IMPROVEMENT of MECHANICAL PROPERTIES of NATURAL JUTE FIBER REINFORCED COMPOSITES by SURFACE MODIFICATION PROCESS

MASTER of SCIENCE THESIS

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We have read the thesis entitled **"IMPROVEMENT of MECHANICAL PROPERTIES of NATURAL JUTE FIBER REINFORCED COMPOSITES by SURFACE MODIFICATION PROCESS"** completed by **NARİN KARABULUT** under supervision of **ASSOC. PROF. DR. MEHMET AKTAŞ** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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THESIS DECLARATION

I declare that the thesis work presented here is, to the best of my knowledge an belief, original and the result of my own investigations, either in part or whole, with due to reference to the literature and acknowledgement of collaborative research and discussions. This master thesis was completed under the guidance of Assoc. Prof. Dr. Mehmet AKTAŞ, at the Graduate School of Natural and Applied Sciences of Uşak University.

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IMPROVEMENT of MECHANICAL PROPERTIES of NATURAL JUTE FIBER REINFORCED COMPOSITES by SURFACE MODIFICATION PROCESS

(M.Sc. Thesis)

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ABSTRACT

In this study, the effect of fabric surface modification has been investigated on the mechanical properties of woven jute fabric reinforced laminated composite plates.

Primarily, woven jute fabrics have been retained in the rate of 2% NaOH solution for 20 hours. Then, the woven jute fabrics have been allowed to dry at room temperature during 3 days. Dried fabrics have been again retained at room temperature for 15 days after processing them in the NaOH solution in the ratio of 5%, 10% and 15% for 4 hours. The woven jute fabrics were placed into an oven at 70 celcius degrees for 30 minutes in order to eliminate the humidity.

For the investigation of the effect of different thermoset resins on the mechanical properties (tensile, compression and shear) of woven jute fabrics, which have expose to surface modification process, woven jute epoxy, woven jute polyester and woven jute vinylester laminated composite plates were manufacture by using epoxy, polyester and vinylester resins.

The woven jute reinforced laminated composites have been produced by hand lay-up method at 8MPa pressure and 105°C by using the temperature and time controlled hydraulic press. After test samples were cut according to ASTM standards, the mechanical properties (tensile, compression and shear) of them were determined by using UTEST universal tensile-compression test device with 50kN load capacity at

1mm/min cross-head velocity. The mechanical properties (tensile, compression and shear) of woven jute reinforced composite test samples were determined at room temperature.

As a result of experiments, the mechanical properties of woven jute/epoxy laminated composites have been occurred higher than the mechanical properties of woven jute/polyester and woven jute vinylester. The mechanical properties increase up to a certain ratio of NaOH after this level they decrease.

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DOĞAL JÜT LİFİ TAKVİYELİ KOMPOZİTLERİN MEKANİK ÖZELLİKLERİNİN YÜZEY MODİFİKASYON İŞLEMİYLE İYİLEŞTİRİLMESİ

(Yüksek Lisans Tezi)

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ÖZET

Bu çalışmada; dokuma jüt kumaş takviyeli kompozit plakaların mekanik özelliklerine kumaş yüzey modifikasyonun etkisi incelenmiştir. Öncelikle dokuma jüt kumaşlar %2 oranındaki NaOH çözeltisinde 20 saat bekletilmiştir. Daha sonra, dokuma Jüt kumaşlar 3 gün boyunca oda sıcaklığında kurumaya bırakılmıştır. Kurutulmuş kumaşlar %5, %10 ve %15 oranında NaOH çözeltisinde 4 saat bekletildikten sonra tekrar oda sıcaklığında 15 gün boyunca bekletilmiştir. Daha sonra dokuma jüt kumaşların nemini almak için etüvde (70°C) 30 dakika bekletilmiştir.

Farklı termoset reçinelerin yüzey modifikasyonu işlemine tabi tutulmuş dokuma jüt kumaşların mekanik özelliklerine (çeki, bası ve kayma) etkisini incelemek için epoksi, polyester ve vinilester reçineler kullanılarak dokuma jüt/epoksi, dokuma jüt/polyester ve dokuma jüt/vinilester tabakalı kompozit plakalar üretilmiştir.

Dokuma jüt takviyeli tabakalı kompozitler ısı ve zaman kontrollü hidrolik preste 105°C ve 8MPa basınç altında el yatırma yöntemi ile üretilmiştir. Deney numuneleri ASTM standartlarına göre kesildikten sonra mekanik özellikleri (çeki, bası ve kayma) 50kN kapasiteli UTEST üniversal çekme-basma cihazında 1mm/dak. hızda belirlenmiştir. Dokuma jüt takviyeli kompozit deney numunelerinin mekanik özellikleri (çeki, bası ve kayma) oda sıcaklığında belirlenmiştir.

Deneyler sonucunda dokuma jüt/epoksi tabakalı kompozitlerin mekanik özellikleri genel itibariyle dokuma jüt/polyester ve dokuma jüt/vinilester tabakalı kompozitlerin mekanik özelliklerinden daha yüksek çıkmıştır. Mekanik özellikler belirli bir NaOH oranına kadar artarken sonrasında azalmaktadır.

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CHAPTER ONE
INTRODUCTION

1.1 Introduction

Composite materials play an important role in many engineering applications due to their superior properties such as high strength to weight ratio, high stiffness, durability, corrosion resistance and fatigue resistance. These entire features find in a single material is an extremely rare condition.

In general; the composites have just two phases, one of them is continues phase as matrix and the other is dispersed phase as particulate or fiber. The composite materials can be classified based on matrix phase as metal-matrix composites (MMC), ceramic-matrix composites (CMC) and polymer -matrix composites (PMC).

In recent years, polymer-matrix composites (PMC) are being used in many applications such as automotive, sporting goods, marine, electrical and industrial constructions, household appliances, etc. due to their high strength and stiffness, lightweight and high corrosion resistance [1].

Polymer is also classified into two categories as thermoplastics (polyethylene, polyether ether ketone, polyvinyl chloride, polystyrene, polyolefin etc.) and thermosets (epoxy, polyester, vinylester and phenol-formaldehyde etc.) which reinforce different types of fibers like natural (plant, animal, mineral) and man-made fibers for different applications [2].

Nowadays, various types of natural fibers have been investigated for use in composites including flax, hemp, jute straw, wood, rice husk, wheat, barley, oats, rye, cane (sugar and bamboo), grass, reeds, kenaf, ramie, oil palm, water hyacinth, kapok, paper mulberry, banana fiber, sisal, coir and papyrus [2].

The large amount of hydroxyl group in cellulose gives natural fiber hydrophilic properties and the adhesion between the fibers and polymer matrices is generally insufficient. Poor interfacial adhesion leads to a decline in mechanical properties of the composites and reduce their potential as reinforcement [3-5].

The poor interfacial adhesion in natural fiber reinforced composites can be improved by surface treatment. Chemical treatments such as alkali, silane, acetylation and isocyanides can be increased the interface adhesion between the fiber and matrix. Also, the water absorption of natural fiber reinforced composites can be decreased by these chemical treatments. Alkaline treatment and mercerization is the most used chemical treatments of natural fibers for thermoplastics and thermosets [3].

The natural fibers are increasingly used in the last decade due to their biodegradable, recycled and especially do not damage to the human body.

In this thesis; the mechanical properties of woven jute/epoxy, woven jute/polyester and woven jute/vinylester laminated composites were investigated after surface modification by different NaOH solution such as 0% (untreated), 5%, 10% and 15%.

1.2 Literature Review

The composites based on natural fibers are embedded in thermoset matrices such as epoxy, polyester, vinylester, phenol formalaldehyde, etc., after surface modification. Afterwards, the mechanical properties particularly interlaminar shear stress can be improved by surface modification. Therefore, treatments of natural fibers are the common scientific phenomenon as discussed below:

Gassan and Bledzki [6] have improved the mechanical properties of unidirectional jute/epoxy composites up to 60% by treating the surface of fibers at 26% NaOH solution in weight for 20 minutes at 20^oC. Ray et al. [7] have treated the 35 wt% jute fiber reinforced vinylester composites for 0, 2, 4, 6 and 8 hours at 30°C. Afterwards, jute/vinylester composites were subjected 5% NaOH solution for 4 hours. Subsequently, they have observed that approximately 20%, 23% and 19% improvement in the flexural strength, the flexural modulus and the interlaminar shear strength, respectively.

Liu and Dai [8] have increased the interlaminar shear strength of jute/polypropylene composites after alkali procedure. And they have observed that the jute fibers have uneven surface after alkali process. Seki [9] has treated interfacial strength of jute/epoxy and jute/polyester by treatment with 5% NaOH concentration and also by siloxane bonding agent. After that the interfacial strength of composites was increased from 13 MPa to 19.85 MPa for epoxy resin and it was increased from 8.82 MPa to 17.64 MPa for polyester resin.

Razera and Frollini [10] have investigated the properties of jute/phenolic composites after 5% NaOH surface treatment. They have reported that the mechanical properties of composites were increased, while the moisture absorption of them was reduced. Weyenberg et al. [11] have increased the tensile strength and the modulus of flax fiber reinforced composites about 30% after alkali process by expelling the pectin substance from fiber. Mishra et al. [12] have determined the tensile strength of sisal reinforced composites under high rate condition following embedding the sisal fibers in 5% NaOH solution.

Park et al. [13] have examined the surface shear stress on the jute reinforced polypropylene composites treated with siloxane. They have reported that the surface shear stress was increased after treatment process. Gassan and Gutowski [14] have investigated the mechanical properties of jute/epoxy composites after oxygen plasma and UV light applications. They have observed that the oxidation procedure decreases the strength of jute fiber reinforced epoxy composites. Also they have reported that the mechanical properties of jute reinforced composites can be improved with the application of UV light. Xu et al. [15] have investigated the morphological, dehumidification and staining characteristics of bamboo fiber by alkali treatment as argon plasma. They have reported that the surface roughness of bamboo fiber was increased after argon plasma process.

Seki et al. [16] have reported that the interlaminar shear resistance of jute/polyester composites subjected to low and radio frequency can be improved by oxygen plasma process up to 72% and 129%, respectively. Mäder and Gliesche [17] have investigated the flexural strength and flexural modulus of flax/epoxy and ramie/epoxy composites. The flax and ramie fibers were embedded in 3% silane solution at 80°C. They have found out that the flexural strength of flax/epoxy composites was reduced and the flexural modulus of flax/epoxy composites was increased about 20%, however, a remarkable increase in the flexural strength and nearly 20% increase in the flexural modulus was occurred in the ramie/epoxy composites. Sever et al. [18] have examined the effect of different silane binding substance on the mechanical properties of the jute/polyester composites. They have reported that the best interfacial resistance between the jute fiber and polyester was provided in the case of 0.3% silane binding substance.

Nair et al. [19] have done an experimental study to investigate the thermal stability of sisal fibers reinforced polystyrene matrix composites. The sisal fibers was retained in 18% NaOH solution and then it was embedded to a solution of glacial acetic acid and finally it was kept in a solution of acetic anhydride containing H_2SO_4 for 1 hour. They have seen that the thermal stability of sisal/polystyrene composite was markedly modified. In addition to this the sisal fiber has roughly surface after this kind of alkali processing. Khan et al. [20] have investigated the mechanical and thermal properties of jute/polypropylene composites after treatment with potassium dichromate. They have concluded that the best mechanical performance was occurred at 0.02% potassium dichromate concentration. However, alkali treatment was not affected the thermal properties of jute/polypropylene composites.

Mohanty et al. [21] have examined the bending resistance of jute/polypropylene composites after surface modification with MAH_gPP binding substance. The bending resistance of jute/polypropylene composites is increased up to 72.3% at 5% MAH_gPP

solution. Alawar [22] has studied the mechanical properties of date palm fiber after soda and hydrochloric acid treatments. The results showed that the remarkable increase in tensile strength and considerable improvement in surface morphology were occurred. However, hydrochloric acid was negatively affected the tensile strength and surface of date palm fibers. Mohanty et al. [23] have examined the influence of the chemical surface modification on the properties of biodegradable jute/polyester composites. The effect of different treatments on the fiber surface was investigated. Results showed that the mechanical properties of jute/polyester composites like tensile and bending strengths were increased as a result of surface modification. The tensile strength of biodegradable polyester was increased more than 40% as a result of reinforcement with jute fabric, which was treated by alkali process.

Prasad et al. [24] have done a study to improve the tensile strength, Young’s modulus and flexural strength of coir fiber/polyester composites subjected to alkali treatment as 5% NaOH at 28°C. An improvement of the tensile strength and Young’s modulus of the composites was observed up to 15% and 40%, respectively. In addition the alkali treatment on the coir fiber was improved the flexural strength of the polyester resin composites nearly 40%. Sydenstricker et al. [25] have observed that the shear strength of sisal/polyester composites was increased from 2.6MPa to 6.9MPa in the case of fiber surface treatment by 2% NaOH at room temperature for 1 hour.

Aktaş [26] have investigated the temperature effect on the mechanical and the impact behavior of glass/epoxy laminated composite plates. As a result of this study; the energy absorbed capability, mechanical properties and CAI strength of the composite plates based on polymer were decreased by increasing temperature. Sarıkanat [27] has examined the influence of 3% oligomeric siloxane concentration on the tensile, flexural and interlaminar shear (ILSS) strengths of the alkalized jute/epoxy composites. The results from this study showed that the ILSS strength was increased from 14.18MPa to 22.82MPa for alkalized jute/epoxy composites.

1.3 Purpose of Thesis

The mechanical properties especially interlaminar shear stress of natural fibers/fabrics reinforced composite laminated plates can be increased by surface modification such as alkali, plasma, corona discharge, heat treatment etc. Oil, hemicelluloses, pectin and other unknown materials are removed from fiber surface by these modification methods. Therefore, in this study, the mechanical properties of woven jute/epoxy, woven jute/polyester and woven jute/vinylester laminated composites were determined by using a remarkable surface modification process as NaOH treatment. For this purpose, woven jute fabrics were subjected to 5%, 10% and 15% NaOH solution to modify the interface strength between woven jute and different resins such as epoxy, polyester and vinylester. The mechanical properties of these natural composite structures were also determined without surface modification (0% NaOH) for compression to treated (5%, 10% and 15% NaOH) composite structures.

1.4 Thesis Outlines

This thesis is organized into six chapters. **Chapter 2** will be talk about the types of composite materials, manufacturing processes of polymeric composites, application areas of composites, and finally, natural fibers used in composite materials. **Chapter 3** will be concern about the surface modification processes, which can be increased the adhesion resistance between the matrix and fibers. **Chapter 4** will be discussed the determination of mechanical properties of composites, theoretically. **Chapter 5** also consists of three sub-chapters. First sub-chapter deals with the surface modification process to the woven jute fabric at different NaOH solutions. Second sub-chapter is about the manufacturing process of woven jute/epoxy, woven jute/polyester and woven jute/vinylester laminated composites. Final sub-chapter talks about the determination of mechanical properties of composites, experimentally. **Chapter 6** contains conclusion of experimental results and discussion.

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CHAPTER TWO

COMPOSITES and NATURAL FIBERS

2.1 Definition of Composites

Composite materials are made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with different characteristics from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter or less expensive when compared to traditional materials [28].

Although; the car seen in figure 2.1 has been produced carbon, kevlar and glass fibers for obtaining minimum stiffness and maximum lightweight, the different structures of composite materials were used in the construction of aircraft (Figure 2.2).

Figure 2.1 A car produced by carbon, kevlar and glass fibers [29]

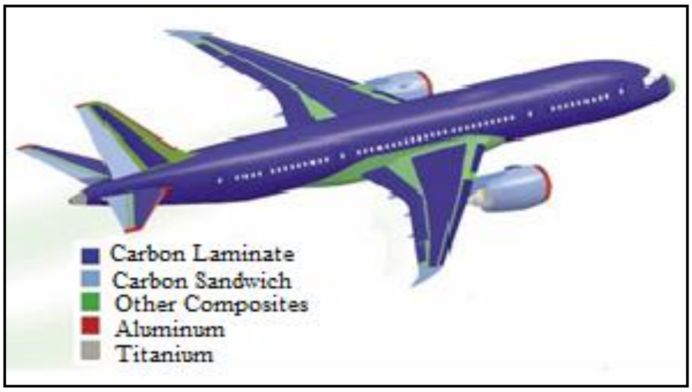


Figure 2.2 Use of composite materials in different bodies of an aircraft [30]

The first example of composite materials was found in nature. Since the earliest ages, people used the vegetable or animal fibers in brittle materials to eliminate the fragility feature of brittle materials. One of the best examples of this is adobe material. In the production of adobe material; clay-mud, straw, vine-like branches, stalks and fibers were used to increase the strength of adobe structure (Figure 2.3-2.4).

The composite materials were used in an engineering application at the beginning of the 1940s. However, nowadays, the composite materials are used commonly in many industries such as aerospace, automotive, sports, marine, and consumer goods industries.

Figure 2.3 Production of adobe material [29]

Figure 2.4 Straw mixture of clay in the mud [29]

2.2 Classification of Composites

Composite materials can be classified as fiber reinforced composites (Figure 2.5a), particle-reinforced composites (Figure 2.5b), laminated composites (Figure 2.5c) and hybrid composites (Figure 2.5d) [31].

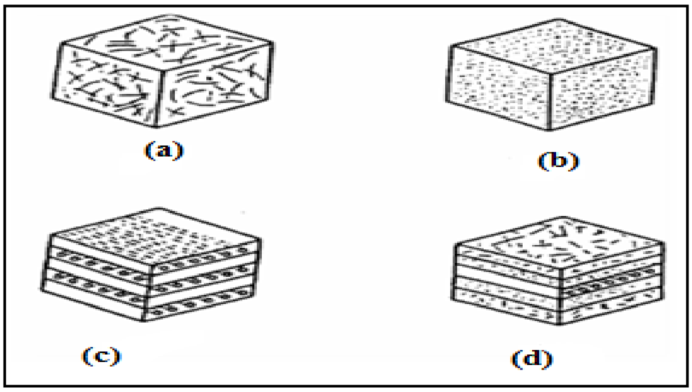


Figure 2.5 Classification of composite materials

2.2.1 Fiber-Reinforced Composites

This composite type is occurred by taking place the thin fibers in the matrix structure. Placement of fibers in the matrix is an important phenomena due to affect the strength of the composite materials. The fiber-reinforced composites can be long fibers or short fibers. The long fibers are placed parallel to each other in the matrix, hence, the mechanical properties in the longitudional directions are higher than the transverse directions. The short fibers are distributed homogeneously in the matrix, therefore, the mechanical properties are nearly equal strength in all directions. The strength of fibers is the most important in terms of strength of composite structures. Furthermore, by increasing the length/diameter ratio of fibers, the amount of load transmitted to fibers increase. Another important factor in the strength of composite structure is the bond between the fiber and matrix [31].

2.2.2 Particle-Reinforced Composites

Particle-reinforced composites are obtained by the presence of particles in a matrix material. They are nearly isotropic structures. Strength of the particle-reinforced composites depends on the hardness of the particles. Structures containing ceramic particles are more hardness and have high temperature than the metal matrix. The production of aircraft-engine parts is preferred from this kind of structures. The macroscopic or microscopic particles can be formed in matrix. In general, the average particle size embedded in matrix is greater than 1mm, and the particle volume fraction is usually used more than 50% [28,31].

2.2.3 Laminated Composites

The laminated composites are the oldest and most commonly used composites. Very high strength values are obtained with the composition of the layers. Their heat and moisture resistance is better than the conventional materials. The laminated composite materials are preferred instead of metallic materials due to their lightweight and strength. Fiber reinforced laminated composites are commonly used as face material in aircraft structures, for instance, in wings and tail groups [28,31].

2.2.4 Hybrid Composites

Hybrid composites are basically composed of two or more composite structures to obtain a better structure. For instance; the kevlar fiber is cheaper than the graphite fiber, however, tensile properties of graphite is better than the kevlar. In addition, the graphite fiber has low toughness and it is expensive than kevlar. These two fibers are composed to obtain a new kind of composite structures called “hybrid composites”.

The toughness of hybrid composite is better than graphite composite. At the same time its cost is lower than and also tensile properties become higher than from the kevlar composites.

In general, hybrid composites are grouped as follows:

1. Hybrid composites contain different two or more layers. Each layer provides characteristics in a particular direction and a particular type of fiber can be used in each layer. The layers are stacked in the desired manner according to the purpose.
2. As a mixture of two or more of the fibers in the same layer, and the layers are combined as desired to obtain the hybrid composite [31].

2.3 Types of Composite Material

Composite materials are divided into five main categories depending on the matrix material such as metal matrix composites, ceramic matrix composites, carbon-carbon composites, nano-composites and polymer matrix composites.

2.3.1 Metal Matrix Composites

The main structure of these composite materials is the metal matrix. The selection of these materials is virtually no limit. Metal matrix composites are increasingly used as an alternative material to traditional metallic materials. Metal matrix composites provide high toughness and strength, high temperature properties and higher heat stability, high corrosion resistance in most environments, higher ductile properties and can be combined by conventional methods. Due to these superior properties, metal matrix composites are used in automotive, aerospace and defense industry [32].

2.3.2 Ceramic Matrix Composites

Ceramic materials have high temperature resistant and lightweight. Ceramic matrix composites exhibit very low elongation at break, low toughness, and tend to thermal shocks. On the other hand, they have very high elasticity modulus and operating temperatures [33]. These products are mainly used in place of sandwich armors, a wide variety of military structures and space vehicles. Carbon, ceramic and glass fibers are added to ceramic matrix for the special conditions such as high temperature. The strength and toughness of ceramic matrix composites can be increased by added ceramic fibers into ceramic matrix materials. In recent studies, the ceramic matrix composites based on alumina and zirconia is not only used in the rocket or space tools applications, but also use in the human body as a biomaterials [28].

2.3.3 Carbon-Carbon Composites

In recent years, the extensive researches were investigated about the carbon-carbon composites due to their usage in military and civilian aircraft, missiles and aerospace vehicles. Carbon-carbon composites are produced by placement of carbon fibers into the carbon matrix. Thus, the refractory property as well as a combination of high strength and toughness is provided. In the carbon-carbon composites, carbon matrix may be changed as much as amorphous carbon graphite. Therefore, the properties of carbon-carbon composites vary in a wide range [34].

2.3.4 Nano-Composites

Nano composites are occurred with the best properties of the same or different material groups in order to collect a single nano-level material. Carbon fibers and multi-walled carbon nanotubes are used in order to increase the conductivity of polymers. In this way, anti-static coating materials can be produced. One of the applications of the nano-composites is typically used as a filler material in a matrix structure. For example, resistance of tires may be increased by using carbon black as a filler material [35]. An example of nano-composite in outer of wheel is illustrated in figure 2.6. Nano-materials based on nano-composite provide the high strength/weight ratio, for example, the carbon/epoxy nano-tube in the wings of wind turbine [36].


(a) (b)

Figure 2.6 An image of (a) nano-composite and (b) the carbon black matrix materials in car tires [37]

2.3.5 Polymer Matrix Composites

Polymers such as polypropylene, nylon or polyethylene are observed that some important differences when compared to conventional materials. Therefore, polymers are increasingly used day to day. The polymers have several advantages; such as easily moulding, lower density, resistant to chemical influences and corrosion, using an insulator against to heat and electricity. Although, the strength and modulus of polymers are high, the density of them is low per unit weight or volume. So, polymers can be found in the aerospace and aviation industries [38]. Polymer matrix is divided into two groups such as thermosets and thermoplastics. After heated and shaped the conversion of the old structure of thermoset is not possible due to the change in microstructure. Thermoplastics can be dissolved when heated again due to weak bonds in the structure of polymers. This type of plastic is heated to soften and harden when cooled after being shaped. The most important in these polymers are acrylic, cellulose acetate, nylon polyamide, polycarbonate [39]. Epoxy, polyester and vinylester are widely used as matrix materials in reinforced composites. Their physical and mechanical properties (Table 2.1) depend on the length of cross link, density and the size of molecules. Mainly application areas of polymeric matrix composites are marine applications, automotive and other transportation industries and sports equipment due to their corrosion resistance and light weight [28].

Table 2.1 The physical and mechanical properties of polymeric matrix materials [40,41]

Property	Epoxy	Polyester	Vinylester
Density (g/cm^3)	1.1-1.4	1.2-1.5	1.044
Modulus of elasticity (GPa)	3-6	2.0-4.5	3.2
Poisson’s ratio	0.38-0.4	0.37-0.39	---
Tensile strength (MPa)	35-100	40-90	80
Compression strength (MPa)	100-200	90-250	---
Thermal conductivity (W/m°C)	0.1	0.2	---
Thermal expansion (°C)	50-300	50-110	---
Heat distortion temperature (°C)	50-300	50-110	---
Solidifies tensile (%)	1-2	4-8	---
Water absorption (%)	0.1-0.4	0.1-0.3	0.150

2.3.5.1 Thermosets

The commonly used thermosets are epoxy, polyester, vinylester and phenolic resins which are discussed below:

Epoxy resins

Epoxy resins can be used with all kinds of fibers and can be liquid or solid [42]. They are especially used for airplanes. Epoxy resins have better water resistant and adhesion properties than polyester and vinylester; hence, they are used for the construction of boats. The epoxy resins are used in high-performance boats as the primary building material [43]. The hardening speeds of epoxy resins can be controlled by selecting the appropriate hardener in the requirements of the process. Generally, an anhydride or amine hardener is added to the hardening reaction. Each hardener shows the different hardening profile and different characteristics to the final product [42]. Product made from epoxy resins can be used in different areas specially pipes and tanks (Figure 2.7) due to their resistance to chemicals, durability, flexible and good adhesion properties and unique polymer surface coatings [44].

(a) (b)

Figure 2.7 The usage of epoxy resin in pipes (a) and tanks (b) [29]

Polyester resins

Polyester resins are the most common resin in manufacturing of composite materials. These are collected in two groups as unsaturated and saturated polyesters. Saturated polyester resins are used in the injection moulding process [45]. Unsaturated polyester resins are used in the construction of fiber-reinforced materials. Polyester resins are classified storage lifetime. Generally, a small amount inhibitor should be added to slow down the movement of the gelation during the manufacture of polyester resin. For use in moulding, several auxiliary products are added to polyester resin. These products are usually the catalyst accelerator additives such as pigments, fillers, supplements for chemical resistance. The polymerization rate is very slow for polyester resins; therefore, the catalyzer and accelerator must be added to polyester resins to obtain a faster polymerization process [43]. The polyester resins show good properties in terms of mechanical and chemical resistance, low prices, and flexible usage of intended design. They soak to fiberglass very well. Therefore, in general, the glass reinforced plastic materials are manufactured from this resin [45,46].

The polyester resins have high tensile rate in the range of 5%-12%. This is the most important disadvantages of polyester resins. This situation can cause buckling of the fibers under compression stress. Therefore, the compression strength is low. The other disadvantages of polyester resins are unsmooth surface, low corrosion resistance, absorbs water easily and short shelf life and particularly after alkali process, they emits the toxic styrene gas emits to environments [46].

Vinylester resins

Vinylester resins are suitable for wet lay down. Vinylester resins are produced in a similar manner to polyester resins and they show the similar curing characteristic of epoxy resins. This polymer is generally used for pipes, storage tanks and chemical plants for their chemical resistance [47,48]. In recent years, the polyester-vinylester resins have been used together for obtain a better materials and hardware. An example of polyester-vinylester production for ATV engine is illustrated in figure 2.8.

Figure 2.8 The usage of polyester-vinylester resins in ATV engine [29]

Phenolic resins

Phenolic resins are supplemented with constant asbestos fiber until 300°C and they can be also used until 1000°C. The viscosity of phenolic resins is high but evaporation feature in the curing process leads to the formation of air pockets and the surface quality of product based on phenolic resins are decreased after this curing process. Phenolic resins can be applied up to 250°C for hardening [46]. The general advantages and disadvantages of phenolic resins are high fire resistance, low cost, quite is fragile and low surface quality and extremely harmful in the wet state [30].

2.3.5.2 Thermoplastics

Thermoplastics are found in a hard case at low temperatures and when they are heated; they become a homogenized liquid. Many types of thermoplastic can be used as matrix by comparing with thermosets. A few advantages of thermoplastics are as superior fracture toughness, long shelf life, recycling capacity and hardening process to provide a safe working environment, high hardness and impact resistance, reshaped by heating. The main reason of thermoplastics do not prefer in composite materials as matrix: the high cost in the production, provide low processing at room temperature, and lower production time. Thermoplastics are expensive than thermosets. And they can be used in the range of 60°C to 245°C [49]. The commonly used thermoplastics in the production of composite materials are polypropylene, nylon 6.6, polycarbonate, polyethylene and polyamide 6.

Polypropylene (PP)

Polypropylene is one of the most important groups of thermoplastics. It finds in a wide application area with excellent chemical resistance, low density, high impact resistance, good electrical resistance, high mechanical strength, low humidity taking, reasonable price, and easy of processing. Mechanical and temperature properties of the polypropylene products depend on the ambient conditions. The most important advantage of polypropylene is excellent stiffness/strength ratio. Unreinforced polypropylene material is suitable for applications below 0°C [50]. Thermal performance of polypropylene varies depend on the heat exposure time of the heat source. Filled or reinforced polypropylene groups can be used up to 100°C. When polypropylene exposed to heat; high dimensional stability and too much bending weakness can be shown. Polypropylene has easily workability in each injection machine. Polypropylene is a material with low humidity of moisture content less than 0.2% cases where does not require pre-drying [50].

Naylon 6.6

The naylon 6.6 is obtained by joining lots of monomer units together of two distinct molecules: hexamethylenediamine (HMD) and adipoyl chloride. HMD is composed of two primary amines and six alkane groups. When HMD reacts with adipoyl chloride, the formation of a new functional group is occurred. This new dimer can continue to react with other amines and acid chlorides to produce a longer chain of amide linked molecules. Nylon 6.6 is most important thermoplastics in the production of clothing, rope, and carpets. Nylon 6.6 can be melted and moulded to fit any desired shape. It is used for pipes, zippers, and wire insulation [51].

Polycarbonate (PC)

Polycarbonate is thermoplastic with high performance, low specific weight, high impact resistance, low moisture grabbing rate, good heat insulation, heat-stability and oxidative stability of the melt, easy to process and workability [52]. Polycarbonate is synthesized from a highly durable plastic of Bisphenol-A. Although it has good resistance against the impact, it can be worn out very easily. As shown in figure 2.9, it is transparent and has better light transmittance than many plastics [51].

(a) (b)

Figure 2.9 Polycarbonate (a) sheet and (b) mini cups [29]

Polyethylene (PE)

Polyethylene has high impact resistance, low wear resistance, high chemical resistance, water-sucking, wide operating temperature, self-lubricating, and easy cleaning and not to create bacteria. Polyethylene is used in various industries. In machine industry; friction plates and gears, in coal and mining industry: bunkers, tanks and silos, in paper industry: the vacuum box cover, hydro-foil box; in the food and packaging industry: meat, fish, a cutting board [52].

Polyamide 6 (PA6)

Polyamide 6 creates the most important group of engineering plastics. The advantages of polyamide 6 is perfect hardness/strength ratio adaptation, high mechanic resistance, good electrical insulation, flame retardance, high chemical resistance, high wear resistance, easy of processing, perfect price/performance ratio. The polyamide 6 is prone to moisture. This negative property is depending on the composition of the additives. For this reason, polyamide 6 should be taken dry before it is processed [53]. The mechanical and physical properties of thermoplastics are given in Table 2.2 for comparison.

Table 2.2 Some properties of thermoplastics at 20°C [38,54,55]

Property	**Polypropylene**	**Nylon 6.6**	**Polycarbonate**	**Polyethylene**	**Polyamide6**
Density (g/cm^3)	0.90	1.14	1.06-1.20	0.958	1.13
Modulus of elasticity (GPa)	1.0-1.4	1.4-2.8	2.2-2.4	0.85	3
Poisson's ratio	0.3	0.3	0.3	---	0.39
Tensile strength (MPa)	25-38	60-75	45-70	23	60-70
Tension strength (%)	>300	40-80	50-100	---	---
Thermal conductivity (W/m°C)	0.2	0.2	0.2	0.23	---
Thermal expansion (10^{-6} °C)	110	90	70	---	6-10
Heat distortion temperature (°C)	60-65	50-110	110-140	---	---
Melting temperature (°C)	175	264	---	---	220
Water absorption (24h) (%)	0.03	1.3	0.1	---	9-10

2.4 Manufacturing Processes of Polymeric Composites

Many different techniques have been developed to produce polymeric composite materials. These techniques are discussed below:

2.4.1 Hand Lay-Up Method

Hand lay-up method is generally used for boats, tanks and building panels. In the production, the woven fibers as a reinforcing material are usually selected. But in order to gain additional strength and modulus of elasticity also glass, carbon or other fibers can be added in to manufactured structure [56]. The hand lay-up procedure is mentioned below step by step according to figure 2.10 [46].

(1) The wax should be applied to the mould to remove the product easily from the mould, (2) applying the second separator by using polyvinyl alcohol with sponge, (3) applying the high viscosity resin with brush, (4) preparing fibers, (5) mixing the hardener with resin, (6) applying the mixed resin by brush, (7) applying the paint roller to avoid the air bubbles in structures, and (8) the process is continued until the desired thickness and hardening and then the product is removed from the mould [46].

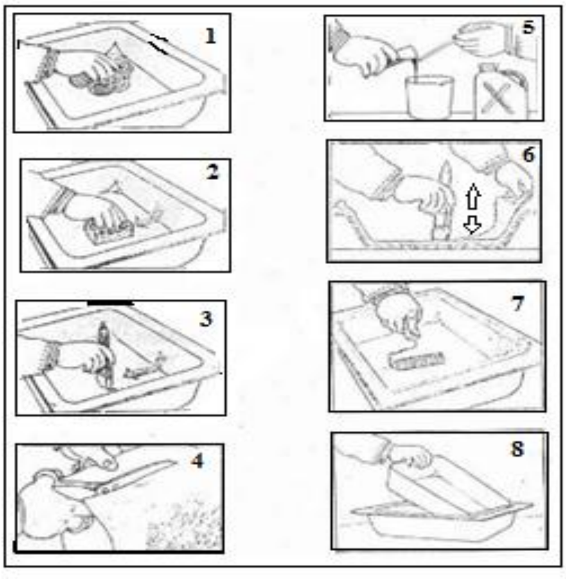


Figure 2.10 Composite production by hand lay-up method [46]

2.4.2 Spraying Method

This method is an improved form of hand lay-up technique and use for complex shapes. Similar to the hand lay-up method, spraying method (Figure 2.11) is used for boats, tanks and shower units [53].

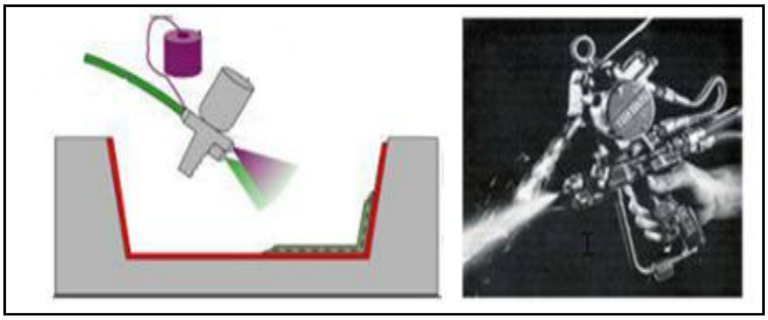


Figure 2.11 An illustration of spraying method and the spray gun [54]

For spraying process, the resin and reinforcement materials are used in a spray gun with a capacity of 450kg-800kg per hour. In this process, the spray gun cuts the fibers in the range of 20-40mm [56].

2.4.3 Vacuum Bagging Moulding Method

A higher volume fraction can be achieved by this method than the hand lay-up method. This is possible by adding semi-hardened resin into fiber and fabric structures (Figure 2.12). After the fibers are cooled from 120°C-180°C to room temperature, they are cut in the desired length, shape and fiber orientation [46,57].

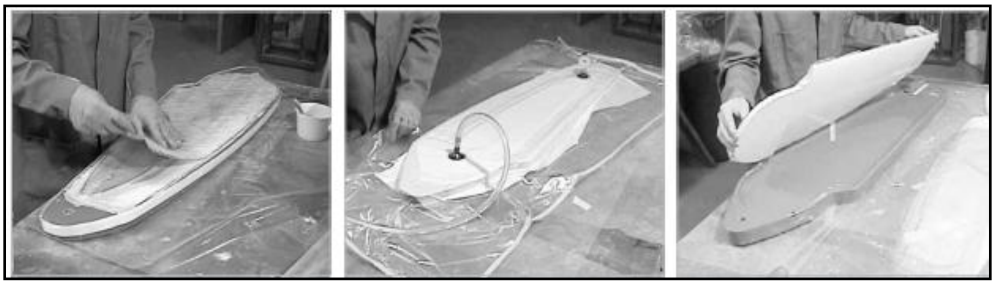


Figure 2.12 Vacuum bagging moulding method [58]

The advantages of this method; resins and fibers can be selected in the most appropriate way, resins and hardeners do not need to stocking, complex shapes are easily obtained, and the quality of finished products is very high. The graphite/epoxy, glass/epoxy and kevlar/epoxy prepregs are preferred for this method [57].

2.4.4 Filament Winding Method

By the filament winding method, a continuous fiber is formed on a mandrel by wrapping to obtain specific angles. There are two types of wrapping. These are dry winding and wet winding. In the wet winding; the fibers are immersed in the resin just before the wrapping on the mandrel. This method is suitable for production of cylindrical parts such as pressure vessels (Figure 2.13a), warehouse, pipe and rocket bodies (Figure 2.13b). The epoxy and polyester is the most widely used resin. By this method, approximately 80% fiber volume fraction can be achieved [46].

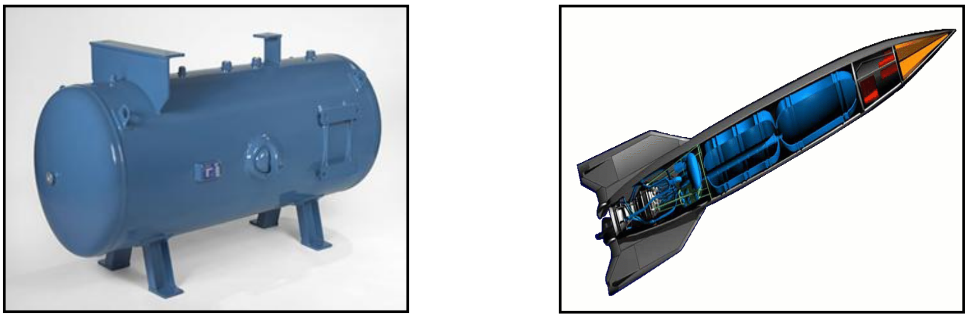

(a) (b)

Figure 2.13 An example of (a) pressure vessel and (b) rocket body manufactured by filament winding method [59]

2.4.5 Resin Transfer Moulding (RTM) Method

The composite production by this method is more rapid and long life to compare with the manually systems. This method is necessary to use two pieces mould. Previously, the reinforcement material is placed into mould to fill the mould cavity and the mould is closed. Resin is pumped into mould under pressure. This process requires much more time. Matrix injection can be applied cold, warm or heated up to 80°C. In this method, vacuum can be used for removal of the air bubble. The complex parts can be produced with this method, for instance, some parts of Formula

1 cars (Figure 2.14a) and Concorde aircraft (Figure 2.14b) are manufactured from this method.


(a) (b)

Figure 2.14 Some parts of the Formula 1 cars (a) and the Concorde aircraft (b) are made by RTM [30]

2.5 Application Areas of Composites

The application areas of composite materials are very wide. Composite materials are preferred for many industries. Therefore, composite materials are not difficult to find an industry branch. Most extensive usage of composite materials can be seen in the transportation industry. The reason for this is that the composites have good mechanical properties and lightness. The usage areas of composite materials are discussed below:

2.5.1 Aerospace Industry

In recent years; the composite materials are widely used in aerospace industry instead of metallic materials. When comparing to conventional materials, boron/epoxy and carbon/epoxy have superior mechanical properties for the construction of aircraft. The mechanical properties of composite materials and metallic materials are given in Table 2.3 [60].

Table 2.3 The mechanical properties of metallic and composite materials [61,62].

Material	**Density (g/cm^3)**	**Elastic modulus (GPa)**	**Specific modules (E/p)**	**Tensile strength (GPa)**
Steel (3140)	7.90	200	25	1.85
Alum. ASG(6061)T6	2.70	70	26	0.35
Alum.AU4GI (2024)74	2.80	73	26	0.29
Alum.A25G4 (7075)T6	2.80	76	27	0.45
Titanium T6V	4.40	119	27	1.14
Boron/Epoxy	2.10	270^a	129^a	2.00^a
Boron/Alum.	2.70	225^b	83^a	1.25^b
Graphite /Epoxy	1.70	208^a-10.3^b	122^a	1.34^a-0.03^b
Carbon/Epoxy	1.50	142^a-10.3^b	95^a	1.60^a-0.07^b
Kevlar/Epoxy	1.35	80^a-5.5^a	59^a	1.38^a-0.03^b
Glass/Epoxy	2.20	53^a-12.4^b	24^a	1.45^a-0.04^b
Carbon/Polyester	1.68	127.5^a-7.6^b	76^a	1.52^a-0.04^a
Kevlar/Polyester	1.40	76^a-5.5^b	54^a	1.20^a-0.02^b
Glass/Polyester	1.80	39^a-9.6^b	22^a	1.13^a-0.02^b

a: The direction of fibers and b: the direction of perpendicular to the fibers

2.5.2 Automotive Industry

In the automotive industry; the composite materials are used for their lightness to save more fuel. The automotive industry uses glass fibers as main reinforcement material. Table 2.4 represents the use of matrix in the automobile industry according to application areas and production methods [63].

Table 2.4 The rate of matrix used in automobiles between 1988 and 1993 [64]

Applications	**Use (10^6 kg)**	**Matrix materials**	**Use (10^6 kg)**	**Production method***	**Use (10^6 kg)**
Fender	42	Polyester	42	RM	40
Seat	14	Polypropylene	22	RET	20
Hood	13	Polycarbonate/PBT	10	IM	13
Radiator	4	Polyethylene	4	MEP	5
Ceiling	4	Epoxy	4	FW	3
Other	12	Other	7	Other	8
Total	**89**	**Total**	**89**	**Total**	**89**

*Where RM is ready moulding, RET is reinforced extruded thermoplastic, IM is injection moulding, MEP is mould extra power, and FW is fiber winding

2.5.3 Sports Industry

The use of composite materials is very common in the sports and entertainment industry. Composite materials are preferred according to other materials due to their, light weight, strength and vibration characteristics. Composite materials are extensively used in sports industry such as golf clubs, racing boots, tennis rackets (Figure 2.15a), skis, fishing rods (Figure 2.15b), bicycles etc. [63].


(a) (b)

Figure 2.15 The tennis rocket (a) and fishing rod (b) made of composites [29]

2.5.4 Marine Industry

Composite materials have good corrosion resistance, light weight, and fuel efficiency. These properties provide more speed and more comfortable for marine industry. In general, glass fiber reinforced plastic composites are used in marine industry. The ship, yacht, passenger ferries, sea boats, lifeline etc. are manufactured from composite materials [63].

2.5.5 Consumer Goods Industry

Composite materials are used for sewing machines, doors, bathtubs, desks, computers, printers, etc. in the consumer goods industry. Most parts of these products are made of short fiber composites. For this kind of products, the ready moulding and injection moulding methods are used [63].

2.6 Natural Fibers Used in Composite Materials

Natural fibers have been used 3000 years ago in the ancient Egypt, where straw and clay were mixed together to build walls. Over the last decade, polymer composites reinforced with natural fibers have received its peak usage level at the academic world and various industries. There are a lot of natural fibers which can be applied as reinforcement or fillers. An organigram for the classification of the various natural fibers is presented in figure 2.16.

The most important types of natural fibers used in composite materials are flax, hemp, jute, kenaf and sisal. Jute is an important fiber with a number of advantages. Jute has high specific properties such as low density, less abrasive behavior, good dimensional stability and harmlessness. Jute textile is a low cost and ecofriendly product and is abundantly available, easy to transport and has superior durability and moisture retention capacity. It is widely used as a natural fiber for plant mulching and rural road pavement construction. The biodegradable and low priced jute products merge with the soil after providing nourishment to the soil. Being made of cellulose, jute does not generate toxic gases during combustion. The specific properties of jute fiber can compare to the glass fiber and some other fibers (Table 2.5).

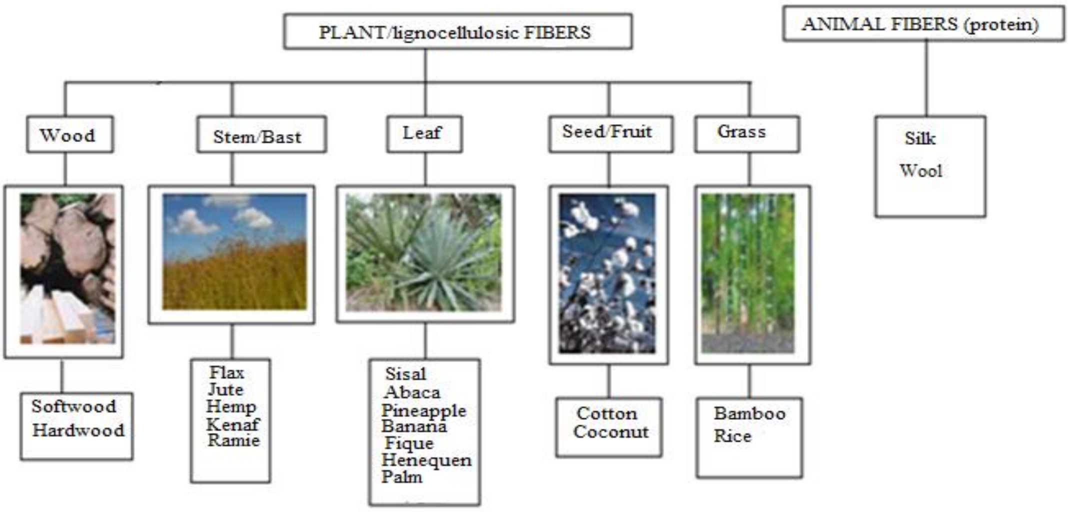


Figure 2.16 Classification of natural fibers which can be used as reinforcement or fillers in polymer matrices [64]

Table 2.5 The properties of jute fiber in comparison with other fibers [64].

Fiber	**Density (g/cm^3)**	**Tensile modulus (MPa)**	**Elasticity modulus (GPa)**	**Elongation at break (%)**
Jute	1.3-1.45	393-773	13-26.5	1.16-1.5
Flax	1.5	345-1100	27.6	2.7-3.2
Ramie	1.5	400-938	61.4-128	1.2-3.8
Sisal	1.45	468-640	9.4-22.0	3-7
Coir	1.15	131-175	4-6	15-40
E-glass	2.5	2000-3500	70	2.5
S-glass	2.5	4570	86	2.8

The Asian markets have been using natural fibers for many years. For example, jute is a common reinforcement in India. The North American market for natural fibers in the year 2000 is in building applications (75%) (Figure 2.17), whereas, other applications especially in the automotive industry have been grown at increasing rate [65].

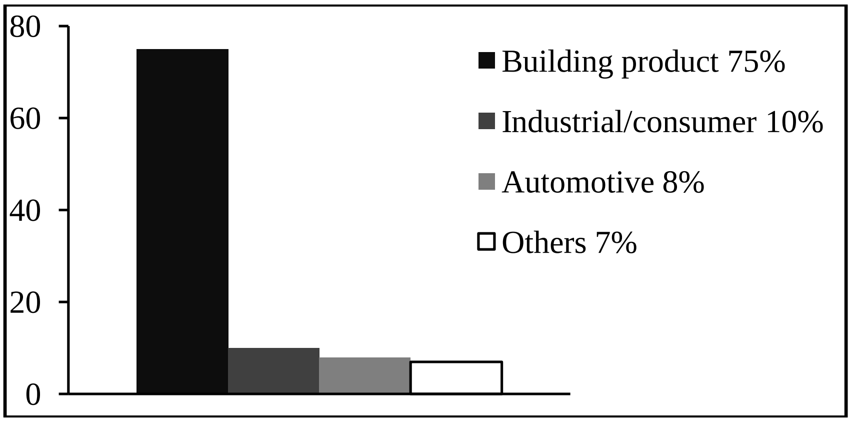


Figure 2.17 North American market demand of natural fiber composites in 2000 [66]

2.6.1 Jute Fibers

Jute fibers are obtain from two herbaceous annual plants, white Corchours capsularis (white jute) originating from Asia and Corchours olitorius (Tossa jute) originating from Africa. Next to cotton, it is the second most common natural fiber, cultivated in the world and extensively grown in Bangladesh, China, India, Indonesia and Brazil [67].

The jute plants (Figure 2.18) grow six to ten feet in height and has no branches. The stem of the jute plants is covered with thick bark, which contains the fibers. In two or three months, the plants grow up and then are cut, tied up in bundles and kept under water for several days for fermentation. Thus, the stems rot and the fibers from the bark become loose. Then the cultivators pull off the fibers from the bark, wash very carefully and dry them in the sun.

Figure 2.18 The harvest of jute plants [29]

Jute is multicelled in structure (Figure 2.19). The cell wall of a fiber is made up of a number of layers: the so-called primary wall (the first layer deposited during cell development) and the secondary wall (S), which again is made up of the three layers (S1, S2 and S3)**.** As in all lignocellulosic fibers, these layers mainly contain various amounts of cellulose, hemicellulose and lignin. The individual fibers are bonded together by a lignin-rich region known as the middle lamella. Cellulose attains highest concentration in the S2 layer (about 50%) and lignin is most concentrated in the middle lamella (about 90%) which, in principle, is free of cellulose. The S2 layer is the thickest layer and dominates the properties of the fibers [68].

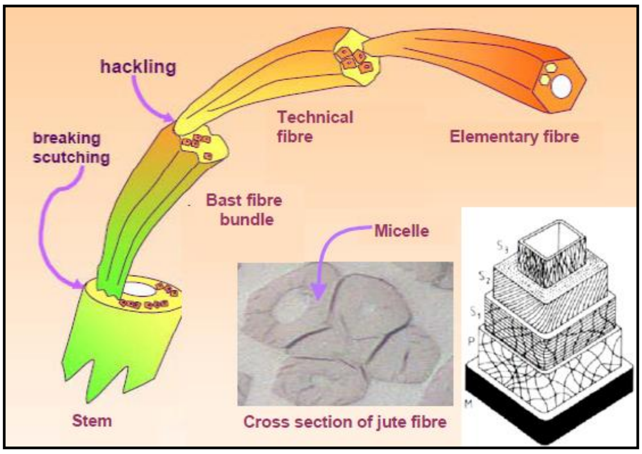


Figure 2.19 The scheme of jute fiber structure [68]

Hemicelluloses are also found in jute plant fibers. Hemicelluloses are polysaccharides bonded together in relatively short branching chains. They are intimately associated with the cellulose microfibrils, embedding the cellulose in a matrix. Hemicelluloses are very hydrophilic and have lower molecular masses than both cellulose and lignin. The degree of polymerization is about 50-200. The two main types of hemicelluloses are xylans and glucomannans.

The jute fiber is polygonal or oval in cross section with a lumen. The structure of jute fiber (Table 2.6) is influenced by climatic conditions, age, the fermentation process, and the chemical composition [65].

The jute fiber possesses moderately high specific strength and stiffness. Therefore, it is suitable as reinforcement in a polymeric resin matrix. However, it exhibits considerable variation in diameter along with the length of individual filaments. The properties of the fiber depend on size, maturity and processing methods. The density, electrical resistivity, ultimate tensile strength and initial modulus of jute fibers are related t the internal structure and chemical composition of fibers [69-70].

Table 2.6 The composition of jute fibers [68]

Substances	Weight
Cellulose	61-71.5
Hemicellulose	13.6-20.4
Pectin	0.2
Lignin	12-13
Moisture content	12.6
Wax	0.5

2.6.2 Flax Fibers

The flax fibers are obtained from the stem of flax plant. The flax plant is grown for seed and fiber (Figure 2.20).


(a) (b)

Figure 2.20 The flax seed (a) and plant (b)

An appearance of flax fibers is given in figure 2.21. The small rooms can be seen at angular fiber cells. Oils and waxes are available inside the outermost of thin layers.

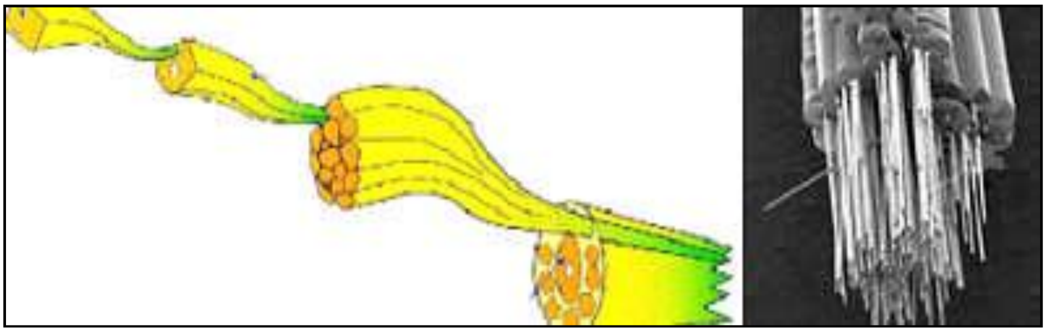


Figure 2.21 Physical structure of flax fiber

The distinguish properties of the flax fibers as below:

- Fiber thickness is between 14-25µm.
- Length of the fiber bundle is between 30 and 90cm. The length of a single fiber between 7 and 8cm.
- The flax is yellowish-white in color and it is slightly bluish.
- Elongation at break is 1.8% (at dry condition) and 2.2% (at wet condition).
- Strength is more than 20% in case of wet.
- Specific gravity of the flax fiber is 1.5g/cm^3 [71].

2.6.3 Sisal Fibers

Sisal plant (Figure 2.22) grows in hot and humid weather. Sisal plant is grown in Brazil, Africa and Indonesia. When it comes to the age of 7-8 it can be used for fiber production. Up to 3% of sisal fibers are obtained by the rebuttal method.

Figure 2.22 The sisal plant

Sisal fibers have adherent cell bundles. The sisal fibers lengths are 100cm. The sisal fibers contain approximately 65% cellulose. The sisal fibers have high moisture absorption feature, quite high strength and resistance to salt water. The sisal fibers have higher flexibility than the other fibers. Thus, it is used as knitting jobs, ship ropes (Figure 2.23), in agriculture and shipping binding materials [71].

Figure 2.23 The products are obtained from sisal fibers

2.6.4 Ramie Fibers

The ramie fiber cells are located in the bundles of ramie plant (Figure 2.24) under the body of the crust. Harvesting can be done when the leaves of plants start to turn yellow. Crust parts of ramie plants can be cut by means of knife while the plant is still wet (Figure 2.25).

The foreign substances on the ramie plant can be removed by applying rebuttal process. After this process, the ramie fibers can be softer and better tilted. These fibers are used for construction of rope, upholstery fabrics, and a variety of local clothing items [71].

Figure 2.24 The ramie plant

Figure 2.25 The obtaining of ramie plant

2.6.5 Hemp Fibers

The hemp fibers are used in many industrial applications. Fiber length and efficiency depend on the distance between the nodes. The hemp fibers are located in the bundles at crust. The fibers are bright and its color is yellow-brown. There are 30-50 fiber cells in the hemp fiber bundles [72-74]. The hemp plant (Figure 2.26a) fiber’s cross-section is polygonal as shown in the figure 2.26b. Iodine sulfuric acid mixture can be used to distinguish of hemp fiber. Its lumen is yellow and its cellulosic wall is blue, other parts of hemp fibers are yellowish green color. Hemp fibers are highly resistance to alkalis. Hemp fibers are providing very good strength and absorbency [72].

The concentrate inorganic acids can be damaged to hemp fibers due to their cellulosic structure. Weak acid can be caused a loss of temperature resistance. Therefore, the organic acids are selected for surface treatment of hemp fibers [72,73].

(a) (b)

Figure 2.26 (a) The hemp plant and (b) the cross-section spectacle of hemp fiber

CHAPTER THREE
SURFACE MODIFICATION PROCESS

3.1 Introduction

Fibers are exposed to surface modification process for improving their adhesion with thermoset and thermoplastic materials. The purpose of surface modification process is to increase the bonding strength between fiber and matrix without affecting the basic properties of the fibers. Some of the surface modification processes are mentioned below:

3.2 Alkali Process

Reinforced fibers are usually treated in different temperatures or time with varying concentrations of sodium hydroxide (NaOH). Plant fibers are polar character due to hydroxyl groups (cellulose) in the surface. Some materials such as pectin, lignin and vaks can be located in the fibers which prevent the connection in the matrix-fiber interface. The weaken interface adhesion is adversely affect the mechanical properties of the composites. Alkali process is increased the free energy on the fiber surface. At the same time, the fiber/resin interfacial surface improves by the alkali process (Figure 3.1) [75]. Alkali process also reduces the degree of cellulose polymerization [76].

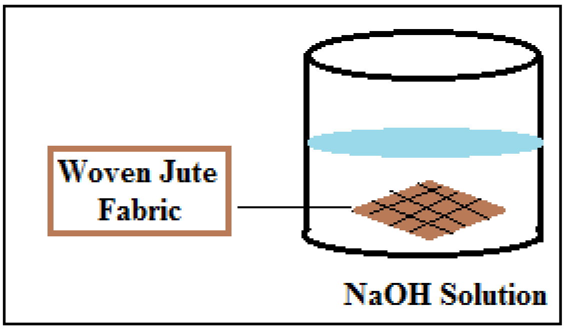


Figure 3.1 Alkali process implemented to the woven jute fabric

3.3 Blasting Process

Blasting is explained as use of abrasive particle such as ceramics under high pressure in order to make the surface smoother. The desired roughness of surface can be set up by the particle size. Also, for the blasting of biomedical materials, the particles should be chemically stable and biocompatible. Usually alumina, titania or hydroxyapatite particles are applied for blasting treatments [77].

3.4 Plasma Process

Plasma process is preferred due to do not need an aqueous environment for the realization. While only the material on the surface changing during plasma treatment, volumetric properties can remain constant after the procedure [78]. Wear or accumulation of material occurs on the surface in the plasma environment. Weak covalent bonds on the surface are break off by abrasion on the surface. The gases are products as a result of the interaction between the plasma and solid surface (Figure 3.2).

Corrosion in the materials occurs after evaporation of the substance. Total surface area is increased after with wear, hence, the adhesion property of materials is improved. With plasma polymerization, a thin film layer occurs on the surface it is gained to material some properties such as water/oil/dirt repellency, antimicrobial and power retardant [79].

Today, the wetting property of the fiber surface, high chemical reactivity, advanced water-repellent feature and fiber surface cleaning are improved by the plasma process [80].

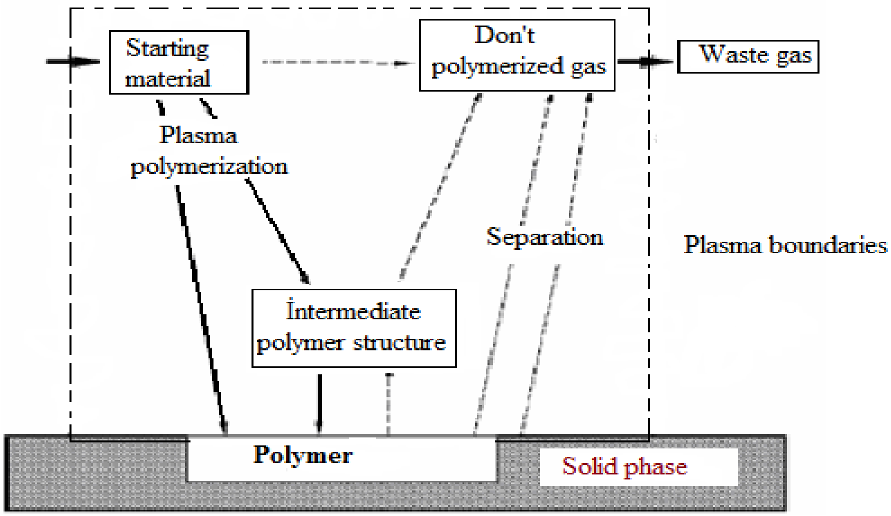


Figure 3.2 The polymerization and wearing during plasma process [81]

3.5 Corona Discharge

Electrical corona discharge is the formation of high energy fields by the ionization thin wires. Discharge energy must be sufficient to stimulate ionized atoms and molecules (Figure 3.3).

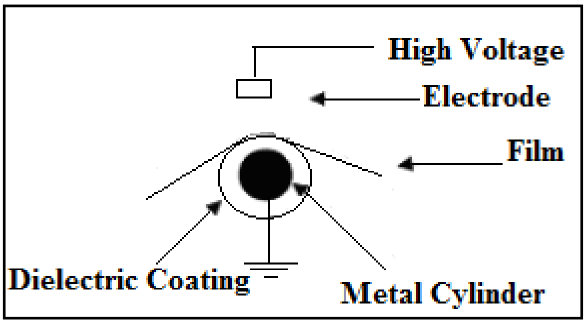


Figure 3.3 Schematic view of the corona discharge

Ions excite the neutral species and photons by electron discharge. The formation of radical on the fiber surface can be occurred after this event. Disadvantages of this process can be counted nonuniformity, the small holes on surface can be occurred, and the control of process is difficult. The main reason of nonuniformity is random form of ion and electron energy. A small are (corona blows) is heated the surface and thus the formation of cavities are occurred on surface [82]. The hydrophilicity of cellulosic fibers such as cotton, flax, hemp and their mixture and also synthetic fibers is increased as a result of the corona treatment which is under atmospheric conditions at 20 to 40 kHz frequency [83].

3.6 Heat Treatment

In the heat treatment, oxidation occurs on the polymer/fabric surface as in corona discharge. Activation of radical and ions, stimulation of molecules occurs with the effect of high temperatures. As shown in the figure 3.4 the lower part of the driver is control by the gas burner. This kind of modification is generally used to improve adhesion. Heat treatment parameters are air/gas ratio, the gas flow rate, processing time and the distance between sample and flame [84].

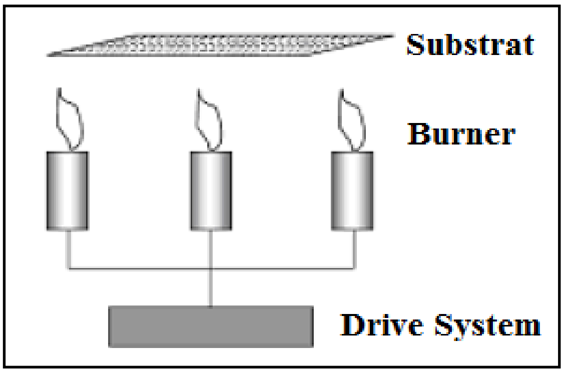


Figure 3.4 Heat treatment

3.7 Oxidation Processes

The oxidation process can be done in three different ways. These are controlled in dry gas, solution, electrochemical oxidation [85]. These processes provide the weak connected layers located on the surface removal. Oxidation processes on the surface increases the mechanical link between fiber and resin. For this purpose (carbonyl, carboxyl and hydroxyl groups) are used on the surface. Only carbon fibers can be used for dry gas oxidation at high temperatures [86]. Under 1800°C temperatures CO_2, Cl_2, NO_2-NO and NH_3 oxidizing gases can be used [87]. Oxidation the dry depends on the halogen, metal oxide, hydroxide on the surface of fiber structure. In this case, the surface is burned irregularly and more of the active surface can be produced. If the processing time increases, the fiber strength decreases.

For the oxidation process nitric acid, hypochlorite, and chromite acid solvents is carried out with aqueous solutions. The most widely used oxidation solution is done with nitric acid. Results of oxidation process depend on the process time, temperature and the type of fiber.

Electrochemical oxidation is frequently used because of easy controllability and due to nitric acid, ammonium carbonate, ammonium sulphate and sodium bicarbonate compound can be easily used.

3.8 UV Radiation Process

UV rays are located between X-rays and visible rays in electromagnetic spectrum (200-400nm). These rays are invisible and non-ionizing rays. From the visible rays to UV rays, the wavelength will be smaller with amount of energy and the frequency will be increased. When UV rays touches any surface, the UV rays will be lossed it's energy. After this event the new functional groups can be occurred on the surface with weak bond. In this way, the antistatic properties of the surface are removed by the effect of photooxidation while the wettability of materials, i.e., adhesion properties is increased [88,89]. Especially, UV rays are used for natural fiber/fabrics, to modify the surface properties [90].

3.9 Ion (Beam) Bombardment Process

In ion bombardment, process one or more atoms of the element is bombarded on the material surface as the positive ions with high energy. At the end of the process, varies surface compound of the material is appeared. Ion modification can be applied using two different methods [91].

3.9.1 Direct Implantation

Ion beam of the elements are implanted directly to the surface (Figure 3.5). The shorter duration of vaccination is more economical due to with high ion beam current (20-50mA) [91].

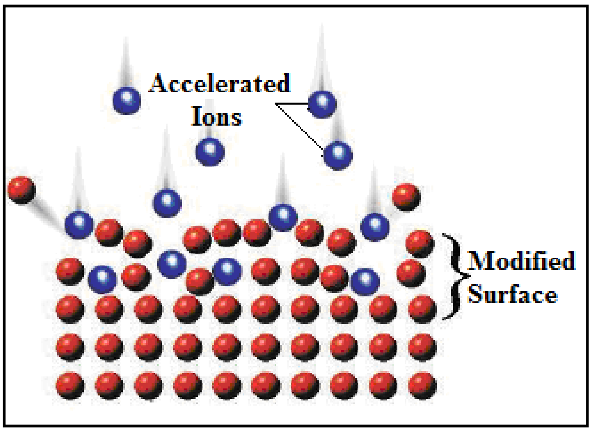


Figure 3.5 Direct implantation into material surface [91]

3.9.2 Plasma Ion Vaccination Process

In this system, sample is loaded with very short pulses and very high negative voltage. When the ions collide with the surface, the bond breaks and the free radicals are formed. Surface roughness and the polymer properties vary with ion bombardment in noticeable levels [91].

CHAPTER FOUR

DETERMINATION of MECHANICAL PROPERTIES

4.1 Introduction

For determination of the mechanical properties of woven jute/polyester, jute/epoxy and jute/vinlyester laminated composites plates with six layers was produced. The determination of mechanical properties is discussed below:

4.2 Determination of the Tensile and In-plane Shear Stiffness Properties

According to the ASTM D 3039 standard test method, longitudinal Young modulus E_1, poisson's ratio ν_{12} and longitudinal tensile strengths X_t are obtained by using longitudinal direction of six layered woven specimens. The dimensions of the specimens test have 12.7mm wide and 229mm long (Figure 4.1a). Transverse Young modulus E_2 and transverse tensile strengths Y_t are also obtained by using transverse direction of six layered woven specimens. Test geometries of the specimens are 25.4mm wide and 229mm long (Figure 4.1b). To define the shear modulus, G_{12}, a specimen whose fiber direction is 45° from the loading direction is illustrated in figure 4.1c [26].

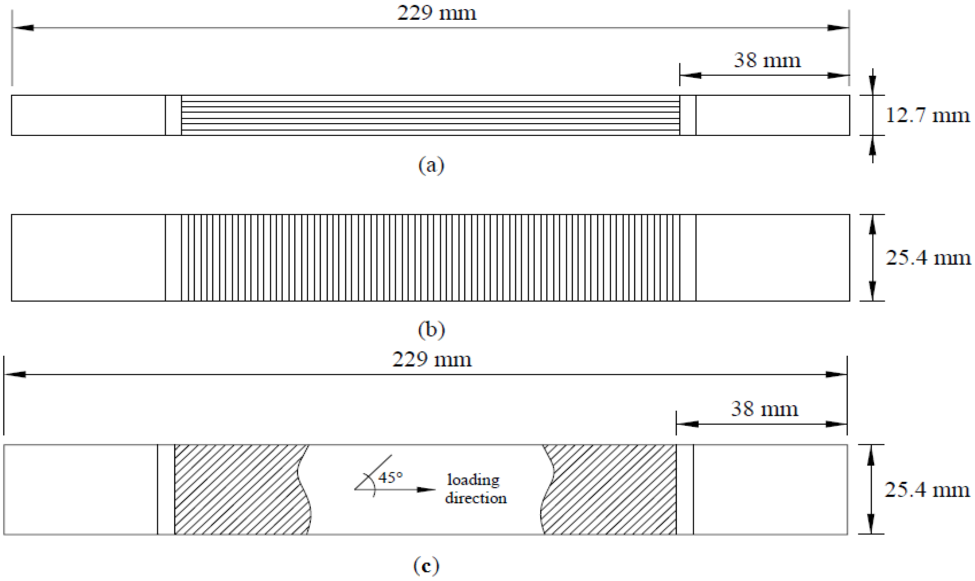


Figure 4.1 The dimensions of the specimens (a) for longitudinal (E_1, ν_{12}, X_t), (b) for transverse (E_2 and Y_t) properties and (c) for the shear modulus G_{12} [26]

The tensile strength in the longitudinal and transverse directions (X_t and Y_t) are determined by dividing the failure load to cross-section area of the longitudinal and transverse specimens, respectively [92].

The in-plane shear modulus, G_{12}, is defined as;

$$G_{12} = \frac{1}{\left(\frac{4}{E_x} - \frac{1}{E_1} - \frac{1}{E_2} + \frac{2v_{12}}{E_1}\right)} \tag{4.1}$$

Where E_1 and E_2 are modulus of elasticity in the longitudinal and transverse directions, E_x is elasticity modulus in 45° fiber direction and v_{12} is major poisson's ratio of woven jute reinforced composites.

4.3 Determination of the Compressive Properties

According to the ASTM D 3410 standard test method, specimens must be 140mm long and specimens are trimmed 6.4mm and 12.7mm widths for longitudinal and transverse specimens, respectively. After bonded the tab at the side of both standard specimens, gage length of the specimen is remained as 12.7mm (Figure 4.2).

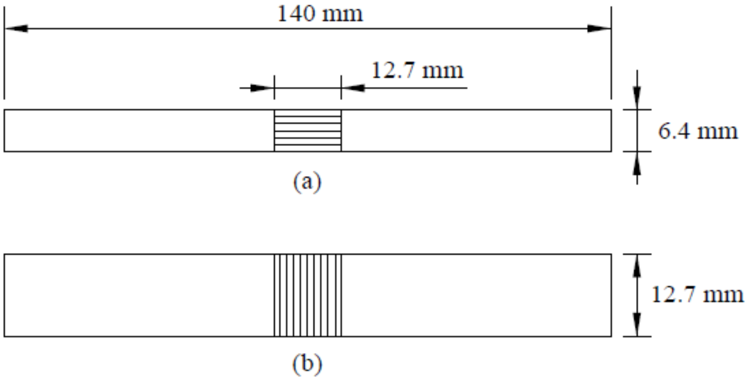


Figure 4.2 The dimensions of the compression test specimens (a) for longitudinal (X_c), and (b) for transverse (Y_c) strengths [26]

Longitudinal and transverse compressive strength of woven jute reinforced composite specimens (X_c and Y_c) are calculated by dividing the failure load to the cross-sectional area of the specimen as Eq. (4.2).

$$X_c = {P_{failure}}/{A} \text{ (longitudinal)} \qquad Y_c = {P_{failure}}/{A} \text{ (transverse)} \tag{4.2}$$

4.4 Determination of the Shear Properties

Shear test of a composite material is performed to determine the shear strength. According to the ASTM D 5379 standard test method specimens must be 20mm wide, 80mm long and 4mm notch depth at the center and notch angle 90° (Figure 4.3) [93].

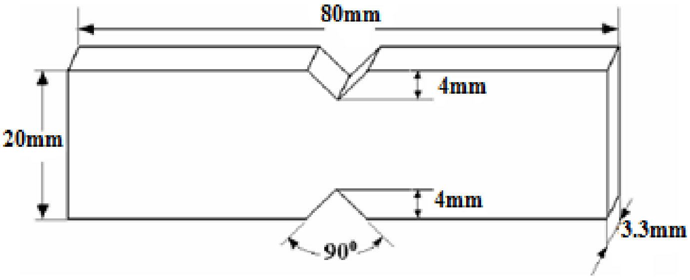


Figure 4.3 The dimensions of the shear test specimens

The average shear stress applied through the notched section and shear strengths (S) of the specimens are calculated as:

$$S = {P_{max}}/{L.t} \tag{4.3}$$

Where, P_{max} is the failure load, and L.t is the effective area of woven jute composite specimens.

4.5 Determination of Fiber Volume Fractions of Fibers, Resin and Voids

A variety of methods exist for determination of fiber volume ratio, an important property of a composite. The fiber volume fraction of a composite may be determined by chemical matrix digestion, method the burn-off method or by photomicrographic method.

The matrix digestion method is standardized as ASTM D 3171 and consists of dissolving the (polymer) matrix in a hot digestion medium-concentrated nitric acid for epoxy matrix composites or sulfuric acid followed by hydrogen peroxide for polyamides and PEEK or other digestion media. After the matrix is dissolved, the fibers are weighed. The volume fractions are calculated from the weights and densities of the constituents.

The resin burn-off method (ASTM D 2584) is sometimes used for glass fiber composites because glass fibers are resistant to oxidation at the temperatures required burn-off the matrix (500°C to 600°C). Similar to the chemical matrix digestion method, the fibers are weighed after the matrix has been removed to enable calculations of fiber volume fractions.

The photomicrographic method is not an ASTM standard, but it provides an independent estimate of the fiber volume fraction. The method requires a photopgraph of a polished cross section of a composite and many samples to produce reliable results [92].

In the view of above mentioned, the fiber volume fraction in weight can be calculated from the weights of the fibers and matrix (W_f and W_m). The volume fraction of fibers V_f and the void volume V_v is determined as below [92].

Fiber volume fraction $V_f = \frac{volume\ of\ fibers}{volume\ of\ composite}$ (4.4)

Fiber weight ratio $W_f = \frac{weight\ of\ fibers}{weight\ of\ composite}$ (4.5)

Matrix volume fraction $V_m = \frac{volume\ of\ matrix}{volume\ of\ composite}$ (4.6)

Matrix weight ratio $W_m = 1 - W_f$ (4.7)

Void volume ratio $V_v = 1 - V_f - V_m$ (4.8)

4.6 Strain and Displacement Measurements

The engineering constants were defined in terms of the stress-strain response of the composite, and the specimen compliance was defined in terms of the displacement at the point of load application. To measure strains and displacements of test specimens, the three most common transducers can be used as strain gages, extensometers and linear variable differential transformers (LVDT).

In this thesis extensometer is used to measure strains. A typical single-axis extensometer is shown in figure 4.4. Extensometers often contain strain gages bonded to the arms of the device. As the arms deflect, the strain gages are activated just as discussed above. Thus, these units are sometimes also called strain gage extensometers which are distinguish from the much less commonly used dial gage and optical extensometers.

The gage length of typical extensometers changes in the range of 12mm to 50mm. A commonly used gage length is 25mm. Thus, the gage length of an extensometer tends to be much longer than that for a strain gage, which can be an advantage or a disadvantage depending upon the application [92].

Figure 4.4 Typical single-axis extensometer, mounted on a tensile specimen.

4.7 Testing Machines

Most modern machines can apply both axial tensile and compressive loading (Figure 4.5). They can be operated in force or strain control as well as displacement control. They can include stress-strain, stress-displacement and strain-strain (for Poisson's ratio) plots, tabulations of axial stiffness, Poisson's ratio, ultimate strength or whatever quantity is desired.

Each universal testing machine is designed to have a maximum load capacity. Small units may have a load capacity of only a few hundred newton and sometimes even less. There is no limit on maximum load capacity. Machines of 10MN capacity and larger exist, and are used routinely. However, a very common capacity for most composite testing is of 100kN. Some test methods will require a large machine [92].

Figure 4.5 Typical electromechanical universal testing machine

CHAPTER FIVE
EXPERIMENTAL METHOD

5.1 Introduction

This experimental study is composed from three sub-chapters. First sub-chapter is about the surface modification process to the woven jute fabric at different NaOH ratio (0%, 5%, 10% and 15%). Second sub-chapter is about the manufacturing process of the composite plates by hand lay-up at the room temperature. Mechanical experiments are composed as tensile test, compressive test and shear test in the third sub-chapter.

5.2 Materials

Woven jute fabrics with 300g/m^2 are assured from the Jutsan Company. They were cut the 80x100cm^2 dimensions for manufacturing laminated composite material. The sodium hydroxide (NaOH), which will be used for surface modification, is received from Düzey Lab. polyester resin (polipol351) and vinylester (polives701) resin as matrix materials were received from Yücel Group. Also methyl-ethly-ketone peroxide (MEKP) as the catalyst and 6% cobalt as accelerator was received from the Yücel Group. The epoxy resin (DTE 1100) as other matrix materials and hardener (DST 1105) were bought from the Duratek Company. The micro film which is used to prevent adhesion to the mold during the production of composite plates is received from Yenipak Company. This micro film is ability of nonstick and can be used up to 250°C the thickness of micro film is 19µm. Composite plates with six layers have been produced at the Uşak University Composite Manufacturing Laboratory by using a hydraulic press at 105°C and 8MPa pressure by hand lay-up method. The mechanical properties of the woven jute reinforced laminated composites were determined by using UTEST tension-compression device with 50kN load capacity at 1mm/min cross speed and at room temperature.

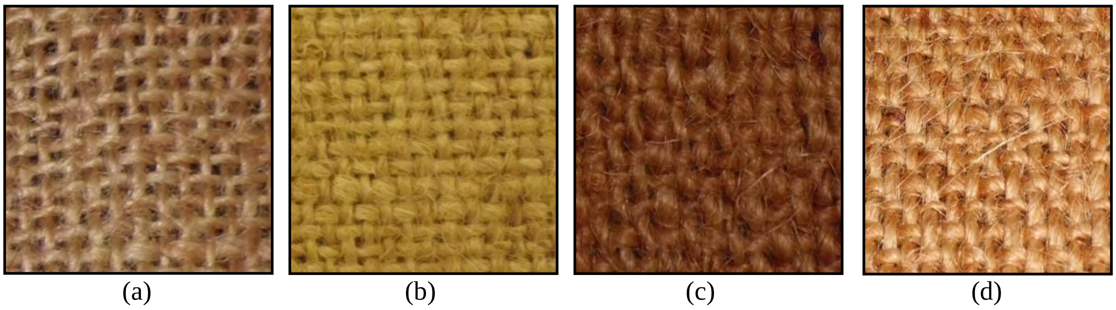
5.3 Methods

5.3.1 Alkalization of Woven Jute Fabric

The woven jute fabrics were soaked in 2% NaOH solution as shown in figure 5.1 for 20 hours. Thus, on the surface of woven jute fabrics are cleaned from dirt, oil, cellulose and lignin. Then the woven jute fabrics were washed by tap water and then they were dried at room temperature for 3 days.

Figure 5.1 Woven jute fabrics were soaked in NaOH solution

After that dried woven jute fabrics were again employed at 5%, 10% and 15% NaOH solution as shown in figure 5.1 for 4 hours. After the surface modification process, the woven jute fabrics were dried at room temperature for 15 days. As shown in the figure 5.2, the surface of woven jute fabrics were seen to be rougher than untreated (0%) woven jute fabrics. Also, the woven jute fabric were darkened up to 10% NaOH solution, after this level it lightens it’s darkness color. At the end, the woven jute fabrics were placed into an oven at 70°C for 30 minutes in order to eliminate the humidity.



(a) (b) (c) (d)

Figure 5.2 Woven jute fabrics after the (a) 0%, (b) 5%, (c) 10% and (d) 15% NaOH solution.

5.3.2 Preparation of Experimental Samples

The dehumidified woven jute fabrics are ready to production of layered composite. For manufacturing woven jute/polyester and woven jute/vinylester layered composites, 4g cobalt (accelerator) and 14mlt MEKP (catalyst) was mixed to 1000g polipol351 resin and polives701 resin, respectively. For manufacturing woven jute/epoxy layered composites, 74% epoxy resin was mixed with 26% hardener. Layered composites were produced as six woven jute fabric layers by hand lay-up method at room temperature as seen in figure 5.3a. As a result of surface modification, the resin absorbed capability of woven jute fabrics is increased by the increasing of NaOH solution percentage. After preparation of woven jute reinforced laminated composite plates with six layers, the plates are located into a time and temperature controlled hydraulic press as shown in figure 5.3b.

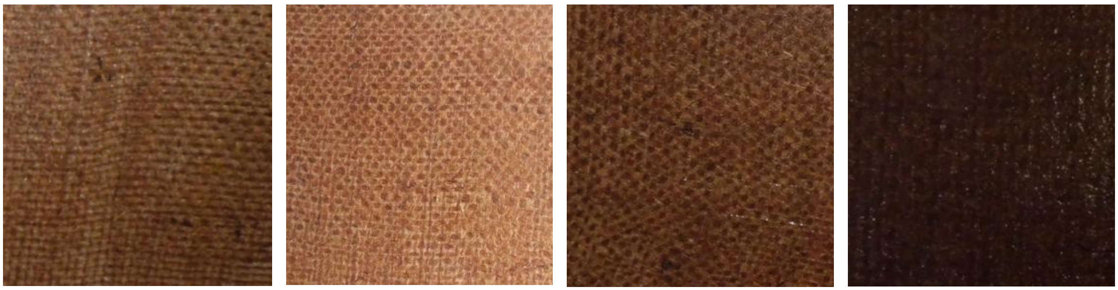

(a) (b)

Figure 5.3 (a) Hand lay-up method and (b) hydraulic press

Laminated composite plates were allowed to stand at room temperature for 3 days after production. Then, tensile and compressive test samples were cut by using BOSCH brand diamond saw (Figure 5.4) according to ASTM D 3039 and ASTM D 3410, respectively. The woven jute/polyester, woven jute/vinylester and woven jute/epoxy laminated composite plates are given in figure 5.5-figure 5.7 for 0%, 5%, 10% and 15% NaOH solution. It can be seen from figures, the jute fabric can be changed its colors at different level of NaOH solutions.

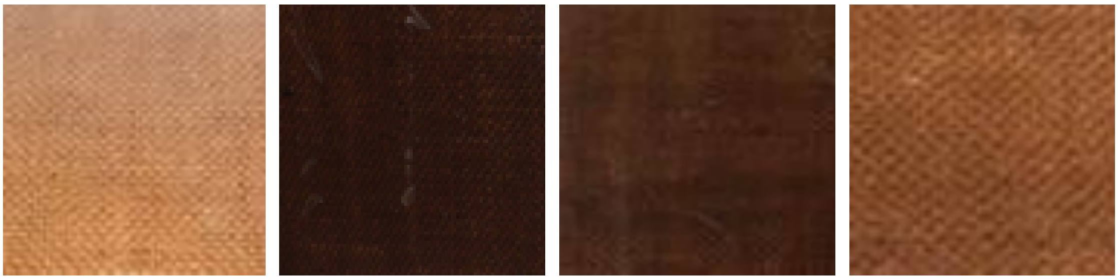
Figure 5.4 The cutting of test samples with BOSCH brand diamond saw

After curing process the composites materials were observed as follows.



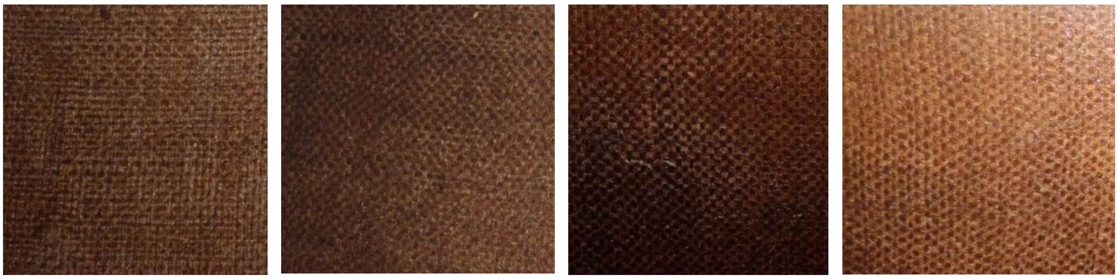
(a) (b) (c) (d)

Figure 5.5 Woven jute/epoxy laminated composites in (a) 0%, (b) 5%, (c) 10% and (d) 15% of NaOH solution.



(a) (b) (c) (d)

Figure 5.6 Woven jute/polyester laminated composites in (a) 0%, (b) 5%, (c) 10% and (d) 15% NaOH solution.



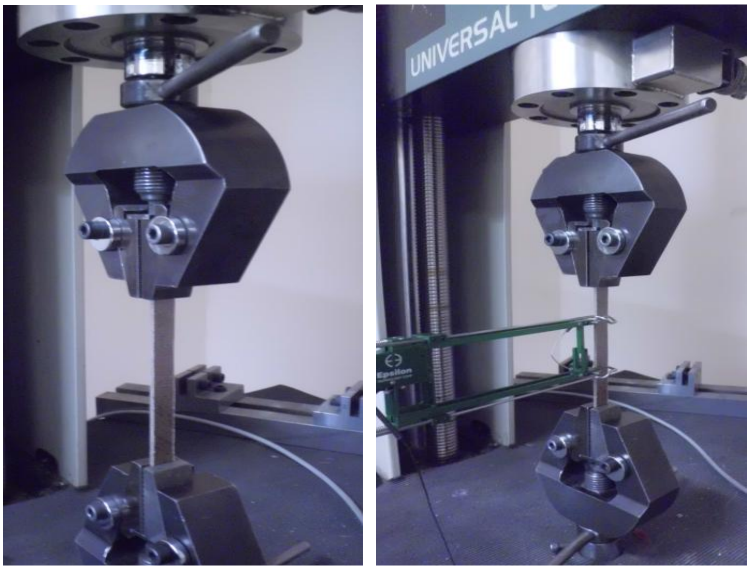
(a) (b) (c) (d)

Figure 5.7 Woven jute/vinylester laminated composites in (a) 0%, (b) 5%, (c) 10% and (d) 15% of NaOH solution.

5.4 Mechanical Tests

5.4.1 Tensile Tests

After the experimental test specimens were cut according to ASTM D 3039 standard, their mechanical properties were determined at UTEST tensile-compression machine with a capacity of 50kN at 1mm/min (Figure 5.8a). The tensile test specimens are loaded gradually up to failure loads in axial direction. After placing the tensile test sample in the cross-head, an extensometer is connected to the sample for find the modulus of elasticity (Figure 5. 8b). And also, the damage samples are seen after the tensile test as shown in figure 5.9. The elongation of the samples was read from the indicator as shown in figure 5.10.



(a) (b)

Figure 5.8 (a) Tensile test specimens were placed in the cross-head and (b) the connection of extensometer to the specimens

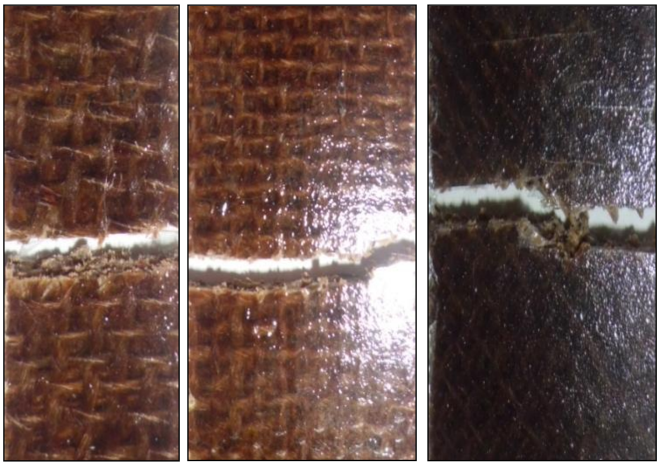

(a) (b) (c)

Figure 5.9 The sample damages in the (a) fiber, (b) perpendicular to the fiber and (c) 45° to the fiber direction after tensile test

Figure 5.10 The experimental setup

5.4.2 Compression Tests

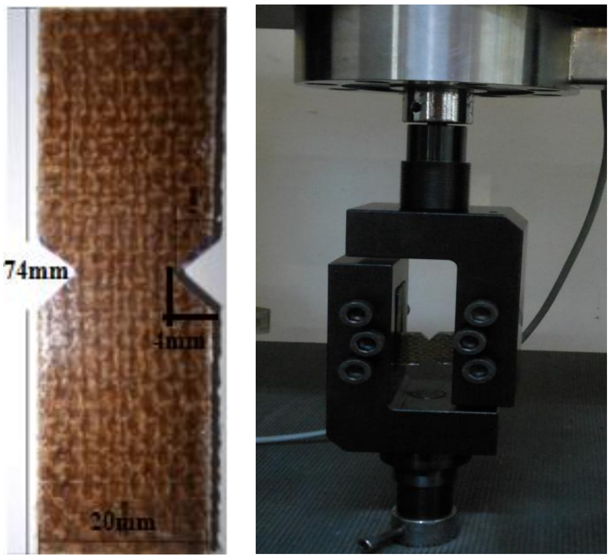
Dimensions were cut 100mm length and 6.4mm width because of the small cross-head of the compression apparatus (Figure 5 11a). Thus, compression test the samples weren’t buckled under compressive load. After that, the damage samples are seen after the compression test as shown in the figure 5.11b and 5.11c.

(a) (b) (c)

Figure 5.11 (a) Compression test specimens were placed into cross-head, the sample damages in the (b) fiber, (c) perpendicular to the fiber direction after tensile test

5.4.3 Rail Shear Tests

The rail shear test samples were cut 20mm wide and 74mm long according to the ASTM D 5379 standard test method (Figure 5.12a). In accordance with the ASTM D 5379, a notch with 4mm depth must be located with at the center of shear test samples.



(a) (b)

Figure 5.12 The shear specimens (a) were placed in Rail Shear Test Apparatus (b)

CHAPTER SIX

RESULTS and DISCUSSION

6.1 Introduction

In this thesis, the mechanical properties of woven jute/epoxy, woven jute/polyester and woven jute/vinylester composite samples are investigated after surface modification with different NaOH (0%, 5%, 10% and 15%) solution. The tensile, compressive and shear tests are applied to determine the mechanical properties of woven jute reinforced composite samples. The experimental tests have done at room temperature. Seven samples are tested for each feature (E_1, E_2, E_{45}, X_t, Y_t, X_c, Y_c and S) and the average of these tests results were taken.

Primarily, the fiber volume fraction in weight of woven jute/polyester, woven jute/epoxy and woven jute/vinylester composites were calculated. Seven samples in $5x5cm^2$ dimensions were cut from each laminated composite plates. Fiber volume fraction was calculated as following formula. Average weight of each composite sample was calculated as shown in Table 6.1.

$$\text{Fiber volume fraction} = \frac{\text{Weigth of fiber}}{\text{Total weigth of laminated composite}} * 100 \qquad (6.1)$$

It can be seen from Table 6.1 that the fiber volume fraction of untreated (0%) woven jute/epoxy laminated composite was calculated as 70%. Fiber volume fraction of woven jute/epoxy composite samples treated with 5%, 10% and 15% NaOH according to untreated samples were decreased as 17%, 19% and 6%, respectively. The fiber volume fraction of untreated (0%) woven jute/polyester laminated composite was calculated as 46%. Fiber volume fraction of woven jute/polyester composite samples treated with 5%, 10% and 15% NaOH according to untreated samples were decreased as 4%, 11% and 13%, respectively. The fiber volume fraction of untreated (0%) woven jute/vinlyester laminated composite was calculated as 69%. Fiber volume fraction of woven jute/vinylester composite samples were decreased as 4% for 5% NaOH and were increased as 7% and 4% for 10% and 15%, respectively, according to untreated samples.

Table 6.1 Fiber volume fraction for the composite samples

NaOH (%)	Woven jute/epoxy (%)	Woven jute/polyester (%)	Woven jute/vinylester (%)
0	70	46	69
5	58	44	66
10	57	41	75
15	66	40	72

6.2 Experimental Results of Woven Jute/Epoxy Composites

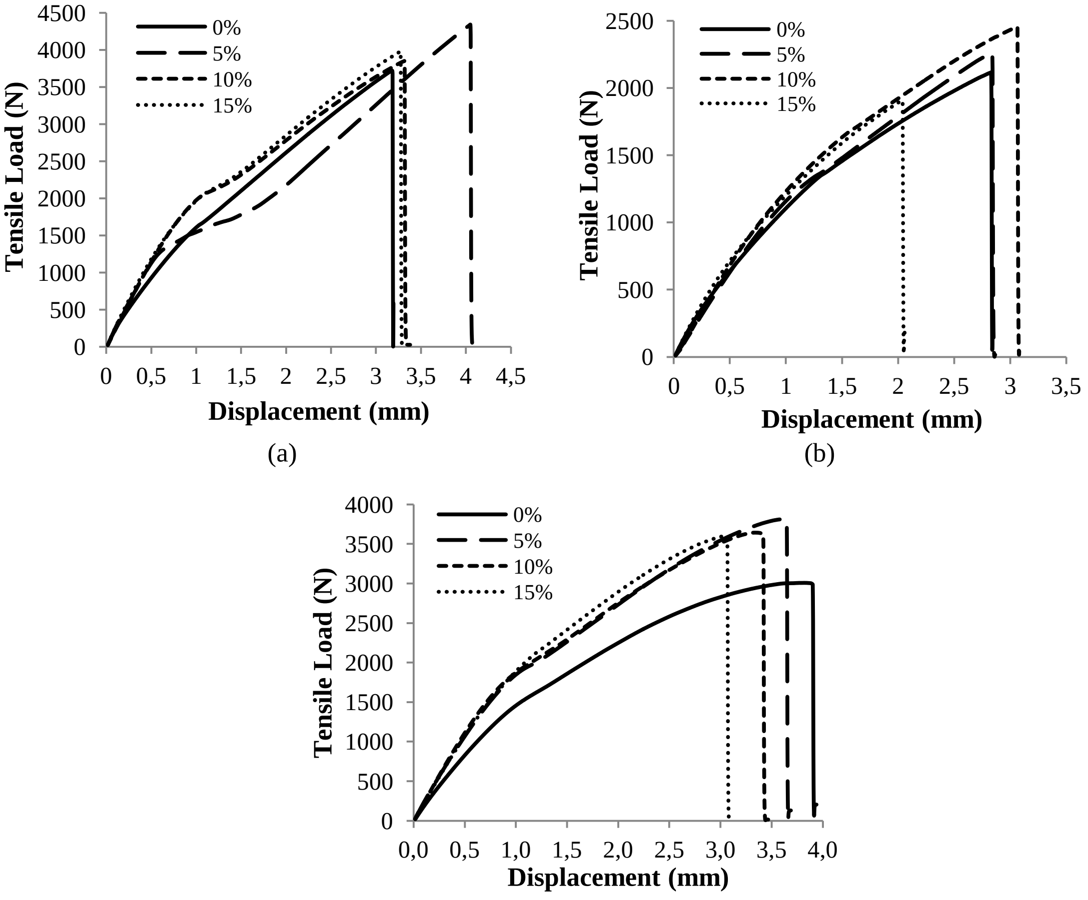
The variation of mechanical properties of woven jute/epoxy composite samples is given in Table 6.2 according to percentage of NaOH solution. The variation of them will be discussed later by graphical representation.

Table 6.2 Mechanical properties of woven jute/epoxy composites

NaOH (%)	E_1 (MPa)	E_2 (MPa)	E_{45} (MPa)	X_t (MPa)	Y_t (MPa)	X_c (MPa)	Y_c (MPa)	S (MPa)
0	8247	8058	5294	61	59	45	39	11
5	7956	7581	6895	54	50	53	44	16
10	8206	7921	7571	52	57	67	46	15
15	9324	8615	7729	61	54	39	53	15

The tensile load-displacement curves of (a) fiber direction, (b) perpendicular to the fiber direction and (c) 45° to the fiber direction for woven jute/epoxy composites are given in the figure 6.1. As shown in the figure 6.1a, although untreated (0%) woven jute/epoxy composite sample has minimum tensile load (3721N) and minimum displacement (3.18mm), the maximum tensile load (4342N) and maximum displacement (4.07mm) were occurred for 5% NaOH. Additionally, the tensile loads and displacements of woven jute/epoxy composite samples for 10% and 15% NaOH were obtained as 3853N and 3981N, 3.27mm and 3.25mm, respectively.
Understood from figure 6.1b, although 15% NaOH woven jute/epoxy composite sample has minimum tensile load (1907N) and minimum displacement (2.04mm),

the maximum tensile load (2453N) and maximum displacement (3.06mm) were obtained for 10% NaOH. Besides, the tensile loads and displacements of woven jute/epoxy composite samples for 0% and 5% NaOH were obtained as 2117N and 2263N, 2.78mm and 2.83mm, respectively. As shown in the figure 6.1c, although untreated (0%) woven jute/epoxy composite sample has minimum tensile load (3007N) and maximum displacement (3.81mm). The maximum tensile load (3811N) with displacement of 3.61mm was obtained for 5% NaOH. Although 15% NaOH woven jute/epoxy composite sample has minimum displacement (3.03mm) with tensile load of 3600N. The tensile load and displacement of woven jute/epoxy composite sample for 10% were appeared 3641N and 3.33mm, respectively.

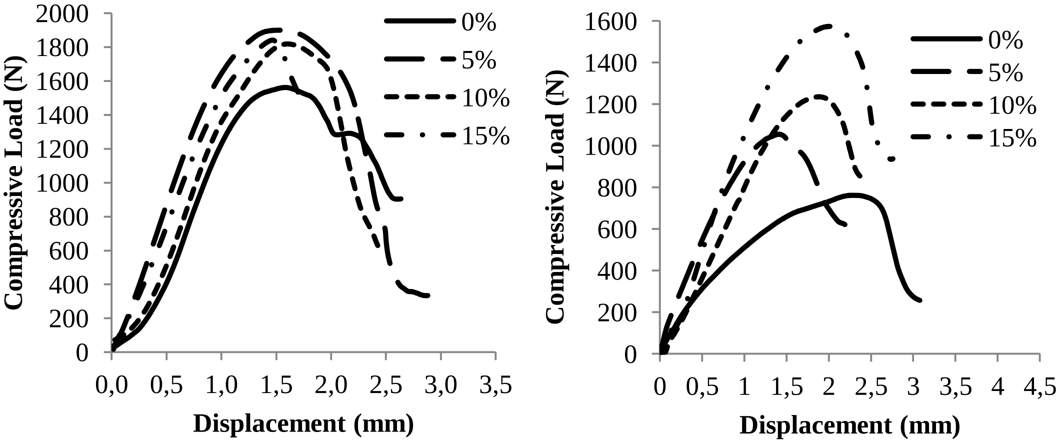


(a) (b)

(c)

Figure 6.1 The tensile load-displacement curves of woven jute/epoxy composites for (a) fiber direction (b) perpendicular to the fiber direction and (c) 45° to the fiber direction

The compressive load-displacement curves of (a) fiber direction and (b) perpendicular to the fiber direction for woven jute/epoxy composites are given in the figure 6.2. As shown in the figure 6.2a, although woven jute/epoxy composite sample in the fiber direction has maximum compressive load (1899N) for 5% NaOH, it has minimum compressive load (1562N) for untreated (0%). However, the compressive loads for 10% and 15% NaOH solutions were obtained as 1818N and 1842N, respectively. As shown in the figure 6.2b, although untreated (0%) woven jute/epoxy composite sample in the perpendicular to the fiber direction has minimum compressive load (761N) and the maximum compressive load as 1574N was obtained for 15% NaOH. Also, the compressive load for 5% and 10% NaOH woven jute/epoxy composite samples were occurred as 1055N and 1235N, respectively.



(a) (b)

Figure 6.2 The compressive load-displacement curves of woven jute/epoxy composites for (a) fiber direction and (b) perpendicular to the fiber direction

The modulus of elasticity of fiber direction, perpendicular to the fiber direction and 45° to the fiber direction for woven jute/epoxy composites samples depend on the percentage of NaOH are given in the figure 6.3. Modulus of elasticity in the fiber direction (E_1) was obtained as 8247MPa for untreated (0%) NaOH. For woven jute/epoxy composite samples treated with 5%, 10% and 15% NaOH, the modulus of elasticity have changed according to untreated (0%) sample as 4% (decrease), 1% (decrease) and 13% (increase), respectively. Modulus of elasticity in the perpendicular to the fiber direction (E_2) was found as 8058MPa for untreated (0%) NaOH. For woven jute/epoxy composite samples treated with 5%, 10% and 15% NaOH, the modulus of elasticity have changed according to untreated (0%) sample as 6% (decrease), 2% (decrease) and 7% (increase), respectively. Modulus of elasticity in the 45° to the fiber direction (E_{45}) was calculated as 5294MPa for untreated (0%) NaOH. The modulus of elasticity for woven jute/epoxy composite samples treated with 5%, 10% and 15% NaOH was increased according to untreated (0%) samples as 30%, 43% and 46%, respectively.

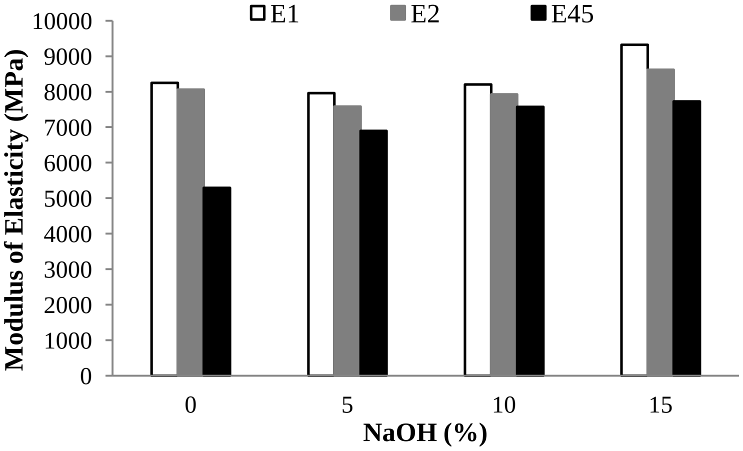


Figure 6.3 The modulus of elasticity of woven jute/epoxy composite samples depending on the NaOH percentage

The shear strength versus NaOH (%) curve for woven jute/epoxy composite samples is given in the figure 6.4. The shear strength of untreated (0%) samples was obtained as 11MPa. The shear strengths of woven jute/epoxy composite samples treated with 5%, 10% and 15% NaOH were increased according to untreated (0%) samples as 45%, 36% and 36%, respectively. It can be say from this figure, the shear strength of woven jute/epoxy composites was not affected after 10% NaOH solution.

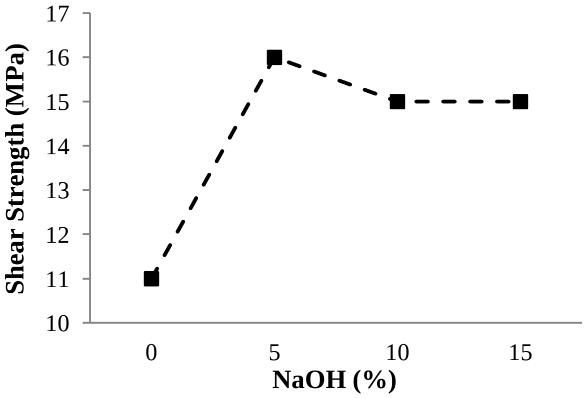


Figure 6.4 The shear strength versus NaOH (%) curve for woven jute/epoxy composite samples

Tensile strength and compressive strength versus NaOH (%) curves of woven jute/epoxy samples are given in the figure 6.5. The tensile strength in the fiber direction (Figure 6.5a) of untreated (0%) NaOH was obtained as 61MPa. The tensile strengths of woven jute/epoxy composite samples treated with 5%, 10% and 15% NaOH were changed according to untreated (0%) samples as 11% (decrease), 15% (decrease) and 0% (not change), respectively. The tensile strength in the perpendicular to the fiber direction was calculated as 59MPa for untreated (0%) NaOH. The tensile strength of woven jute/epoxy composite with 5%, 10% and 15% NaOH were decreased samples treated according to untreated (0%) samples as 15%, 3% and 8%, respectively. The compressive strength in the fiber direction (Figure 6.5b) for untreated (0%) NaOH was obtained as 45MPa. The compressive strength of woven jute/epoxy composite samples treated with 5%, 10% and 15% NaOH solutions were changed according to untreated (0%) samples as 18% (increase), 49% (increase) and 13% (decrease), respectively. The compressive strength in the perpendicular to the fiber direction (Figure 6.5b) was calculated as 39MPa for untreated (0%) NaOH. The compressive strength of woven jute/epoxy composite samples treated with 5%, 10% and 15% NaOH were increased according to untreated (0%) samples as 13%, 19% and 36%, respectively.

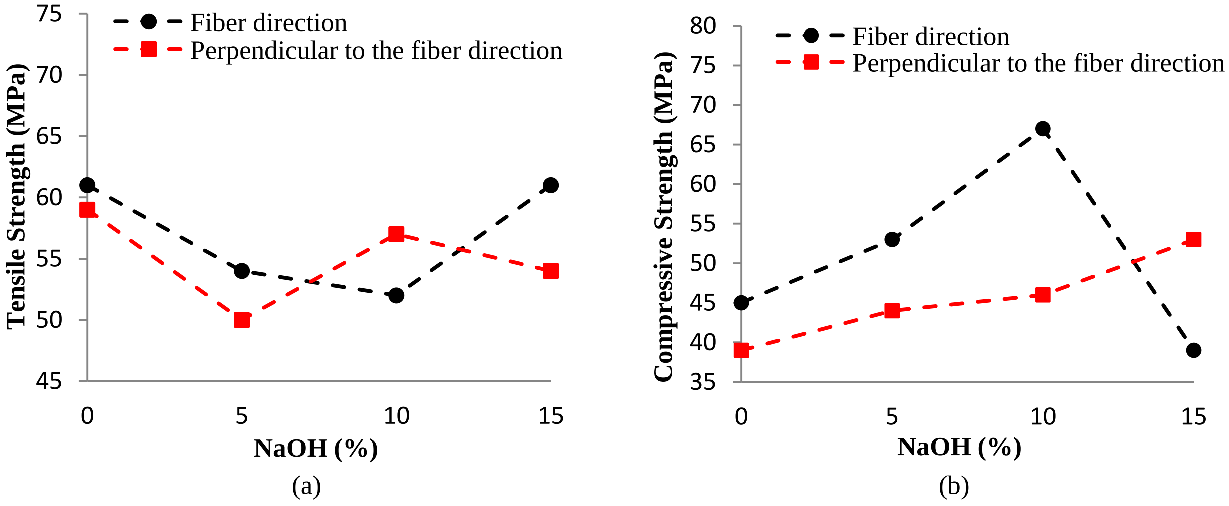


Figure 6.5 The tensile (a) and compressive (b) strengths variation of woven jute/epoxy composite samples depend on NaOH percentage

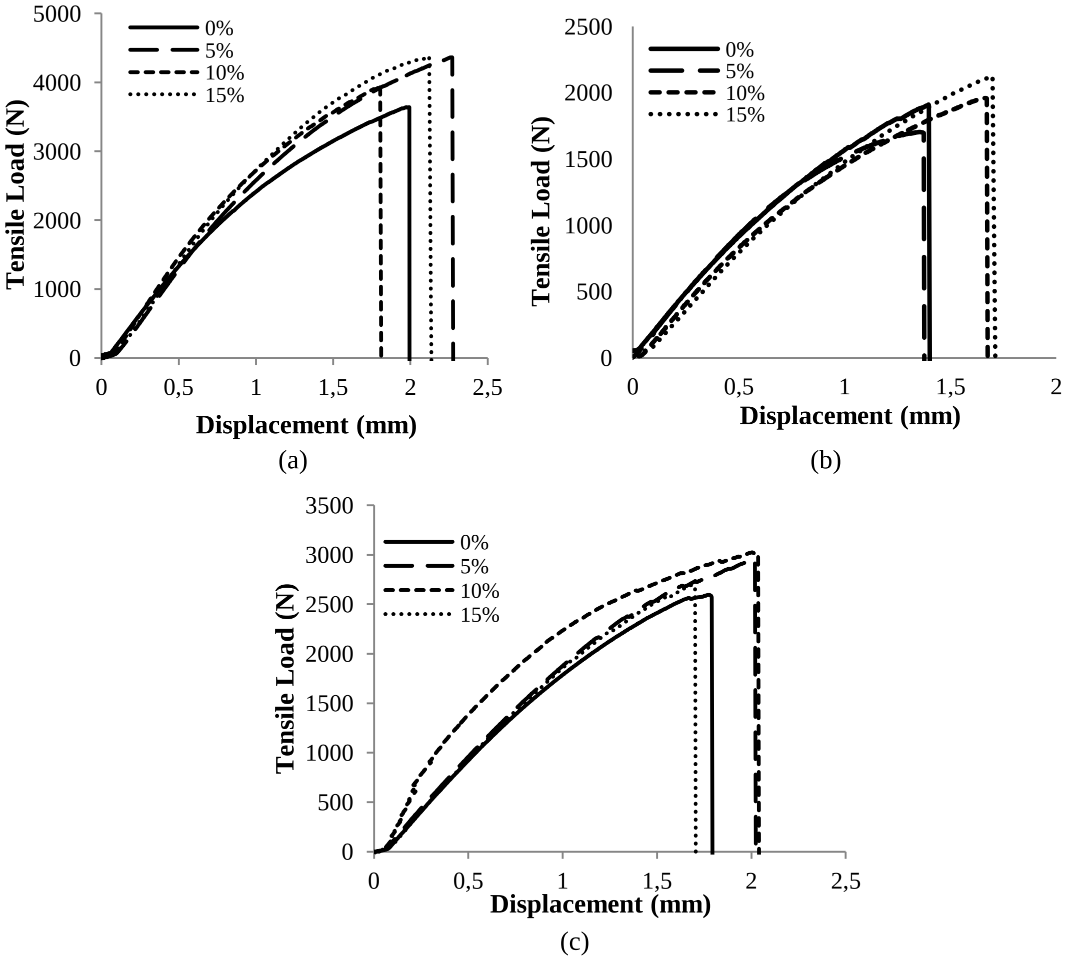
6.3 Experimental Results of Woven Jute/Polyester Composites

According to percentage NaOH solution, the mechanical properties of woven jute/polyester composite samples are given in Table 6.3. The graphical representation and discussion of these datas will be given later.

Table 6.3 Mechanical properties of woven jute/polyester composites

NaOH (%)	E_1 (MPa)	E_2 (MPa)	E_{45} (MPa)	X_t (MPa)	Y_t (MPa)	X_c (MPa)	Y_c (MPa)	S (MPa)
0	6726	6491	4825	38	37	62	78	17
5	7678	7419	4997	45	40	77	87	15
10	8988	8619	5017	42	52	73	112	16
15	8595	8352	5163	92	27	109	82	17

The tensile load-displacement curves of fiber direction (a), perpendicular to the fiber direction (b) and 45° to the fiber direction (c) for woven jute/polyester composites are given in the figure 6.6. As shown in the figure 6.6a, although untreated (0%) woven jute/polyester composite sample has minimum tensile load (3782N) with 1.97mm displacement. The maximum tensile load was occurred as 4540N with 2.12mm for 15% NaOH. Although, 5% NaOH woven jute/polyester composite sample has maximum displacement (2.26mm), its tensile load is 4428N. Furthermore, the tensile load and displacement of woven jute/polyester composite sample for 10% was attained 4150N and 1.97mm, respectively. As shown in the figure 6.6b, although the maximum tensile load was obtained as 2306N with 1.69mm displacement for woven jute/polyester composite samples with 15% NaOH. The minimum tensile load (1756N) and minimum displacement (1.38mm) was occurred for 5% NaOH. Besides, the tensile loads and displacements of woven jute/polyester composite samples for 0% and 10% NaOH were attained 1904N, 1958N, and 1.4mm, 1.66mm, respectively. As shown in the figure 6.6c, 0% woven jute/polyester composite sample has minimum tensile load (2672N) with 1.77mm displacement. The maximum tensile load of 3164N with displacement as 2.00mm was obtained for 10% NaOH. Although 5% NaOH woven jute/polyester composite sample has maximum displacement (2.03mm) with 3094N tensile load. Furthermore, the tensile load and displacement of woven jute/polyester composite sample for 15% was attained as 2794N and 1.68mm, respectively.



(a) (b)

(c)

Figure 6.6 The tensile load-displacement curves of woven jute/polyester composites for (a) fiber direction, (b) perpendicular to the fiber direction and (c) 45° to the fiber direction.

The compressive load-displacement curves of fiber direction (a) and perpendicular to the fiber direction (b) for woven jute/polyester composites are given in the figure 6.7. As shown in the figure 6.7a, although untreated woven jute/polyester composite sample in the fiber direction has minimum compressive load (3855N). 10% NaOH woven jute/polyester composite sample has maximum compressive load as 4641N. In addition, the compressive loads for 5% and 15% were obtained as 3869N and 3928, respectively. As shown in the figure 6.7b, although 15% NaOH woven jute/polyester composite sample in the perpendicular to the fiber direction has maximum compressive load (2076N). The minimum compressive load was obtained as 1400N for 10% NaOH. Also, the compressive load of untreated

NaOH woven jute/polyester composite sample was obtained as 2031N. Furthermore, the compressive load was obtained as 1997N for 5% NaOH.

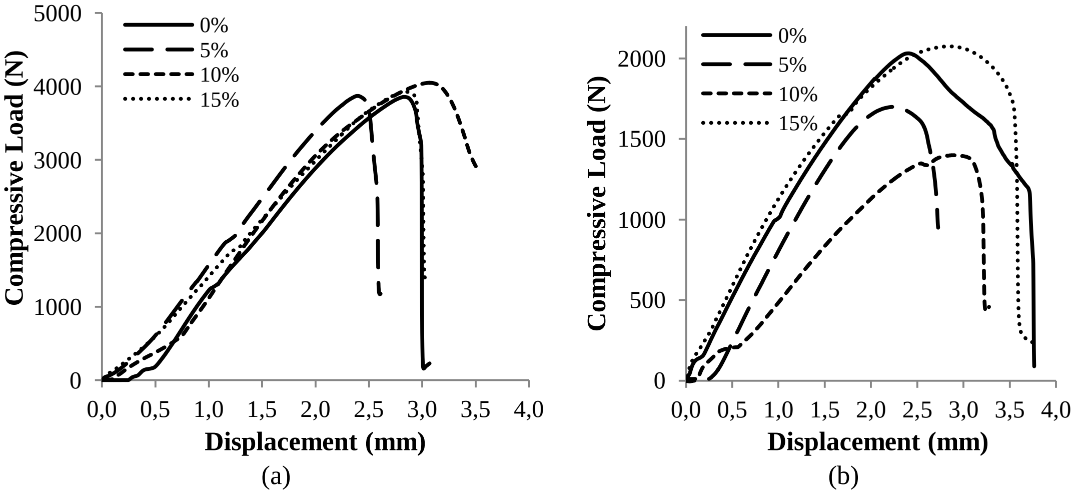


Figure 6.7 The compressive load-displacement curves of woven jute/polyester composite samples for (a) fiber direction and (b) perpendicular to the fiber direction

The modulus of elasticity versus percentage of NaOH for fiber direction, perpendicular to the fiber direction and 45° to the fiber direction for woven jute/polyester composites are given in the figure 6.8. Modulus of elasticity in the fiber direction (E_1) was obtained as 6726MPa for untreated composite samples. The modulus of elasticity for woven jute/polyester composite samples treated with 5%, 10% and 15% NaOH according to untreated (0%) sample were increased as 14%, 34% and 28%, respectively. The modulus of elasticity in the perpendicular to the fiber direction (E_2) was found as 6491MPa for untreated samples. The modulus of elasticity for woven jute/polyester composite samples treated with 5%, 10% and 15% NaOH was increased according to untreated (0%) sample as 14%, 33% and 29%, respectively. The modulus of elasticity in the 45° to the fiber direction (E_{45}) was calculated as 4825MPa for untreated (0%) NaOH. The elasticity modulus for woven jute/polyester composite samples treated with 5%, 10% and 15% NaOH was increased according to untreated (0%) sample as 3%, 4% and 7%, respectively.

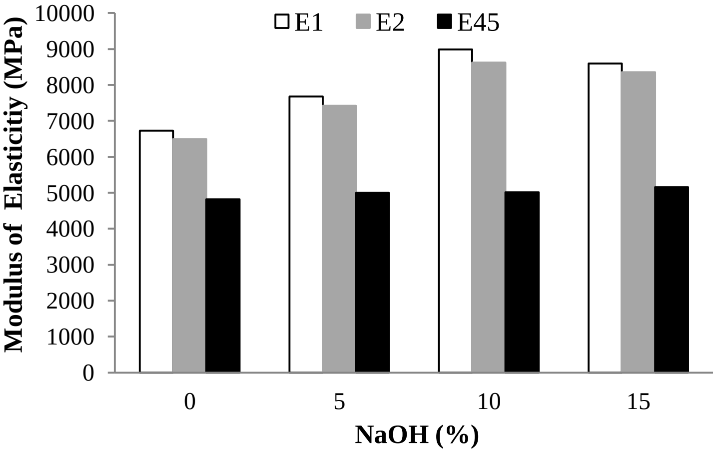


Figure 6.8 The variation of modulus of elasticity depending on the NaOH (%) for jute/polyester composites

The shear strength versus NaOH (%) curve for woven jute/polyester composites is given in the figure 6.9. The shear strength of untreated samples was obtained as 17MPa. The shear strength for woven jute/epoxy composite samples with 5%, 10% and 15% NaOH was changed according to untreated (0%) sample as 12% (decrease), 6% (decrease) and 0% (not change), respectively.

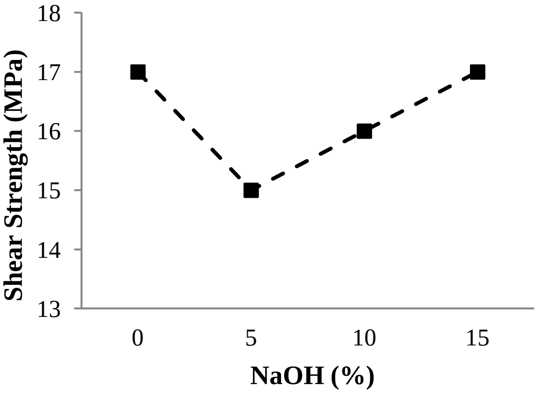
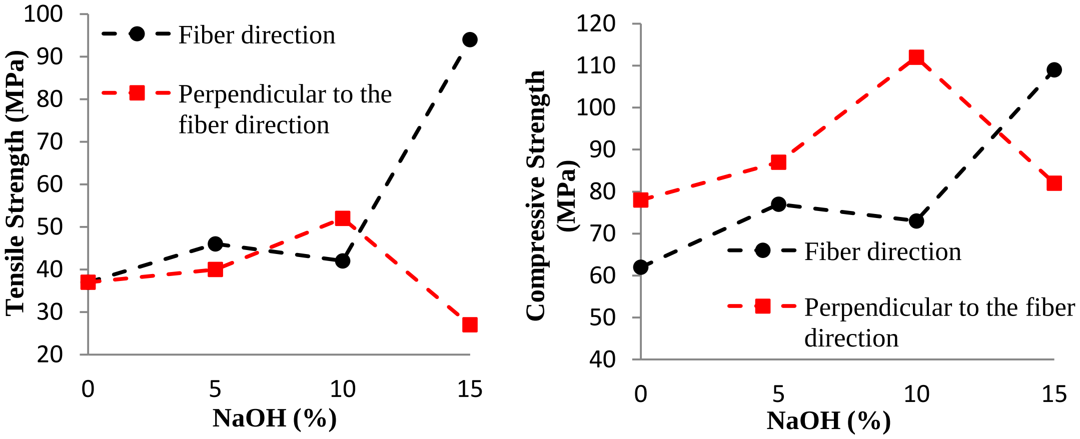


Figure 6.9 The shear strength versus NaOH (%) for woven jute/polyester samples

The tensile strength and compressive strength versus NaOH (%) curves of woven jute/polyester samples are given in the figure 6.10. The tensile strength in the fiber direction (Figure 6.10a) of untreated samples was obtained as 38MPa. The tensile strength of woven jute/polyester composite samples with 5%, 10% and 15% NaOH was increased according to untreated (0%) sample as 18%, 11% and 142%, respectively. The tensile strength in the perpendicular to the fiber direction was calculated as 37MPa for untreated (0%) NaOH. The tensile strength woven jute/polyester composite samples with 5%, 10% and 15% NaOH have changed according to untreated (0%) sample as 8% (increase), 41% (increase) and 27% (decrease), respectively. The compressive strength in the fiber direction (Figure 6.10b) of untreated samples was obtained as 62MPa. The compressive strength of woven jute/polyester composites with 5%, 10% and 15% NaOH was increased according to untreated (0%) sample as 24%, 18% and 76%, respectively. The compressive strength in the perpendicular to the fiber direction (Figure 6.10b) was calculated as 78MPa for untreated samples. The compressive strength for woven jute/polyester composites with 5%, 10% and 15% NaOH was increased according to untreated (0%) sample as 12%, 44% and 5%, respectively.



(a) (b)

Figure 6.10 The variation of (a) tensile and (b) compressive strength for woven jute/polyester composites

6.4 Experimental Results of Woven Jute/Vinylester Composites

The mechanical properties of woven jute/vinylester composite samples are given in Table 6.4 according to NaOH percentage. The detailed investigation of this table will be done later.

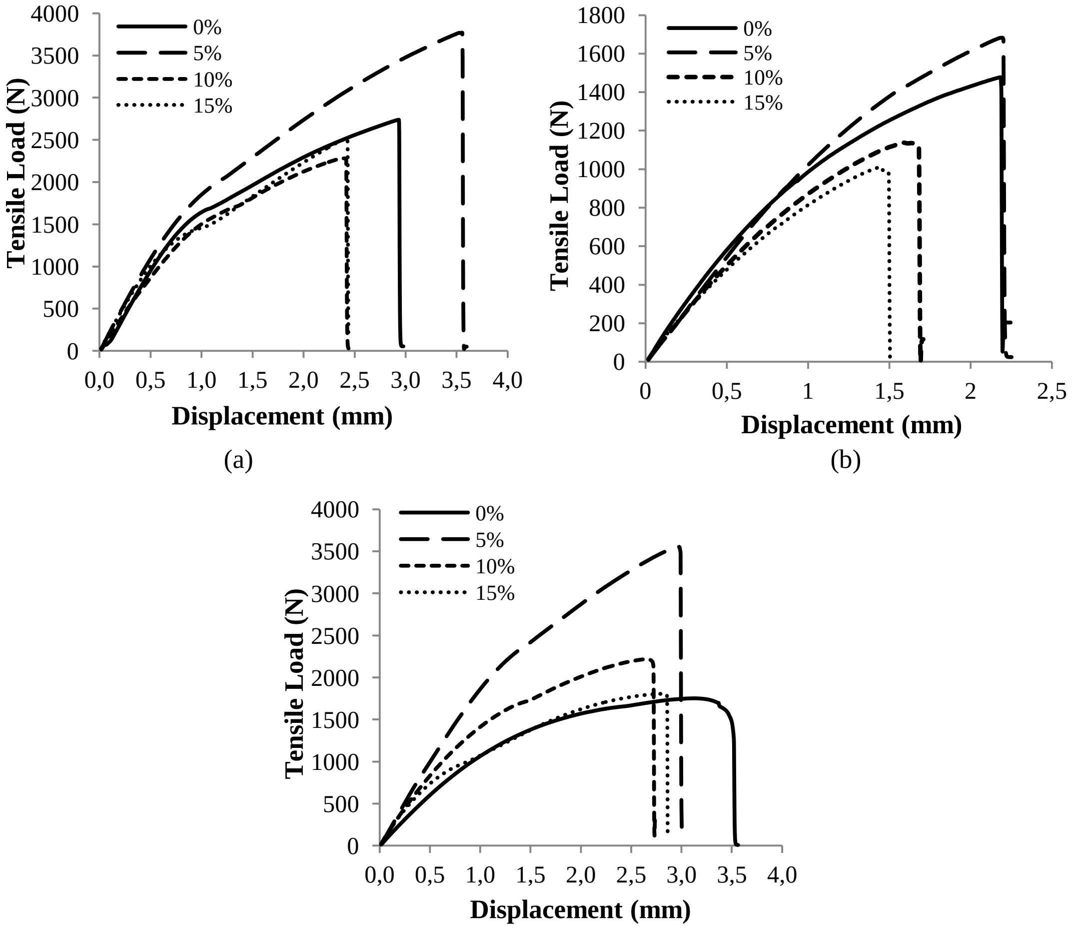
Table 6.4 Mechanical properties of woven jute/vinylester composites

NaOH (%)	E_1 (MPa)	E_2 (MPa)	E_{45} (MPa)	X_t (MPa)	Y_t (MPa)	X_c (MPa)	Y_c (MPa)	S (MPa)
0	7605	7021	3587	41	38	18	23	8
5	8380	7178	7340	58	42	44	37	10
10	8200	6997	6649	30	31	29	22	11
15	7865	6320	6605	36	25	43	24	12

The tensile load-displacement curves of fiber direction (a), perpendicular to the fiber direction (b) and 45° to the fiber direction (c) for woven jute/vinylester composites were given in the figure 6.11. As shown in the figure 6.11a, although 5% NaOH woven jute/vinylester composite sample has maximum tensile load (3770N) and maximum displacement (3.52mm). The minimum tensile load (2279N) and minimum displacement (2.43mm) were obtained for 10% NaOH. In addition, the tensile loads and displacements of woven jute/vinylester composite samples for untreated (0%) samples and for samples with 15% NaOH were obtained as 2736N and 2516N, 2.92mm and 2.43mm, respectively. As shown in the figure 6.11b, although the woven jute/vinylester composite sample with 15% NaOH has minimum tensile load (1013N) with 1.44mm displacement. The maximum tensile load (1683N) and maximum displacement (2.19mm) were obtained for sample with 5% NaOH. Besides, the tensile loads and displacements of woven jute/vinylester composite samples for 0% and 10% NaOH were attained 1477N and 1137N, 2.16mm and 1.60mm, respectively. As shown in the figure 6.1c, although untreated (0%) woven jute/vinylester composite sample has minimum tensile load (1754N) with maximum displacement (3.6mm). The maximum tensile load (3554N) with 2.97mm displacement was occurred for 5% NaOH. Although 10% NaOH woven jute/vinylester composite sample has minimum displacement (2.65mm) with 2217N tensile loads, the tensile load and displacement of woven jute/vinylester composite sample for 15% was attained 1806N and 2.80mm, respectively.

The compressive load-displacement curves of fiber direction (a) and perpendicular to the fiber direction (b) for woven jute/vinylester composites are given in the figure 6.12. As shown in the figure 6.12a, the untreated (0%) woven jute/vinylester composite sample has minimum compressive load (348N). The maximum compressive load (881N) was obtained for 15% NaOH. Also, The compressive load of woven jute/vinylester composite samples was occurred as 793N for 5% NaOH and as 502N for 10% NaOH samples.

As shown in the figure 6.12b, the maximum and minimum compressive load of woven jute/vinylester composite sample was obtained as 1377N for 5% NaOH, and as 955N for 10% NaOH, respectively. Also, the compressive load of untreated and 15% NaOH woven jute/vinylester composite sample was occurred as 1025N and 1201N, respectively.

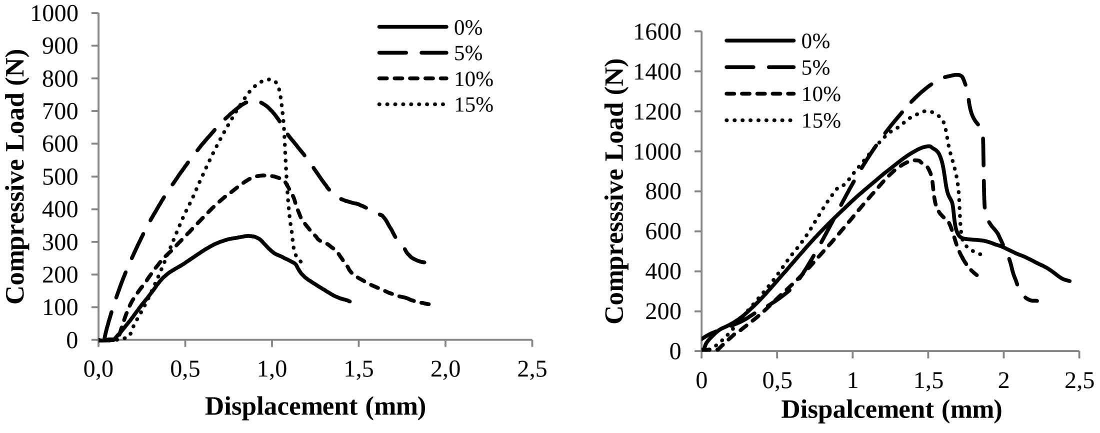


(a)

(b)

(c)

Figure 6.11 The tensile load-displacement curves of woven jute/vinylester composites for (a) fiber direction, (b) perpendicular to the fiber direction and (c) 45° to the fiber direction



(a) (b)

Figure 6.12 The compressive load-displacement curves of woven jute/vinylester composites for (a) fiber direction and (b) perpendicular to the fiber direction

The modulus of elasticity-NaOH (%) variation for fiber direction, perpendicular to the fiber direction and 45° to the fiber direction for woven jute/vinylester composites are given in the figure 6.13. The modulus of elasticity in the fiber direction (E_1) was obtained as 7605MPa for untreated samples. For woven jute/vinylester composite samples with 5%, 10% and 15% NaOH the modulus of elasticity was increased according to untreated (0%) sample as 10%, 8% and 3%, respectively.

The modulus of elasticity in the perpendicular to the fiber direction (E_2) was found as 7021MPa for untreated (0%) NaOH. For woven jute/vinylester composites with 5%, 10% and 15% NaOH, the modulus of elasticity have changed according to untreated (0%) sample as 2% (increase), 1% (decrease) and 10% (decrease), respectively.

The modulus of elasticity in the 45° to the fiber direction (E_{45}) was calculated as 3587MPa for untreated (0%) NaOH. For woven jute/vinylester composite samples with 5%, 10% and 15% NaOH, the modulus of elasticity was increased according to untreated (0%) sample as 105%, 85% and 84%, respectively.

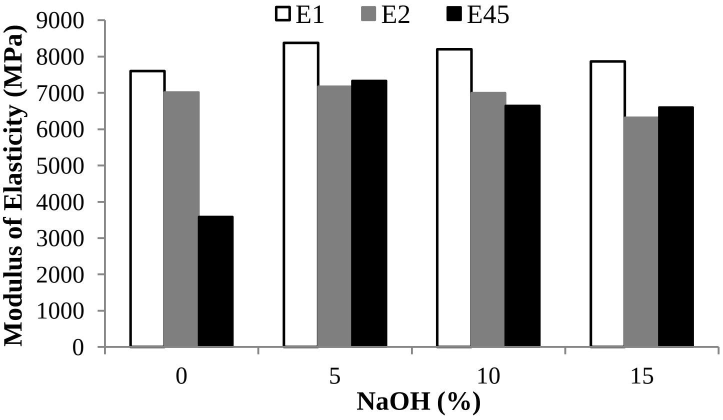


Figure 6.13 The modulus of elasticity for jute/vinylester composite samples

The shear strength-NaOH (%) curve for woven jute/vinylester composite sample is given in the figure 6.14. The shear strength of untreated sample was obtained as 8MPa. The shear strength for woven jute/vinylester composites with 5%, 10% and 15% NaOH were increased according to untreated (0%) sample as 25%, 37% and 50%, respectively.

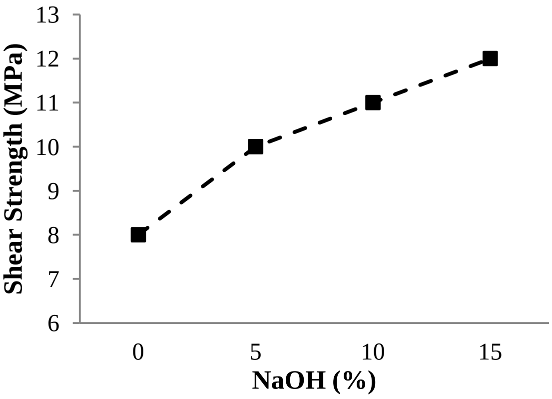


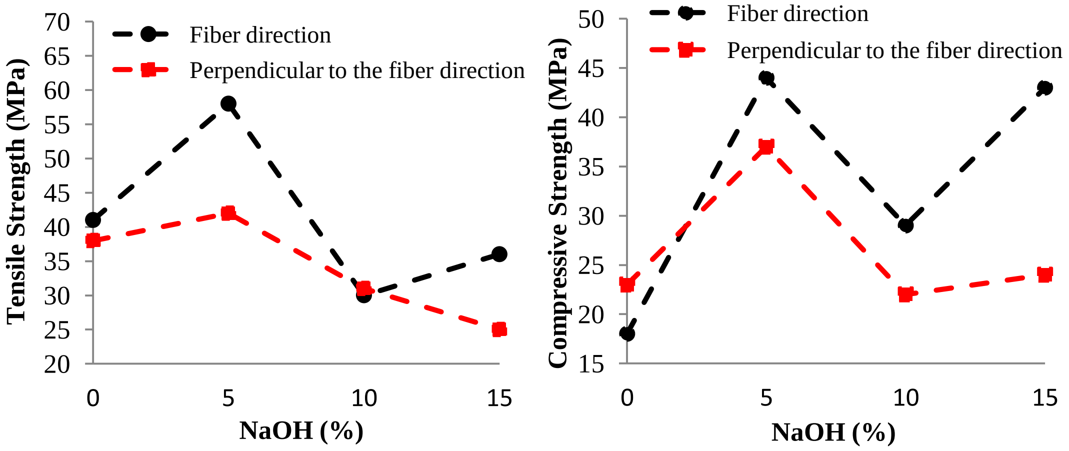
Figure 6.14 The variation of shear strength-NaOH (%) for woven jute/vinylester composite samples

The tensile strength and compressive strength curves of woven jute/vinylester composite samples are given in the figure 6.15. The tensile strength in the fiber direction (Figure 6.15a) for untreated was obtained as 41MPa. The tensile strength in the fiber direction for woven jute/vinylester composite samples treated with 5%, 10% and 15% NaOH have changed according to untreated (0%) sample as 41% (increase), 27% (decrease) and 12% (decrease), respectively.

The tensile strength in the perpendicular to the fiber direction was calculated as 38MPa for untreated (0%) NaOH. For woven jute/vinylester composites with 5%, 10% and 15% NaOH, the tensile strength in the perpendicular to the fiber direction was changed according to untreated (0%) sample as 11% (increase), 18% (decrease) and 34% (decrease), respectively.

The compressive strength in the fiber direction (Figure 6.15b) for untreated (0%) NaOH was obtained as 18MPa. For woven jute/vinylester composite samples treated with 5%, 10% and 15% NaOH, the tensile strength according to untreated (0%) sample was increased as 144%, 61% and 139%, respectively.

The compressive strength in the perpendicular to the fiber direction (Figure 6.15b) was calculated as 23MPa for untreated (0%) NaOH. The compressive strength for woven jute/vinylester composite samples treated with 5%, 10% and 15% NaOH have changed according to untreated (0%) sample as 61% (increase), 4% (decrease) and 4% (increase), respectively.



(a) (b)

Figure 6.15 The varition of (a) tensile and (b) compressive strength for woven jute/vinylester composite samples

6.5 The General Comparison for Woven Jute Reinforced Composite Structures

The variation of modulus of elasticity in the fiber direction (E_1) is given for woven jute reinforced composite samples treated with different NaOH solutions in figure 6.16. The highest and the lowest elasticity modulus values in fiber direction are obtained in the woven jute/epoxy with 15% NaOH and in the untreated woven jute/polyester, respectively.

The modulus of elasticity in the fiber direction is decreased as 3.5% according to untreated samples for woven jute/epoxy samples with 5% NaOH. The E_1 values are increased for jute/polyester and jute/vinylester samples as 14.2% and 10.2% by the 5% NaOH, respectively. The woven jute/polyester samples are showed maximum value in the 10% NaOH according to other composite samples. Although woven jute/epoxy samples and woven jute/vinylester samples have almost the same value, they have increased according to untreated samples as 0.5% and 7.8%, respectively. E_1 values are increased as 13.1%, 27.8% and 3.4% for woven jute/epoxy, woven jute/polyester and woven jute/vinylester samples with 15% NaOH according to untreated samples, respectively.

The variation of modulus of elasticity in the perpendicular to the fiber direction (E_2) was represented in the figure 6.17. From the figure; the maximum and minimum values were obtained as woven jute/epoxy with 15% NaOH and as woven jute/polyester with 0% NaOH, respectively. The modulus of elasticity in the perpendicular to the fiber direction is decreased as 5.9% for woven jute/epoxy samples from 0% to 5% NaOH. According to untreated samples, E_2 values for jute/polyester and for jute/vinylester samples at 5% NaOH were increased as 14.3% and 2.2%, respectively. According to 0% NaOH samples the woven jute/epoxy, woven jute/polyester and woven jute/vinylester samples with 10% NaOH were changed as 1.7% (decrease), 32.8% (increase) and 0.3% (decrease), respectively. In addition, E_2 values were changed in accordance with untreated samples as 6.9% (increase), 28.7% (increase) and 10% (decrease) for woven jute/epoxy, woven jute/polyester and woven jute/vinylester samples with 15% NaOH, respectively.

The modulus of elasticity in 45° fiber direction for woven jute/epoxy, woven jute/polyester and woven jute/vinylester were given in figure 6.18. It can be seen from figure that the woven jute/vinylester samples have minimum E_{45} value in the

0% NaOH, they have maximum E_{45} value in the 5% NaOH. Also, woven jute/vinylester samples have increased as 104.6% in the 5% NaOH from 0% NaOH. Woven jute/epoxy samples and woven jute/polyester samples with 5% NaOH were increased as 30.2% and 3.6%, according to untreated samples, respectively. Woven jute/epoxy samples have maximum E_{45} value in the 10%-15% NaOH according to other composite samples. In addition, woven jute/polyester samples have minimum E_{45} value in the 10%-15% NaOH. Woven jute/epoxy samples, woven jute/polyester samples and woven jute/vinylester samples with 15% NaOH were increased as 46%, 7% and 84.1%, according to untreated samples, respectively.

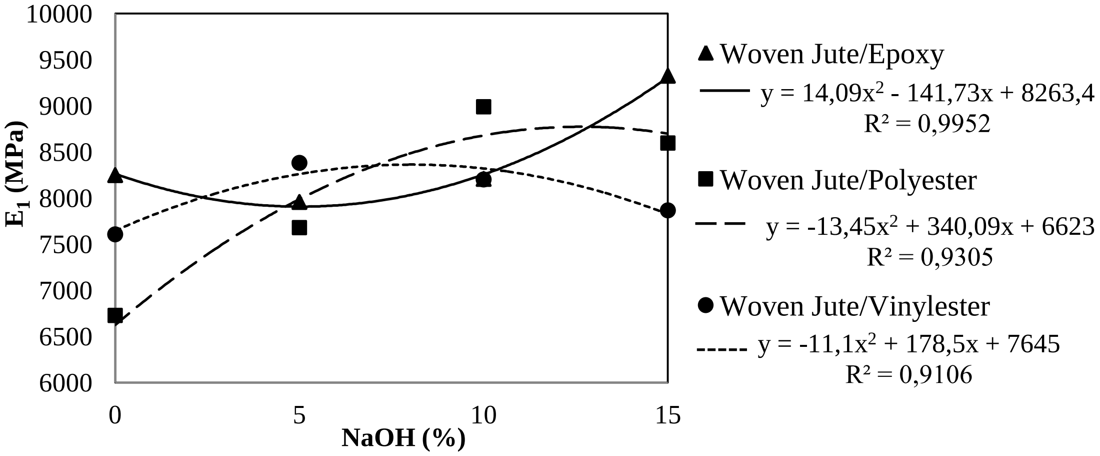


Figure 6.16 The modulus of elasticity (E_1) curves depending on the NaOH (%)

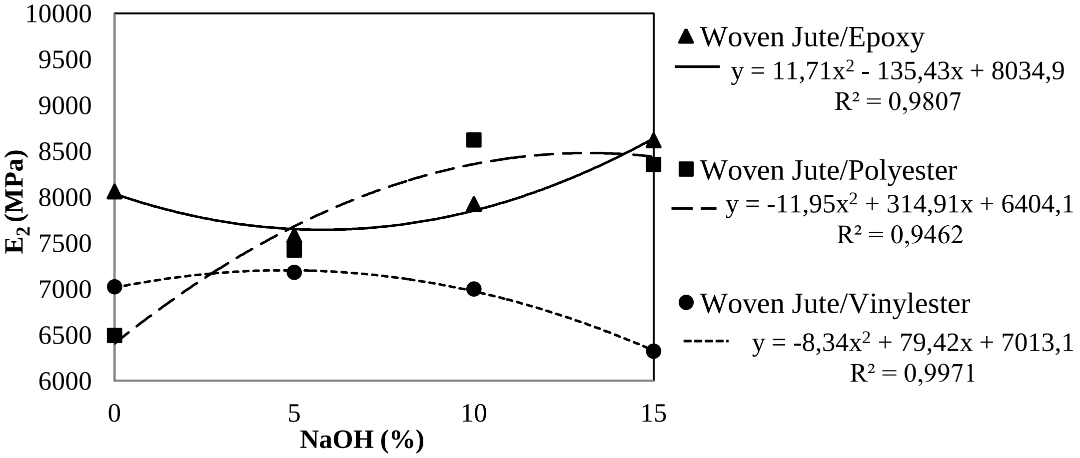


Figure 6.17 The modulus of elasticity (E_2) curves depending on the NaOH (%)

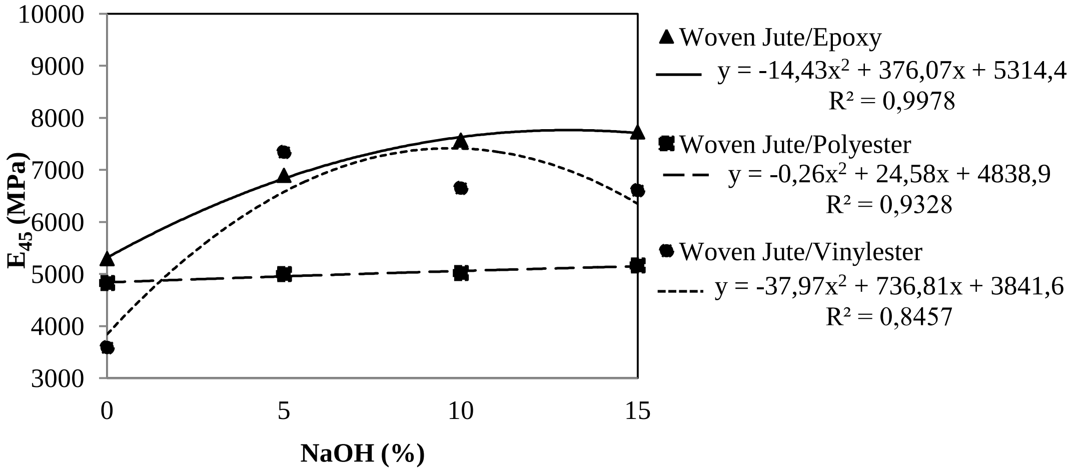


Figure 6.18 The modulus of elasticity in 45° to the fiber direction (E_{45}) curves depending on the NaOH (%)

The tensile in the fiber direction strength versus NaOH percentage for woven jute reinforced composite samples was illustrated in figure 6.19. It can be clearly say that the woven jute/polyester samples have minimum value and woven jute/epoxy samples have maximum value for untreated samples. Woven jute/vinylester samples have maximum value for the sample with 5% NaOH and they have increased 41.5% from 0% to 5% NaOH. Woven jute/epoxy samples and woven jute/polyester samples have altered in the 5% NaOH as 11.5% (decrease) and 24.3% (increase), respectively. Woven jute/vinylester samples have minimum value for 10% NaOH and woven jute/epoxy samples have maximum value for 10% NaOH. Woven jute/vinylester samples have minimum value though woven jute/polyester samples have maximum value for 15% NaOH. Woven jute/epoxy samples, woven jute/polyester samples and woven jute/vinylester samples were changed as 0%, 154.1% and 12.2% from 0% NaOH to 15% NaOH, respectively.

The tensile strength perpendicular to the fiber direction depend on NaOH (%) was given in the figure 6.20. Woven jute/epoxy composite samples have maximum value while woven jute/polyester composite samples have minimum value for untreated samples. Woven jute/epoxy, woven jute/polyester and woven jute/vinylester composite samples are changed as 15.3% (decrease), 8.1% (increase) and 10.5% (increase) from 0% to 5% NaOH. Again woven jute/epoxy composite samples show maximum value according to other composite samples with 10% NaOH. Woven jute/vinylester composite samples have illustrated minimum value in the 10% NaOH. The woven jute/epoxy, woven jute/polyester and woven jute/vinylester samples with 10% NaOH were changed in accordance with untreated samples as 3.4% (decrease), 40.5% (increase) and 18.4% (decrease). Although woven jute/epoxy composite samples have maximum value, and woven jute/vinylester composite samples have minimum value for the sample with 15% NaOH. The tensile strength was decreased from 0% NaOH to the 15% NaOH as 8.5%, 27% and 34.2% for woven jute/epoxy, woven jute/polyester and woven jute/vinylester, respectively.

The compressive strength in fiber direction versus NaOH (%) curve was given in the figure 6.21. The minimum and maximum compressive strength was obtained from woven jute vinylester and woven jute/polyester samples with 0% NaOH, respectively. The compressive strength in the sample with 5% was increased as 17.8% for woven jute/epoxy 24.2% for woven jute/polyester and 144.4% for woven jute vinylester. The woven jute/polyester composite samples have maximum value and woven jute/vinylester composite samples have minimum value for the samples with 10% NaOH. The woven jute/epoxy and woven jute/polyester composite samples with 15% NaOH have minimum and maximum values, respectively, and their value was changed 13.3% (decrease) from untreated and 75.8% (increase) from 0% NaOH samples. The changing in the compressive strength from 0% to 15% NaOH for woven jute/vinylester is as 138.9% (increase).

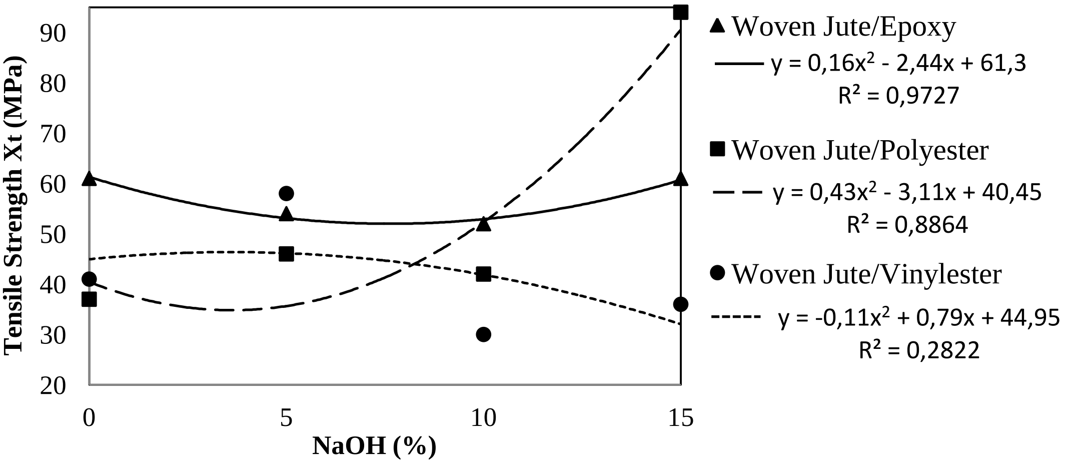


Figure 6.19 The tensile strength (X_t) in the fiber direction curves depending on the NaOH (%)

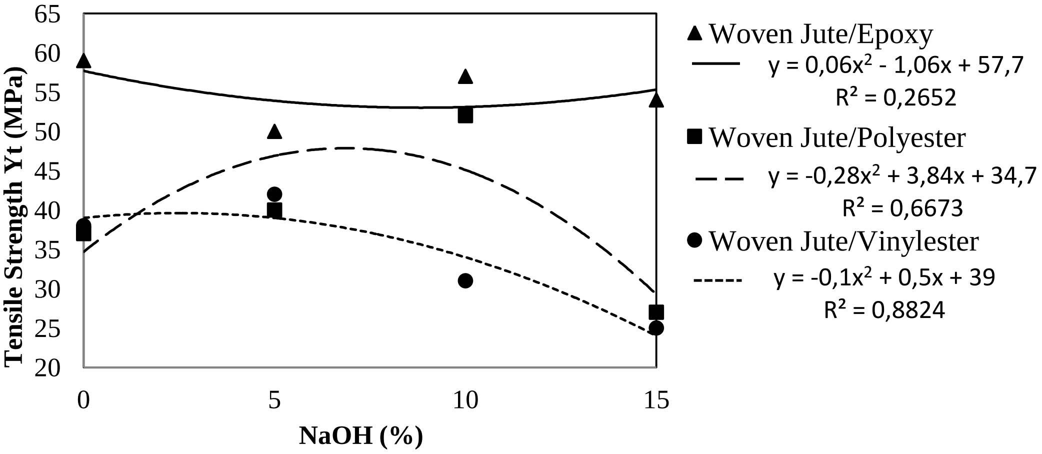


Figure 6.20 The tensile strength (Y_t) in perpendicular to the fiber direction curves depending on the NaOH (%)

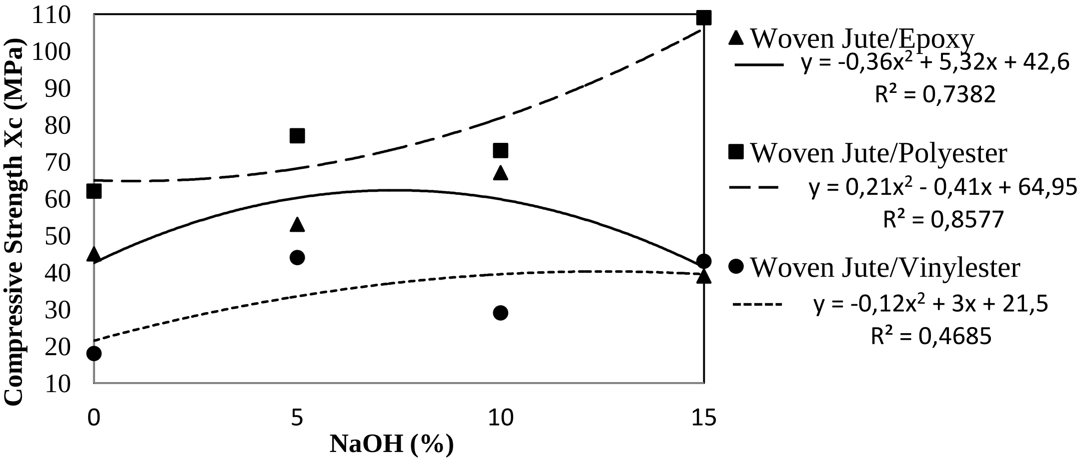


Figure 6.21 The compressive strength (X_c) variation in fiber direction depending on the NaOH (%)

The compressive strength in perpendicular to the fiber direction versus NaOH (%) curve has given in the figure 6.22. It is clear from figure that the maximum and minimum compressive strength were obtained for woven jute/polyester and for woven jute/vinylester composite samples in the whole NaOH solutions. The changing in the compressive strength for woven jute/polyester are as 11.5% (increase), 43.9% (increase) and 5.1% (increase) for the sample with 5%, 10% and 15%, respectively. The compressive strengths are increased as 12.8%, 17.9% and 35.9% for the woven jute/epoxy samples with 5%, 10% and 15% NaOH, respectively. At the end, the increasing (60.9%) was occurred for woven jute vinylester in the sample with 5% NaOH. almost no change was obtained in the sample with 10% and 15% NaOH from untreated samples.

The shear strength versus NaOH (%) curve was given in the figure 6.23. Although woven jute/polyester composite samples have maximum shear value, the woven jute/vinylester composites samples have minimum shear value in the 0% NaOH. The shear strength for woven jute/epoxy, woven jute/polyester and woven jute/vinylester samples with 5% NaOH were changed as 45.5% (increase), 11.8% (decrease) and 25% (increase), respectively. For 10% NaOH solution, although woven jute/vinylester composite samples have minimum shear value, their shear value increased as 37.5%. Additionally, woven jute/polyester composites samples have maximum shear value, and their shear value was decreased as 5.9% in the 10% NaOH. Woven jute/epoxy composite samples were increased as 36.4% in the 10% NaOH in accordance with untreated samples. Woven jute/vinylester composite samples have minimum shear value and their shear values were increased as 50% in the 15% NaOH. Woven jute/polyester composite samples have maximum shear value and their shear values were not changed. And, woven jute/epoxy composite samples were increased as 36.4% in the 15% NaOH.

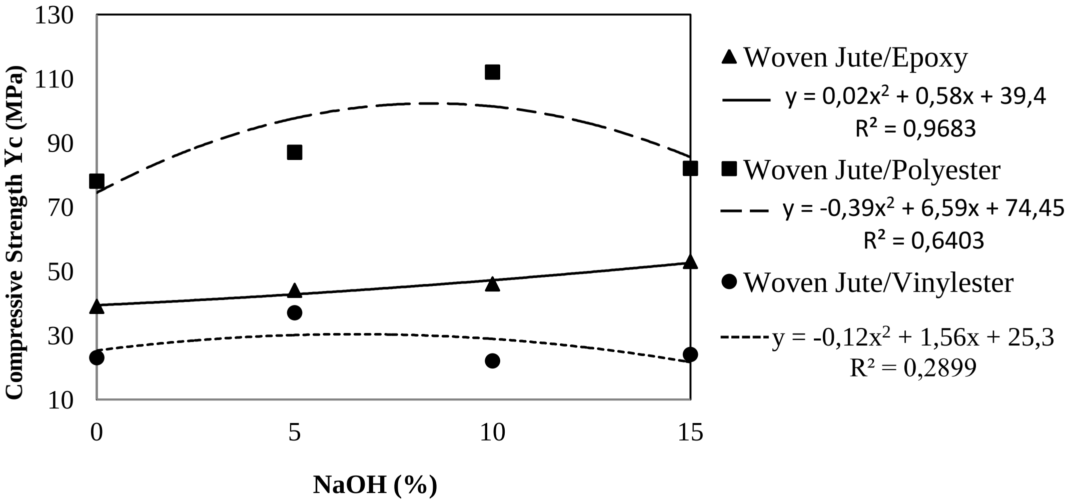


Figure 6.22 The compressive strength (Y_c) in perpendicular to the fiber direction curves depending on the NaOH (%)

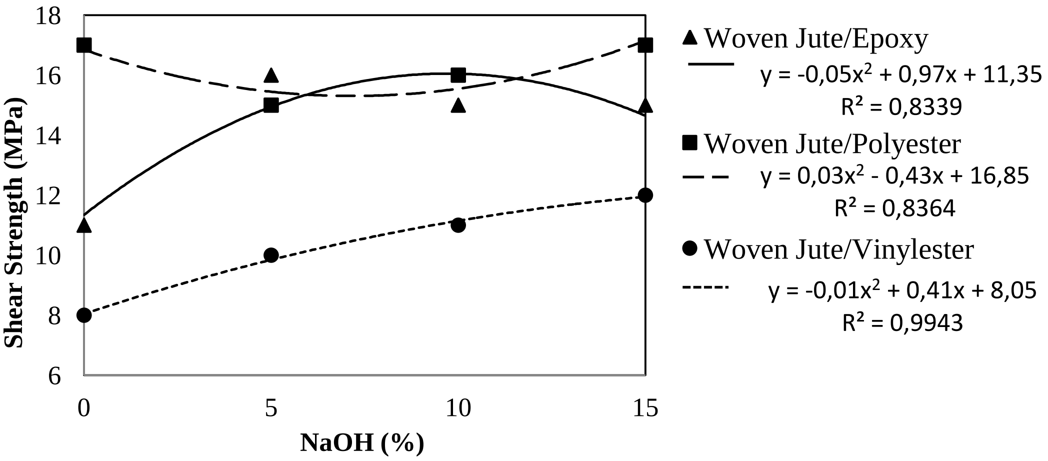


Figure 6.23 The shear strength curves depending on the NaOH (%)

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