ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

Ayperi Tuğçe TOSUN

EFFECTS OF NATURAL REINFORCEMENT AGENTS ON MECHANICAL PERFORMANCE OF COMPOSITE MATERIALS

DEPARTMENT OF AUTOMOTIVE ENGINEERING

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ABSTRACT

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Composite materials are one of the prominent and popular topics of materials science in recent years. Unlike alloys, in composite materials, there is a physical interaction between at least two different materials without a chemical interaction. These materials basically consist of a matrix element which acts as a body by providing toughness and ductility to the material and holding the structure together and a reinforcement element that gives hardness and durability to the material. In recent years, different natural fibers which are renewable, recyclable and cost effective have been started to be used instead of synthetic fibers (glass, carbon etc.) which have been widely used as reinforcement element. In this study, production of polymer matrix composite materials which contains various natural fibers (jute and cotton) as reinforcement elements by vacuum assisted resin transfer molding method was achieved. Polymer composites which have five different configurations by stacking jute and cotton fabrics layer by layer were generated and the experimental results of tensile test, impact test, hardness test, water absorption capacity test, scanning electron microscope analysis were compared with pure jute and pure cotton reinforced polymer composites.

Key Words: Composite, Natural Reinforcement, Polymer Matrix

ÖZ

YÜKSEK LİSANS TEZİ

DOĞAL TAKVİYE ELEMANLARININ KOMPOZİT MALZEMELERİN MEKANİK PERFORMANSINA ETKİLERİ

Ayperi Tuğçe TOSUN

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Son yıllarda malzeme biliminin öne çıkan ve büyük ilgi gören konularından birisi de kompozit malzemelerdir. Alaşımlardan farklı olarak kompozit malzemelerde en az iki farklı malzeme arasında kimyasal bir etkileşim meydana gelmeksizin, fiziksel bir etkileşim vardır. Bu malzemeler temelde malzemeye tokluk, süneklik kazandırıp yapıyı bir arada tutarak bir gövde vazifesi gören matris ve malzemeye sertlik, dayanıklılık kazandıran takviye elemanlarından oluşurlar. Son yıllarda takviye elamanı olarak yaygın bir şekilde kullanılan sentetik elyaflar (cam, karbon vb.) yerine, yenilenebilir, geri dönüşüme uğratılabilir ve ekonomik olan farklı doğal elyaflar kullanılmaya başlanılmıştır. Bu çalışmada, takviye elemanı olarak çeşitli doğal lifler (jüt ve pamuk) içeren polimer matrisli kompozit malzemelerin vakum destekli reçine transfer kalıplama yöntemi ile üretimi gerçekleştirilmiştir. Jüt ve pamuklu kumaşların katman katman istiflenmesiyle beş farklı konfigürasyona sahip polimer kompozitler oluşturulmuş ve çekme testi, darbe testi, sertlik testi, su emme kapasitesi testi, taramalı elektron mikroskobu analizlerinin deneysel sonuçları saf jüt ve saf pamuk takviyeli polimer kompozitler ile karşılaştırılmıştır.

Anahtar Kelimeler: Kompozit, Doğal Takviye, Polimer Matris

EXTENDED ABSTRACT

Material science is a very important branch that is related to many disciplines. The main areas of interest in material science are material properties, selection of suitable materials for various working conditions, and the discovery of new materials. Materials science categorizes materials according to their specific properties and aims to identify these materials, determine their mechanical and physical properties, and examine the material as micro and macro manner.

Materials are generally examined in three groups; metals, ceramics and polymers. Composite materials, which can be expressed as the fourth main group, are produced by combining two or more of the above-mentioned basic classes and are one of the favorite topics of recent years. Composite refers to a material composition of at least two materials. The aim with the creation of composite structures is to produce new materials that combine the best properties of the materials combined with each other in macro dimensions (without chemical interaction). These properties can be hardness, toughness, impact resistance, thermal conductivity, lightness, rigidity, flexibility etc., according to the application area.

With these superior properties, composite materials have been widely preferred in recent years, especially in the automotive, aerospace and defense industries where weight reduction is extremely important and critical.

In composite materials, there is no chemical interaction between materials with different properties as in alloys, and the interaction is only physical. These materials basically consist of a matrix, which acts as a body by providing toughness and ductility to the material and holding the structure together, and a reinforcement element that provides hardness and durability to the material.

Carbon and glass fibers are generally preferred as reinforcement elements. These are synthetic elements. In recent years, various natural fibers used instead of these elements which are generally not possible to be recycled have started to be preferred by researchers. The use of renewable, recyclable and economical natural fibers as reinforcement elements is also valuable in terms of obtaining an environmentally friendly material.

Especially in the century we live in, the fact that we are facing serious problems such as environmental pollution, global warming and the reduction of petroleum-based product sources has revealed the necessity of increasing the interest in natural materials to be used instead of synthetic materials.

Since synthetic reinforcement elements create great problems for nature, natural reinforcement elements can be considered as an alternative to them due to their more environmentally friendly structure.

This study experimentally concentrates on the production of polymer matrix composite materials which contains various natural fibers as reinforcement elements in order to obtain more environmental friend and cost effective structures. The mechanical performance tests such as tensile, impact and hardness were conducted to show mechanical performance of the specimens. Besides those mechanical characteristics, water absorption capacities and morphological features of the fractured surfaces were also observed.

Various natural fabric configurations composed of jute and cotton were stacked layer by layer to produce natural fiber reinforced polymer matrix with vacuum assisted resin transfer molding method. Pure jute and pure cotton fabrics were selected as reference specimens in order to see the effects of various configurations.

The obtained mechanical properties show that polymer matrix composite materials with natural reinforcement elements can be used in various applications.

GENİŞLETİLMİŞ ÖZET

Malzeme bilimi bir çok bilim dalıyla ilişkisi olan çok önemli bir daldır. Malzeme biliminin başlıca ilgilendiği konular malzeme özellikleri, çalışma şartlarına uygun malzeme seçimi, yeni malzemelerin keşfi gibi konulardır. Malzeme bilimi, malzemeleri belirli özelliklerine göre kategorize eder ve bu malzemeleri tanımayı, mekanik ve fiziksel özelliklerini tespit etmeyi, malzemenin mikro ve makro boyutta incelenmesini hedefler.

Malzemeler genel olarak üç grupta incelenirler; metaller, seramikler ve polimerler. Dördüncü ana grup olarak ifade edilebilecek olan kompozit malzemeler ise yukarıda belirtilen temel sınıflardan iki veya daha fazlasının bir araya getirilmesiyle üretilir ve son yılların gözde konularından birisidir. Kompozit en az iki malzemeli bir malzeme kompozisyonunu ifade eder. Kompozit yapıların oluşturulması ile hedeflenen durum birbirleriyle makro boyutlarda (kimyasal etkileşime girmeksizin) bir araya getirilen malzemelerin en iyi özelliklerini kombine etmeye yarayan yeni malzemeler üretmektir. Bu özellikler uygulama alanına göre sertlik, tokluk, darbe dayanımı, ısıl iletkenlik, hafiflik, rijitlik, esneklik vb. olabilmektedir.

Bu üstün özellikleri ile kompozit malzemeler son yıllarda özellikle ağırlık azaltmanın son derece önemli ve kritik olduğu otomotiv, havacılık ve savunma sanayiinde yaygın şekilde tercih edilmektedirler.

Kompozit malzemelerde alaşımlarda olduğu gibi farklı özellikteki malzemeler arasında kimyasal bir etkileşim söz konusu olmayıp etkileşim sadece fizikseldir. Bu malzemeler temelde malzemeye tokluk, süneklik kazandırıp yapıyı bir arada tutarak bir gövde vazifesi gören matris ve malzemeye sertlik, dayanıklılık kazandıran bir takviye elemanından oluşur.

Takviye elemanı olarak genellikle karbon ve cam elyafı tercih edilmektedir. Bunlar sentetik elemanlardır. Son yıllarda ise geri dönüşümleri genellikle mümkün olmayan bu elemanlar yerine kullanılan çeşitli doğal elyaflar araştırmacılar tarafından sıklıkla tercih edilmeye başlanılmıştır. Yenilenebilir, geri dönüşüme uğratılabilir ve ekonomik olan doğal elyafların takviye elemanı olarak kullanılmaları çevreci bir malzeme elde edilmesi açısından da kıymetlidir.

Özellikle yaşadığımız yüzyılda çevresel kirlilik, küresel ısınma ve petrol kökenli ürün kaynaklarının azalması gibi ciddi problemlerle karşı karşıya olmamız, sentetik malzemelerin yerine kullanılacak doğal malzemelere olan ilginin ciddi şekilde artması gerekliliğini ortaya çıkarmıştır.

Sentetik takviye elemanları doğa için büyük problemler yaratığından dolayı doğal takviye elemanları daha çevreci yapılarından dolayı bunların yerine alternatif olarak düşünülebilir.

Bu çalışma, daha çevre dostu ve uygun maliyetli yapılar elde etmek için takviye elemanı olarak çeşitli doğal lifler içeren polimer matrisli kompozit malzemelerin deneysel olarak üretimine odaklanmaktadır. Numunelerin mekanik performansını göstermek için çekme, darbe ve sertlik gibi mekanik performans testleri yapılmıştır. Bu mekanik özelliklerin yanı sıra numunelerin su emme kapasiteleri ve kopmuş yüzeylerin morfolojik özellikleri de gözlemlenmiştir.

Vakum destekli reçine transfer kalıplama metoduyla doğal takviye elemanlı polimer kompozitler üretmek için jüt ve pamuk kumaşlar çeşitli konfigürasyonlarda istiflenmiştir. Çeşitli konfigürasyonların etkilerini görmek için saf jüt ve saf pamuklu kumaşlar referans numune olarak seçilmiştir.

Elde edilen mekanik özellikleri doğal takviye elemanlı polimer matrisli kompozit malzemelerin çeşitli uygulamalarda kullanılabilir olduğunu göstermektedir.

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ABBREVIATIONS

GMT	:	Glass-fibre-mat-reinforced thermoplastics
NaOH	:	Sodium Hydroxide
NMT	:	Natural-fibre-mat-reinforced thermoplastics
PLA	:	Polylactic acid
SEM	:	Scanning Electron Microscopy
VARTM	:	Vacuum assisted resin transfer molding
WA	:	Water absorption
RJ	:	Pure jute configuration
RC	:	Pure cotton configuration
C1	:	Jute-cotton-jute-cotton-jute-cotton configuration
C2	:	Cotton-jute-jute-jute-jute-cotton configuration
C3	:	Jute-cotton-cotton-cotton-cotton-jute configuration
C4	:	Jute-jute-cotton-cotton-jute-jute configuration
C5	:	Jute-jute-jute-cotton-cotton-cotton configuration

1. INTRODUCTION

Material science is one of the most important areas in engineering field which has mostly pioneered innovations and developments along history. The fact that some eras were called by material names (bronze age, iron age etc.) shows how important this science is.

Material science brings engineering, chemistry and physics together in an interdisciplinary way as shown in Figure 1.1. The main objective of this science is to discover materials and to match the correct materials for a specific product with desired purpose. This matching can be achieved by considering weight, strength, electrical conductivity, chemical stability, resistance to corrosion and cost effectiveness of materials (Wieda et al., 2008).

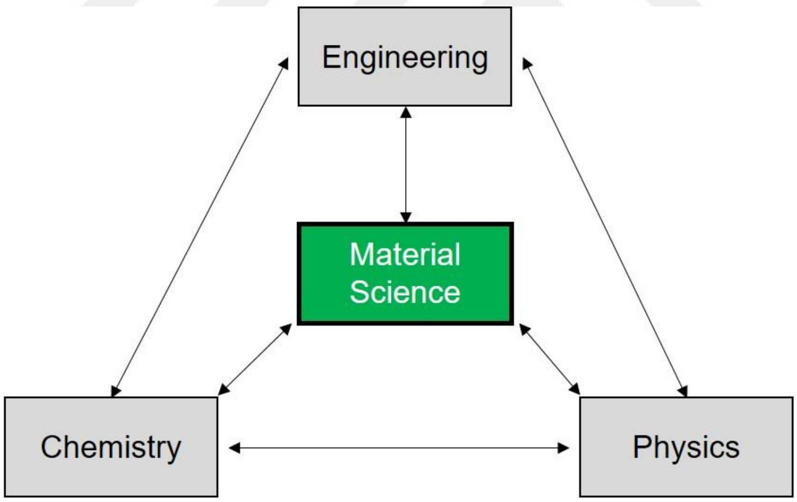


Figure 1.1. Multidisciplinary approach of material science (Wieda et al., 2008)

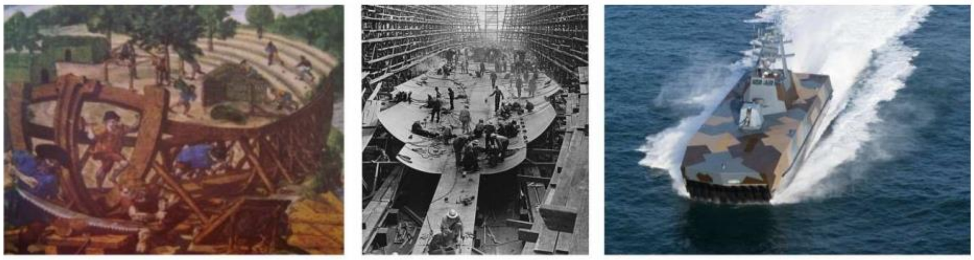
Solid materials can basically be categorized by metals, ceramics and polymers. On the other hand, composite materials which can be stated as fourth major group is generated by using combination of two or more of basic classes mentioned above. Recently, composite materials have been an attractive and popular subject in material science to study for researchers. This interest is due to the unique properties provided by composite materials.

Figure 1.2. Examples of common objects used as metals, ceramics and polymers, respectively (Callister, 2007)

Composite materials can be formed by use of two different materials at least. When these different materials which have their own certain characteristics such as lightness, stiffness, corrosion resistance, flexibility, durability etc. come together physically, a composite structure and more advanced material properties is obtained. Unlike alloys, there is no chemical interaction between the materials contained in composite structures. Interaction is only in a physical sense.

Since these superior characteristics of composites, they find themselves a wide range of application areas such as automotive, architecture, aerospace, marine, energy etc. Although utilization of composite structures have firstly been started at aerospace industry in 1970s, miscellaneous engineering structures as spacecraft, automobiles, bridges, sport equipments have started to be produced by composites of the late years. Higher strength/density ratios of them play an important role at the widespread use of them. Especially, automotive industry which is the locomotive of the economy in developed countries has started to replace metallic parts with composites with parallel to the progresses and developments in material and manufacturing technology (Mahajan and Aher, 2012).

There is an observable transformation tendency in engineering structures from conventional materials to composite materials. Figure 1.3 and Figure 1.4 demonstrated that wood-steel-composite transition in ship construction by years and composite parts of Boeing 787 Dreamliner, respectively. These illustrations obviously reveal attention to composites instead of conventional materials.



Wood *1850* *Steel* *2020* *Composites*

Figure 1.3. Ship construction development (Pastuszak and Muc, 2013)

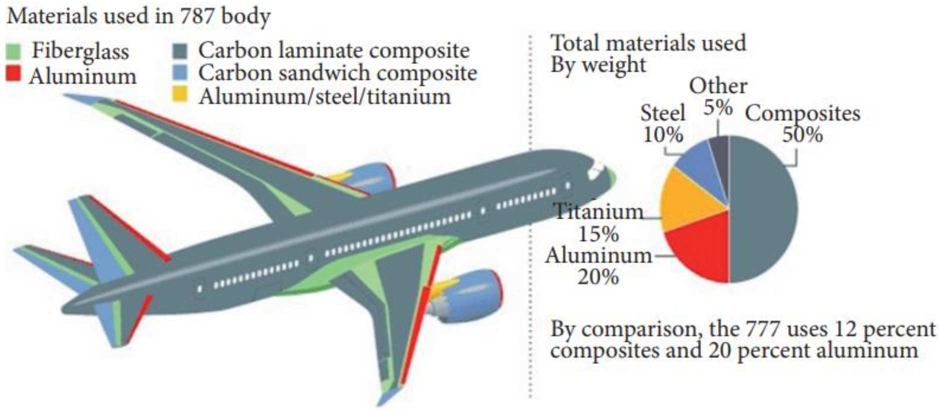


Figure 1.4. Various materials used in an aircraft (Alemour et al., 2019)

Composite materials basically consist of a matrix and reinforcement element. Matrix provides toughness and ductility to the material as a body by holding the structure together, whereas, hardness and durability of the material is ensured by reinforcement element and the structure is fundamentally represented by Figure 1.5.

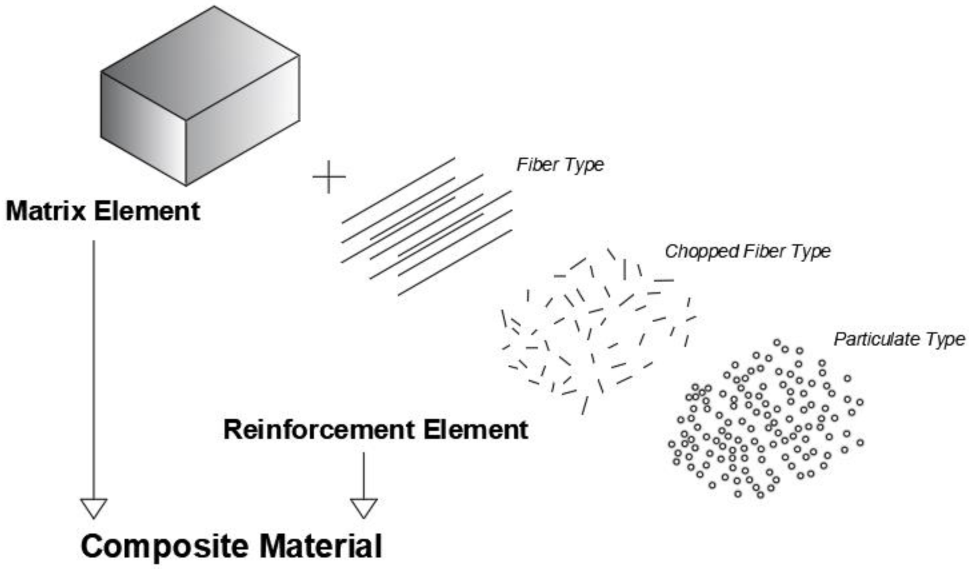


Figure 1.5. Schematic demonstration of composite structure

Classification of composites can be achieved in a variety of ways according to the matrix material, reinforcement element, the shape and placement of the reinforcement elements etc. A general classification was given in Figure 1.6.

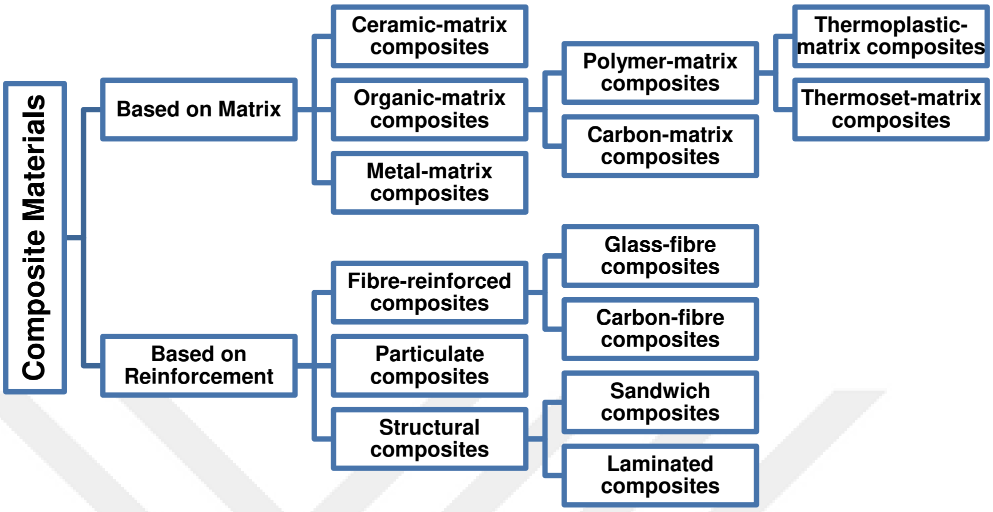


Figure 1.6. Composite material classification (Yang et al., 2012)

The major expectations from composite materials are improvement of both thermal and mechanical properties of the material. Economic and environmental concerns on production period are other important points to be considered by researchers.

Polymer-matrix composites are well-known with their considerable advantages such as biodegradability, low density, high strength and stiffness, corrosive resistance, endurance to prolonged stresses (static and dynamic), operation with wider temperature ranges, good tribological properties (Antipov et al., 2016, Çakmakkaya et al., 2019). Fiber reinforced polymer matrix composites consist of load carrier fibers as reinforcement element to supply rigidity and strength and polymer matrix element to hold structure in stable position and orientation. Commonly, synthetic fibers such as glass, carbon and aramid have been utilized to reinforce the composite structure. Besides use of synthetic fibers, utilization of natural fibers has been come into prominence in recent years. Scientists have started to research assessment of natural fibers as reinforcement element in polymer matrix composites. Environmental concerns, unsustainable petroleum and man-made materials consumption have led them concentrate on surveying natural fibers as environmental friendly materials (Mahir et al., 2019, Mohammed et al., 2015).

Natural fibers can simply be defined as fibers that are not produced by synthetically or manmade. These kinds of fibers can be produced from directly nature or animals. The main content of natural fibers consists of lignin, pectin, hemicelluloses and wax (Asokan et al., 2012). Figure 1.7 classifies the natural fibers.

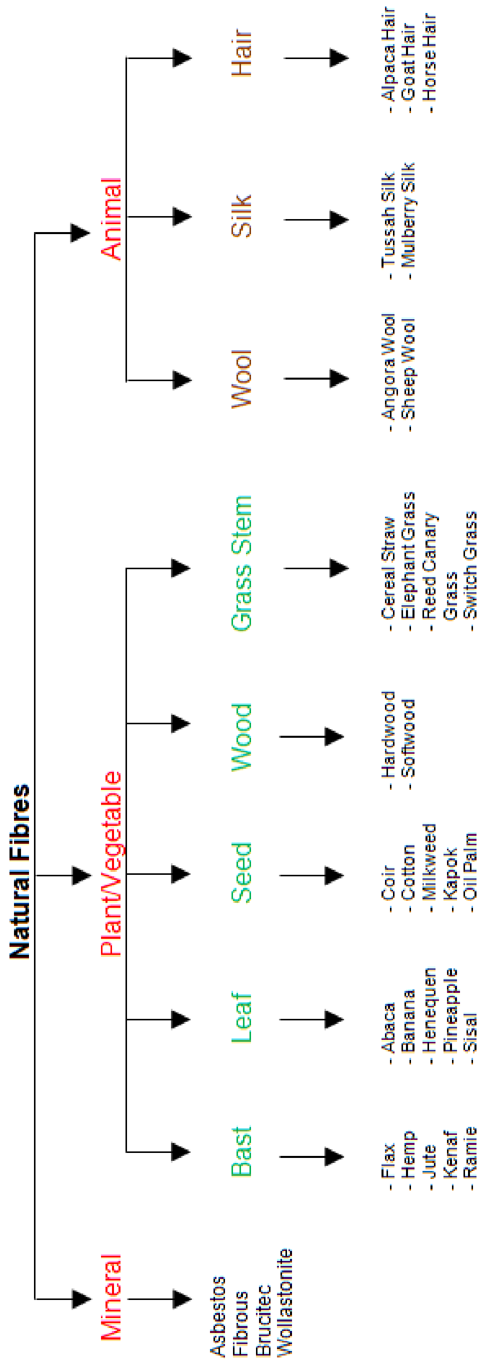


Figure 1.7. Classification of natural fibers (Ngo, 2018)

Natural fibers present various advantages over synthetic ones. In addition to their environmentally friend nature they contribute to obtain light weight composites. For example, natural fibers density and glass fiber density values are 1.2-1.6 g/cm^3 and 2.4 g/cm^3, correspondingly (Girijappa, et al., 2019). Natural fibers find place themselves in many applications such as biomedical, architecture and automotive etc. They exhibit sufficient outcome by the perspective of mechanical properties. Hydrophilic nature of natural fibers seems as an only drawback in front of utilization (Asokan et al., 2012). Table 1.1 and Table 1.2 summarize the mechanical properties and absorption tendency of moisture of some natural fibers.

Table 1.1. Mechanical properties of some natural fibers (Vijayan and Krishnamoorthy, 2019)

Fiber Type	Density (g/cm^3)	Elongation at Break (%)	Tensile Strength (MPa)	Young's Modulus (GPa)
Cotton	1.5-1.6	7-8	287-597	5.5-12.6
Jute	1.3	1.5-1.8	393-773	26.5
Flax	1.5	2.7-3.2	345-1035	27.6
Hemp	-	1.6	690	-
Ramie	-	3.6-3.8	400-938	61.4-128
Sisal	1.5	2-2.5	511-635	9.4-22
Coir	1.2	30	175	4-6
Silk	-	20-25	252-528	7.32-11.22
Banana	1.3	7	500	1.4
Wool	-	25-35	122-175	2.34-3.42
Bagasse	1.25	-	290	17
Bamboo	1.5	3	575	27
Kenaf	-	-	295	22
Elephant Grass	-	5	178	5.6

Table 1.2. Moisture absorbency of some natural fibers (Vijayan and Krishnamoorthy, 2019)

Natural Fibers	Moisture Absorption Tendency (%)	
	Absorbency	Transverse swelling in water
Jute	12.5	20-22
Banana	10-15	16-20
Coir	10-12	5-15
Flax	7	20-25
Mesta	13	20-22
PALM	10-13	18-20
Sisal	10-12	18-20
Wood	-	-
Sun Hemp	10-11	18-20
Ramie	5-6	18-20

The problems such as rapid running out of conventional energy sources of world, global warming have increased interest in both renewable and biodegradable energy sources and materials. Therefore, passing to natural fibers from synthetic equivalent is extremely valuable in order to produce more green composite materials. Emerging trends in the world natural fiber industry also confirm this fact as shown in Figure 1.8.

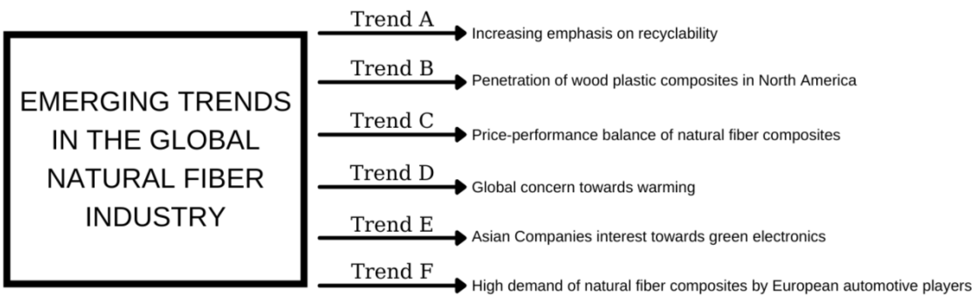


Figure 1.8. Emerging trends in the global natural fiber industry (Lucintel, 2011)

As known, there are possibly big problems in synthetic reinforcement agents such as disposal of them after expiration date. This drawback can be eliminated by natural reinforcement elements since they have compostable characteristics. This study experimentally concentrates production of polymer matrix composite materials which contains various natural fibers as reinforcement elements in order to obtain more environmental friend and cost effective structures. The mechanical performance tests such as tensile, impact and hardness were conducted to show mechanical performance of the specimens. Besides those mechanical characteristics, water absorption capacities and morphological features of the fractured surfaces were also observed.

2. LITERATURE SURVEY

Although synthetic reinforcement elements such as carbon, aramid and glass fibers etc. are commonly used in composite production, sustainability and environmental concerns have directed researchers towards natural reinforcement elements. Renewable and biodegradable nature of natural fibers has gotten attention around the world recently (Yıldızhan et al., 2018).

In composite material production, various natural reinforcement elements were evaluated by researchers in order to reveal their availability. The assessments were generally performed through mechanical tests such as tensile, flexural, impact and hardness etc. and morphological observations with Scanning Electron Microscopy (SEM).

Garkhail et al. (2000) studied mechanical properties of composite material that used flax fibres and polypropylene matrix. They concluded that the stiffness of flax based natural-fibre-mat-reinforced thermoplastics (NMT) was comparable to e-glass based glass-mat-reinforced thermoplastics (GMT). Cost effectiveness of natural-fibre-mat-reinforced thermoplastics is notable due to price-competitive character of flax fibres. They finally revealed that flax based NMTs can compete with glass based GMT in stiffness critical structures. On the other hand, when the strength and impact behaviours are critical in an application, flax based NMTs require being enhanced and optimized.

Kengkhetkit and Amornsakchai (2012) utilized pineapple leaf waste for plastic reinforcement. They reinforced polypropylene with pineapple leaf fibre to show potential application of use.

Graceraj et al. (2016) investigated fatigue strength of the jute fiber reinforced hybrid polymer matrix composites. Blend of cashew nut shell liquid and polyester resin for the improvement of composite structure were used. Use of hybrid polymer with jute fibre as reinforcement element revealed that fatigue strength could be improved. Finally, they suggested that hybrid polymer composite with jute fibre could possibly be used in various application areas such as automotive where cyclic loadings occur.

Sullins et al. (2017) studied the hemp fiber reinforced polypropylene composites. They searched the effects of material treatments on the mechanical behaviors of composite structure. The treatment was realized by chemically treating hemp fiber with sodium hydroxide (NaOH) and/or addition of maleic anhydride grafted polypropylene to the polypropylene matrix. Material treatment enhanced the mechanical properties of the composites.

Ramesh et al., (2014) evaluated the mechanical property of banana fiber reinforced polymer composites. They prepared different samples with various fiber volume fractions by hand lay-up method with epoxy matrix element. The samples were 40% banana fiber + 60% epoxy resin, 50% banana fiber + 50% epoxy resin, 60% banana fiber + 40% epoxy resin. The specimens subjected to tensile, flexural and impact tests. They concluded that 50/50 % for banana fiber and epoxy resin can withstand higher loads in comparison to other volume fractions.

Shahril et al. (2017) studied reinforcement of kenaf fiber in natural rubber composite for automotive engine rubber mounting. They prepared different samples with various kenaf fiber/natural rubber volume fractions as 2/98, 4/96, 6/94 and 0/100 by percent. Highest tensile strain value was obtained with natural rubber with 2% kenaf fiber as 397%. On the other hand, 4% kenaf fiber with natural rubber gave the best tensile strength as 0.46252 MPa.

Techapoowapat and Meesane (2012) studied applicability of the natural bombyx silk fiber polymer composites in medical applications. The results were compared with synthetic carbon fiber polymer composites. Experimental results showed that although synthetic carbon fiber polymer composite exhibited higher mechanical performance including tensile strength, hardness and flexural tests than natural bombyx silk fiber polymer composite, the natural polymer composite had the advantages of lower weight and thickness ratio in comparison to synthetic polymer composites.

Ravindran et al. (2021) synthesized and evaluated the mechanical behaviour of natural fiber (banana and jute) reinforced vinylester hybrid composites. NaOH was used for chemical treatment of natural fibres and vacuum infusion method was chosen for fabrication. Tensile, flexural and impact tests were selected for mechanical characterization. Results showed that tensile strength of jute fiber reinforced composite was higher than banana fiber reinforced composite while mechanical strength of banana fiber reinforced composite was higher than jute fiber reinforced composite.

Chen and Lin (2018) manufactured and investigated the properties of jute and cotton reinforced composites. They used epoxy and polylactic acid (PLA) as thermoset and thermoplastic matrix elements, respectively. The prepared specimens were exerted to tensile, compression and three-point bending tests. Experimental outcomes showed that cotton reinforced both PLA and epoxy composites exhibited similar compressive strengths. Brittle fracture of jute reinforced composites was observed in tensile test. On the other hand, cotton/PLA composite had higher three-point bending break strength than jute/PLA composite.

Prakash et al. (2018) investigated flax fiber reinforced polymer matrix composites. They tried to determine tensile, hardness, impact and chemical features of natural flax fiber reinforced composites. They concluded that increased fiber volume may tend to increase the composite strength. Satisfied results were obtained through impact, hardness and chemical tests for the possible utilization of composite in various engineering applications.

Saradava et al. (2016) characterized hemp fiber reinforced polyester composite mechanically. The composite structure consisted of natural hemp fiber and polyester. Composites were prepared with varying proportions of fiber and resin (percentages of 5/95, 7,5/92,5, 10/90, 12,5/87,5, 15/85 and 17,5/82,5). 10%

fiber + 90% resin composite gave the best properties. Fiber addition improved the compressive strength of composites and authors suggested to use these composites in applications which requires vibration damping and isolation purpose. Eventually, they proposed natural hemp reinforced polyester composite as environmentally friend and sustainable material compared to conventional materials.

Tiwari and Singh (2016) fabricated bamboo/hemp natural fiber reinforced polymer composites. They aimed to find flexural strength of natural fiber reinforced polymer composites. Hemp and bamboo fibers, Epoxy Resin LY 554/6 and Hardener HY951 were utilized for the production of composite structure. Four different samples which were 20% bamboo fiber + 80% epoxy with hardener, 20% hemp&bamboo fiber + 80% epoxy with hardener, 20% hemp fiber + 80% epoxy with hardener, 100% epoxy with hardener were prepared for tests. Lowest flexural strength was obtained as 79.19 MPa for epoxy with hardener (no reinforcement elemet). The flexural strength values of bamboo fiber reinforced epoxy resin, hemp&bamboo fiber reinforced epoxy resin and hemp fiber reinforced epoxy resin were 83.22 MPa, 87.24 MPa and 100.9 MPa, respectively. They obtained improvement on flexural strength values with natural fiber reinforcement agents compared to material generated with pure epoxy resin.

Helaili et al. (2021) identified the mechanical properties of natural alfa plant fiber (tipa tenacissima L.) reinforced epoxy composite. The distribution of alfa fibers was random in structure. Tensile test showed that Alfa fiber reinforced (10% volume fraction) composite increased elastic modulus by 24.16% in comparison to epoxy. Besides that, failure stress has reached to 28.01 MPa value with use of alfa fibers whereas it was 14.64 MPa for unreinforced epoxy.

Atiqah et al. (2020) characterized the impact and hardness properties of honeycomb natural fibre reinforced epoxy composites. Izod impact test and Brinell hardness test were applied to the specimens. Morphological analyses were conducted by Scanning Electron Microscopy (SEM) analysis. Casting method was used for composite production. Reinforcement element and resin were mixed via mechanical stirrer. Samples prepared were 60% epoxy + 40% hardener, 60% epoxy + 37% hardener + 3% honeycomb natural fibre, 60% epoxy + 34% hardener + 6% honeycomb natural fibre, 60% epoxy + 31% hardener + 9% honeycomb natural fibre, 60% epoxy + 28% hardener + 12% honeycomb natural fibre. Among all, highest impact strength and hardness values were obtained as 98 J/m and 58.09 HB, respectively, for the 9% (by weight) honeycomb natural fibre reinforced composite.

Sarikaya et al. (2019) produced different fiber reinforced (birch, palm and eucalyptus) epoxy composites in order to assess their mechanical properties. Birch, palm and eucalyptus reinforced epoxy composites gave 29.53 MPa, 42.24 MPa and 45.28 MPa tensile stress values, respectively. With the same order as tensile results given above, bending stresses were obtained as 58.83 MPa, 68.58 MPa and 79.92 MPa and impact energy values were obtained as 0.105 J, 0.13 J and 0.124 J. They concluded that fiber type strongly affects the mechanical properties of composites.

Ramasamy et al. (2021) characterized hybrid natural/synthetic fiber reinforced epoxy composites. The tensile, flexural, double shear, impact, hardness and de-lamination tests were performed for mechanical characterization. Fabrication of composites was conducted by hand lay-up process. Finally, they agreed that hybridization of reinforcement elements (kenaf fiber + kevlar fiber) improved the mechanical properties of the composites.

Reddy and Hussain (2013) developed and tested natural fiber reinforced composites with polyester resin. Sisal, hemp and combination of sisal/hemp were used as natural reinforcement elements. Mechanical test results were compared with results of normal plastics. Overall of all, sisal/hemp reinforced composites gave the best results.

Siva et al. (2021a) investigated the mechanical properties of hybrid sisal and banana reinforced epoxy composites. Layer stacking was achieved with sequence of sisal-banana-banana-sisal. The results of this hybrid composite were compared with the results of sisal/epoxy and banana/epoxy composites. Results showed that sisal/epoxy composite had the best mechanical features among all. The tensile, flexural and impact strength values were 24.5 MPa, 80.45 MPa and 1.76 J, respectively.

Siva et al. (2021b) evaluated the mechanical properties of sisal/kenaf/aloe vera reinforced hybrid epoxy composites. Different configurations which were sisal/kenaf/aloe vera + epoxy, kenaf/aleo vera/sisal + epoxy, kenaf/sisal/aloe vera + epoxy for hybridization purpose were tried by hand lay-up method in order to fabricate composites. The mechanical properties determined were tensile strength, flexural strength, impact strength and hardness. Results showed that kenaf/sisal/aloe vera + epoxy configuration exhibited highest tensile strength, flexural strength and impact energy whereas sisal/kenaf/aloe vera + epoxy gave highest hardness value of all. Finally, they suggested kenaf/sisal/aloe vera + epoxy arrangement for the possible automobile applications.

Dawit et al. (2021) investigated the mechanical properties of natural acacia tortilis fiber reinforced polyester composite. Composite fabrication was achieved with hand lay-up method. They concluded that acacia tortilis fiber reinforced polyester composite can compete with other natural reinforced composites such as sisal, kenaf and coir composites with its satisfied strength and Young's modulus values.

Nascimento et al. (2021) characterized natural yucca aloifolia L. fiber reinforced polypropylene composites. Polypropylene matrix was reinforced with 10%, 20% and 30% of yucca aloifolia L. fibers. Mechanical characterization was made by tensile test, impact test (Izod) and scanning electron microscopy. The best mechanical analysis results were obtained for 30% fiber composite. Compared to neat polymer matrix, increase of 16.35% in yield strength and increase of 31.69 in Young's modulus were obtained. The results of impact test showed that increased amount of fiber make the composite structure more fragile. As conclusion, yucca aloifolia L. fibers have a big potential to be use in polymer matrix composites.

3. MATERIAL AND METHOD

3.1. Materials

3.1.1. Natural Reinforcement Agent

In this thesis, fabrics of jute and cotton were used as natural reinforcement agents. Fabrics were purchased from a local firm in Adana. Fabrics before preparation of test samples can be seen from Figure 3.1.

Figure 3.1. Fabrics of reinforcement agents

3.1.2. Matrix

Vinyl ester resin was used as matrix element. Besides that, a curing agent and accelerator were utilized in matrix structure. Table 3.1 summarized the properties of materials in matrix.

Table 3.1. Properties of materials in matrix structure

	Resin	**_Curing Agent (Hardener)_**	**_Accelerator_**
Chemical	Vinyl Ester	Methyl Ethyl Ketone Peroxide	Cobalt(II) 2-Ethyl Hexanoate
Brand	-	AKPEROX A60	AKCOBALT KXC6
% used	-	_2% of resin (by weight)_	_%0.2 of resin (by weight)_

3.2. Methods

3.2.1. Vacuum Assisted Resin Transfer Molding (VARTM)

Vacuum assisted resin transfer molding (VARTM) is one of the frequently used techniques in order to produce composite materials. Especially, this technique is proper for mass production. In this method, stacked reinforcement elements in vacuum bag are wet by resin via vacuum force and left for curing. Vacuuming guarantees minimizing air cavities (Yıldızhan, 2020). Figure 3.2 shows the schematic view of VARTM method.

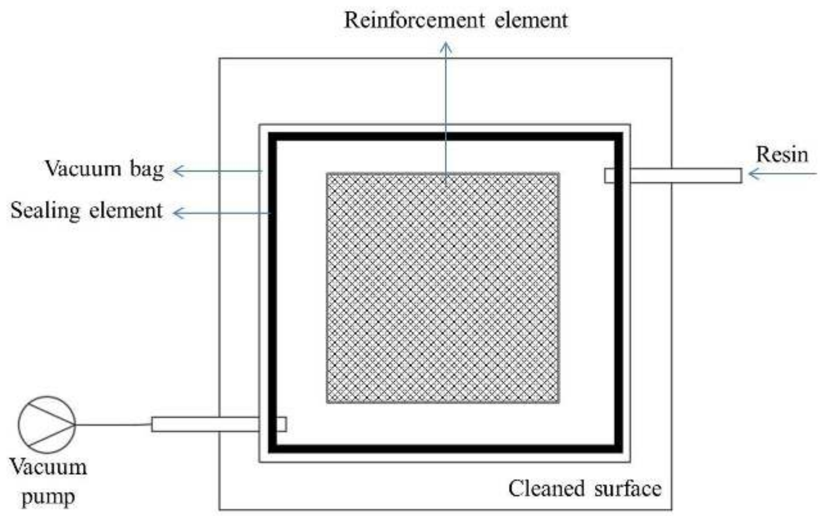


Figure 3.2. VARTM method illustration

3.2.2. Fabrication of Composites

Various natural fabric configurations composed of jute and cotton were stacked layer by layer to produce natural fiber reinforced polymer matrix. Pure jute and pure cotton fabrics were selected as reference specimens in order to see the effects of various configurations. Figure 3.3 revealed the details of configurations used in study.

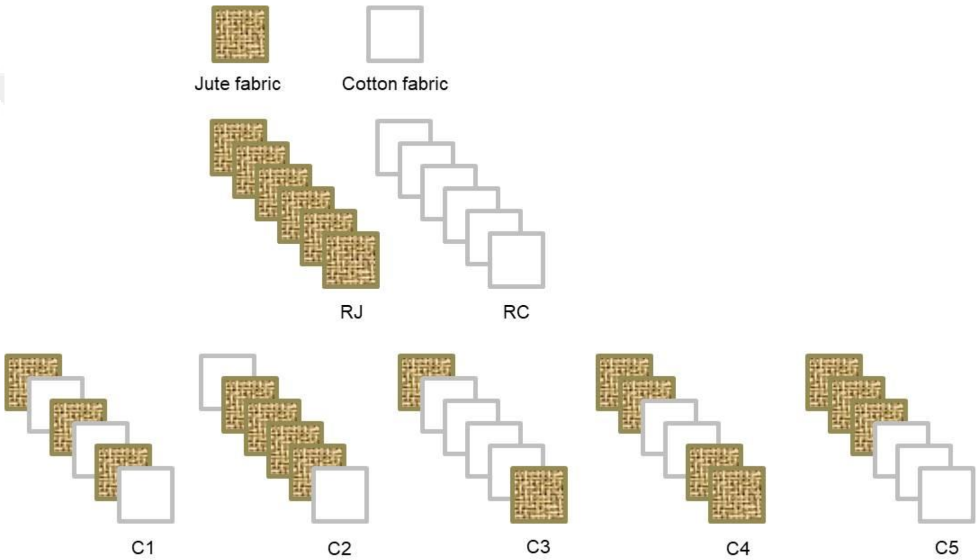


Figure 3.3. Specimen configurations

RJ and RC were reference specimens in order to make comparison between hybrid arrangements of jute and cotton fabrics. On the other hand, C1, C2, C3, C4 and C5 state various configurations which can clearly be seen from Figure 3.3. Tensile test specimens and impact test specimens consisted of 6 and 12 layers of fabrics, respectively. 12 layers were generated by double usage of each fabric shown in above Figure 3.3.

Fabrics were cut with suitable dimensions for tensile and impact test specimens. As shown in Figure 3.4, bigger fabrics were used for production of tensile test specimens whereas smaller fabrics were used for production of impact test specimens.

Figure 3.4. The cut fabrics to produce tensile and impact test specimens

VARTM method was utilized in order to produce natural fiber reinforced composite materials. A table which has a glass surface was used as mold in order to lay the fabrics on it. First of all, table was cleaned with thinner to ensure that surface is perfectly clean. Then, a kind of mold release wax was applied to the surface and left for about 30 minutes. It enables removal of produced composite material from mold easier. Figure 3.5 showed the wax material and application of it.

(i) (ii)

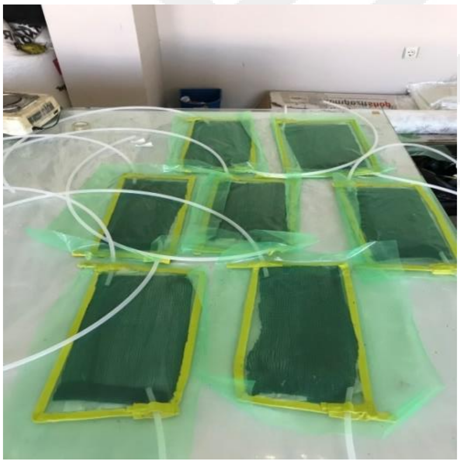
Figure 3.5. (i) Mold release wax (ii) application to the surface

After applying mold release wax, fabrics were laid according to the specified configurations and surrounded by sealing tape. Peel ply and infusion mesh was put on the top of the fabrics. The intent of peel ply usage is to remove the composite material from infusion mesh and vacuum bag easily. Infusion mesh helps distribution of resin along mold properly. Figure 3.6 demonstrated layout of peel ply and infusion mesh on fabrics. Then, two hoses are attached to the rectangular areas shown in Figure 3.7 via sealing tape. Ends of the hoses were connected to the resin container (inlet) and vacuum pump (outlet). Finally the structure was covered with vacuum bag as seen in Figure 3.7 with assuring there was no air leakage through sealing tape and vacuum bag.

(i)

(ii)

Figure 3.6. (i) Peel ply at the top of fabrics (ii) infusion mesh at the top of peel ply



(i)

(ii)

Figure 3.7. (i) Vacuum bag and hose connections (ii) vacuum pump

After all arrangement, the resin was started to inject into a vacuum bag. -760 mmHg value must be seen on vacuum pump to start injection. At that point, vacuum was started and it was cut out after ensuring the fabrics were totally wet. Eventually, the obtained structure was left at room temperature for about 24 hours to be cured. Figure 3.8 illustrated the absorption of resin by reinforcement elements.

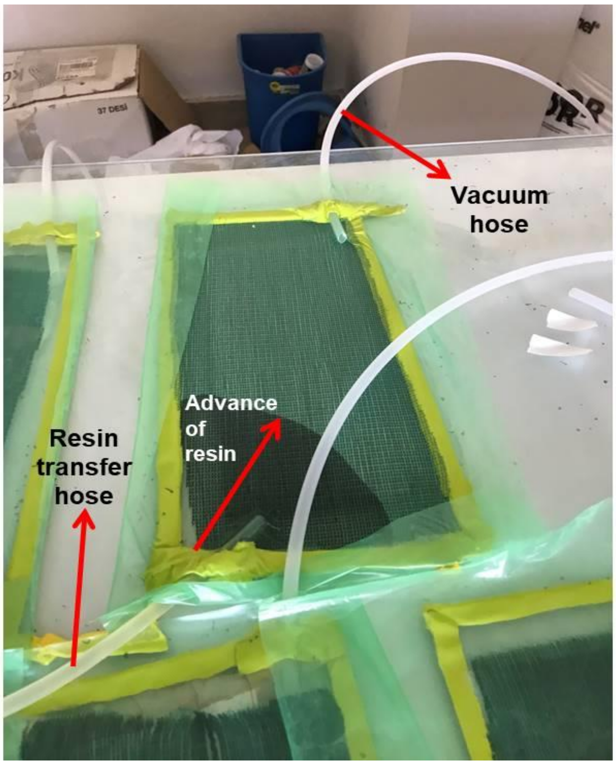


Figure 3.8. Absorption of resin by vacuum force

Figure 3.9 demonstrated the fabricated composites to be cut in accordance with tensile and impact tests at the end of the curing period. After cutting process, the length, width and thickness values of tensile and impact test specimens were 250 mm x 25 mm x 2,5 mm and 125 mm x 12,5 mm x 5 mm, correspondingly, as shown in Figure 3.10.

(i)

(ii)

Figure 3.9. Fabricated composites to be cut for (i) tensile (ii) impact tests

(i) (ii)

Figure 3.10. (i) Tensile (ii) impact test specimens

3.2.3. Experimental Works

3.2.3.1. Tensile Test

Tensile test is one of the fundamental tests in material engineering which characterizes the mechanical performance of the materials. The data obtained from tensile test contains very useful information about the material in order to use in design, analysis and material development steps. Tensile test is realized with applying a force (F) to a specimen from both ends in opposite directions. Applied force will cause to obtain reduced cross-section depending on the elongation of material due to the fact that conservation of matter as shown in Figure 3.11.

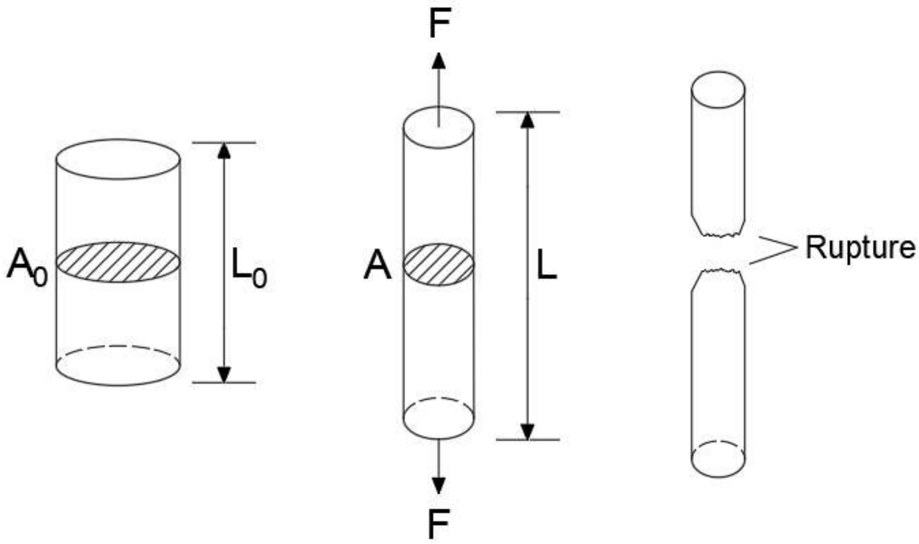


Figure 3.11. Material rupture under tensile test

An engineering stress-strain curve can be obtained after tensile test with the utilization of the following equations. This curve contains valuable outputs about the material such as yield stress, Young's modulus (E), ultimate strength, fracture strength etc.

$$\sigma_E = \frac{F}{A_0} \tag{3.1}$$

$$\varepsilon_E = \frac{L - L_0}{L_0} = \frac{\Delta L}{L_0} \tag{3.2}$$

$$E = \frac{\sigma}{\varepsilon} \quad \text{(valid in elastic region)} \tag{3.3}$$

whereas, σ_E, ε_E, F, A_0, L_0, L, and E are engineering stress, engineering strain, applied load, initial cross-section, initial length, instantaneous length and Young's modulus, respectively. A typical stress-strain curve is illustrated in the Figure 3.12.

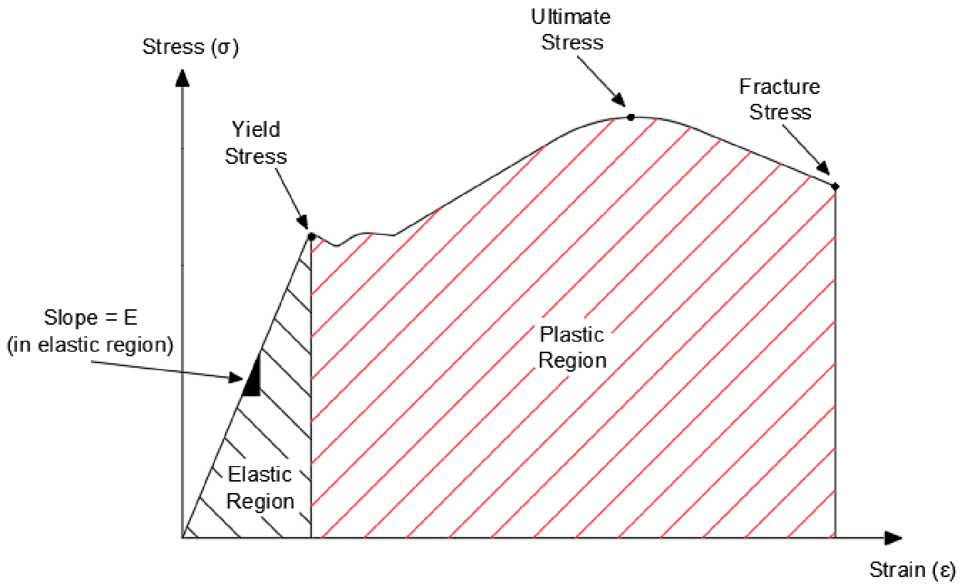


Figure 3.12. A typical stress-strain curve

Tensile tests were performed with 60 tons ALŞA hydraulic tensile test device.

3.2.3.2. Impact Test

Impact test determines the fracture behaviors of materials under dynamic loading conditions. On the other hand, impact resistance of a specimen can be specified through breakage. As shown in the following Figure 3.13, Charpy impact test was conducted in this study. The logic behind the test based on the conservation of energy principle. When the hammer is elevated to height of H, E_1 potential energy is gained to the hammer. Then, the hammer is released and strikes the sample. Finally it rises to height of h with potential energy E_2. It can clearly be seen that there is a difference between the potential energy values at starting position (E_1) and end position (E_2) of hammer. The difference E is absorbed by the sample during the process and can be called as impact energy value.

$$E_1 = mgH \tag{3.4}$$

$$E_2 = mgh \tag{3.5}$$

$$E = E_1 - E_2 \tag{3.6}$$

whereas, m and g are the mass of hammer and gravitational acceleration, respectively.

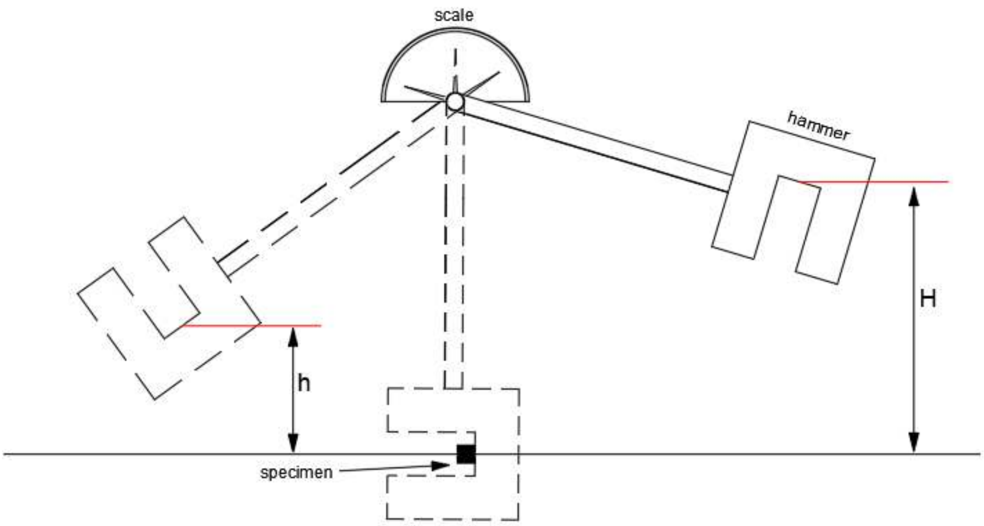


Figure 3.13. Charpy impact test

Charpy Impact Test Device (TOTOMAK) used in tests was demonstrated in Figure 3.14.

Figure 3.14. Charpy impact test device

3.2.3.3. Hardness Test

Hardness of a material can be described as resistance ability to deformation. In this study, a digital Vickers hardness tester (Jiashan - THV-1 MD) was utilized. Figure 3.15 and Table 3.2 demonstrated the hardness test device and device specifications, respectively.

(i) (ii)

Figure 3.15. Vickers hardness tester (ii) interface of tester

Table 3.2. Vickers hardness tester specifications

Brand / Model	Jiashan / THV-1 MD
Test Forces	*0,01 kgf - 0,025 kgf - 0,05 kgf - 0,1 kgf, 0,2 kgf - 0,3 kgf - 0,5 kgf -1 kgf*
Hardness Range	*8HV - 2900HV*
Microscope	*100X for observation 400X for measurement*
Dwell Time	*0 - 60 s*

Vickers hardness calculation can be achieved by the following calculations. F, d_1 and d_2 are applied load and diagonal lengths of indentation area, respectively, as shown in Figure 3.16.

$$HV = 1{,}854\frac{F}{d^2} \tag{3.7}$$

$$d = \frac{d_1+d_2}{2} \tag{3.8}$$

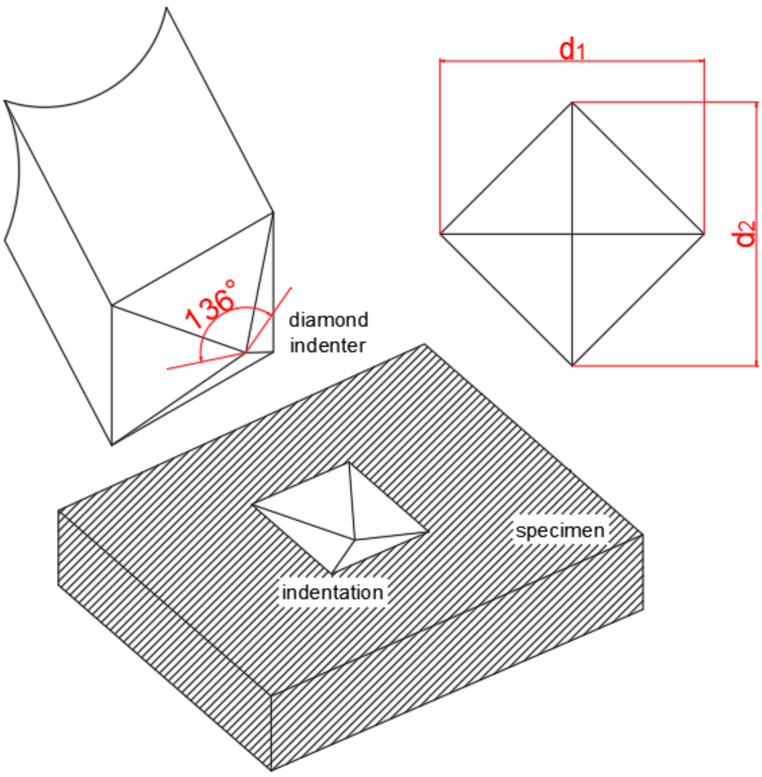


Figure 3.16. Vickers indentation and hardness measurement

3.2.3.4. Water Absorption Test

Water absorption test determines the water absorption capacity of the specimens when they are exposed the water. Specimens are immersed in a container with water and weight measurements were conducted periodically by waiting them in water between certain time periods. The difference between the initial weight before water exposure and weights after water exposure indicates the water absorption capacity of a specimen. Figure 3.17 showed the details of the procedure.

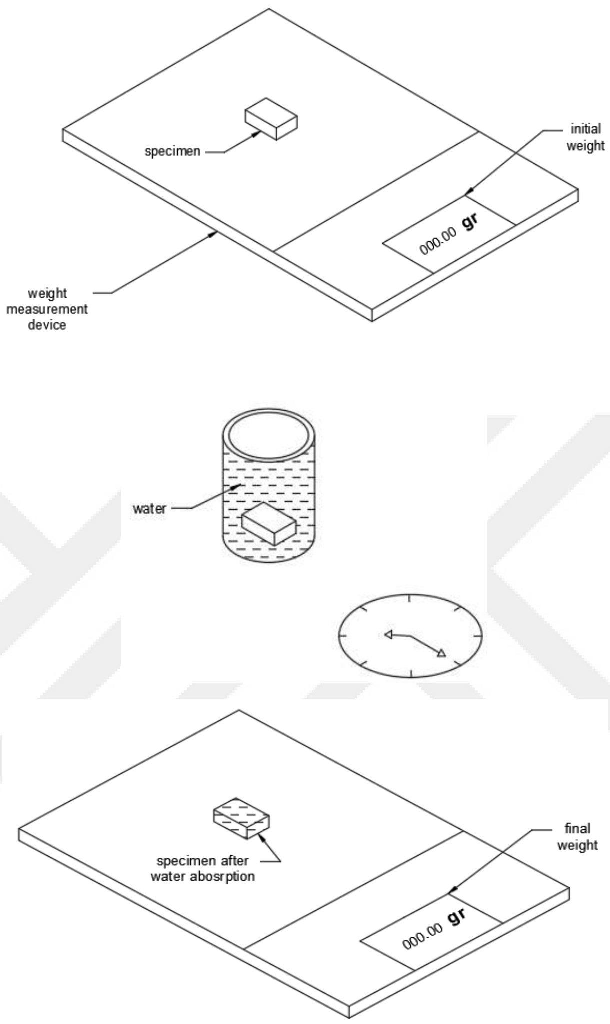


Figure 3.17. Water absorption test procedure

When we stated the initial and final weights with W_i and W_f, the amount of water absorbed by percent (WA) can be calculated with the following formula:

$$\mathrm{WA}\ \% = \frac{W_f - W_i}{W_i} \times 100 \tag{3.9}$$

3.2.3.5. Scanning Electron Microscope (SEM) Analyses

Scanning Electron Microscope (SEM) has the ability of scanning the material surface with electron beam in order to get images from the material. These images can be utilized to interpret morphological features, microstructure and breaking mechanisms by focusing the surfaces. FEI Quanta 650 Field Emission SEM device (Figure 3.18) was utilized in analyses.

Figure 3.18. SEM analysis device

4. RESULTS AND DISCUSSIONS

Tensile tests were conducted in Mersin Ticaret Ve Sanayi Odası Tedarik Zinciri Test ve Ar-Ge Merkezi. Impact, hardness and water absorption tests were performed in Material Laboratory in Automotive Engineering Department of Çukurova University. On the other hand, SEM analyses were conducted in Central Research Laboratory of Çukurova University.

4.1. Tensile Test Results

All tests were performed three times and results were averaged. From Figure 4.1 to Figure 4.4, tensile strength, elongation, yield strength and modulus of elasticity values of materials were illustrated. From Table 4.1 to Table 4.4, change percentages in tensile test results of hybrid arrangements (C1, C2, C3, C4 and C5) with respect to reference specimens (RJ and RC) were given.

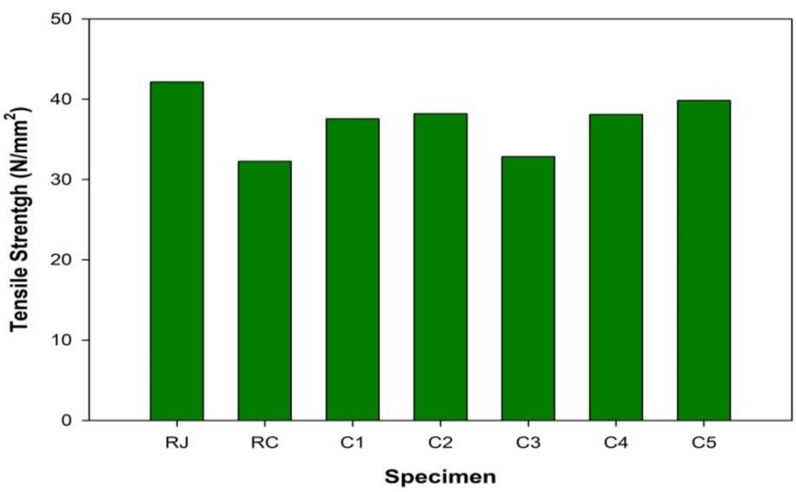


Figure 4.1. Tensile strength values of specimens

Table 4.1. Change percentages of tensile strength with respect to reference specimens

		Tensile Strength (N/mm^2)	Change Compared to RJ (%)	Change Compared to RC (%)
Reference Specimens	RJ	42,16		
	RC	32,25		
Hybrid Arrangements	C1	37,56	-10,91	16,47
	C2	38,19	-9,42	18,42
	C3	32,85	-22,08	1,86
	C4	38,1	-9,63	18,14
	C5	39,85	-5,48	23,57

The minimum tensile strength value was obtained for RC as 32,25 N/mm^2 whereas maximum was 42,16 N/mm^2 for RJ. Tensile strength values of all hybrid arrangements lay between RC and RJ. The tensile strength of all hybrid configurations were enhanced compared to RC and worsened compared to RJ.

Jute fibers have higher strength than cotton fibers (Yıldızhan et al., 2018). Thus, specimen of RJ had the highest tensile strength. C1 and C5 configurations had the same layer numbers of jute and cotton fibers, but C5 configuration had slightly higher tensile strength. This could be due to the better interlaminar interaction of jute and cotton layers with each other. C3 configuration had the lowest tensile strength among other hybrid configurations but it was slightly higher than RC specimen. The jute layers on the top and bottom of the specimen slightly improved the strength but the effect was not significant. The C2 specimen also showed lower performance than RJ specimen due to the effect of cotton layers on the top and bottom of the specimen. The adhesion and interlaminar interactions of jute and cotton fibers were the main reasons for the decrements when jute and cotton fibers were combined.

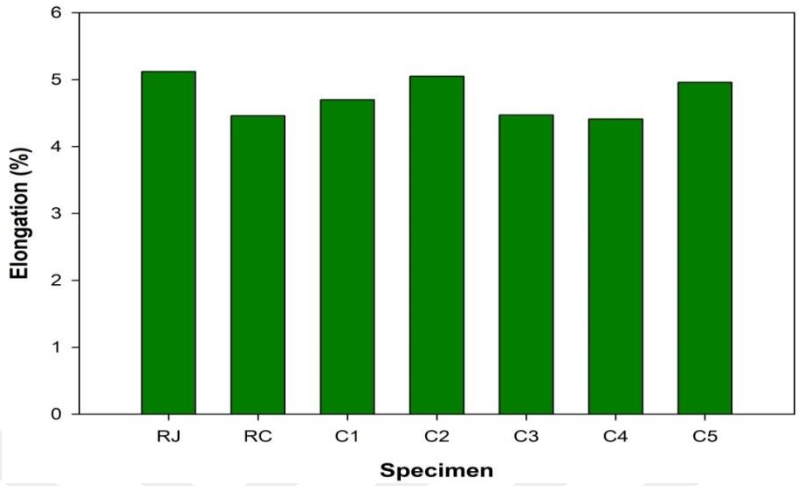


Figure 4.2. Elongation values of specimens

Table 4.2. Change percentages of elongation with respect to reference specimens

		Elongation (%)	Change Compared to RJ (%)	Change Compared to RC (%)
Reference Specimens	RJ	5,12		
	RC	4,46		
Hybrid Arrangements	C1	4,7	-8,20	5,38
	C2	5,05	-1,37	13,23
	C3	4,47	-12,7	0,22
	C4	4,41	-13,87	-1,12
	C5	4,96	-3,13	11,21

The minimum elongation value was obtained for C4 as 4,41 (%) whereas maximum was 5,12 (%) for RJ.

The elongation values at break point of jute and cotton fibers were given as 1,5-10 % and 3-10 %, respectively (Yıldızhan et al., 2018). The cotton fibers have higher elongation values. But the experimental results showed that when those fibers are used for composite material fabrication, the decisive parameter for the elongation of the specimens is the matrix material. When experimental results were examined, the elongation values were quite similar with no meaningful differences since all the composites were fabricated with the same matrix material.

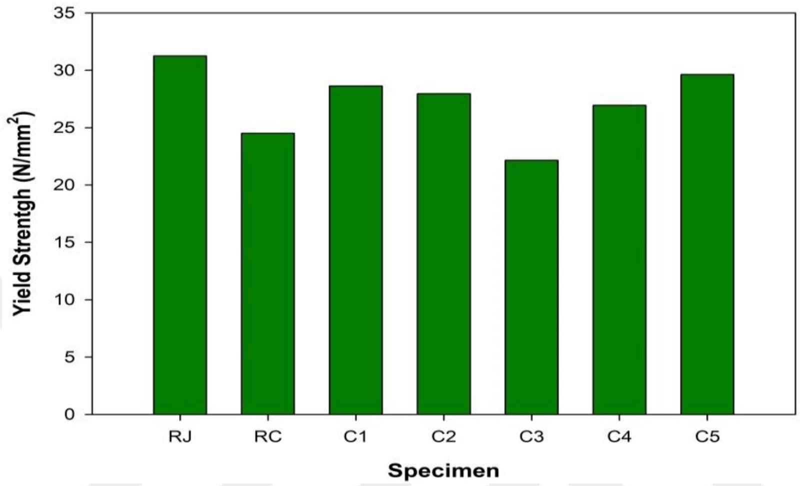


Figure 4.3. Yield strength values of specimens

Table 4.3. Change percentages of yield strength with respect to reference specimens

		Yield Strength (N/mm^2)	Change Compared to RJ (%)	Change Compared to RC (%)
Reference Specimens	RJ	31,25		
	RC	24,51		
Hybrid Arrangements	C1	28,63	-8,38	16,81
	C2	27,96	-10,53	14,08
	C3	22,15	-29,12	-9,63
	C4	26,95	-13,76	9,96
	C5	29,63	-5,18	20,89

The minimum yield strength value was obtained for C3 as 22,15 N/mm^2 whereas maximum was 31,25 N/mm^2 for RJ.

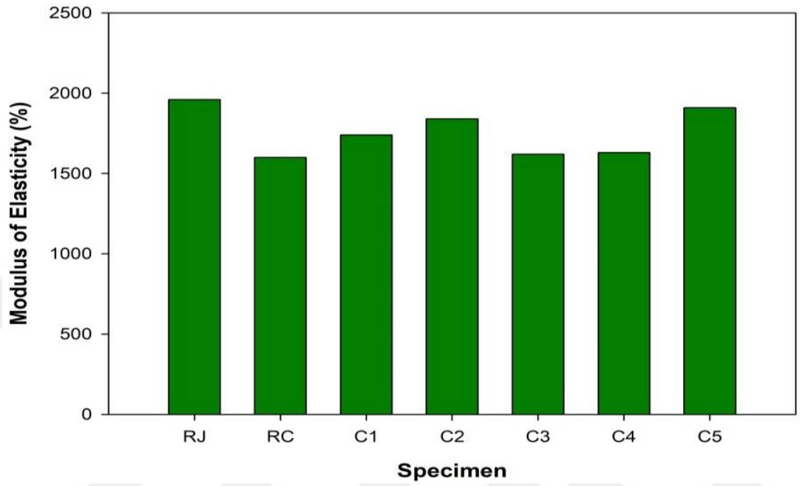


Figure 4.4. Modulus of elasticity values of specimens

Table 4.4. Change percentages of modulus of elasticity with respect to reference specimens

		Modulus of Elasticity (MPa)	Change Compared to RJ (%)	Change Compared to RC (%)
Reference Specimens	RJ	1960		
	RC	1600		
Hybrid Arrangements	C1	1740	-11,22	8,75
	C2	1840	-6,12	15
	C3	1620	-17,35	1,25
	C4	1630	-16,84	1,875
	C5	1910	-2,55	19,375

The minimum modulus of elasticity value was obtained for RC as 1600 MPa whereas maximum was 1960 MPa for RJ. Modulus of elasticity values of all hybrid arrangements lay between RC and RJ.

The C5 showed higher modulus of elasticity than C1 even the layer numbers were equal. This could be due to the better interfacial adhesion of jute and cotton layers with each other. The lowest value was for C4 specimen. This could be due to the poor adhesion of cotton fibers in the center of the specimen.

4.2. Impact Test Results

Impact test results of the composite samples are given in Table 4.5. The results show that RC had lower impact energy than RJ. With the hybridization, the impact energies were within the range of reference samples of RJ and RC. The results shows that the hybrid samples show higher impact energy when the jute reinforcement is dominant. The highest impact energy was found as 51±2,7 when the reference specimen of jute (RJ) was tested.

Table 4.5. Impact test results of composite specimens

		Impact Energies (J)
Reference Specimens	RJ	51±2,7
	RC	43±3,5
Hybrid Arrangements	C1	47±5,3
	C2	49±2,5
	C3	44±4,8
	C4	48±3,6
	C5	45±5,1

The higher impact energy absorption of the jute dominated composites was observed after the test results and the higher energy absorption of the jute composites are parallel to the tensile test results. Due to the higher strength of jute fibers and better compatibility with the material jute dominant samples showed better mechanical performance than the cotton dominated composites. The configurations on the other had slight effect on the impact properties of the composite samples. The effect of used fiber in the sample had more viable effect than the configuration itself.

4.3. Hardness Test Results

The hardness results of the specimens are given in Table 4.6. The results revealed that the combination of the fibers laminated has no significant effect on surface hardness. It was seen that the hardness values are dominated by the matrix material and there was slight matrix layer on all composites that covers the fiber materials. Thus, the hardness values of all composites were similar to each other.

Table 4.6. Hardness test results of the composite specimens

		Hardness (HV) (1 kgf load and 10 seconds dwell time)
Reference Specimens	RJ	12.55±1,3
	RC	10,11±1,4
Hybrid Arrangements	C1	10,25±1,1
	C2	10.20±1,05
	C3	12,64±1,5
	C4	12,72±1,1
	C5	11,10±1,1

The hardness test results revealed that there are not meaningful effects of the fiber type or the configuration. The determinative parameter for the surface hardness values of the samples was the matrix material. Since the material was same for all the composite samples, the hardness values were quite similar to each other.

4.4. Water Absorption Test Results

Each specimen was waited in a water container and weight measurements were conducted at certain time periods in order to see how the absorbed water in materials changed with time. After the samples were placed in water, measurements were taken hourly for the first 6 hours. Other measurements were taken at 24, 48 and 120 hours after the specimens were placed in container. The weights at 0 hour correspond to the dry weights of each specimen. From Figure 4.5 to Figure 4.11, measurements were showed graphically.

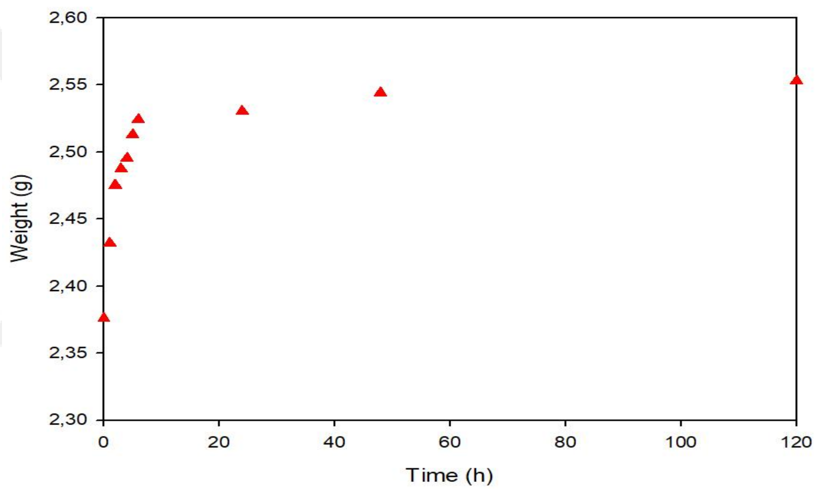


Figure 4.5. Water absorption results of RJ

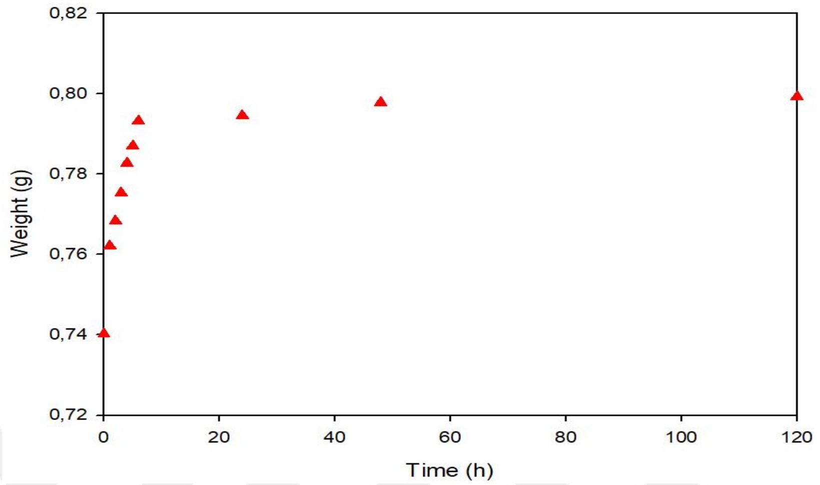


Figure 4.6. Water absorption results of RC

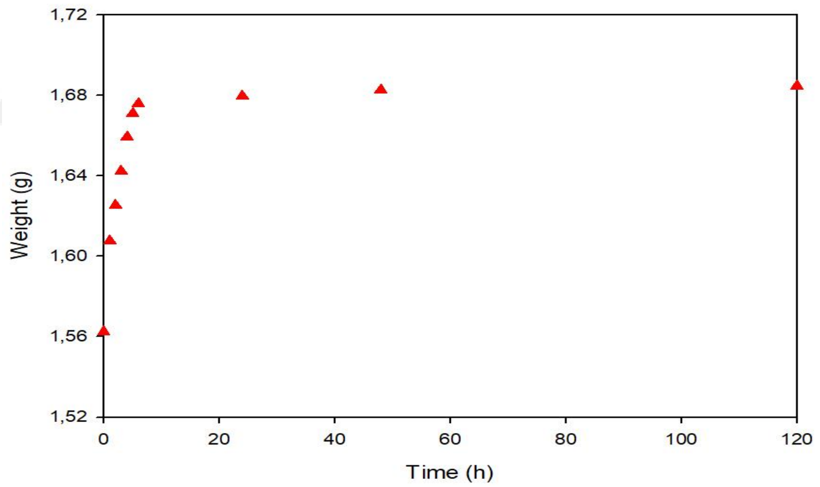


Figure 4.7. Water absorption results of C1

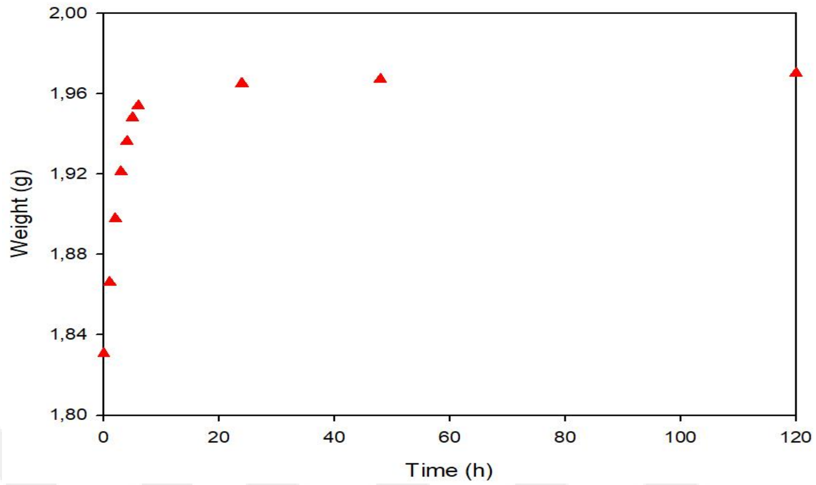


Figure 4.8. Water absorption results of C2

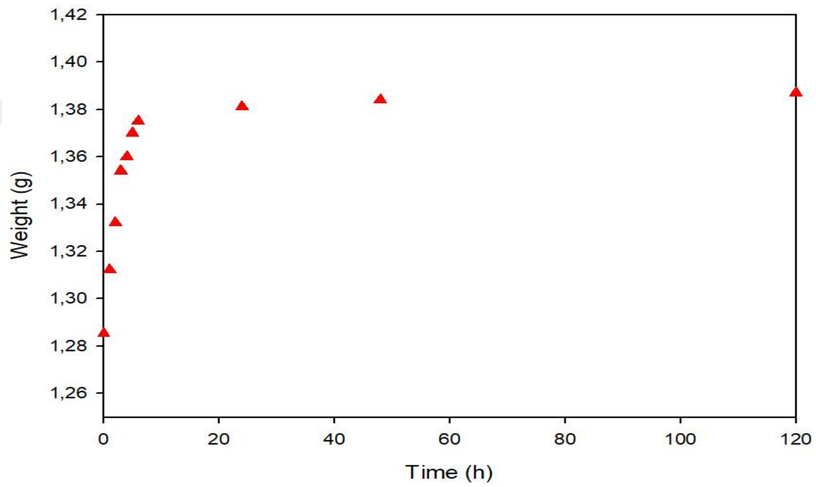


Figure 4.9. Water absorption results of C3

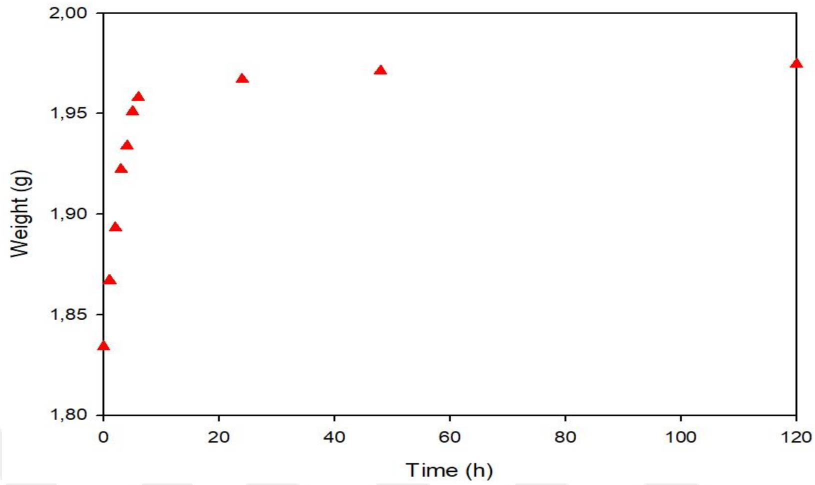


Figure 4.10. Water absorption results of C4

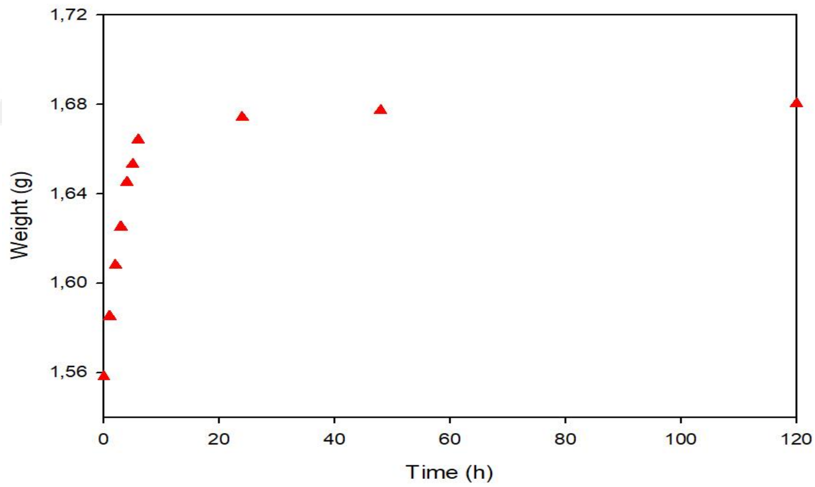


Figure 4.11. Water absorption results of C5

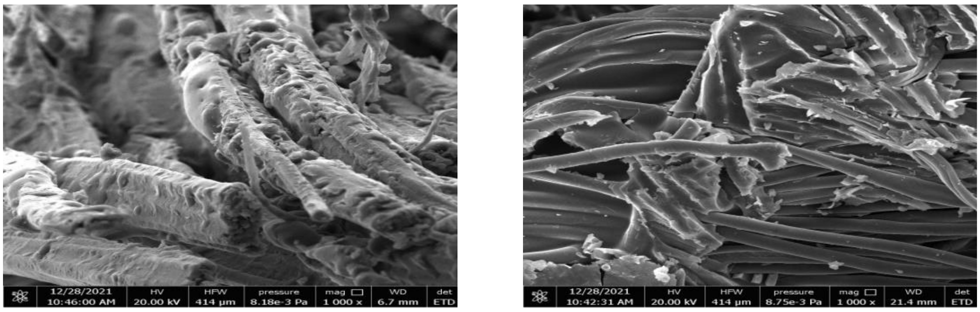
Table 4.7. Water absorptions (%)

	*Water Absorption (%)**						
Time (h)	***RJ***	***RC***	***C1***	***C2***	***C3***	***C4***	***C5***
1	2,36	2,95	2,88	1,93	2,08	1,79	1,74
2	4,17	3,81	4,01	3,67	3,63	3,21	3,22
3	4,67	4,75	5,11	4,94	5,34	4,79	4,31
4	5,01	5,75	6,19	5,76	5,80	5,44	5,59
5	5,75	6,33	6,94	6,41	6,58	6,37	6,10
6	6,23	7,16	7,25	6,74	6,97	6,75	6,81
24	6,48	7,35	7,50	7,34	7,44	7,24	7,45
48	7,07	7,78	7,69	7,45	7,67	7,47	7,64
120	7,45	7,98	7,82	7,62	7,90	7,65	7,84

**Each % values were given compared to dry weight of specimens*

4.5. SEM (Scanning Electron Microscope) Analyses Results

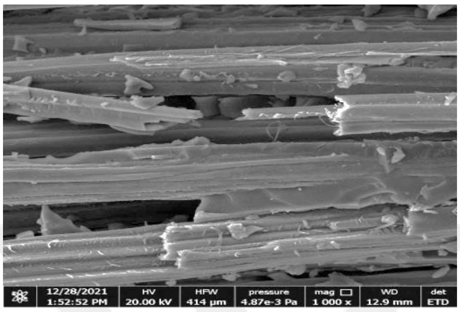
As seen from the Figure 4.12 and Figure 4.13 that SEM images of test specimens were obtained through their fractured surfaces after performing of tensile test. SEM images contribute to evaluate the microstructure and fracture mechanisms of the specimens.



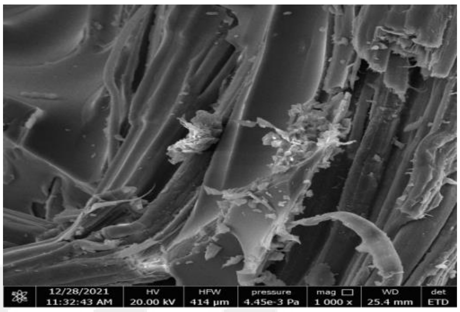
(i) (ii)

Figure 4.12. 1000x SEM image of (i) RJ (ii) RC

It is understood from the SEM images that jute fibers had better compatibility with the matrix material. The higher tensile strength and impact energies of the reference jute samples and jute dominant arrangements can be explained with better compatibility. From the SEM images, it is seen that breakages of jute fibers were occurred with a more ductile manner than cotton fibers. The low interphase strength of cotton and matrix material caused lower tensile and impact strength.

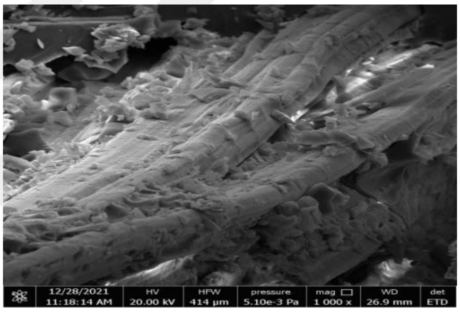


(i)

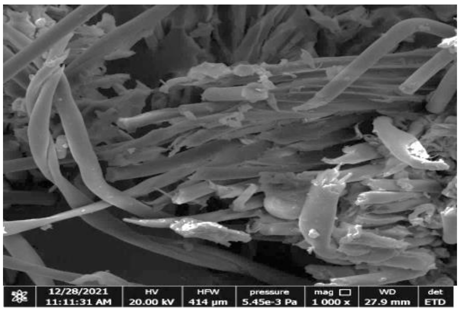


(ii)

(iii)



(iv)



(v)

Figure 4.13. 1000x SEM images of (i) C1 (ii) C2 (iii) C3 (iv) C4 (v) C5

From the SEM images the fiber pullouts and fiber bucklings are observable. The most of the failures occurred due to fiber pullouts. Fiber breakages indicate that a good interphase adhesion was maintained especially for the jute fibers but, the cotton fibers had lower interphase adhesion strength in comparison with jute fibers. Due to higher strength and better interaction with material, jute fiber dominated samples showed better mechanical performance and the SEM images supports these findings.

5. CONCLUSIONS

In this thesis, effects of natural reinforcement elements on mechanical characteristics of polymer matrix composites were investigated. Jute and cotton fabrics as reinforcement agents and vinyl ester as matrix element were utilized to be used in order to fabricate composites with VARTM technique. Besides pure jute and cotton, various configurations of them were also evaluated in composite structures and results were compared. Tensile test, impact test, hardness test, water absorption capacity test and SEM analysis were performed and following conclusions can be sequenced through experiments:

- The minimum tensile strength value was obtained for RC as 32,25 N/mm^2 whereas maximum was 42,16 N/mm^2 for RJ. Tensile strength values of all hybrid arrangements lay between RC and RJ. Jute fibers in hybrid arrangements improved the tensile strength of composites.
- The minimum elongation value was obtained for C4 as 4,41 (%) whereas maximum was 5,12 (%) for RJ. Elongation values were quite similar since decisive parameter is matrix material on this behavior.
- The minimum yield strength value was obtained for C3 as 22,15 N/mm^2 whereas maximum was 31,25 N/mm^2 for RJ.
- The minimum modulus of elasticity value was obtained for RC as 1600 MPa whereas maximum was 1960 MPa for RJ. Modulus of elasticity values of all hybrid arrangements lay between RC and RJ.
- The highest impact energy was found as 51±2,7 J when the RJ was tested whereas lowest was 43±3,5 J for RC . With the hybridization, the impact energies were within the range of reference samples of RJ and RC. Jute dominant configurations showed better impact energy performance since higher strength values of jute fibers.

- The results revealed that the combination of the fibers laminated has no significant effect on surface hardness. The decisive parameter is matrix material for hardness values. The hardness of RJ and RC were 12.55±1,3 and 10,11±1,4, respectively. The hardness values of all reference and hybrid composites were similar to each other.
- Water absorption percentages were similar for all composites. At the end of the 120 hours, the percentage values of all configurations laid between 7,45 (for RJ) and 7,98 (for RC).
- As seen from SEM images, jute and jute dominant reinforced composites had better compatibility with the matrix material.

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