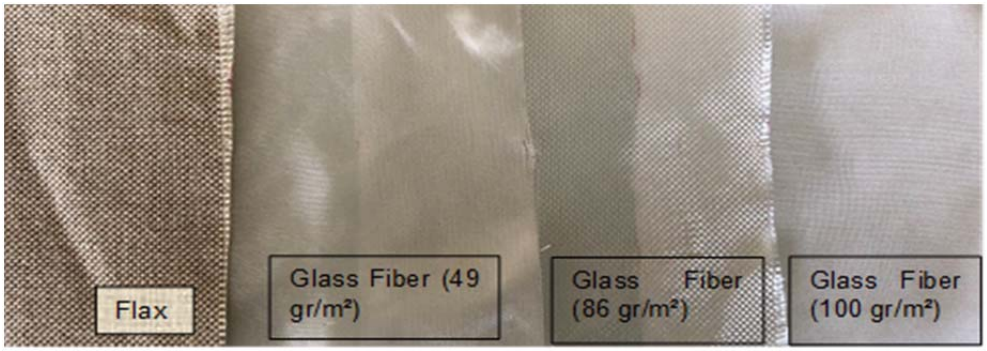


Figure 3.18. Fabric samples respectively; Flax, Glass fiber (49 gr/m²), Glass fiber (86 gr/m²), Glass fiber (100 gr/m²)

3.2.2.Matrix Materials

Matrix materials are in liquid form and can be cured at room temperature. In accelerator L160 (country of origin: Istanbul, Turkey) and as a hardener in LH260S (country of origin: Istanbul, TURKEY) created the epoxy resin mixture for the matrix material system.

L160 Infusion epoxy resin systems are the products used in aviation, automotive, marine, aerospace, wind propellers and defense industries, which are widely used in advanced composite parts manufacturing in the world. The L160 system, which has aviation certificate, can be easily used in infusion applications that are not very large. It cures at room temperature and parts that meet civil aviation standards can be obtained by post curing. Properties of epoxy and hardener were given in Table 3.5 (Kompozitshop, n.d.).

Table 3.5. Epoxy and Hardener Properties

	L160 Infusion Epoxy	H260S Hardener
Operating temperature (° C)	-60 / +50 without heat treatment -60 / +80 by applying heat treatment	-
Process temperature (° C)	+10 / +50	-
Density (g / cm³)	1,13-1,17	0,93-0,97
Viscosity (mPas)	700-900	80-100
Refractor index	1,5480-1,5530	1,4980-1,4985
Amine value (mgr KOH / gr)	-	450-500
Measurement Conditions	25°C	25°C

3.3. Method

3.3.1. Preparation Process of Matrix Materials

One of the most important points to be considered in the manufacture of composites is to determine the mixing ratios of matrix materials. These rates were prepared as 100: 36 ±2 by weight according to the manufacturer's specifications. If these chemicals are less necessary, they will defect the manufactured product, which will prevent the adherence of the fabric and resin and harden the sample. In other cases, using it more than necessary may cause the resin to solidify.

3.3.2. Manufacturing of Composite Materials

Four different types of composites were produced for this research. A quarter of the produced parts were made of 100% flax fabric and the rest as glass and flax hybrid composite. Glass fibers were classified according to their weight and the sample codes produced were determined as in Table 3.6.

Table 3.6. Specimen Codes

Composite Codes	Fabric types
FL	Flax
G49	Glass Fiber (49 gr/m²)
G86	Glass Fiber (86 gr/m²)
G100	Glass Fiber (100 gr/m²)
FLG49	Flax/Glass Fiber (49 gr/m²)
FLG86	Flax/Glass Fiber (86 gr/m²)
FLG100	Flax/Glass Fiber (100 gr/m²)

These parts were produced in Cukurova University Automotive Engineering Laboratories with vacuum supported resin transfer molding technique. Composite fabrication was carried out at room temperature (20 ° C ± 2 ° C). The production steps of this system from Figure 3.19 to 3.26 were shown.

Production stages were as follows:

I. First, the surface was cleaned with substances such as acetone and thinner.

II. A layer of mold separator material was applied to the surface one layer, if necessary, a second layer can be applied after fifteen minutes**.**

III. The fabrics were laid on the surface in the specified order and then peel ply and infusion mesh was placed on the end respectively.

IV. Infusion and vacuum hoses were attached to the infusion mesh with a sealant strip to stabilize the position of the laid fabrics and to ensure a homogeneous resin flow.

V. The frame was determined by vacuum sealing tape. Two hoses were affixed to the frame as input and output.

VI. The vacuum bag was carefully installed around the frame so that there was no air leak.

VII. The vacuum pump was run to test for air leaks.

VIII. Simultaneously, epoxy resin was prepared in the calculated amount and the vacuum machine started.

IX. When the pressure gauge showed -760 mm-Hg, the infusion was continued until the entire surface got wet.

X. The vacuum pump was operated until it absorbed the required amount of resin, the vacuum pump and all holes must be closed when the process was finished.

XI. After waiting 24 hours in this position for the sample to cure, the vacuum bag opened and the infusion mesh, peel layer was separated from composite product. The composite products produced were kept in the oven for 1 hour at 60 ° C. The production stages mentioned were shown below:

Figure 3.19. Mold release wax applied surface

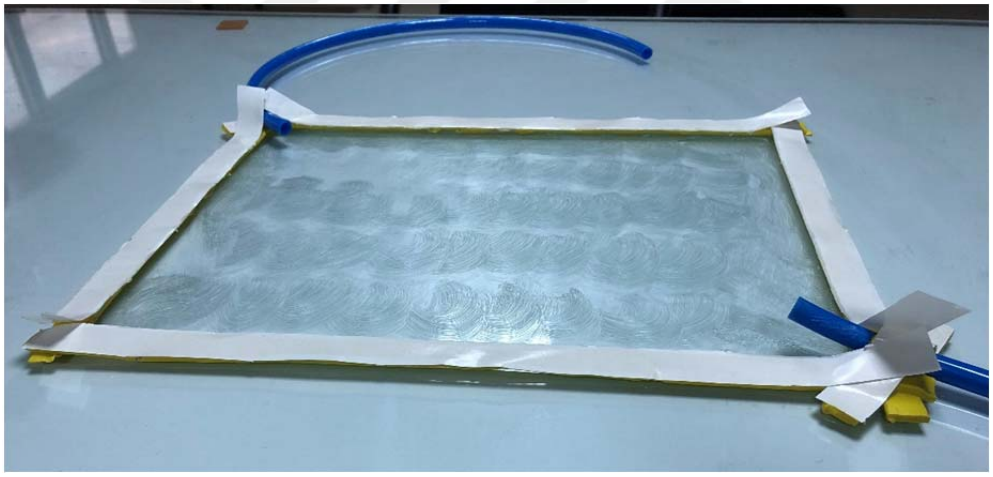


Figure 3.20. Vacuum hoses attached to system

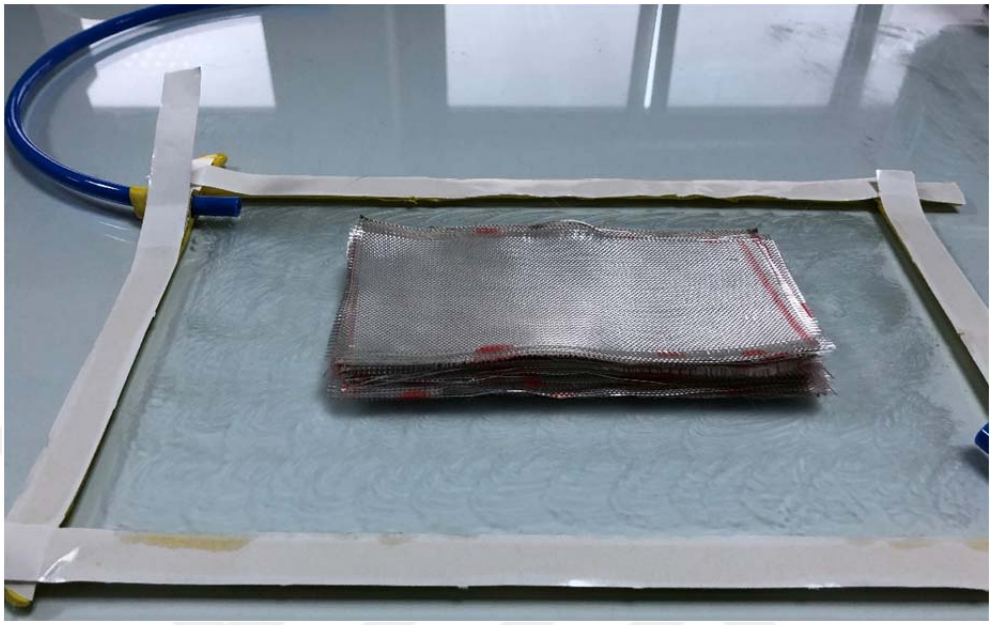


Figure 3.21. Layered fabrics were placed in frame

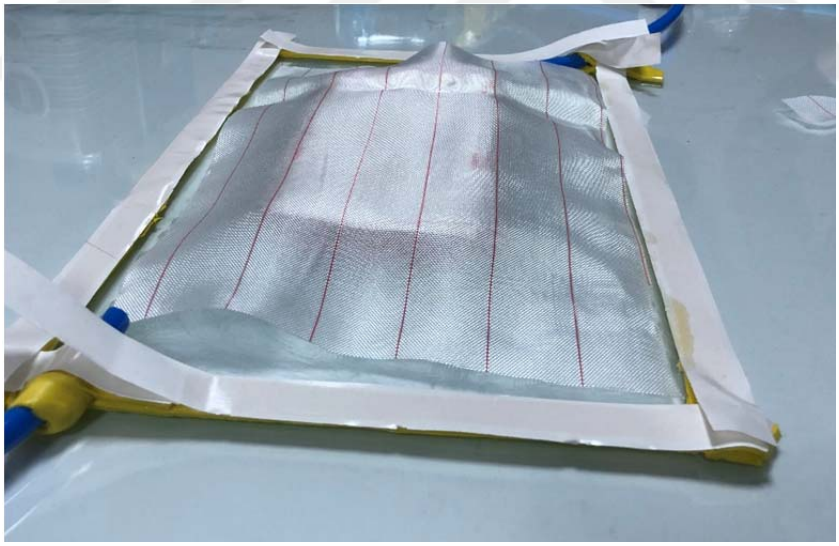


Figure 3.22. Peel ply laid on the sample

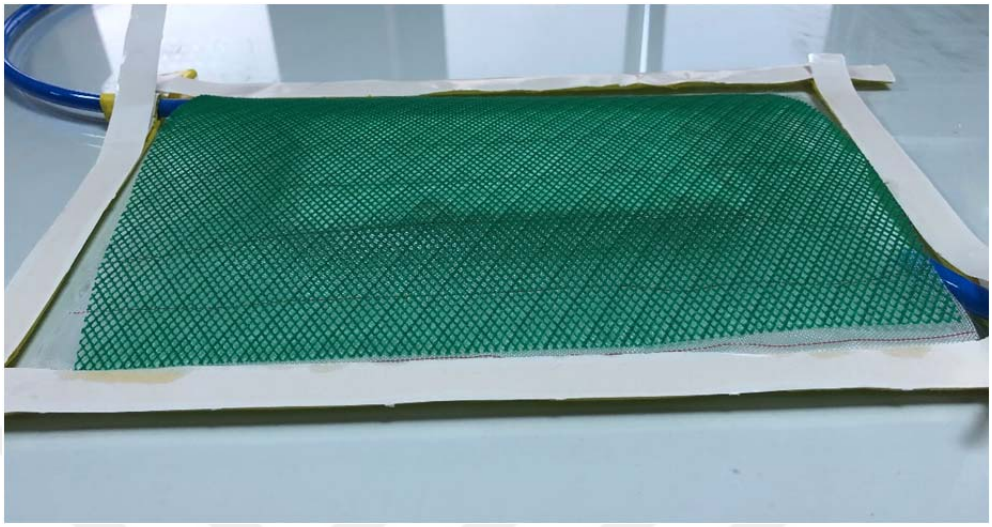


Figure 3.23. Infusion filter laid on the sample

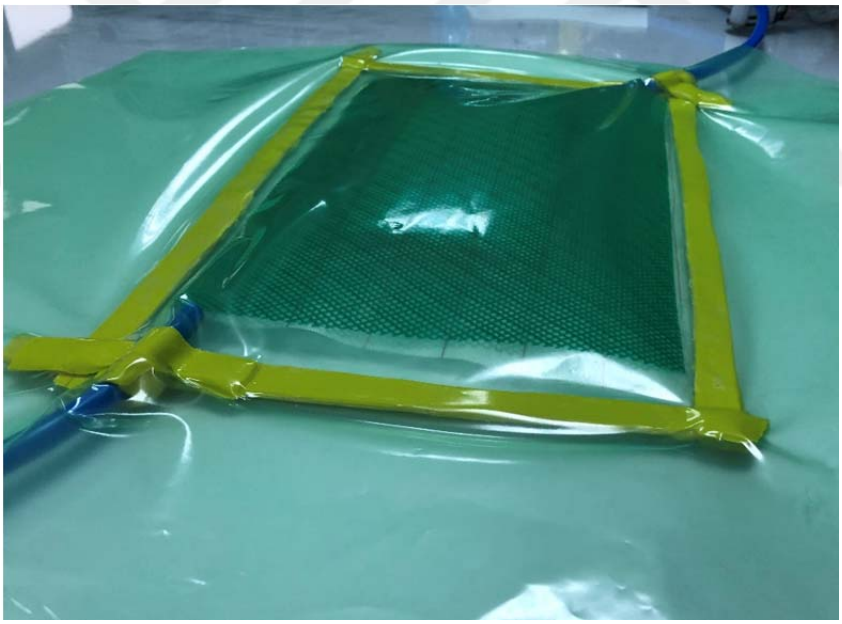


Figure 3.24. Vacuum bag attached to system

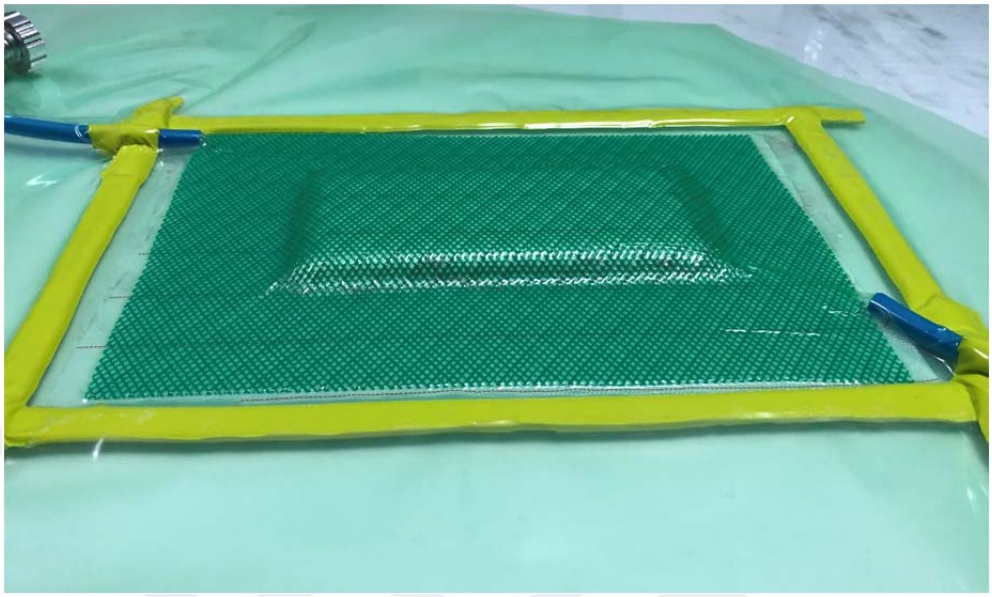


Figure 3.25. Vacuumed material before process begins

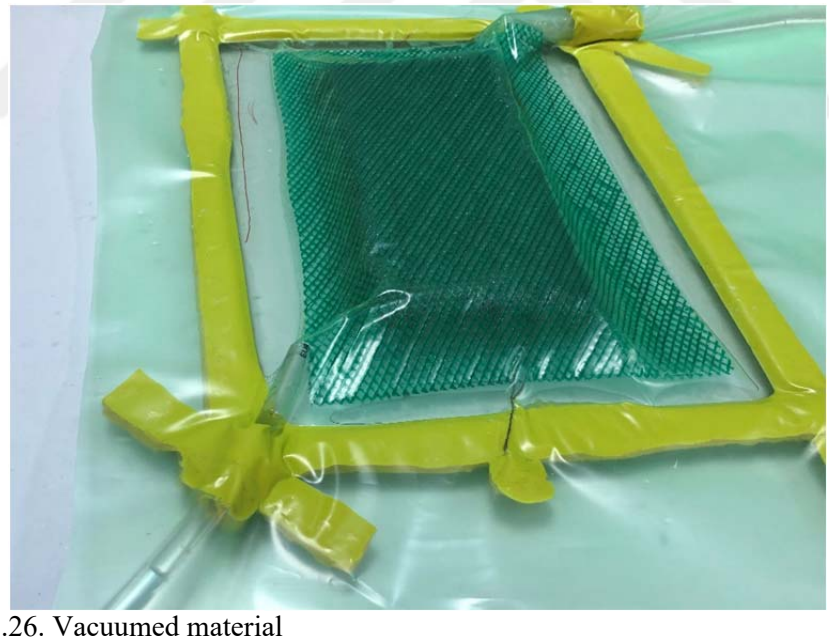


Figure 3.26. Vacuumed material

Twelve different fabric-reinforced composite materials were produced using this method. Three of these were pure flax-reinforced composites, while the other nine were composite hybrid structures of glass fiber and flax.

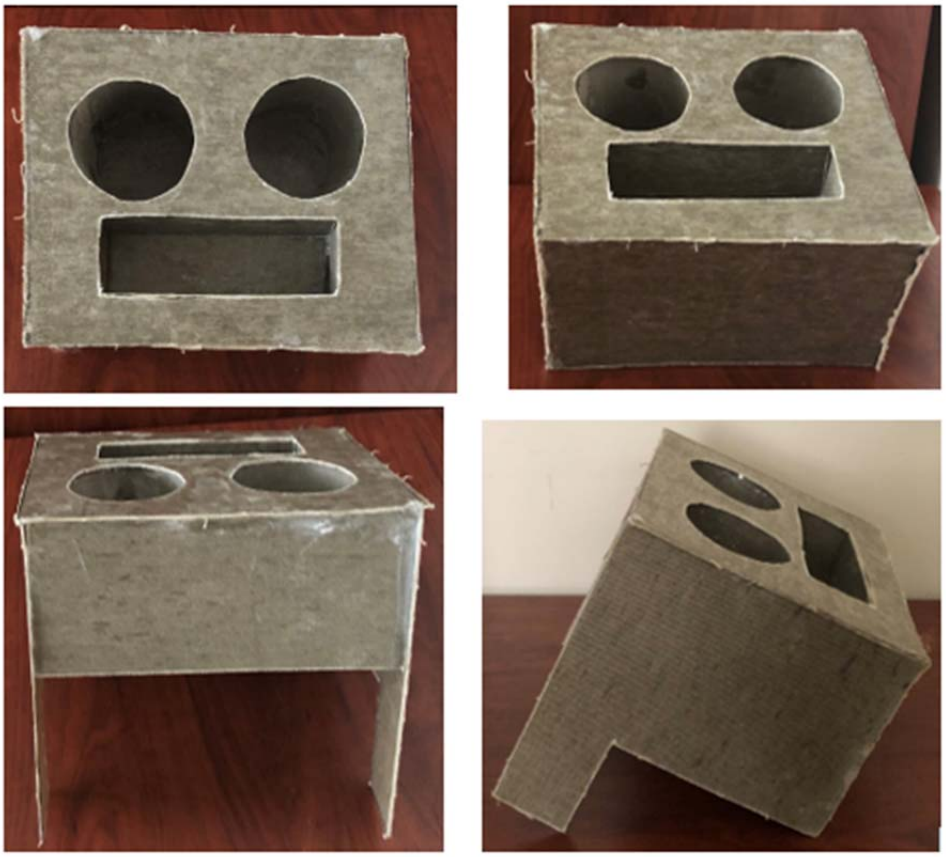


Figure 3.27. Cup holder product

Figure 3.27 indicated the cup holder composite product which was made by fabric reinforced samples. Compliance of the produced part with the standard part dimensions in the automobile interior has been taken into consideration.

3.3.3. Experimental

3.3.3.1. Thermal Analysis

In this study, thermogravimetric analysis and differential scanning calorimetry were used to analyze the thermal properties of fabric reinforcement, epoxy resin matrix and composite structures. Both thermal analysis, Thermogravimetric Analysis (TGA) and Differential scanning calorimetry (DSC) analysis were performed at CUMERLAB (CUKUROVA UNIVERSITY CENTRAL RESEARCH LABORATORY).

3.3.3.1.1. Thermogravimetric Analysis

Thermal analysis, which is an ideal analytical method for the good shifting of industrial production technology of different polymeric materials, especially considering fiber reinforced composites, is a guide in understanding the structure-property relationship and understanding the molecular design. It also provides an important benefit in determining the thermal stability of materials. Thermogravimetry (TG) method is one of the methods used to examine the thermal properties of polymeric materials. Thermogravimetric data include a series of thermal degradation steps in the material, weight loss of the material at each stage, and threshold temperature (Joseph et al., 2003).

Mettler Toledo TGA 3+ analyzer in CUMERLAB was used to perform thermogravimetric analysis (Figure 3.28). While the weight of fabric samples varies between 4-9 mg, the weight of composite samples was prepared as 8-27 mg and was put into the aluminum oxide crucible. Then, closed crucibles were placed in the heating tunnel and the experiment was started. The samples were heated at 25 ° C to 600 ° C with a heating rate of 5 ° C / minute in a nitrogen atmosphere. Thermogravimetric analysis of epoxy and stiffener matrix, fabric and composite samples were made to the same measurement standards.

Figure 3.28. Mettler Toledo TGA 3+ analyzer

3.3.3.1.2. Differential Scanning Calorimetry Analysis

DSC is a thermal analysis technique used to record the temperature required to generate a zero-temperature difference between a substance subjected to the same temperature programs at a controlled temperature or in a cooled environment and a reference material. It provides information about a measure of the amount of energy absorbed or developed in a given physical or chemical conversion, such as recorded heat flow, glass transition, melting or crystallization temperatures (Mei and Chung, 2000). With differential scanning calorimetry

(DSC), the heat flow rate in a thermal event can be measured based on time and temperature, thereby producing numerical data on melting and phase transitions in the composite system (Joseph et al., 2003).

In DSC analysis, the analysis was started by first preparing the aluminum crucibles with lids. After that, the sample pieces weighing between 1-22 mg were cut from fabrics and composite products according to the crucible dimensions to be put into the device. The cut pieces were weighed with precise balance and put on the aluminum pot with tweezers and a lid was put on it. Using the ladle press, the sample pieces were sealed in these small cups. Samples were then placed on the DSC instrument (Figure 3.29).

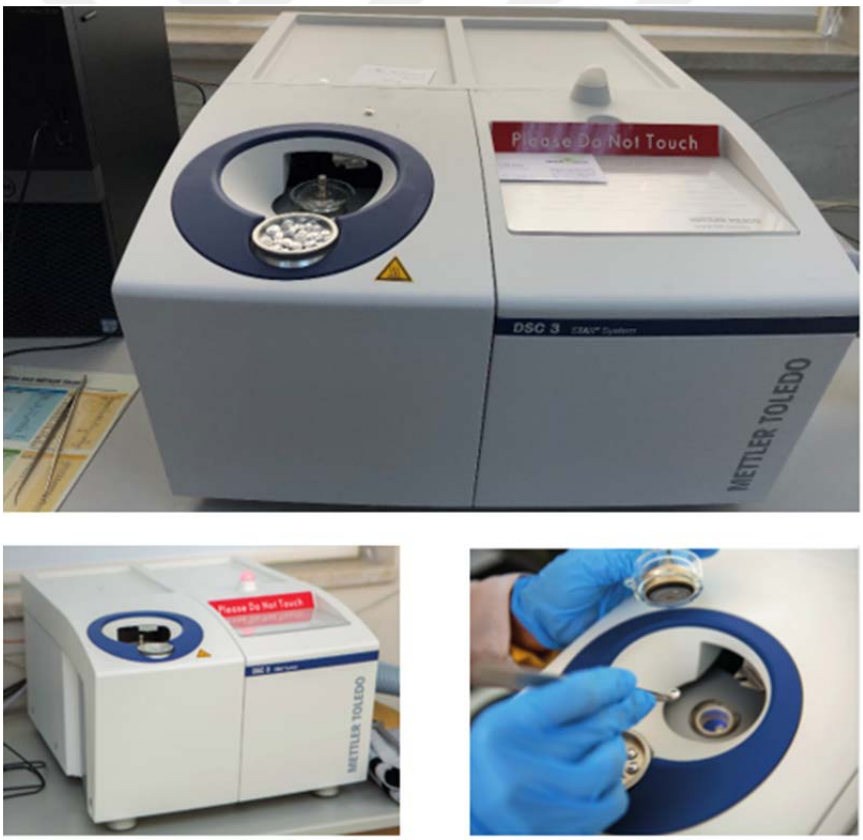


Figure 3.29. Mettler Toledo DSC 3+ analyzer

The Mettler Toledo DSC 3+ device at CUMERLAB was used for analysis, which measures the amount of energy absorbed or released by heating, cooling or keeping the material at a constant isothermal temperature. The analyzes were performed in dynamic state in the following standard procedures:

Raw fabrics in weights of about 1-4 mg, composite products in weights of 14-22 mg, were heated from 20° C to 500 ° C at a heating rate of 10 ° C / minute. The pieces were then cooled to 20 ° C at a rate of 10 ° C / minute.

3.3.3.2. Water Absorption Analysis

The purpose of this analysis is to determine the capacity of manufactured materials to absorb water in normal water by considering ASTM D-5229 standards. Composite samples were saturated with water from the surface during their stay in the container.

Four different flax and glass fiber products, FL, FLG49, FLG86 and FLG100, produced according to ASTM standard were prepared. First, the dry weights of four different products were measured on a digital scale, after which the samples were immersed to water for a certain period of time and the amount of water absorbed by weighing the samples at regular intervals was noted periodically. The test was carried out at room temperature, tap water was used in the containers in which the samples were placed.

The amount of water absorption was calculated by the formula (3.1).

$$M = (W_{\text{i}} - W_d)/(W_d) \times 100 \quad (3.1)$$

W_{i}= Weight Water Absorbed

W_d= Weight Dry material

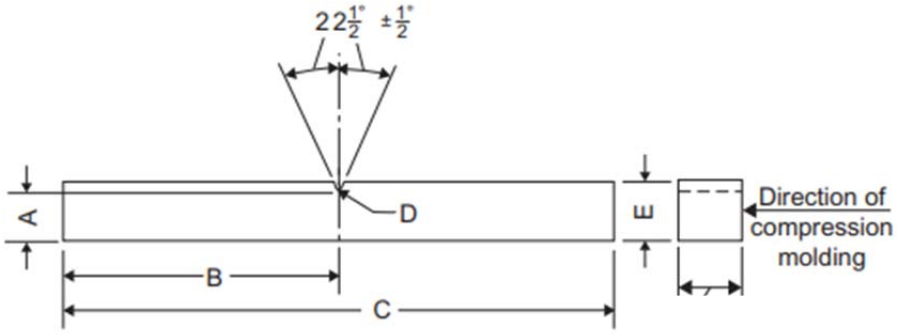
The water absorption test of the materials produced in Figure 3.30 was shown.

Figure 3.30. Water Absorption Test

3.3.3.3. Impact Test Analysis

The Charpy impact test measures the energy absorbed by a standard notched sample as it breaks under an impact load. This absorbed energy shows a measure of the notch toughness of the material being tested and acts as a tool to study the ductile-brittle transition depending on the temperature.

For the Charpy Impact Test, a rectangular sample with a sample size of 125x 12.5x 10 mm was prepared according to the ASTM D 6110 standard, with a 2.0 mm 'V' notch per sample and an angle of 45 ° (Figure 3.31).12 composite samples were taken from the products produced for the analysis of impact resistance. The notches were opened in the middle of each sample with a notch opening device in the Mechanical Engineering Laboratory of Cukurova University (Figure 3.32).



A	10.16 ± 0.05	0.400 ± 0.002
B	63.5 max 61.0 min	2.50 max 2.40 min
C	127.0 max 124.5 min	5.00 min 4.90 min
D	0.25R ± 0.05	0.010R ± 0.002
E	12.70 ± 0.15	0.500 ± 0.006

Figure 3.31. Dimensions of Charpy type test specimen (Ashter, 2014)

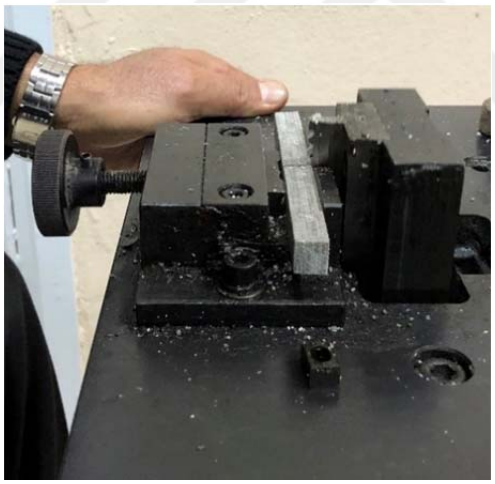


Figure 3.32. Notching device

TOTOMAK Charpy Impact Testing Machine was used to measure the impact resistance of the samples prepared according to the ASTM D 6110 standard (Figure 3.33).

Figure 3.33. Impact tester

In this test, the sample was safely held at both ends, giving the energy value absorbed by the sample by multiplying the hammer in a pendulum arm by the sample made according to the standards. The hammer hits against the notch in the sample being produced. The energy absorbed by the sample is decided by precisely measuring the decrease in the movement of the pendulum arm (Mohammad et.al 2019).

Figure 3.34. Sample placed to test region

The composite samples were placed in the machine as shown in Figure 3.34, and the analysis was done in this way after part placement for each sample tested. The results of the analysis were recorded from the data on the screen of the device (Figure 3.35).

Figure 3.35. Data screen of Charpy impact test machine

After analysis, impact strength can be calculated from the following equation:

Impact strength=E/t x 1000 (3.2)

'E'-Energy used to break(J)

't'-Thickness in mm(Sakthivel and Rajendran, 2014)

3.3.3.4. Hardness Test Analysis

The hardness test was carried out by the machine, which is the AOB Lab product with test loads ranging from 10grf to 1000grf, to estimate the degree of material's abrasion to cut, scratch or indentation (Figure 3.36).

Figure 3.36. Hardness test machine

In materials science, hardness is defined as the materials represent the capacity to resist permanent deformations proportional to the bond strength of their atoms. Like other hardness measurement methods, the Vickers hardness test uses an indentation that generally has an effect called the indentation on the material test sample. Vickers hardness value directly depends on the applied load and the area formed by the indentation formed on the test surface of the material. The indentation used in the Vickers hardness test process has the geometric configuration of a square pyramid made of diamonds at an angle of 136 ° between opposite faces. After the indenter actuation, the material sample presents an indentation region with the approximate shape of a regular lozenge, Figure 3.37.

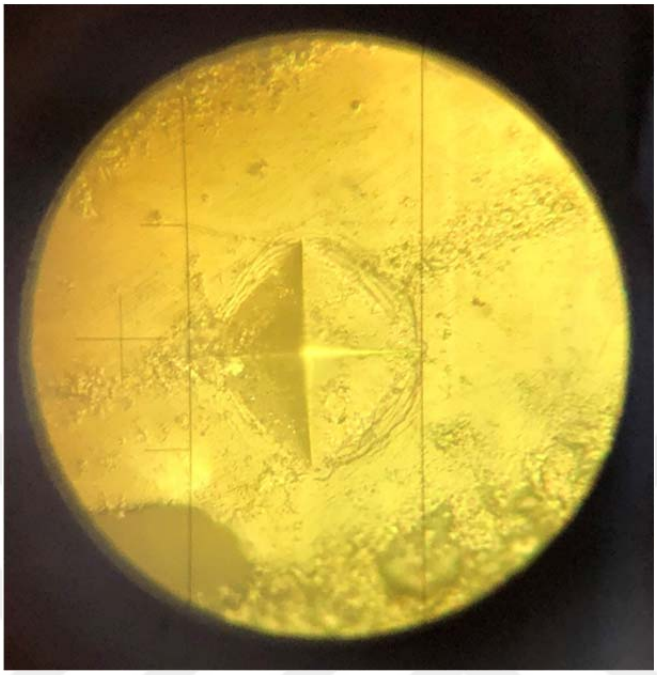


Figure 3.37. Regular lozenge shape

Using the equation below, the hardness value (Vickers Hardness number) is calculated:

$$HV=1.8544F/d^2 \quad (3.3)$$

where the F is the applied load in kgf, d is mean diagonal length in millimeter (Mitchell et al., 2010).

4. RESULTS AND DISCUSSIONS

4.1. Thermal Analysis Results

4.1.1. Thermogravimetric Analysis

An example of the TGA plot of a fabric linen sample obtained from the Mettler Toledo Software Program is shown in Figure 4.1. The change in the weight of a sample with increasing temperature can be seen in this graph. The regions indicated in the figure are the temperatures at which the decreases in sample weight begin.

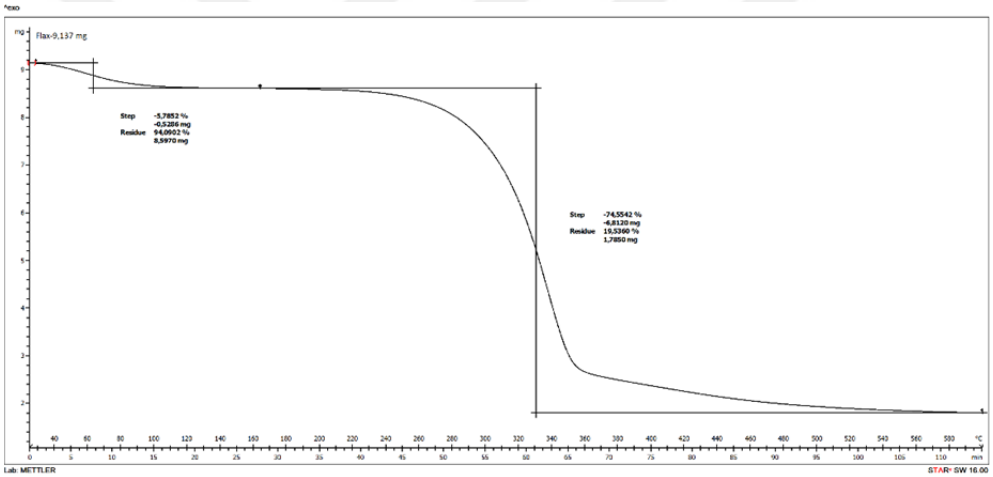


Figure 4.1. TGA graph of a flax fabric

Figure 4.2 shows the TGA plot of the pure linen composite sample obtained from the Mettler Toledo Software Program.

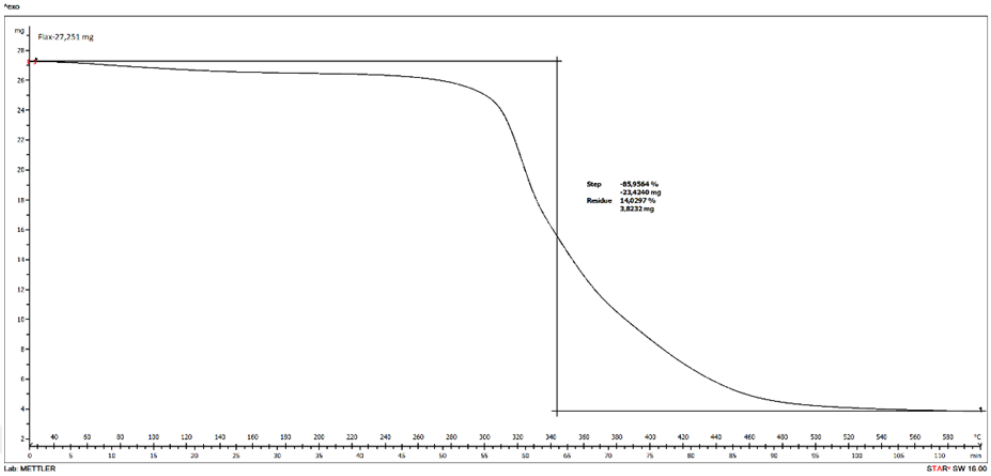


Figure 4.2. TGA graph of a raw flax composite

The initial and final weights of the raw fabric samples and their onset temperatures are given in Table 4.1.

Table 4.1. Weight losses and onset temperatures of raw fabric sample

Fabric Sample	Initial Weight(mg)	Final Weight(mg)	Onset Temperature(°C)
Flax	9.137	1.785	68/332
G49	3.71	3.71	-
G86	7.19	7.19	-
G100	4.35	4.35	-

It was observed that the linen fabric had a weight loss of 74.5% and had two initial temperatures (68 ° C and 332 ° C), while the weight of three glass fiber fabrics of different weight did not change. Since the E-glass fiber did not have a decomposition temperature(Zhou, 2005), no weight loss was observed in the E-glass fabric sample and did not have an initial temperature. On the other part, the

linen fabric sample having two initial temperatures (68 ° C and 332 ° C) may be due to the molecular content of the flax fiber.

It contains 2.0% lignin, 1.8%pectin,1.5%wax,10%water,16.7% hemicellulose and 64.1% cellulose. The initial weight loss of flax fiber between 60° and 100° C corresponds to the evaporation temperature of the water in the sample. The second weight loss is caused by the thermal depolymerization of hemicelluloses and cellulose bonds(Lewin, 2007; Lv et al., 2010; Manikandan Nair et al., 2001; Yang et al., 2007).Figure 4.3, Figure 4.4 and Figure 4.5 show respectively the TGA plots of the FLG49, FLG86, FLG100 composite sample from the Mettler Toledo Software Program.

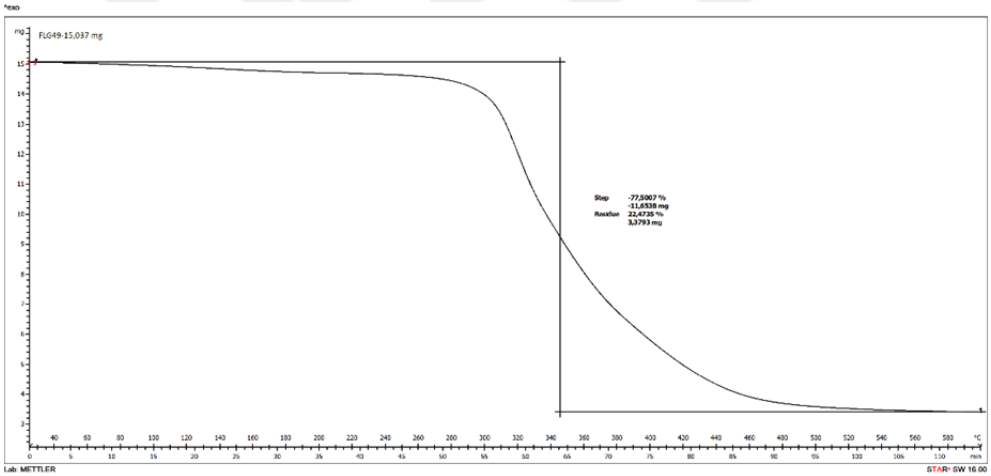


Figure 4.3. TGA graph of FLG49 composite sample

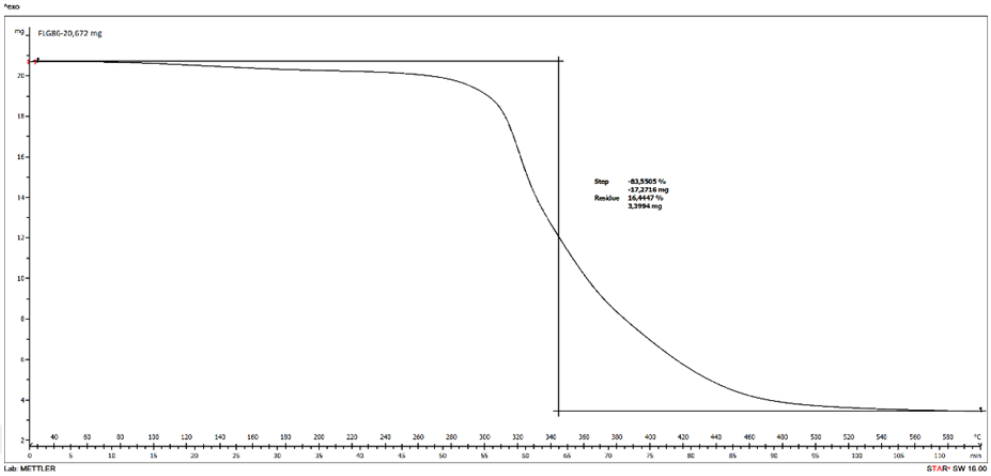


Figure 4.4. TGA graph of FLG86 composite sample

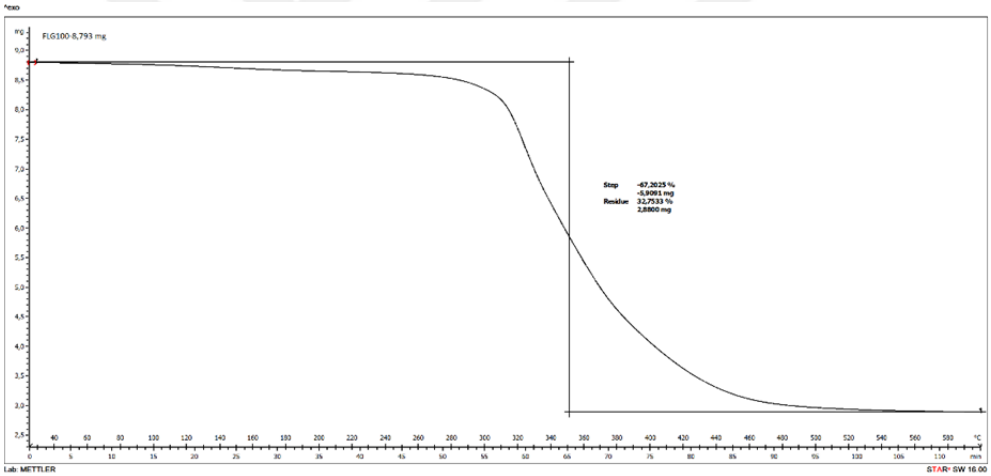


Figure 4.5. TGA graph of FLG100 composite sample

Weight changes and initial temperatures of epoxy resin, linen and glass fiber fabric reinforced composites are shown in Table 4.2. The epoxy resin was heated from 25 ° C to 600 ° C, losing 60.08% of its weight and the temperature at which the decomposition started was 326 ° C. When the decomposition temperatures of pure linen-reinforced composite samples are compared to glass fiber-reinforced composites, the initial temperature of pure linen-reinforced composite is 344 ° C, while the initial temperatures of FLG49, FLG86 and FLG100

glass fiber reinforced composite samples are 346 ° C, 345 ° C, and 352 ° C was obtained respectively. Making hybrid composites of linen fabric reinforced composites with glass fiber of different weight has been observed to increase their decomposition temperature by up to 8 ° C. When the decomposition temperatures of glass fiber fabric reinforced FLG49, FLG86 and FLG100 composites were examined, non-large temperature differences such as minimum 1 ° C and maximum 6 ° C were observed.

Table 4.2. Weight losses and onset temperatures of epoxy and composite sample

Composite Sample	Initial Weight(mg)	Final Weight(mg)	Onset Temperature(°C)
Epoxy resin	31.14	12.43	326
FL	27.251	3.8232	344
FLG49	15.037	3.3793	346
FLG86	20.672	3.3994	345
FLG100	8.793	2.88	352

Considering the weight loss percentages of the samples, the weight loss amount of the epoxy is 60.08%, while the loss of the linen fabric reinforced composite is 85.95% as shown in Figure 4.2. When the data in Figures 4.3,4.4 and 4.5 were examined, it was found that the weight loss percentages of glass fiber reinforced samples were 77.5%, 83.5% and 67.2% for FLG49, FLG86, FLG100 composites, respectively. These percent losses were also found to be less than the weight loss amount of the linen fabric reinforced composite and more than the epoxy weight loss.

Figures 4.6, 4.7 and 4.8 also show the shape of a composite sample before and after the test. As shown in the figures, the raw fabrics remained fibrous after the high temperature in the analysis, while the epoxy resin in the composite sample was

destroyed by high temperature (600 ° C) and only the flax fibers remained in the crucible.

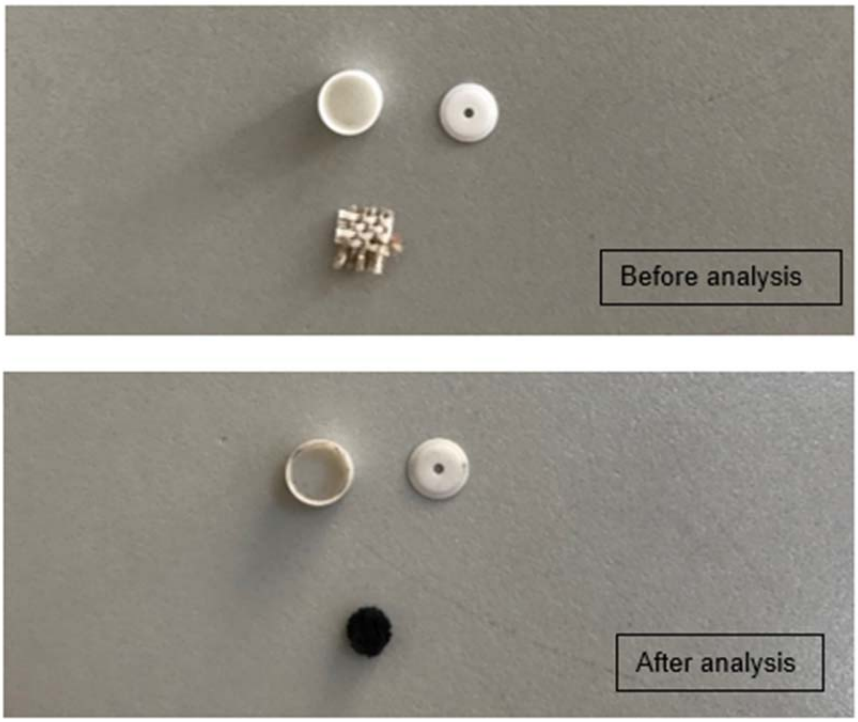


Figure 4.6. Before and after TGA of raw flax sample

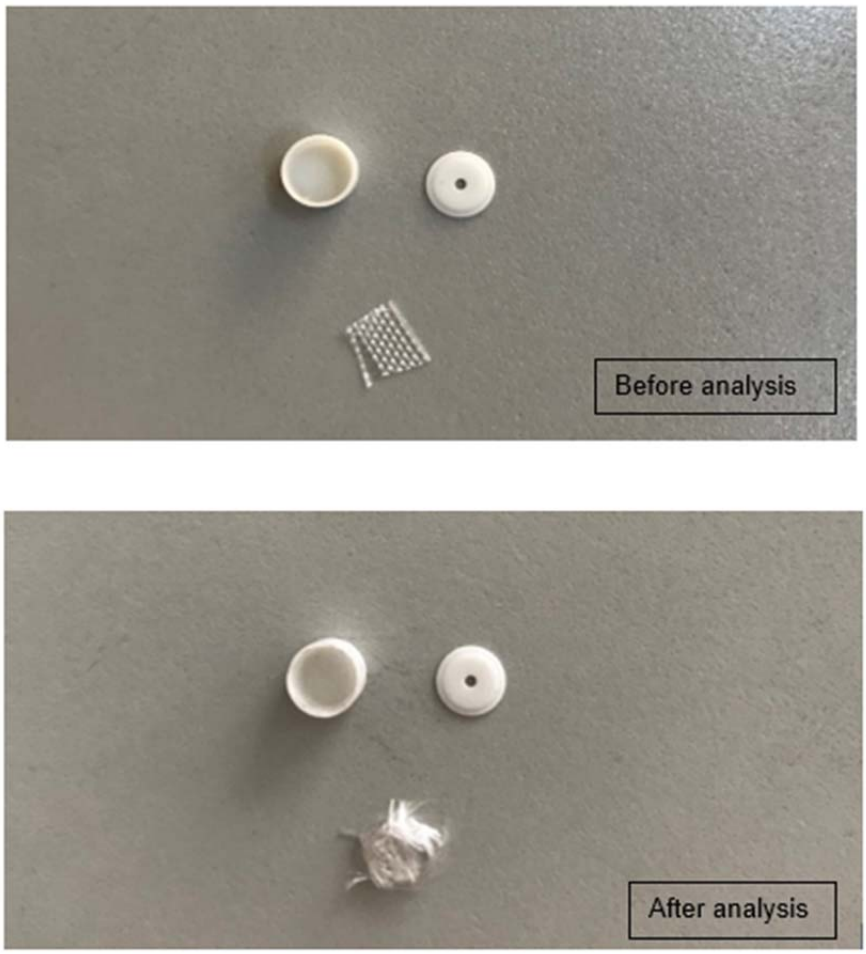


Figure 4.7. Before and after TGA of raw G49 sample

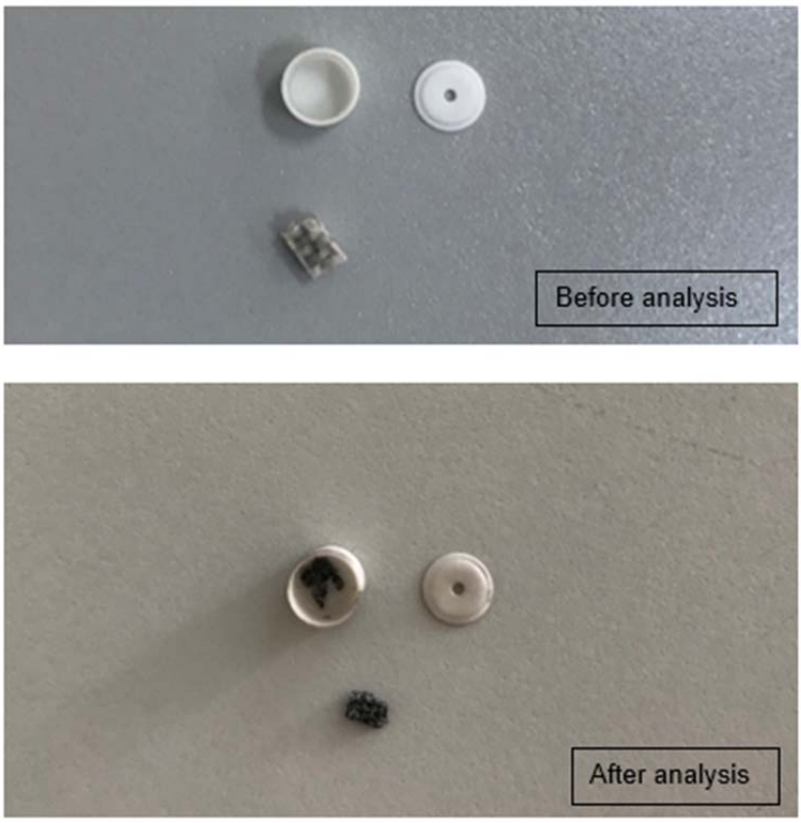


Figure 4.8. Before and after TGA of flax composite sample

4.1.2. Differential Scanning Calorimetry Analysis

DSC graphics of flax and E-glass fabric samples are shown in Figures 4.9, 4.10, 4.11 and 4.12. As seen in Figure 4.9, exothermic reaction at 150 ° C and endothermic reaction took place at 350 ° C in flax fabric during heating and cooling cycle. Amorphous cellulose is known to form hydrogen bonds at 60 ° C and recrystallize at 150 ° C as part of natural fibers. In previous studies, thermal analysis of cellulose fibers was performed and it was stated that crystalline orientation and crosslinking were effective on the pyrolytic behavior of cellulose. An exothermic reaction occurred in the graph because less crystalline material degrades faster with heat and lower thermal stability of flax fibers. In a typical DSC thermogram of cellulosic fibers, it is stated to be an endothermic peak between 370 ° C and 395 ° C, which is often shown to be caused by the production of laevoglucose. This situation explains the endothermic reaction in the graph. As can be seen from the Figure 4.10,4.11 and 4.12, E-glass fabrics did not have any endothermic or exothermic reactions during the heating and cooling cycle because they have high heat resistance, no glass transition and melting temperatures, and also the decomposition temperatures were not between 20 ° C - 500 ° C.

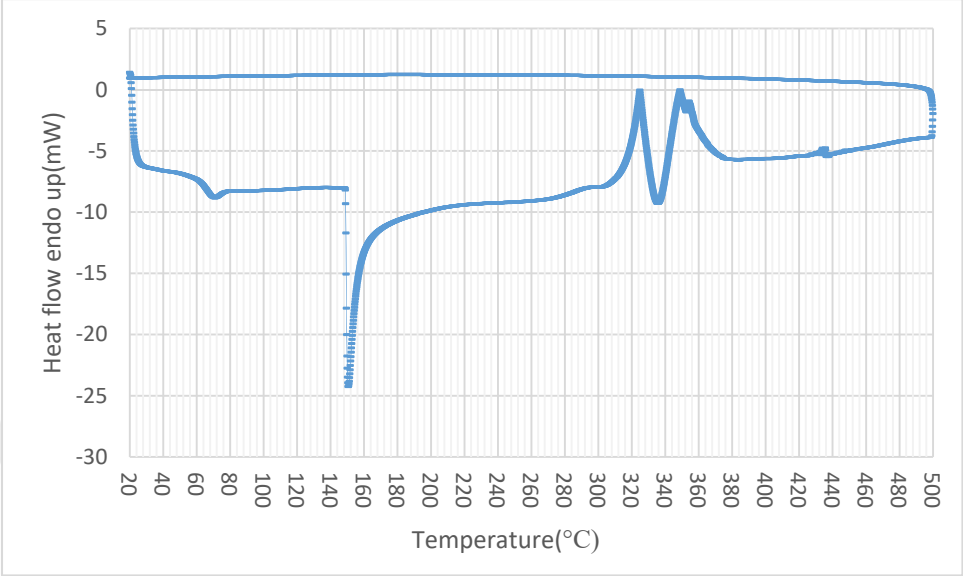


Figure 4.9. DSC graph of raw flax fabric sample

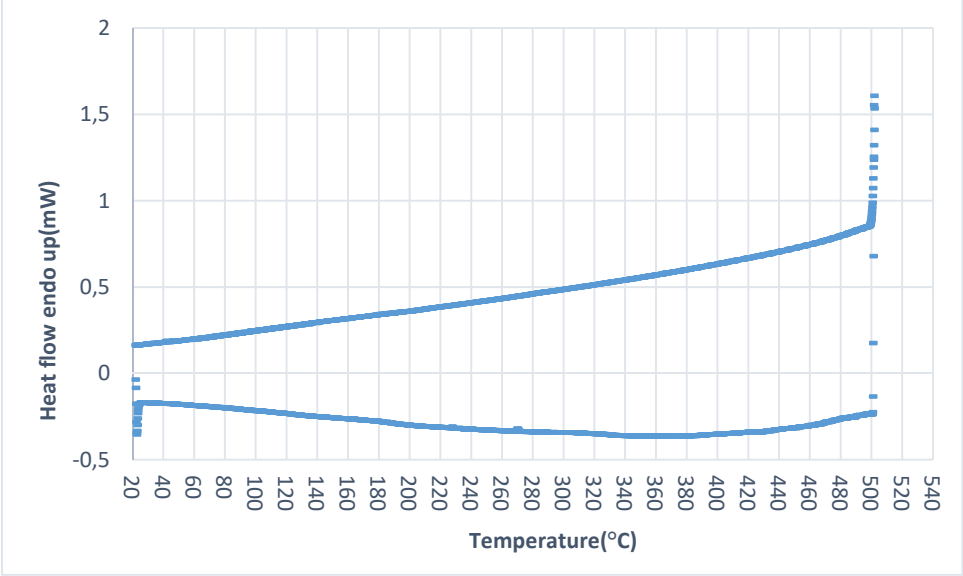


Figure 4.10. DSC graph of G49 fabric sample

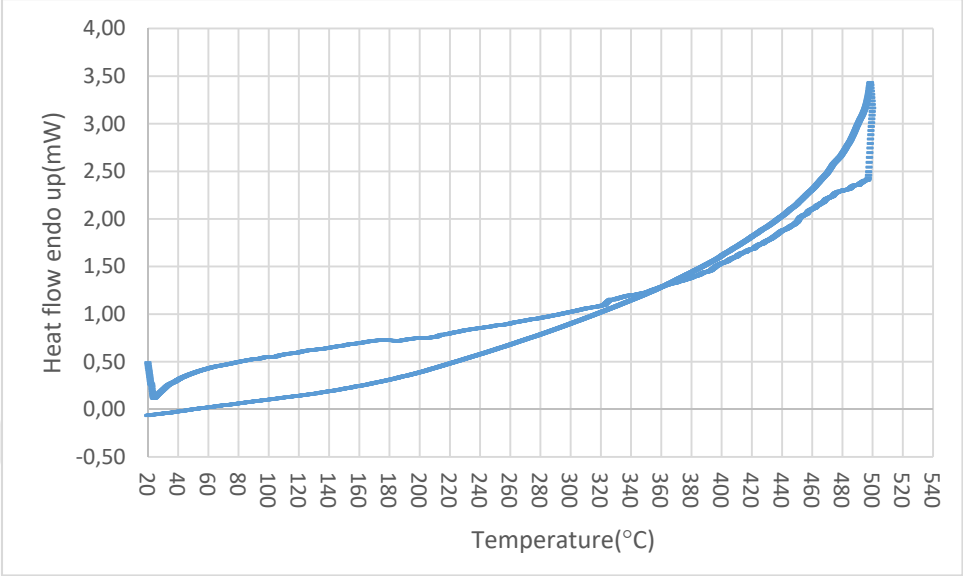


Figure 4.11. DSC graph of G86 fabric sample

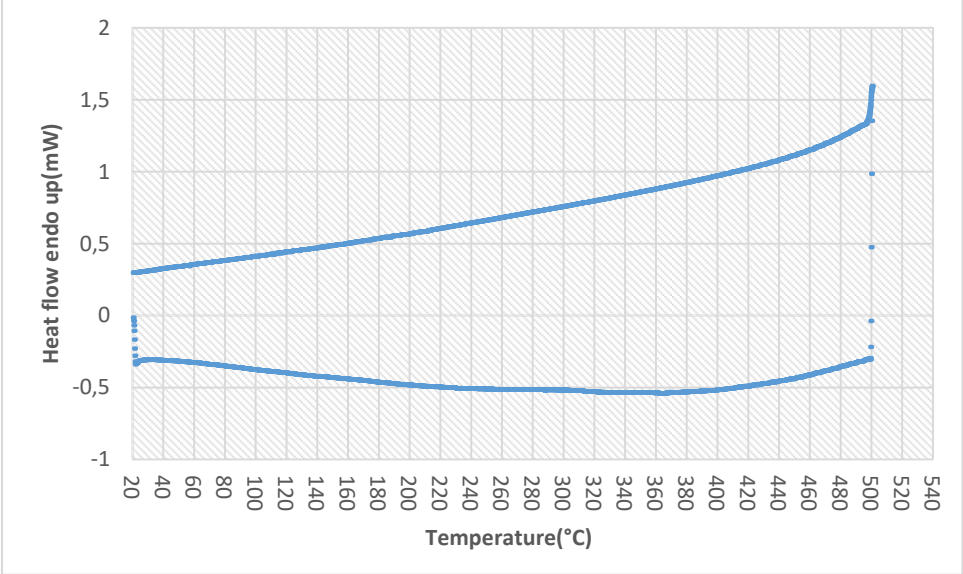


Figure 4.12. DSC graph of G100 fabric sample

The DSC curves of the epoxy resin are shown in Figure 4.13. It was observed from the DSC plot of the epoxy resin (Figure 4.13) that an endothermic

reaction began at 130 ° C, which affected the deterioration of the epoxy resin. In addition, an endothermic reaction occurred, indicating a change in the decay process at about 343 ° C.

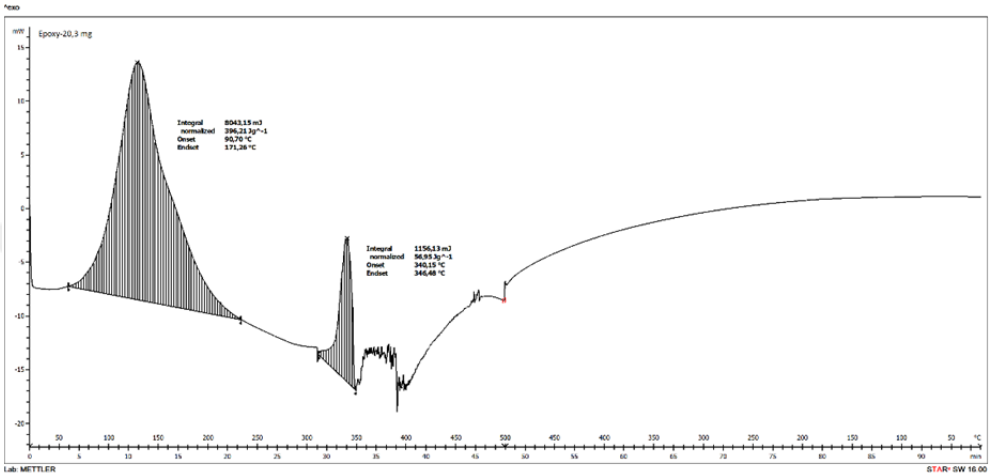


Figure 4.13. DSC graph of Epoxy

Figure 4.14, 4.15, 4.16, 4.17 shows DSC plots of hybrid composite samples reinforced with linen and E-glass fabric. It was observed that the deterioration in flax composite samples started at 148 ° C and peaked at 153 ° C, similar to the raw flax fabric samples. In all examples, an exothermic reaction appears to start at about 150 ° C, indicating degradation of the linen fabric. In addition, exothermic reactions peaked around 160 ° C. There is an onset of an endothermic reaction at approximately 310 ° C in the graphs; it was found that this was similar to the endothermic temperature occurring in raw flax. As mentioned earlier, E-glass is very heat resistant and it can be said that the exothermic reaction that starts at 150 ° C indicates the deterioration of the raw linen fabric. While the epoxy resin had an endothermic reaction at 130 ° C, it was understood that this situation had no significant effect on the phase changes of flax and glass fiber composite materials. The heat flows of flax reinforced composites and flax / glass fiber reinforced composites did not show much difference either.

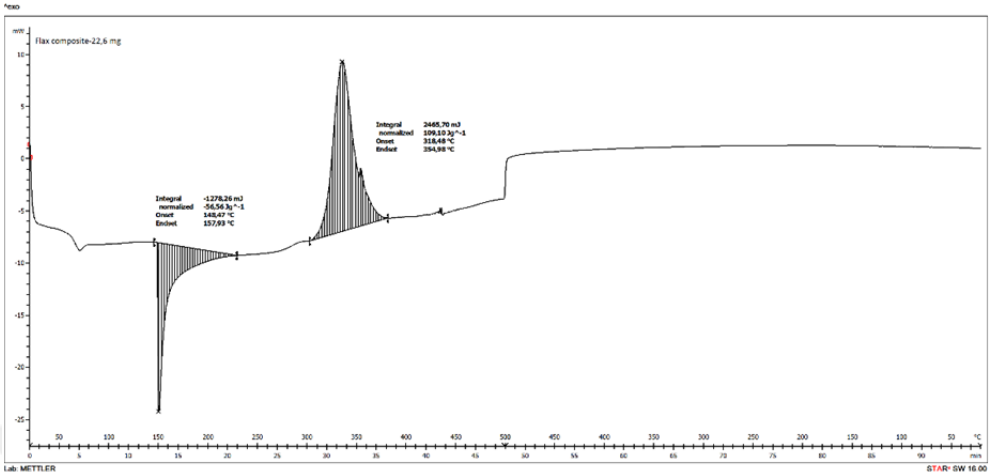


Figure 4.14. DSC graph of Flax composite sample

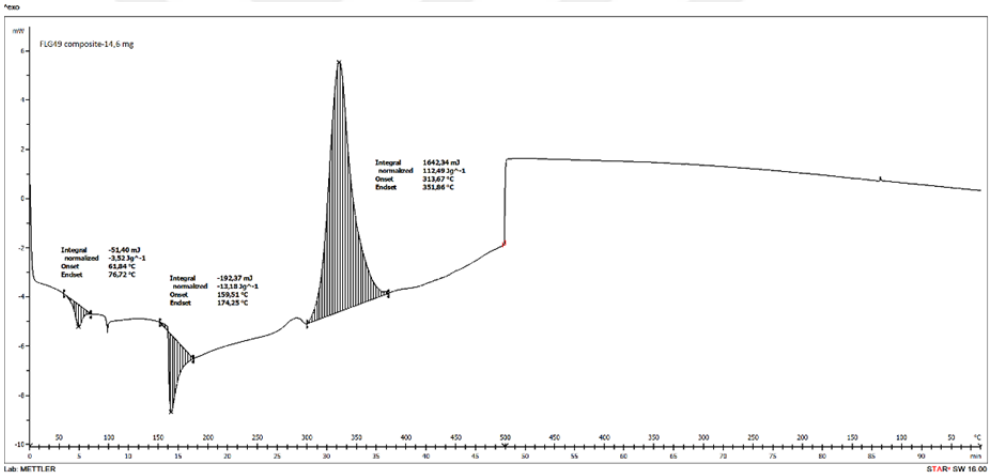


Figure 4.15. DSC graph of FLG49 composite sample

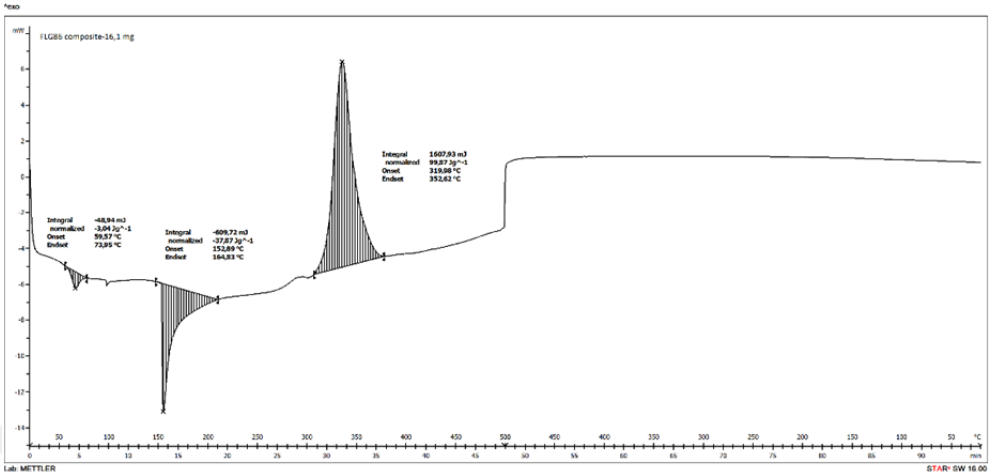


Figure 4.16. DSC graph of FLG86 composite sample

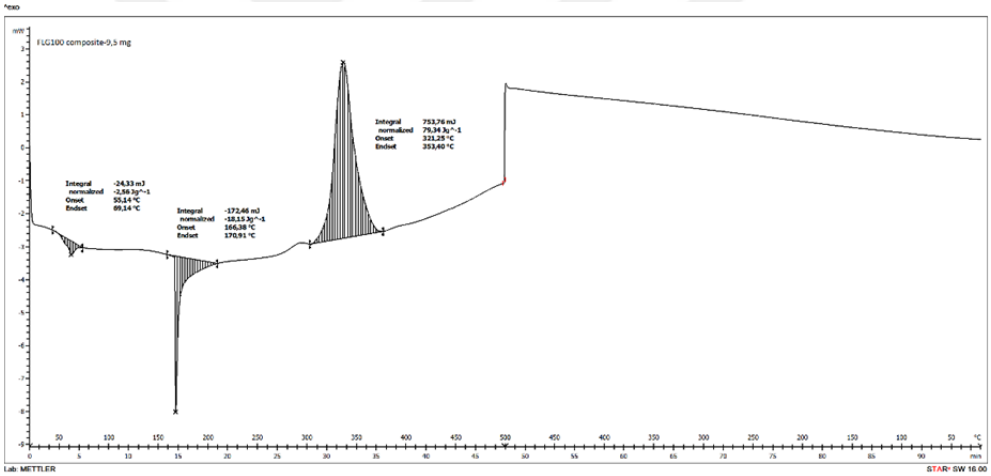


Figure 4.17. DSC graph of FLG100 composite sample

Besides, the temperature at which the exothermic reaction seen on the DSC graph of the raw linen fabric peaked (160 ° C); the composite samples of FL, FLG49, FLG86, FLG100 were also found to peak at about 160 ° C. The situation is the same at the endothermic reaction start temperature (320°C). It was understood from the analyzed samples that changing the placement order of the fabrics or epoxy resin had almost no effect on the phase changes of the samples. Moreover,

although E-glass fabrics have high thermal resistance, it has been found that the phase changes in the composite sample obtained from these materials depend on the properties of the linen fabric reinforcement.

4.1.3. Water Absorption Analysis Results

In the water absorption experiment, the materials were removed from the containers filled with water after 120 hours and weight changes were noted. After 120 hours of data, the available values are tabulated in Figure 4.18, Figure 4.19, Figure 4.20 and Figure 4.21 respectively. These figures indicate the water absorption amount of FL, FLG49, FLG86, FLG100 respectively.

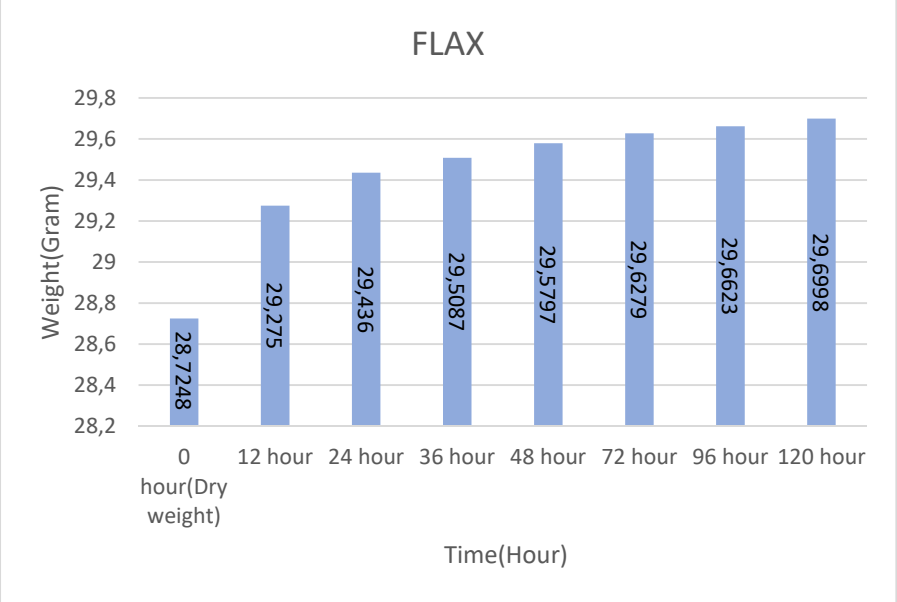


Figure 4.18. Water absorption of pure Flax composite material

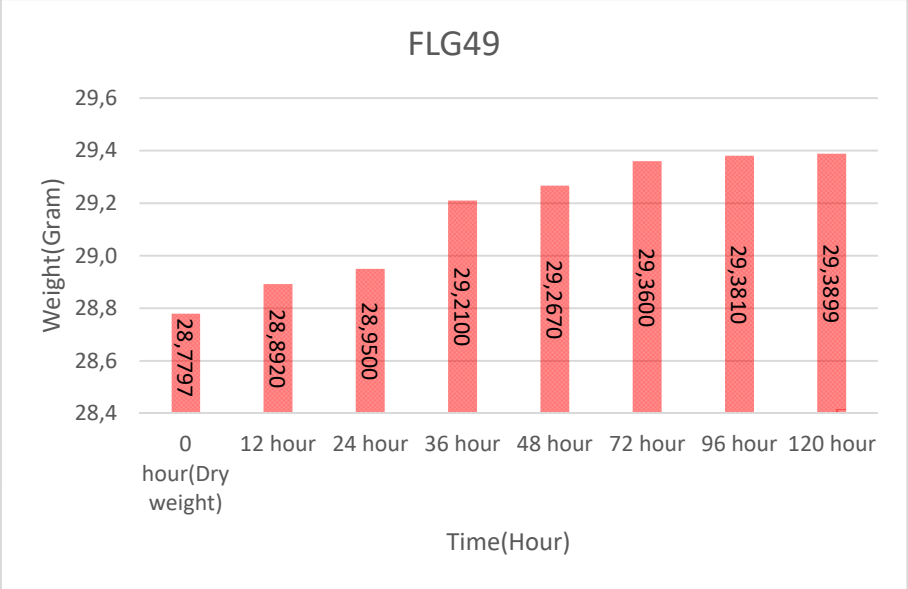


Figure 4.19. Water absorption of Flax and G49 hybrid material

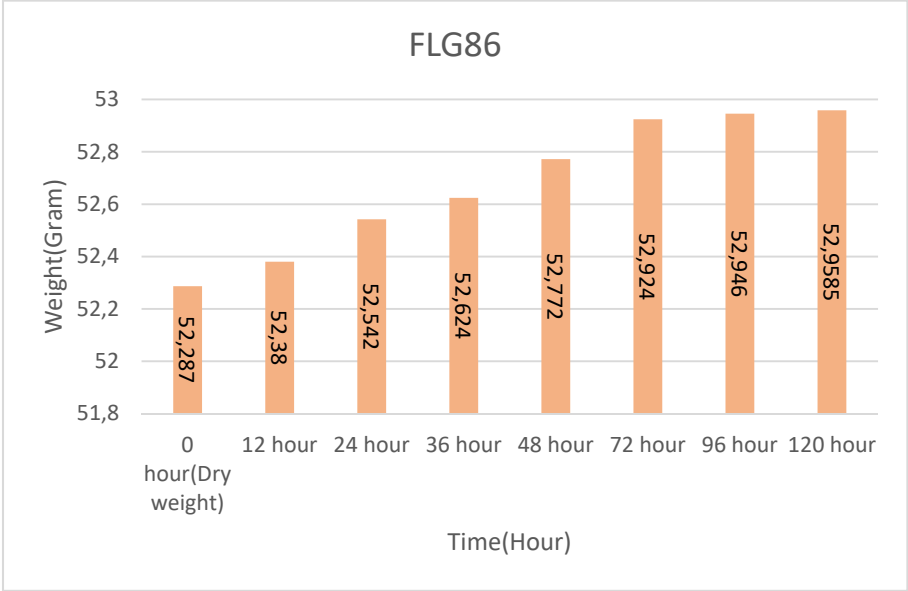


Figure 4.20. Water absorption of Flax and G86 hybrid material

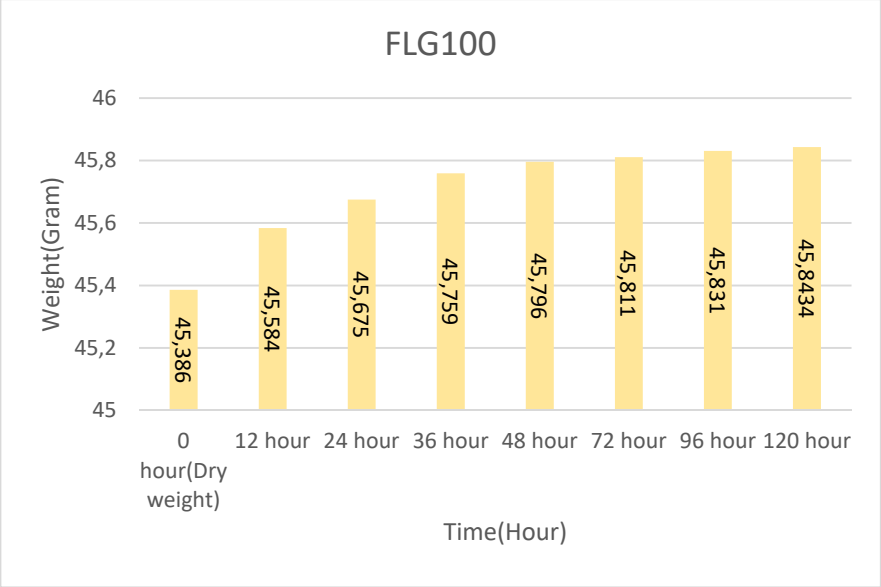


Figure 4.21. Water absorption of Flax and G100 hybrid material

Periodic calculations have shown that FLG100 has the lowest absorption rate of 1%. FLG86 is behind the FLG100 with 1.28% and the absorption ability of different web weights can be observed. The fact that natural flax (FL), which absorbs 3.39% of water at the end of the test, has higher water absorption (2.12%) than FLG49 hybrid composite, indicates that flax loses this feature with resin while it is water-loving material. It should be taken into consideration that there are also factors such as relative humidity, temperature, voids / defects, thickness effects, stacking order and fiber content that affect water absorption.

4.1.4. Impact Test Analysis Results

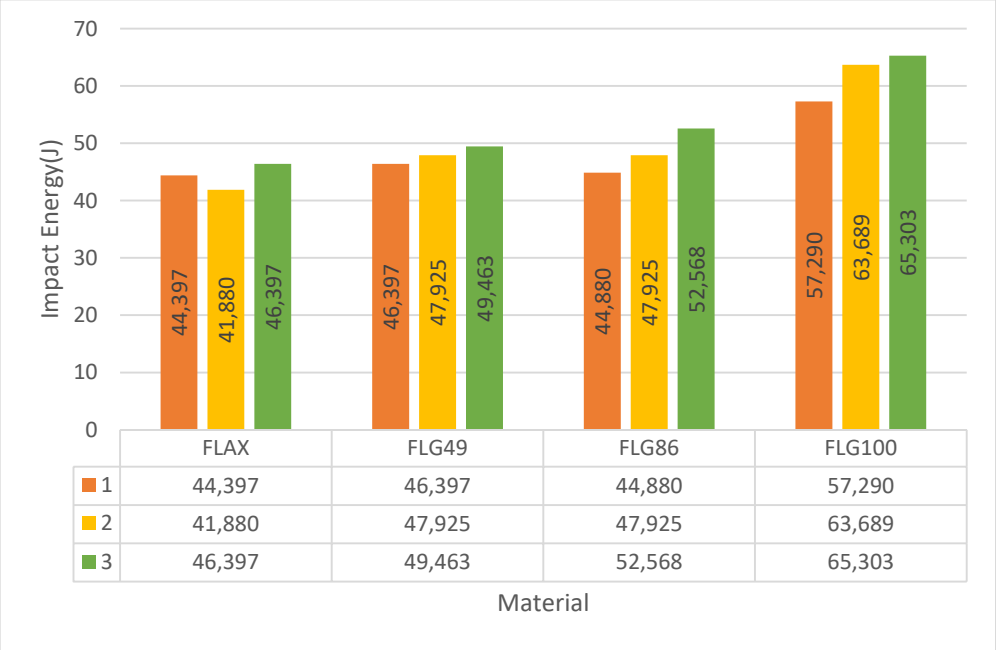


Figure 4.22. Impact energy values of produced composites sample

The impact resistance of the composite samples produced were shown in Figure 4.22. The FLG100 glass fabric reinforced composite was found to have the highest impact energy (57.29-65.303 J) and pure linens had the lowest impact energy (41.88-46.39 J). Visible from this chart that FLG49 (flax/glass fiber reinforced composite) and FLG86 hybrid have similar impact energies. This can be explained by the chemical structure resulting from the production of fabric layers between linen and glass fibers and the adhesion between linen, epoxy and glass fiber layers. By the time the influence of the stacking order was perused, it was found the GGGF sample (57.29 J-65.3J) had the highest impact energy value among the flax /E -Glass reinforced composites, while the GFFF sample had the lowest impact energy (46.39 J) value. In addition, although there was no large difference between the impact energy values of pure flax and Flax / Glass fiber49

hybrid composites, the GFFF sample was found to have slightly higher impact energy than the FFFF. Those obtained from these tested composite parts provide an explanation for the mechanical performance of the gap fractions and the sliding behavior when the parts are subjected to sudden impacts.

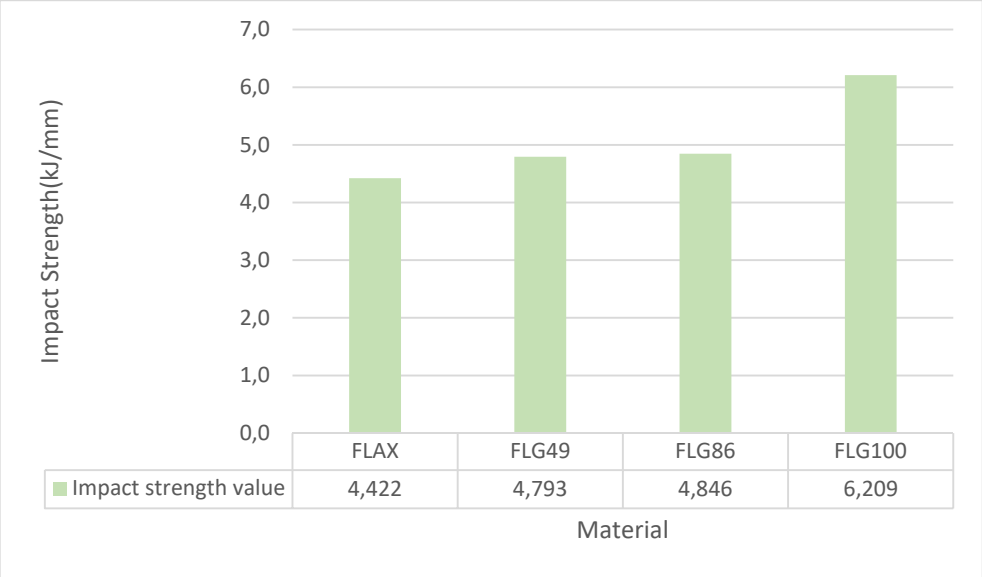


Figure 4.23. Impact strength of composite samples produced

When the impact strength graph was examined (Figure 4.23), it was seen that the glass fiber reinforced fabric (FLG100) had the highest impact energy. The sample made with pure linen fabric composite was found to have the lowest impact strength value. Hybrid composites FLG49 and FLG86 have close impact strength with 4.793 kJ/mm and 4.846 kJ/mm impact strength values, respectively. It is understood that there is not a very strong relationship between the impact strength of changing the fabric arrangement.

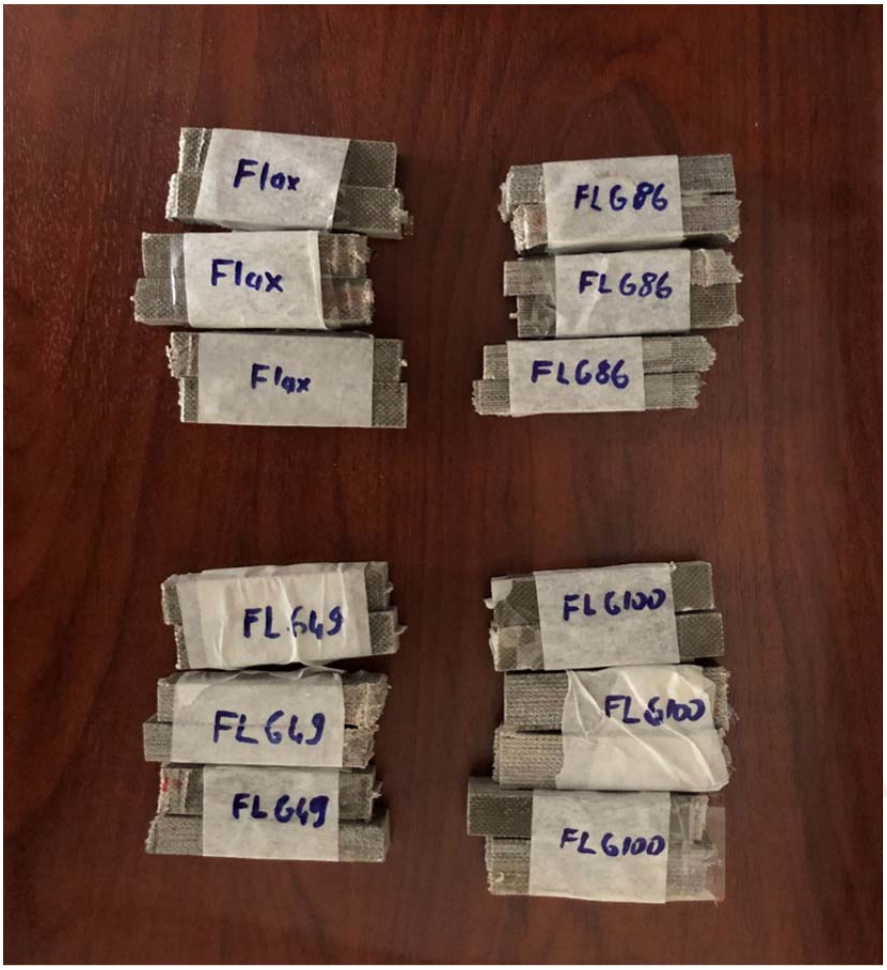


Figure 4.24. Materials after the Charpy Impact test

Figure 4.24 shows the materials after the impact test. In addition, fracture areas of the material after testing have been indicated in Figure 4.25.

Figure 4.25. Fracture zone sections of materials after impact testing

4.1.5. Hardness Test Analysis Results

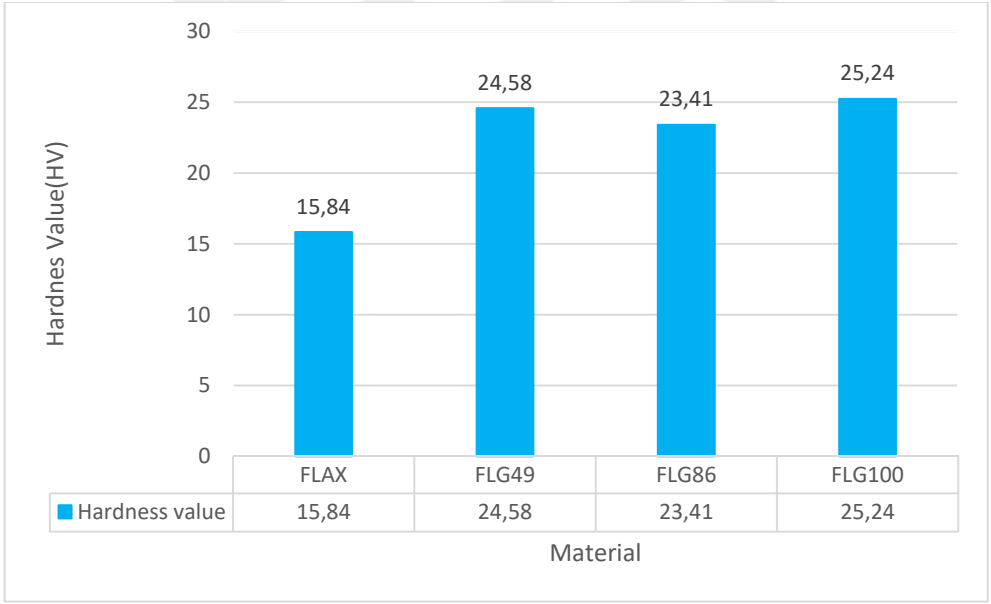


Figure 4.26. Hardness values of composites

The hardness value of the manufactured composites was shown in Figure 4.26. When Vickers hardness test results are examined, it is seen that FLG100 composite has the highest hardness value and flax composite has the lowest hardness value in the produced composites. As can be seen from the graphic, FLG49, FLG86 and FLG100 hybrid composites were found to have close hardness values. The difference between them was found to vary with the amount and order of linen and glass fabric fibers in their structure (e.g. GFGFG in FLG49, FGFGF in FLG86, GGFGG in FLG100). However, compared to the flax composite, it has been concluded that glass fabric reinforcement increases the hardness properties of the composites.

5. CONCLUSIONS

Within the scope of this thesis, natural fiber reinforced hybrid composites have been designed and manufactured. The thermal and mechanical properties of these products were researched and analyzed using three different weights (G49, G86, G100) glass fiber (synthetic fiber) and flax fiber (natural fiber). The results obtained during this treatise can be summarized as the following;

- The results of TGA showed that the raw glass fiber fabrics did not lose any weight as the temperature increased, and the raw linen fabric lost 74.5% of its weight, which is related to the high thermal resistance of the glass fibers.
- In the TGA results of composite products and epoxy resin, a weight loss of 85.9% was observed in the composite product (FL) with a weight loss of 60% in the epoxy resin. This rate was found to be 77.5%, 83.5% and 67.2% in glass fiber reinforced composites (FLG49, FLG86, FLG100), respectively.
- The raw linen fabric showed two decomposition temperatures, while glass fiber fabrics had no decomposition temperature.
- While composite products show close decomposition temperatures, the final values obtained are approximately 20 ° C above the temperature value of the epoxy resin that begins to decompose.
- According to DSC analysis results, an exothermic reaction around 150 ° C and an endothermic reaction around 350 ° C were observed in linen fabric, where glass fiber fabrics did not show exothermic and endothermic reactions due to their thermal stability.
- In the DSC analysis results, an endothermic reaction was observed at epoxy at 130 ° C and 343 ° C.

- It was observed that exothermic reaction starts at approximately 150 ° C and an endothermic reaction occurred at around 310 ° C in composite products with flax and glass fiber. It was understood that these temperature values were similar to the graphic results of the raw linen fabric.
- In water absorption test analysis, it was understood that linen-reinforced composite was the product that absorbed the most water (3.39% weight increase) as expected, while glass fiber of different weight decreased the absorption ability of water.
- According to Charpy test results, it has been found that hybrid composites made by flax with glass fiber reinforced samples of different weights have higher impact values from 9.73% to 28.95% higher than those of pure linen composite reinforced samples.
- Also, when the impact strengths were compared, it was seen that the highest value glass fiber reinforced composite (FLG100) was 1.4 times more than the lowest value flax reinforced composite (FL).
- The hardness of the FLG100 composite is 25.24 HV, while the hardness of the FL composite is 15.84 HV. With glass fiber fabric reinforcement to linen fabric, an increase of 59.34% in the hardness value of the composite appears.
- While the lowest hardness value among glass fiber reinforced composites is seen in FLG86 composite, it is concluded that this difference is negligible with FLG49 as 4.99% and with FLG100 as 7.81%, and the difference is related to the amount and order of glass fiber reinforced composite.
- This indicates that E-glass fabric reinforced composite structures that are hybridized with linen fabric reinforcement are suitable materials for use in the automotive industry.

- It is envisaged that the composite samples produced within the scope of this treatise may find a widespread area in the automotive industry in the future, and composite structures produced due to the low mechanical properties of linen-reinforced products can be used in the automobile interior.

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