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**THE INVESTIGATION OF THE ENVIRONMENTAL
EFFECTS ON COMPOSITE MATERIALS**

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Master's Thesis

Supervised by Asst. Prof. Dr. Suleyman BASTURK

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COMPOSITE MATERIALS**

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DEDICATION

I would like to dedicate this work to my very first teacher, my mother, my first supporter and role model, my wife and my companion throughout the journey and my brothers and sisters. Without you, this dream would never come true.



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I might want to offer my thanks to every one of the individuals who have upheld me all through the regularly extended periods of this voyage. I might want to thank my advisor, Asst. Prof. Dr. Suleyman Basturk for being my compass notwithstanding, when I believed I was lost and being in extraordinary part in charge of the zenith of this work. I might likewise want to thank my supervisor for his supportive exhortation, which incredibly enhanced the nature of this work. Finally, I thank this institution for hosting me during these years, securely earning its place as my home. I am very thankful to my mom and dad, whose values and education motivate me to keep asking questions; to my siblings and family for their infinitely appreciated love and to my country which, although inanimate, keeps me anchored and offers me an example of resiliency.

ABSTRACT

THE INVESTIGATION OF THE ENVIRONMENTAL EFFECTS ON COMPOSITE MATERIALS

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In this research, an investigation of the environmental effects on composite materials has been conducted. The composite material with a polymeric basis was prepared by hand casting and is consisted of epoxy as a base material reinforced by glass fibers and with three layers and in a random direction. The research was carried out on three stages. The first stage is preparing the samples from the composite material that consists of epoxy reinforced with glass fiber. As for the second stage, the prepared samples were exposed to certain environmental conditions where the sample 2 was exposed to moisture for a one month by immersing it in water, and exposing the sample 3 to a temperature of 50 °C for a one month, exposing the sample 4 to a temperature of 70 °C for a one month, while not subjecting the sample 1 to environmental conditions. The third stage is to procedure a hardness, tensile, bending and impact resistance tests on the prepared samples.

It was observed from the results that mechanical properties decrease when exposed to environmental conditions such as moisture and heat, and it was also observed that the effect of moisture is less than the effect of heat on mechanical properties, as well as the temperature effect on the mechanical properties which increases when temperature increases.

Keywords: Environmental effects, Composite materials, Hardness, Impact, Tensile.

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LIST OF ABBREVIATIONS

PMCs	:	Polymer Matrix Composites
CMCs	:	Ceramic Matrix Composites
MMCs	:	Metal Matrix Composites
GF	:	Glass Fiber
UV	:	Ultraviolet rays
NFC	:	Natural fiber composite
PP	:	Polypropylene
SiC	:	Silicon carbide
FRM	:	Fiber reinforced composite material
VF	:	Volume fraction
T_g	:	Glass Transition Temperature
ASTM	:	American Society for Testing Material
I.S	:	Impact Strength
V_f	:	Volume of fiber
V_c	:	Volume of composite

1. INTRODUCTION

Composite materials are composed of two or more materials, one of which is called as a matrix and the other one is called as a reinforcing material. The reinforced material is the form as fibers or particles. The composite materials are divided into three types according to the base materials involved in their composition, these types are polymeric composite, ceramic composite and metal composite. After studying the physical and mechanical properties of these materials, represented by hardness and durability, compression resistance, tensile strength, thermal and electrical conductivity, corrosion resistance, formability and plasticity, have been observed in the properties of these materials [1]. For example, polymers are lightweight, corrosion resistant, and formable, where complex shapes can be manufactured and cannot be resistant to high temperatures (higher than 400 °C) and are insulating materials for electricity and thermal conductivity are low, while ceramic materials (Ceramics) is characterized by high resistance to high temperatures and thermal and electrical insulating materials, high hardness and high resistance to compression forces, but also characterized by brittleness and low resistance to impact and tensile forces. Metals are characterized by high ability to resist loads and durability and non-resistance to the weather. Air being exposed to oxidation [2].

Because of these mechanical and physical properties of composite materials they are suitable for use in certain areas and unsuitable for other areas as many modern industries need materials that have unusual mechanical and physical properties (high hardness and corrosion resistance and resistance to various environmental conditions such as humidity and high temperatures as well as light weight and resistance loads and forces) so that they are economical, inexpensive and suitable for such industrial purposes.

After many studies, it was found that polymer-based composite materials are the best of the three types because of their high mechanical and physical characteristics such as their light weight and high durability, their ease of formation and use in the production of complex shapes, their high resistance to moisture, their resistance to corrosion, their good insulation property for electricity [3].

The composites reinforced by fiber are affecting their mechanical and physical properties such as tensile strength, torsion, hardness, and compression strength of the surrounding environmental

conditions such as humidity, temperature and UV rays. Therefore, it is necessary to study the impact of environmental conditions on composite materials due to their use in different environmental conditions.

1.1 LITERATURE REVIEW

In 2000, Li [4] studied the effect of temperature and humidity on composite materials containing glass fiber and different resins for use in wind turbine blades. The main objective of this study is to find the resins which have more resistant to moisture and temperature where it was used (polyesters, vinyl esters and epoxy). Epoxy and polyester were found to be more sensitive to moisture and temperature, meaning they had greater water absorption. Polyester has a higher environmental resistance with no mechanical properties heavily affected in wet hot air. However, polyester is relatively brittle compared with vinyl esters and epoxy.

In 2017, Herak et al. [5], studied the effect of temperature and moisture content on the tensile behavior of banana fibers. They were prepared the samples containing banana fibers and subjected to environmental conditions where the temperature was varied from -20°C to 220°C and the moisture content between 10% and 90%, after the tensile test was found that the tensile strength is constant in the temperature from 0°C to 100°C , but when the temperature increases above 100°C the tensile strength decreases. The moisture content has no effect on tensile strength.

Eslami and Raouf [6] studied the effects of moisture absorption on glass fibers used to reinforced vinyl ester composite pipes. The main purpose of their study is to investigate the effects of humidity and temperature on the properties of GFRP samples. The results proved that reducing the temperature reduces the diffusion coefficient and moisture absorption.

Seneviratne and Tomblin [7], studied the effect of the environmental factor in the design of the composite materials. Most polymeric materials in the form of a polymeric matrix or polymeric fibers are able to absorb relatively small amounts but potentially large amounts of moisture present in the surrounding environment. Moisture absorption may result in dimensional change, and a lower glass transition temperature of the polymer.

Sethi and Ray [8] studied the environmental effects of polymeric compounds which is reinforced by fibers. The main objective of their research is to study the effect of environmental conditions such as moisture and temperature absorption on the mechanical and physical properties of composite materials reinforced by fiber such as tensile strength, bending and hardness. The study showed that environmental conditions have a clear effect on mechanical and physical properties.

In 2016, Kumar [9] conducted a comparative study of the moisture propagation behavior of a nano-composite compound with a different composition of nano-clay, where the moisture absorption behavior of any fiber-reinforced composite structure is an important study because it affects the mechanical properties of the composite. The propagation phenomenon of any composite material follows the Vic's second propagation law. The purpose of this study is to understand the propagation behavior in nanocomposite structure prepared from epoxy reinforced glass fibers as well as containing nanoclay. This composite material produced by varying proportions of nano plasma such as 2%, 3%, 4%, 5%, 6% and 7%. After composite production, all samples were tested for their behavior in moisture propagation. Low tensile strength due to moisture diffusion of composite materials. The decrease in moisture propagation with the increase of clay content in the compound by up to 6%.

In 2013, Dana and Perronnet [10] studied the propagation of moisture in organic composites. In this study the diffusion of moisture in polymers reinforced by glass fiber was tested through both experiments and theoretical studies. The moisture propagation of clean resins for unidirectional composite panels with different glass fiber ratios was identified by analyzing thermal moisture tests. The main objective of this study is to compare developments, such as the role of fiber volumetric ratio in moisture diffusion coefficients the results obtained from the experiments show that the results are conformity with the results predicted by several previous studies.

Prabhakaran [11] conducted a study on composite materials containing polyamide (PA6) as a base material reinforced with fibers. Polyamide is a thermoplastic polymer, which uses the manufacture of large composite structures such as wind turbine blades. The mechanical and physical properties of polyamide are highly sensitive to moisture, therefore, if polyamide is used as the base material in the production of composite, it leads to the mechanical properties of these composite will depend on the moisture content. In the case of 23 °C, 50% RH, polyamide absorbs about 3% of water. In this study the composite material consists of polyamide as a base

material reinforced by glass fibers in conditions 23 °C, 50% RH. The percentage of glass fiber is different 45% - 50%. The mechanical properties of the composite, such as shear stress and hardness, have been tested, which are often affected by the moisture content of the composite.

Pickering and Efendy [12] studied the recent developments in natural fiber composite and their mechanical properties. There has been a rapid growth in research and innovation in the natural fiber composite (NFC). Attention is warranted because of the advantages of these materials compared to others, such as synthetic fiber compounds, including the impact of environmental conditions and low cost. Great efforts have been made to increase its mechanical performance to increase its use in more fields and industries. This study aims to provide an overview of the factors affecting the mechanical performance of NFCs and the details of its achievements.

Shen and Springer [13] studied moisture absorption and diffusion in composite materials. The absorption and distribution of moisture in composite materials were studied in a specified period of time where the dimensions of the sample are homogeneous, where one or two sides are exposed to wet air or water. The results show that the moisture absorption and moisture distribution are identical when the moisture content and temperature in the surrounding environment are constant. The values of moisture content and their distribution in composite materials were found by testing the composite.

In 2009 Siriruk and Weitsman [14] studied the mechanical properties and environmental effects of polymers and sandwich composites. Composite materials are used in the manufacture of marine vessels where vinyl ester resin is used as a base material reinforced with carbon fiber. The main objective of the research is to study the effects of seawater on the mechanical properties of composite materials which used in shipbuilding. Data on the elastic properties of the composite (shear and Unic coefficient) were collected by special devices to examine these properties. The shear test device showed that the shear modulus value in the water-saturated outer shell of the samples showed a degraded by 72% when the sample was exposed for a long time to seawater.

In 2019 Moudood et al. [15] studied the environmental effect on durability and mechanical performance of a composite made of epoxy reinforced by flax fibers. The increasing use of bio-composite materials in various engineering applications therefore requires a comprehensive

understanding of mechanical performance during exposure to harsh environmental conditions such as temperature, humidity, freezing and other environmental conditions. The mechanical properties of bio-composite materials can be affected when exposed to harsh environmental conditions. In addition, the use of these composite materials in water can shorten their life cycle.

The main objective of the research was to study the effects on the durability and mechanical performance of a composite material consisting of epoxy and flax fibers when exposed to different environmental conditions such as immersion of the sample in water and warm humid environment and in melting ice conditions. The results showed that the mechanical properties of the composite materials deteriorated and affected when exposed to these environmental conditions compared to mechanical properties after manufacture and before exposure to these environmental conditions, where the tensile strength decreased by 9% when the sample is saturated with water compared to the tensile strength of the sample when manufactured and before submerging with water. Also, water affected the bending strength even more, where the bending strength decreased by 64% compared to the bending strength of the sample when manufactured. However, these mechanical properties can be partially restored after samples are dried. Warm, humid environments and melting ice have been found to have very little effect on bio-composite materials.

In 2019, Mouzakisa and Dimogianopoulosb [16] studied the performance and sensitivity of composite materials used in the aircraft industry to change environmental conditions, for example, the hardening behavior of the composite materials which compound from the polyester and glass fibers which is used in the manufacture of wind turbines has been studied by several previous researchers. Since the composite materials have become widely involved in the manufacture of passenger aircraft, it is important to study the exposure of high-performance materials to environmental conditions causing depreciation, such as temperatures, humidity and UV radiation and assess their effect on the mechanical properties of these composite materials. In this research the analysis of acoustic emissions and environmental effects on the composite materials reinforced with carbon fibers have been studied.

In 2019, Nash et al. [17] investigated the effect of environmental conditions on the mechanical properties of thermosetting and thermoplastic as based on composite materials that are used in the marine industries. Where the samples were manufactured by special molds of polymer

reinforced with glass fibers, the effect of immersion in water and in an organic liquid was determined by the shear strength and glass transition temperature (T_g). Thermoplastic plastic had the highest (T_g) of all materials tested, and due to immersion in water, there were greater reductions in shear strength of thermoplastic compared to the rest of the material, the overall performance of the thermoplastic compared with other marine resin systems.

Ellyin [18] studied the effect of environmental conditions on the mechanical properties of the composite materials manufactured from the epoxy reinforced by glass fiber in the form of tubular samples. The main objective of the research was to study the effect of moisture absorption and exposure to high temperatures on the mechanical properties of pipes made of composite materials made of epoxy reinforced with glass fibers. The samples were submerged distilled water at two different temperatures for four months and moisture absorption was recorded. The moisture absorption rate was higher in samples immersed in distilled water at high temperature ($50\text{ }^\circ\text{C}$) compared to samples submerged in distilled water at room temperature ($20\text{ }^\circ\text{C}$). After that, several tests were carried out for the samples and found that the strength and hardness decreased by the presence of moisture and temperature increase.

Joseph et al. [19] studied the environmental effects on the decomposition behavior of the composite materials that manufactured from the polypropylene reinforced sisal fiber. The effect of environmental conditions on the physical and mechanical properties of polypropylene compounds reinforced with sisal fibers, especially the effect of water and UV radiation. The effect of water absorption on the tensile properties of sisal / PP compounds was studied. A decrease in tensile properties was found with increased water absorption. The effect of tensile properties of sisal / PP compounds exposed to UV radiation was studied. Tensile properties were found to decrease with an increase in UV exposure time.

In 2015, Venkatachari and Natarajan [20] studied the torsional properties of composite laminates with curved fiber under the influence of environmental conditions such as humidity and temperature. The results showed that heat and humidity reduce the critical torsion load in composite laminates. Because the heat and humidity reduce stiffness, the effect of heat on the torsion load is greater than that of moisture on the torsion load.

In 2018, Furtado et al [21] studied the mechanical and physical properties of composite materials reinforced with plant fibers and studying the problems in manufacturing and the problems of adhesion of fibers to the base material and the impact of environmental conditions such as humidity, temperature and ultraviolet radiation. The results showed a deterioration in the mechanical and physical properties of composite reinforced with vegetable fibers when exposed to moisture, temperature and ultraviolet radiation.

Dmitriy [22] studied the effects of temperature on mechanical behavior and properties of composite materials by tensile testing. It was observed that tensile strength decreases with increasing temperature as well as temperature affects mechanical properties.

Ding et al [23] studied the impact of environmental factors on sandwich composites consisting of vinyl ester as a base material and glass fibers as a reinforcing material. In the first case, it was exposed to solar radiation with water vapor, in the second case the composite was exposed to temperature for 1680 hours, after that there was a change in weight and deterioration in the mechanical properties of the sandwich composite. In the first case it was found that the sandwich composite lost weight while in the second case increased its weight, as well as the shear strength of a sandwich composite is decreased while, other mechanical properties have deteriorated.

The gap in the literature is that the epoxy was used as a base material and it was reinforced by fiber class to prepare the samples and expose them to different environmental conditions such as humidity and different temperatures in one month. After that, the different tests such as hardness, impact resistance, bending resistance and tensile strength were performed. Then the effect of moisture and temperature on the mechanical and physical properties of the samples were compared.

Main contribution of this research was to study and investigate the environmental effects on the polymeric composite samples such as the effect of moisture and temperature on the mechanical and physical properties. The samples were immersed in water for a certain period of time and then they had been taken out of the water and tested their water's absorbability.

The samples were placed in special ovens with different temperatures such as 50°C and 70°C for one month. Different tests such as hardness test, tensile strength test, impact resistance test and bending resistance were performed. The results obtained from the experiments were

compared to investigate how moisture and different temperatures effect the physical and mechanical properties of composite materials based on epoxy and glass fiber.



2. THEORETICAL ASPECTS

2.1 INTRODUCTION

Composite materials are divided into three types according to the type of material that represents the base material, which are polymeric composites, ceramic composites and metal composites. The three most important types and most commonly used polymer composite material due to their good mechanical and physical properties such as light weight, it is capable of forming, is considered a dielectric material and their thermal conductivity is low. Polymeric composites contain a polymeric material as a base material reinforced fiber or particles. The polymer is divided into two types: thermoplastic polymers and thermoset polymers.

Polymer composites have been widely used in many industries such as aircraft industry, marine shipping industry, wind turbine blade industry and other industries, due to their good mechanical properties.

The mechanical properties of polymeric composites are influenced by environmental conditions such as humidity, temperature and ultraviolet radiation, so it is necessary to study the effect of environmental conditions on the mechanical properties of polymeric composites such as tensile strength, compressive strength and hardness [24].

2.2 COMPOSITE MATERIALS

Composite materials are a mixture of two or more materials of different specifications. These materials combine to produce a compound with the desired specifications. The ingredients can be either organic or inorganic materials, mineral (natural or synthetic).

Composite materials consist of either a polymeric, ceramic or metal base material with good mechanical properties and reinforced with fibers such as glass fibers, nylon fibers, Kevlar fibers, etc. For the purpose of improving the mechanical and physical properties of the composite materials add reinforcing materials such as fibers. The characteristics of the composite materials depend entirely on the properties of the substrate and its reinforcing material as well as on the nature of the interface between them [25].

2.2.1 Classification of Composite Materials

Composite materials are classified into three types according to the base material:

2.2.1.1 Polymer matrix composites (PMCs)

It is one of the most important types of composite materials because it is widely used as it consists of a polymer as a base material (such as epoxy and polyester) fiber reinforced such as glass fibers, carbon fibers, boron fibers and aramid fibers. These materials are the best types because of their high mechanical properties relative to density in addition to ease of manufacture and low cost [26,27].

Polymeric composites are one of the most common types of materials. Interest in these materials has increased dramatically in recent times, as they have been used in many industries such as the manufacture of marine vessels, aircraft parts and the manufacture of air turbine blades because they are lightweight and high durability that led to get the ideal materials at low cost, and as a result, the resins have gained wide fame as a modern material entering the industry, and several alternatives to traditional materials and their alloys in many uses [28,29].

Table 2.1: Mechanical Properties of Polymeric Materials in Composite Materials [29].

Property	Units	Graphite/ epoxy	Glass/ epoxy	Steel	Aluminum
<i>System of units: USCS</i>					
Specific gravity	—	1.6	1.8	7.8	2.6
Young's modulus	Msi	26.25	5.598	30.0	10.0
Ultimate tensile strength	ksi	217.6	154.0	94.0	40.0
Coefficient of thermal expansion	μin./in./°F	0.01111	4.778	6.5	12.8
<i>System of units: SI</i>					
Specific gravity	—	1.6	1.8	7.8	2.6
Young's modulus	GPa	181.0	38.6	206.8	68.95
Ultimate tensile strength	MPa	150.0	1062	648.1	275.8
Coefficient of thermal expansion	μm/m/°C	0.02	8.6	11.7	23

Table 2.2: Mechanical properties of fibers used in polymeric composites [29].

Property	Units	Graphite	Aramid	Glass	Steel	Aluminum
<i>System of units: USCS</i>						
Specific gravity	—	1.8	1.4	2.5	7.8	2.6
Young's modulus	Msi	33.35	17.98	12.33	30	10.0
Ultimate tensile strength	ksi	299.8	200.0	224.8	94	40.0
Axial coefficient of thermal expansion	$\mu\text{in./in./}^\circ\text{F}$	-0.722	-2.778	2.778	6.5	12.8
<i>System of units: SI</i>						
Specific gravity	—	1.8	1.4	2.5	7.8	2.6
Young's modulus	GPa	230	124	85	206.8	68.95
Ultimate tensile strength	MPa	2067	1379	1550	648.1	275.8
Axial coefficient of thermal expansion	$\mu\text{m/m/}^\circ\text{C}$	-1.3	-5	5	11.7	23

2.2.1.2 Ceramic matrix composites (CMCs)

Ceramic composites consist of ceramic materials such as alumina and calcium alumina silicate as a base material reinforced with carbon fiber or silicon carbide. Examples of this type of composite materials are silicon nitride (Si_3N_4) reinforced with silicon carbide (SiC), and glass composite reinforced with carbon fiber [29].

Ceramic composite materials are characterized by high strength, hardness, high temperature resistance, and high oxidation resistance in high temperature. Because of their mechanical properties, they are used in many industries such as the manufacture of aircraft turbines [30].

Table 2.3: Mechanical properties of some ceramic materials [29].

Property	Units	SiC/LAS	SiC/CAS	Steel	Aluminum
<i>System of units: USCS</i>					
Specific gravity	—	2.1	2.5	7.8	2.6
Young's modulus	Msi	13	17.55	30.0	10.0
Ultimate tensile strength	ksi	72	58.0	94.0	34.0
Coefficient of thermal expansion	$\mu\text{in./in./}^\circ\text{F}$	2	2.5	6.5	12.8
<i>System of units: SI</i>					
Specific gravity	—	2.1	2.5	7.8	2.6
Young's modulus	GPa	89.63	121	206.8	68.95
Ultimate tensile strength	MPa	496.4	400	648.1	234.4
Coefficient of thermal expansion	$\mu\text{m/m/}^\circ\text{C}$	3.6	4.5	11.7	23

2.2.1.3 Metal matrix composites (MMCs)

Metallic composites consist of metal as a base material reinforced with fiber. Examples of metals are aluminum, magnesium and titanium. Examples of fiber are carbon fibers and silicon carbide fibers. These materials are reinforced with fiber to improve mechanical properties according to design needs. An example of these mechanical properties which are the elasticity, hardness and strength of the metal can be increased by the addition of fiber, and can reduce the coefficient of thermal expansion and electrical and thermal conductivity of the metal by adding fibers such as silicon carbide. Metal composite materials are characterized by high temperature resistance, moisture insensitivity, highest electrical and heat conductivity.

Its applications include the use of piston heads in automatic motors, gas turbine propeller blades, and radar domes.

Table 2.4: Mechanical Properties of Some Metal material base in Metal Composites [29].

Property	Units	SiC/ aluminum	Graphite/ aluminum	Steel	Aluminum
<i>System of units: USCS</i>					
Specific gravity	—	2.6	2.2	7.8	2.6
Young's modulus	Msi	17	18	30	10
Ultimate tensile strength	ksi	175	65	94	34
Coefficient of thermal expansion	μin./in./°F	6.9	10	6.5	12.8
<i>System of units: SI</i>					
Specific gravity	—	2.6	2.2	7.8	2.6
Young's modulus	GPa	117.2	124.1	206.8	68.95
Ultimate tensile strength	MPa	1206	448.2	648.1	234.40
Coefficient of thermal expansion	μm/m/°C	12.4	18	11.7	23

2.3 POLYMER

It is sometimes called the macromolecule, a molecule of a chemical compound that represents a high molecular weight (10 million), and the chain-shaped molecule is a molecule of a simple compound bound together by covalent bonds. The name of a polymer consists of two segments poly and mer in the sense of multiple units. The term monomer refers to a simple chemical compound with a small molecular weight. The part of this compound has a special structure that can interact with another part of the same type or with another part of another compound and under the appropriate conditions for the formation of the polymer chain [30,31].

2.3.1 Classification of Polymers

Polymers are classified according to their technological properties and scientific uses into the following categories:

2.3.1.1 Thermoplastic

They are hard polymeric materials at normal temperatures, but soften and turn into a paste-like and form that can be changed by hand. If the temperature is increased further, the soft material fuses and liquefies (called thermoplastic polymers), which are most Polymers used in the plastics and synthetic fibers industries. When the cooling material passes through all the previous stages where it gradually solidifies until it returns to take solid state and for this reason these polymers are sometimes called thermoplastic plastics. There are many commercial polymers that within this category are the following: polyethylene, styrene, polystyrene, polycarbonates, polypropylene and others. This classified includes polymers whose properties change with the influence of temperature. When the temperature nears the degree of transition glass becomes flexible and then become more flexible by turning it into viscous fuse. When the molten temperature is lowered, its solid state is restored. This property is used in the manufacture of this important type of polymers, and this is considered the product is one of the most industrially important polymers. Examples of polymers of this type are: polyethylene, polypropylene, polystyrene and others.

Polymers belonging to this species are longitudinally grown (in only one dimension) and sometimes some lateral branching of the chain occurs. These polymers remain mainly extended in two dimensions and not in a third dimension due to the non-overlapping of branches of a chain with branches of another chain adjacent to covalent links.

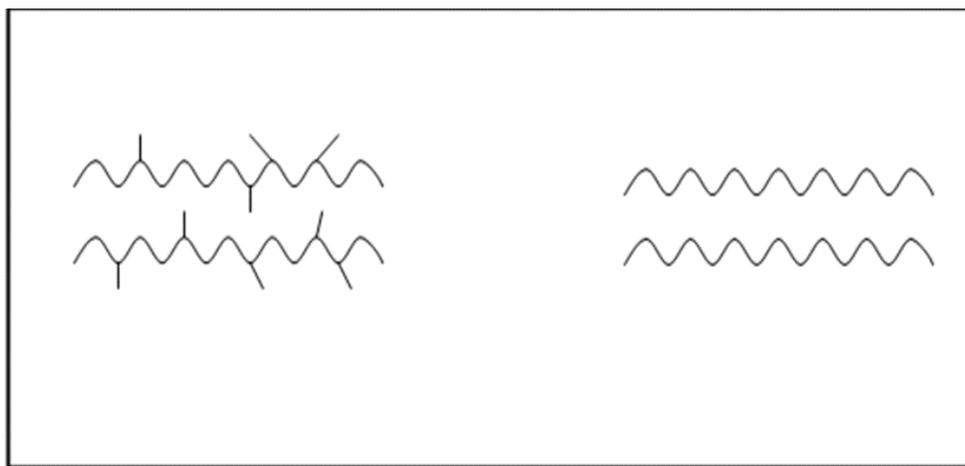


Figure 2.1: shows the growth of polymer chains [32].

Because the polymer stretches only longitudinally, the adjacent chains are bound together by natural secondary attraction forces (non-covalent) so when heating these polymers, thermal energy overcomes weak natural attraction forces and at a low temperature that does not damage the polymer, which does not break the covalent bonds. As a result of the loss of pulling force, polymer chains glide on each other and so these linear polymers are melted and liquefied. Therefore, these longitudinal polymers are classified as thermoplastic or thermoplastic polymers, the basis of all polymers used in the plastics and Industrial fibers such as nylon, polyester and polyethylene [32].

2.3.1.2 Thermosets

This classified includes polymers that do not melt by heating, but heating helps stabilize them in their final form (hardened by heat and pressure while converting their pasts to the desired form in special molds) called thermosetting polymers.

These polymers suffer chemical changes when heated and the polymer chains are intertwined. These polymers, after their heat treatment, become insoluble, non-fusible and poorly conductive of heat and electricity. The chains are bonded together by strong chemical bonds that cannot be easily broken, so these materials cannot be reconstituted when exposed to a certain temperature and the temperature increases, it will carbonize and degrade, meaning that it is not susceptible to temperature below the decomposition temperature. They are characterized by low density, high electrical insulation properties, high thermal insulation, high stiffness and stronger strength. Examples of this type are phenol formaldehyde, epoxy and unsaturated polyester [32].

2.4 COMPONENTS OF COMPOSITE MATERIALS

2.4.1 Matrix

They are either polymers, metals or ceramics. Polymers are usually the most important element in composites because many of the properties of these composites are dominant for this base material. Plastics base materials have higher qualitative tensile strength, more advanced calibration properties in the case of technical industry, less raw material and manufacturing costs and allow for more flexible and efficient design as thermal insulators. This can then

consideration it as the binding material that binds and consolidates the reinforcing material or the primary phase, which strengthens the secondary phase of reinforcing materials [33,34].

2.4.1.1 Epoxy

Epoxy resin is a polymer consisting of two or more epoxy groups as shown in Figure 2.2, epoxy is considered as thermoset. An epoxy hardener is added, the most important hardener is (aromatic, aliphatic amine and anhydride). The hardened materials are added to the epoxy at certain weight ratios to get for good hardening of the epoxy at room temperature.

The lower crosslink density between epoxy groups improves durability and elongation, and higher crosslink density improves chemical resistance. Epoxy is affected by organic solvents as well as moisture when exposed to moisture for a long time [4].

One of the most important mechanical properties of epoxy resin is its high mechanical strength and good adhesion to metals and glass; disadvantages are high cost and difficulty in processing.

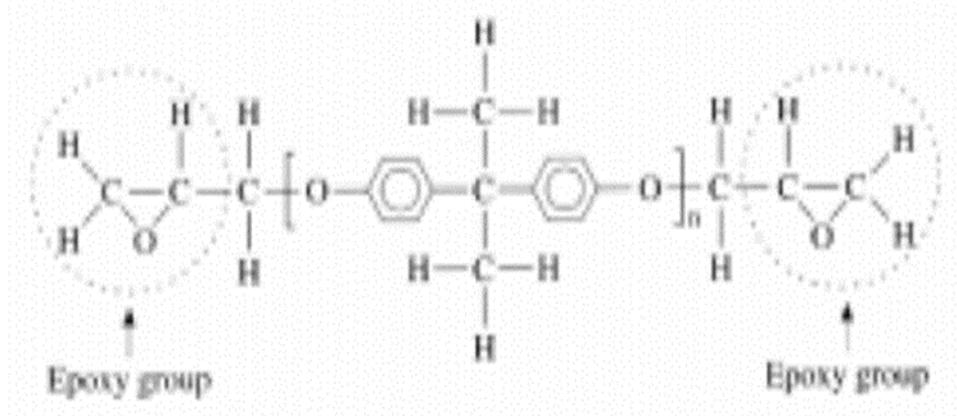


Figure 2.2: explains the reaction of epoxy groups [4].

2.4.1.2 Vinyl ester resins

Phenyl ester is a thermoset. Phenyl ester is derived from epoxy resin, polyester and urethane resin. The high molecular weight in vinyl ester resin leads to increased rigidity, flexibility, reduced solvent resistance as well as a decrease in heat resistance [35]. Figure 2.2 shows the chemical composition of vinyl ester resin.

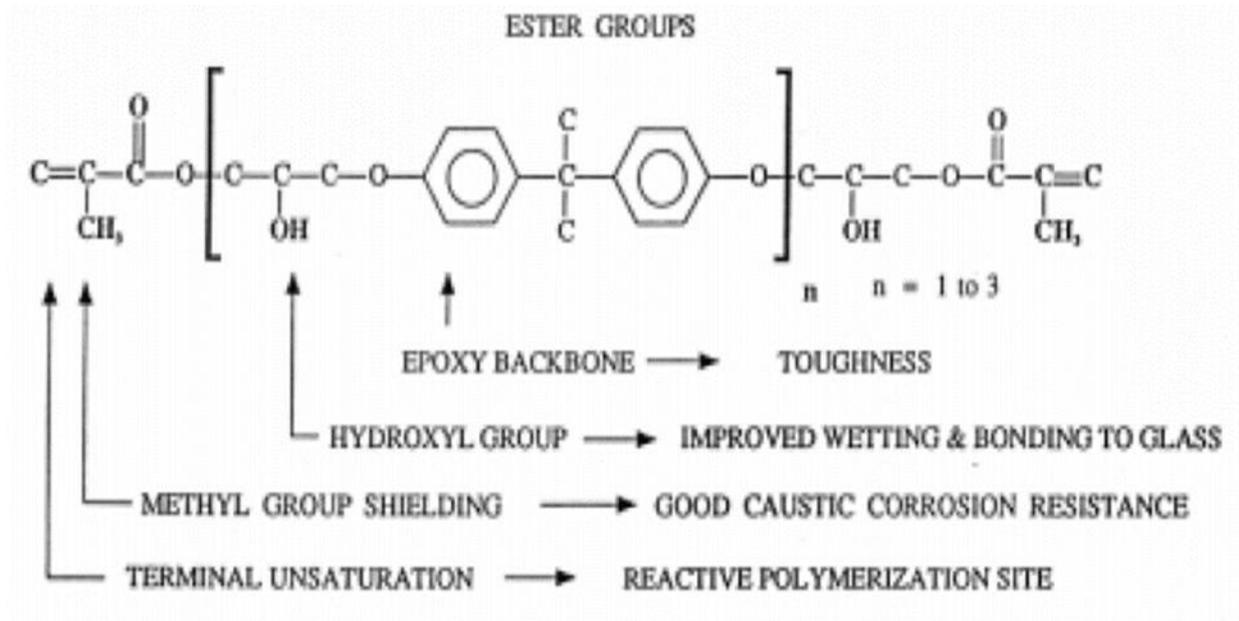


Figure 2.3: Vinyl ester resin [4].

2.4.2 Reinforcements

These materials are added to the base material to improve most of the properties and maintain the desirable qualities. If the reinforcement material improves the strength of the base material, it must be stronger than the base material.

Reinforcing materials shall be ceramic, metal or plastic, characterized by stiffness and high resistance, and may vary in various forms, such as fibers, particles, crusts, sheets or fillings [36].

2.4.2.1 Fibers

Fibers are regular filaments with distinct properties that strengthen the base material in the composite material. The fibers bear the bulk of the load on the composite material. The properties of the composite material which reinforced by fibers are closely related to the properties of the fiber (fiber diameter, Volume Fraction, fiber length, fiber composition) and fibers can be metallic, ceramic, or plastic, natural or synthetic [36].

2.5 ARTIFICIAL FIBERS

Synthetic fibers are the most widely used types of fibers due to their good and desirable specifications. The origin of synthetic fibers is the natural materials. They are treated and manufactured to improve their properties and shape them according to demand these include:

2.5.1 Glass Fiber

Glass fiber is one of the most commonly used materials for reinforcing resins in general, since these fibers are relatively easy to manufacture and form and have good "properties" and have a relatively low economic cost.

Glass fibers are manufactured by mixing the basic components of the glass dryly, such as silica salts, limestone, boric acid and some ingredients such as clay, coal and feldspar stones, then melted in special tanks in an oven whose temperature depends on the type the mixture is usually at a rate of 1260 °C, then the molten glass is passed in a circular container made of platinum with a perforated end to allow the fuse to pass and then pulled and treated and thus obtaining long and thin glass fibers wraps on a fast spinning roller, and as the speed increases the rotation of the roller the lower the diameter of the glass fiber produced, so that a fiber can be produced with a diameter of about 2 micrometers using a rotational speed 300 - 500 m/s, then cooled and spinned to obtain the final forms of glass fibers, and is usually chemical treatment of the surfaces of these fibers to be adherent to the bonding resin where they are treated with materials a chemical called coupling agents [37].

2.5.1.1 Glass fiber properties

Glass fiber has the following properties:

1. Glass fiber has a relatively high durability and when it enters into a plastic medium will produce a composite material of very high-quality resistance.
2. Does not burn or help to combustion as a result of its chemical nature and is characterized by a high degree of fusion.
3. Do not absorb moisture and therefore not exposed to swelling or expansion.

4. Glass fibers are characterized by low linear expansion coefficient and thermal conductivity coefficient, low relative to the base material.
5. Glass fibers are not electrically conductive and therefore they are ideal insulators.

2.5.1.2 Glass fiber types

Glass fiber is produced in different types, each of which has distinctive properties. This is done depending on the nature of the oxides involved in its industry, provided that the basic oxide for all types is silica SiO_2 , while the other oxides are added according to the required specifications for glass fibers, types of glass fiber are the following [38]: -

Glass Fiber Type E

It is a symbol of electrical properties and is the most common form due to the ease and smooth pulling during manufacturing, high durability and stiffness and its properties in electrical insulation and resistance to weather conditions.

Glass Fiber Type C

It is a symbol of corrosion resistance. It has more chemical resistance than type E and is therefore used in chemical applications, but is less durable and more expensive.

Glass Fiber Type S

It is a symbol of the properties of strength and it is more expensive than other types, but what distinguishes it has a high elastic modulus, and great resistance to high temperatures. This type has limited uses, especially as it is used in the manufacture of aircraft, as its high performance justifies its additional cost [39].

Table 2.5: Mechanical and Physical Properties of (E-Glass and S-Glass) [29].

Property	Units	E-Glass	S-Glass
<i>System of units: USCS</i>			
Specific gravity	—	2.54	2.49
Young's modulus	Msi	10.5	12.4
Ultimate tensile strength	ksi	500	665
Coefficient of thermal expansion	μin./in./°F	2.8	3.1
<i>System of units: SI</i>			
Specific gravity	—	2.54	2.49
Young's modulus	GPa	72.40	85.50
Ultimate tensile strength	MPa	3447	4585
Coefficient of thermal expansion	μm/m/°C	5.04	5.58

Table 2.6: The types of glass fibers and their chemical composition [29].

%	E glass	C glass	S glass
SiO ₂	52.4	64.4	64.4
Al ₂ O ₃ .Fe ₂ O ₃	14.4	4.1	25.0
CaO	17.2	13	-
MgO	4.6	3.3	10.3
Na ₂ O.K ₂ O	0.8	9.6	0.3
Ba ₂ O ₃	10.6	4.7	-
BaO	-	0.9	-

2.5.2 Nylon Fibers

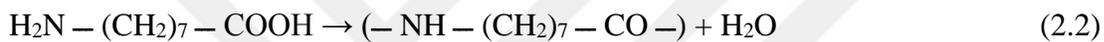
Nylon fibers are manufactured from polyamides, which are thermoplastic polymers prepared from amino acids or their lactam compounds, or from intensification of bilateral acids with

bilateral amines. It was first produced by Dupont company in 1930 and by the world Carothers[40].

These polymers are known commercially as nylon, which was launched the name by Dupont company and later developed the distinctive numbers of different types of nylon such as nylon 6 and nylon 66, and these numbers have special significance. If the number is single, such as 4 or 8, this indicates the preparation of nylon from one raw material is the amino acid containing four or eight carbon atoms, as shown in the following reaction [40]:

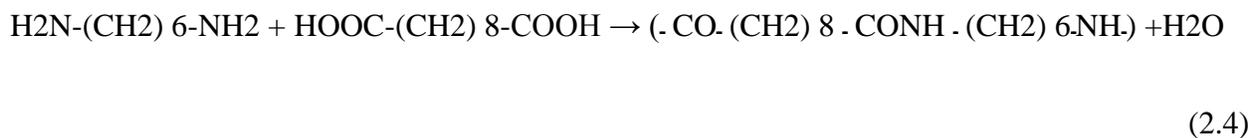
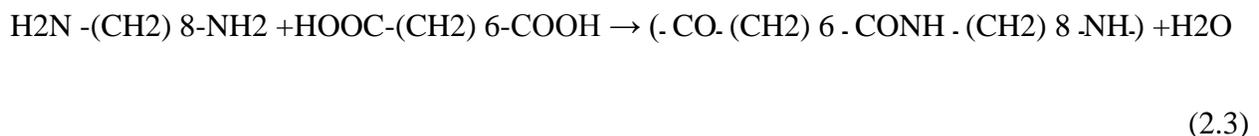


Nylon 4



Nylon 8

If the double number, such as 88 or triple, such as 106, this indicates the preparation of nylon from two materials where the left number indicates the number of carbon atoms in the bilateral acid and right on the number of carbon atoms in the bilateral amine, as shown in the following interactions [40]:



Polyamide fibers are characterized by their ability to form hydrogen bonds through the amide groups, which helps in the regularity of the molecules and stacking, which gives them the ability to high crystallization and thus obtain good qualities of polymer fibers.

Nylon fibers have good mechanical properties and good thermal resistance. They also have glass transition temperatures between 200 °C- 250 °C, polyamides contain moisture content between 2%- 4% at external relative humidity up to 65% [40].

2.5.3 Kevlar Fiber

It is a poly (p-phenyleneterephthalamide) which is prepared by condensation polymerization of two compounds:

- Terephthaloyl Chloride

- p-phenylene diamine

These fibers are in the form of an uninterrupted linear polymeric chain due to the directional bonding of gasoline rings.

2.5.4 Steel Fiber

Many metals are used in the form of wires with high resistance levels and include beryllium wires, tungsten wires and steel wires which are characterized by high strength and low density.

Steel wires are reinforcing materials and are most used for concrete more than polymers and metals. They are also used for reinforcement in case of tires. Steel wires is very fine with a diameter of 0.1 μm with a high resistance of 5 GPa, the components consist as shown in table 2.7.

Table 2.7: The components of iron fibers [40].

C%	Mn%	Si%	S%	(S+P)%	P%	Ni%	Cr%
0.72	0.6	0.2	0.05	0.08 Combined	0.05	0.1	0.05

Because these fibers are used for tires as it does not stick to the tire until it is painted with brass and consists of copper (61%-67%) and zinc (33%-39%) this is because the bonding strength of Cu with rubber is very high as well as brass while the strength of the bonding of steel fibers with rubber is very weak.

2.6 TYPES OF REINFORCEMENT

2.6.1 Composite Materials Reinforced by Particles

They are composite materials consisting of adding small particles as reinforcing materials of the compound where the size of the particles is always greater than 1 μm and the proportion of weight fractions may reach 90% in the composite materials of high addition [41].

Reinforcement occurs when particles are added as reinforcing materials, which increase and improve the mechanical and physical properties, and be in several types and forms, including spherical, cortical, needle and filamentous, where the particles increase the stiffness, increase the resistance to impact and improve the thermal expansion coefficient of the material [42].

The mechanical and physical properties of the composite material reinforced by the particles are influenced by a variety of factors, some of which relate to the properties of the base material. The other depends on the properties of the reinforcing materials such as the type, shape, size and distribution of the particles within the base material, as well as the strength of the bonding between the base material and the particles, the reinforcement have a significant impact on the mechanical and physical properties of the composite material. The composites materials which reinforced by particles are used in many industries, such as the manufacture of cutting heads, where the particles work to prevent deformations in the base material and also withstand the stresses and forces placed on the composite material due to its large size [41,42].

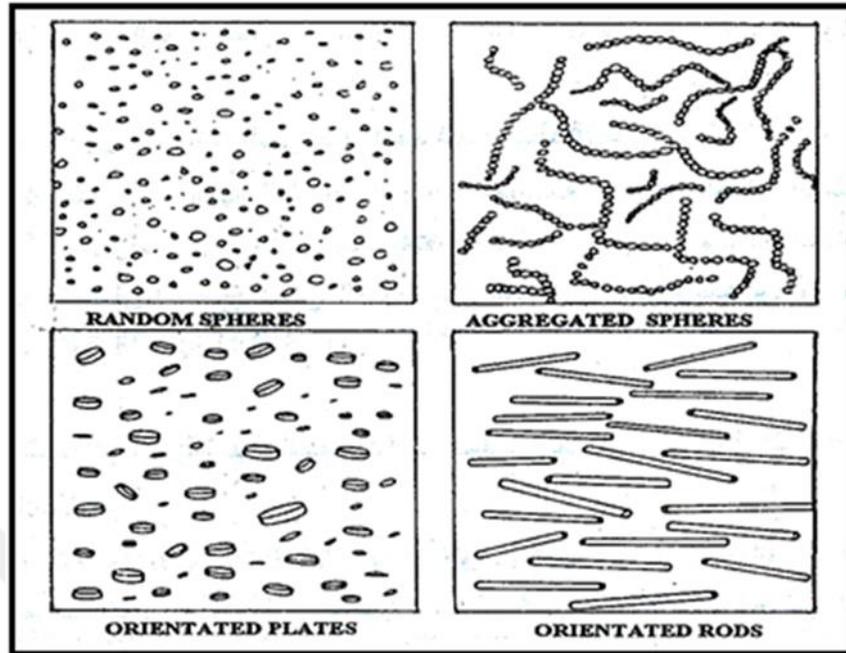


Figure 2.4: Different types of particle reinforcement materials [42].

2.6.2 Composite Materials Reinforced by Fibers

In this type of composite material, the base material is reinforced by fibers. These fibers may be long or short, there are many types of fibers, including polymer fibers such as Kefler fibers and nylon fibers or metal fibers such as steel wire and copper wire or ceramic fibers such as glass fibers. The fiber direction in the base material is one-way or random. Fiber has high mechanical resistance and coefficient of elasticity, while the base material is elongation and does not affect the fiber. The importance of fiber reinforcement is to improve the overall mechanical and physical properties of composite materials [43].

In this type of composite materials, the fiber is immersed in the ground that is either continuous or discontinuous and its volume fraction does not exceed 70% and is called fiber reinforced composite material (FRM). Fibers must have high resistance and elastic modulus to produce materials with high resistance. The important difference between fiber-reinforced composites and those dispersed is that fibers with high elastic modulus bear it almost all the load. The base material for most composites reinforced with fibers can be ceramic, polymeric or metal, which can simultaneously represent fibers. Fibers are largely responsible for revolutionizing composite materials to improve their properties according to use [44].

2.6.2.1 Factors affecting the behavior of the fibers composite

Fiber Direction

The direction of fiber is of great importance in the mechanical and physical properties of composite materials, for example, the tensile strength of the composite materials varies with the direction of the fibers as shown in Figure (2-5) where the tensile strength increases as the angle of the fibers decreases [45].

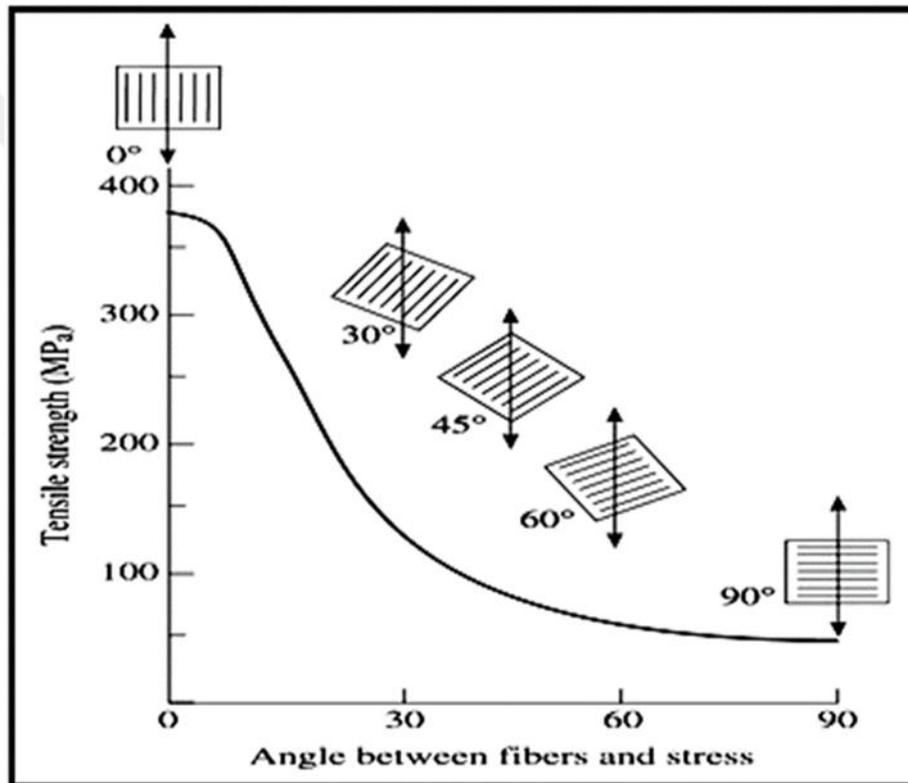


Figure 2.5: The effect of fiber direction on the tensile strength of a composite materials with polymeric basis reinforced by continuous fibers [45].

Fiber Length

The mechanical properties of fiber reinforced materials also depend on the degree to which the load transferred from the base material to the fibers. When the composite material reinforced with non-continuous fibers is subjected to tensile stress, we note that short fibers in the base material will suffer tension as a result of shear stress at the interface these fiber surfaces and shear stresses are of great value at the ends of the fibers experiencing greater tension, the shear

stresses begin to fall as we get closer to the center of the fiber and the tensile stresses in the fiber are zero at the ends and start to increase as shear stress decreases as shown in Figure 2.6 [46].

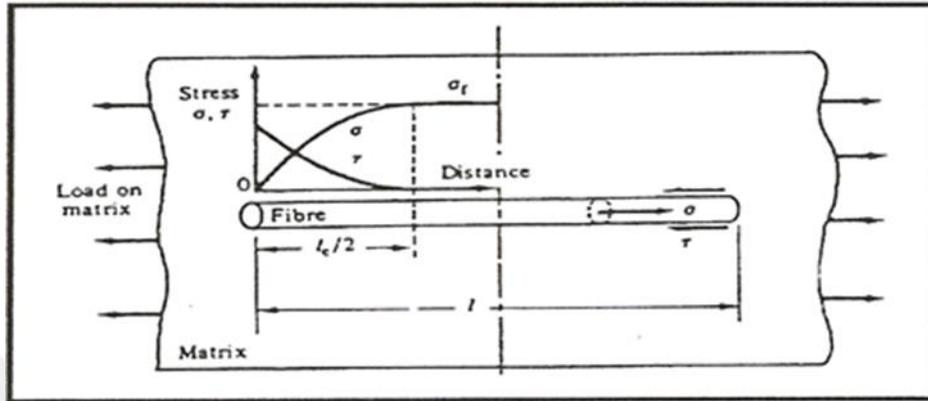


Figure 2.6: The distribution of tensile stress of the fiber and shear stress of the surface along of the short fiber submerged in the base material [46].

Geometric Shape and Area of Fiber Cross-Section

The mechanical properties of fiber reinforced composite materials depend on the geometric shape and the area of the cross-section of the fiber, where the geometric shape can be circular, square, pyramid, or triangle as in Figure 2.7, which shows different forms of fiber cross-section area. It can be circular, square or triangular.

The circular section fiber is the preferred cross-sectional shape and is most commonly used in the reinforcement of composite materials. Stress is concentrated on the end of the fiber and thus helps to distribute the stresses [47].

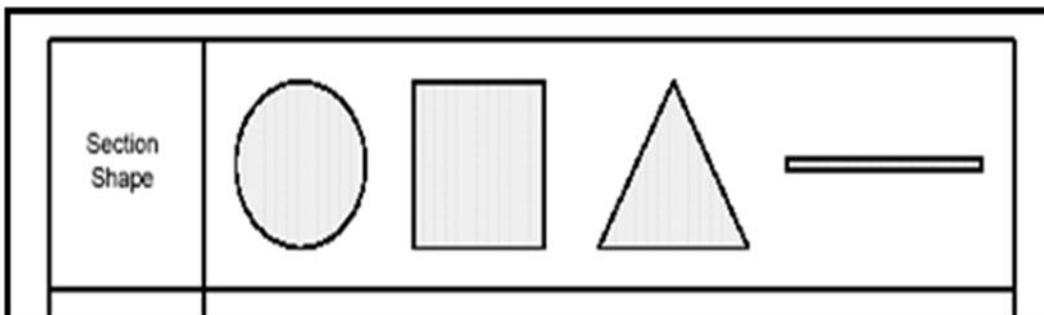


Figure 2.7: Different shapes of the cross-sectional area of the fibers [47].

Volume Fraction

Volume fraction represents the ratio between the volume of fiber to the volume of the composite material, the volumetric fraction affects the mechanical and physical properties of composite materials, where the tensile strength increases when volumetric fraction increases and continues to increase until it reaches a certain value and then begins to decrease as a result of low efficiency of the base material to absorb fiber [45].

$$V_F = \frac{V_f}{V_c} \quad (2.5)$$

whereas:

V_F : Volume fraction

V_f : fiber volume

V_c : composite material volume

The Strength of the Bond Between Fiber and the Base Material

The strength of bonding between the base material and the fiber affects the mechanical and physical properties of the composite materials. As the bonding strength between the fiber and the base material increases, the mechanical properties improve. Therefore, the ideal conditions for the application of composite materials reinforced by continuous fibers is to have a strong bond between fiber and the base material. This is necessary for the loads on the composite materials to move from the base material to the fiber [44].

2.6.3 Laminate Composite Materials

In this type of composite materials, reinforcing materials are used in the form of layers of different materials and consist of two or more layers placed layer upon layer, and laminated composite materials are composed of several layers of the same material as fiber reinforced plastics, but the direction of fibers is different in alternating layers or consist of layers of different materials linked together such as polymer and metal [48].

The use of this type of reinforcement in composite materials leads to the best mechanical and physical properties such as hardness, corrosion resistance, wear resistance, tensile resistance,

compression resistance, durability, light weight and many other properties that can be controlled by reinforcement from a variety of materials [49].

2.7 ENVIRONMENTAL CONDITIONS

Environmental conditions are important in the design of composite materials because environmental conditions have effects on the mechanical and physical properties of composite materials. These effects vary from composite material to other depending on the materials used in the production of the composite material. Environmental conditions include humidity, heat and ultraviolet radiation. In this research we will study the effect of moisture and heat on mechanical properties such as tensile strength, compressive strength and hardness.

2.7.1 Moisture

The immersion of any composite material in the water leads to the absorption of a proportion of water that can be large or few depending on the properties of the material. This amount of absorbed water leads to an impact on the physical properties and mechanical, for example, leads to a decrease in the temperature of glass transition when the rate of humidity increases and also leads to a decrease in tensile strength and modulus of elasticity with the increase of humidity in composite materials. Furthermore, the absorption of moisture leads to swelling in composite materials which brings weight gain. So it is necessary to study the effect of moisture on the mechanical properties of composite materials.

The amount of moisture absorbed in composite materials can be measured by measuring the sample weight before exposure to moisture and measuring the weight after exposure to moisture. The mechanism of moisture diffusion in composite materials can also be determined according to Fick's law [4]. In 1976, Shen and Springer [50] studied the absorption and distribution of moisture in composite materials according to Fick's law as the results and analyzes of many studies, they have found that the absorption and distribution of moisture is appropriate according to Fick's law.

$$\frac{\partial M}{\partial t} = D \frac{\partial^2 M}{\partial z^2} \quad (2.6)$$

whereas: -

D: coefficient of diffusion

M: Moisture content

t: conditioning time

z: thickness

2.7.2 Temperature

Composite materials can be exposed to high temperatures or low temperatures and this will affect the mechanical and physical properties such as tensile strength, hardness and compression resistance, so it is necessary to study the effect of temperature on the mechanical and physical properties of composite materials. For example, exposure of polymeric composites to low temperatures for 30 years makes them more fragile [4].

In recent years the effect of exposure to composite materials at high temperatures has been studied it was found that fiber and base material are affected by high temperatures, affecting mechanical properties such as tensile strength and compressive strength, as well as low temperature effects the mechanical properties [51]. Studies have shown that fracture energy decreases with increasing temperature.

2.8 TESTS

2.8.1 Hardness Test

Hardness is an important mechanical property of composite materials, which can be defined as resistance to stitches or plastic deformation. Hardness can be found by measuring the diameter of the impact on the surface of the material due to the penetration of a steel ball or a pyramid-shaped object under the influence of a particular load. Surface hardness can also be found by measuring the resistance of the material to friction [52].

Some mechanical properties of composite materials, such as tensile strength, compressive strength, wear resistance from friction and other properties that can be predicted through the hardness test results, the depth of the stitches inside the material is a measure of the ability of the

material on the plastic deformation, the hardness test is characterized by the fact that it does not require samples in standard dimensions and is therefore a low-cost test [48].

The hardness is proportional to the tensile strength of the composite materials, whereas the hardness increases with increasing tensile strength and decreases when the tensile strength decreases. High hardness materials have high tensile strength and are linked by the following relationship [53]:

$$\text{Tensile Strength} = K^{\circ} \times \text{Hardness} \quad (2.7)$$

Where K° is constant for a particular material.

There are several methods of measuring hardness, the most important of which are Brinell's test, Shore's test, Rockwell's test and Vicker's test.

2.8.2 Compression Test

Compression is defined as the maximum stress endured by the rigid material under vertical pressure. Compression durability is an important design factor in the manufacture of composite materials, since these materials are frequently subjected to bending stresses, and failure can occur as a result of pressure.

Compression resistance is highly dependent on the properties of the base material and the volume fractions of the composite materials and the test method. Most research has shown that failure to compression resistance depends on the way the pregnancy is projected [54]. Compression resistance can be calculated using the following formula:

$$\sigma = \frac{P}{A} \quad (2.8)$$

Whereas :

σ : Compression resistance (MPa).

P : Maximum load bearing (N).

A : The area (mm²).



Figure 2.8: Compression measuring device.

2.8.3 Tensile Test

A tensile test is a test in which an increased tensile load on a prepared sample according to certain standard specifications, by holding both ends with special equipment and the tensile strength of both ends, thereby increasing the length of the sample as a result of this tensile or pull. Tensile testing is the most common and simple test, and the information obtained from these tests is of particular interest to the designer.

The tensile strength is equivalent to the maximum tensile strength of the sample and is set to depend on the sample section. After cross of the tensile strength points, the material is said to have failed as the breakage of a part of a machine cannot be avoided after transgression of the tensile strength point [55].

This test requires a cylindrical or rectangular test specimen, or the middle part of which is smaller in diameter than the ends, a test device that applies different loads, measures and records them, and an appropriate set of handles to hold the test sample. The test apparatus pulls a small part of the sample, usually called the test section, and uses an extensometer to measure the length of the test part called the gauge length at different weights. Then a diagram is drawn representing

the relationship between stress and strain from which we get many of the properties of the material under test, including:

1. Modulus of elasticity: It is a constant value for each material that represents a measure of the material's ability to longitudinal deformation.
2. Yield strength or Yield Point: It is a value that represents the beginning of the permanent deformation of the sample measured under the influence of the projected load and is used as a maximum value in the design of elastomeric materials.
3. Ultimate strength: It is the highest value of the stress on the model under examination before the failure.



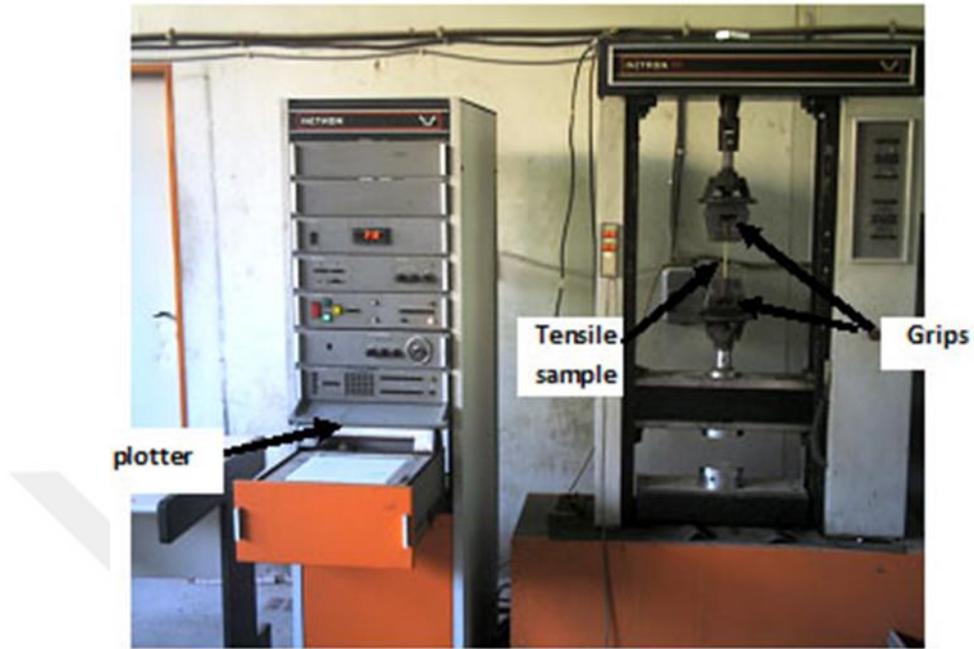


Figure 2.9: Tensile testing devices.

3. EXPERIMENTS

3.1 INTRODUCTION

This chapter includes the practical coverage of the research which provides detailed definition and explanation of the raw materials that will be used in preparing the composite material and its most important characteristics and general properties. It will also be covered the explanation of the method of preparing the composite polymeric material. Moreover, it will be displayed pictures and diagrams of the samples and their dimensions, with a comprehensive explanation of the devices used in the tests represented by the hardness test device, the bending test device, the torsion test device, and a detailed explanation of each test process. It will also be covered some mathematical equations used calculating for the results.

3.2 THE MATERIALS USED

3.2.1 Epoxy

Epoxy is a polymeric material that is thermoset type and is one of the most popular polymers it is widely used despite its high cost due to its high mechanical strength and good adhesion as well as low shrinkage rates. Where it is converted from complex liquids to a solid by physical and chemical methods, and the epoxy resin is one of the most important types of resins used in industry and is used in the treatment of hardening of the organic polyamine to transform it into a thermosetting plastic resin [56].

It is one of the multi-use materials and its most important uses in covering, which give durability, elasticity and resistance to chemicals, as well as one of its most important features low shrinkage, good fatigue strength, low creep rate, and corrosion resistance. It is also used for coating and adhesives. The composite materials formed by the epoxy resin have good properties of electrical insulation because they are saturated, and because of their low elasticity, high fragility and sensitivity to moisture, they led to a restriction in their use in this field [57].

Table 3.1: The most important epoxy resin properties used in the research [58].

Compressive strength	72 MPa
Flexural strength	50 MPa
Tensile strength	20 MPa
Pot life	60 min @ 25 °C
Specific Gravity	1.04
Viscosity	3- 5 poise @ 25 °C
	1- 2 poise @35 °C

3.2.2 Glass Fibers

Glass fiber is used as a reinforcing material added to the epoxy resin to form a composite material with good mechanical and physical properties, where glass fiber type E is used because it is the most used and the least expensive compared to the rest of the types of glass fiber.

Glass is used as a material in the manufacture of fibers due to the following properties it possesses [59]:

1. Easily available material and inexpensive.
2. Brick fibers made from this material can be obtained with simple and inexpensive techniques from molten glass.
3. The tensile strength is high and may reach to 400 MPa. When it is immersed in the base material (plastics), it will produce composite materials of high hardness.
4. High wear resistance.

Glass fibers are manufactured from the molten glass, through which the glass filaments are withdrawn and then collected as strands, and strands are used in the preparation of various glass fiber products (spun, woven, mats).

Table 3.2: Properties of glass fiber used.

Properties	E-glass	Units
Diameter	8-14	μm
Density	2.56	Mg m^{-3}
Young' modulus	76	GN m^{-2}
Poisson's ratio	0.22	
Tensile strength	1.4-2.5 (typical) 3.5 (freshly drawn)	GN m^{-2}
Elongation to break (tension)	1.8-3.2 (typical)	%



Figure 3.1: Glass fiber.

3.3 SAMPLE PREPARATION

Epoxy resin type (Quick mast 105) was used as a base material in preparing Polymeric composite material, which is in the liquid state and can be transformed into a solid state by

adding the hardener, where the hardener is characterized by being a light liquid with viscosity, low density, yellow transparent color and is added to the resin in a ratio of (1:2) and mixed.

After that the samples are prepared by adding the glass fibers to the epoxy, where the proportion of the epoxy is 70% and the percentage of the glass fibers is 30% and the glass fibers are in the form of layers (3 layers) and random direction, then pour the mixture into special molds for each test and leave for 24 hours at room temperature in order to solidify well and then take out the samples from the molds.

Then laboratory tests are performed for sample 1 without exposing it to moisture and heat where the hardness, tensile strength, impact and bending resistance are tested.

As for sample 2, it is exposed to the moisture for a period of one month by immersing it in water, and after that a hardness test, a tensile test, impact resistance test and bending resistance test performed.

As for sample 3, it is exposed to the temperature 50 °C for a period of one months by placing the sample in the accelerated weathering device, and after that a tensile test, hardness test, impact resistance test and bending resistance test are performed.

As for sample 4, it is exposed to the temperature 70 °C for a period of one months by placing it in the accelerated weathering device, after that a hardness test, a tensile test, impact test and a bending resistance test on the sample are performed.

Table 3.3: Environmental conditions to which samples are exposed.

Sample number	Environmental conditions
Sample 1	Room temperature
Sample 2	Immersion in water for one month
Sample 3	The temperature is 50 °C for one month
Sample 4	The temperature is 70 °C for one month

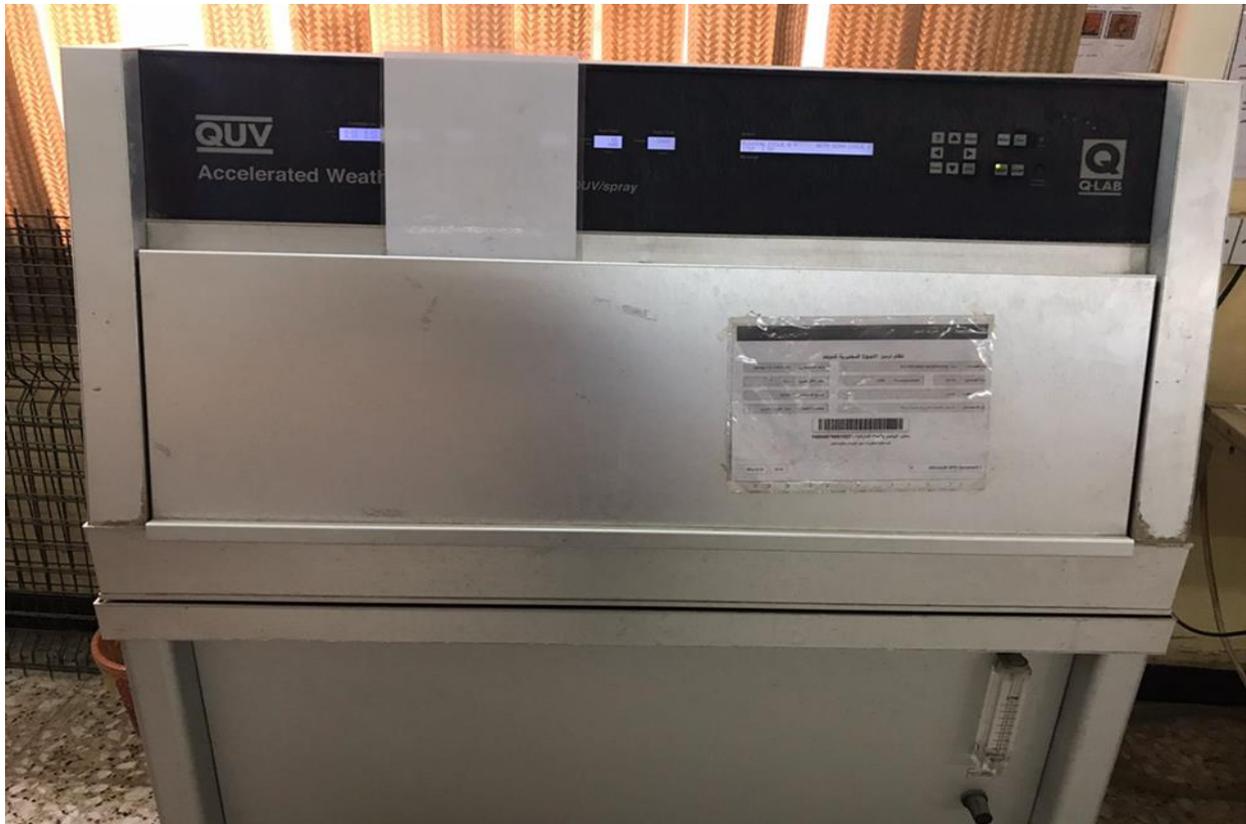


Figure 3.2: Accelerated weathering device.

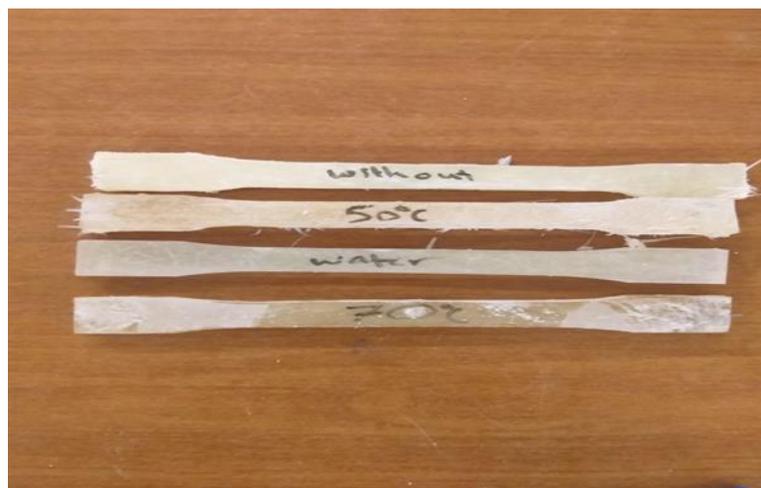


Figure 3.3: Tensile test samples.

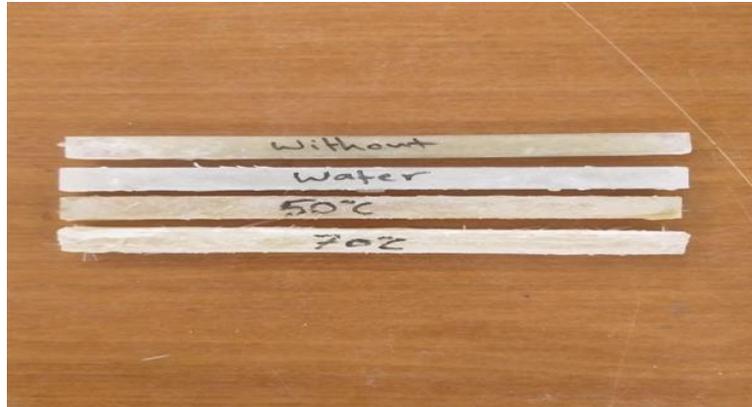


Figure 3.4: Bending test samples.

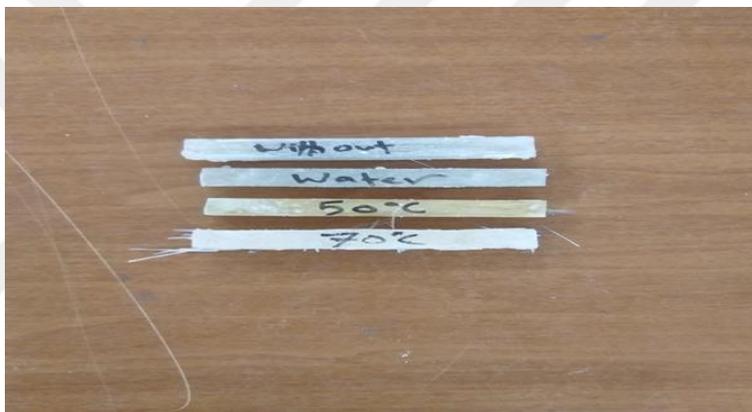


Figure 3.5: Hardness and impact test samples.

3.4 WATER ABSORPTION

The physical test which is the percentage of water absorption was performed using the Archimedes rule according to the international standard, and using a sensitive electric balance and 0.1 mg accuracy according to the following steps:

1. The sample is weighed using a sensitive electrical balance before being immersed in water. This weight is called a dry weight (W_d).
2. The sample is immersed in distilled water for a period of (1 - 6) days, and after its removal, the suspended water is removed on the surface of the sample only, and then the sample is weighed by the sensitive electric balance. This weight is called saturated weight (W_s). And the sample is weighed every day until it reaches saturation.

Then the percentage of water absorption is calculated according to the following equation [60]:

$$\text{Weight Grain} = \frac{W_s - W_d}{W_d} \quad (3.1)$$

Where:-

W_s : Saturated weight.

W_d : Dry weight

3.5 TESTS

3.5.1 Hardness Test

The concept of hardness can be considered as a measure of the plastic deformation that the material suffers from under the influence of external stress. The hardness test was performed using a surface hardness measuring device type (Shore-D), as shown in Figure 3.3 using a point stitch tool. With this penetration of the tool inside the surface of the material under the influence of a specific load, resistance moves directly to the measurement meter to determine the value of the hardness, to appear directly on the device screen. As for the sample used in the test, the sample dimensions are 55x12.5x6 mm. The surface of the sample should be flat and satin.



Figure 3.6: Hardness testing device.

3.5.2 Bending Test

This test is one of the basic tests applied on the composite materials in order to determine the properties of elasticity and plasticity, as the bending resistance of the material is the material's ability to withstand the bending forces that are perpendicular to its longitudinal axis as well as one of the complex tests as it includes more than one type of stress such as tensile stress in the layers of the lower section. Compression stress in the layers of the upper section, and sometimes one of them overcomes the other and causes the material to fail as a whole, as there are some important and influencing factors in this test. It is the type as loading rate, distance between the two predicates and the dimensions of the cross section of the sample [61], and for the purpose of studying the bending behavior of the samples were prepared using the technique of bending three points through the use of Three Point Bending Test. As it is installed the sample has two horizontal anchor points and the load is shed in the middle of the sample from the opposite side of the two anchor points while the sample dimensions are 150x12.5x6 mm. Through the device

diagram, the results are obtained directly in the form of a graphical form (load - deviation) and the curve (bending stress - deflection). Using the equation (3.2) the bending elastic modulus is calculated.

$$E_B = \frac{ms^3}{4bd^3} \quad (3.2)$$

Where:

E_B : Bending elastic modulus (MPa).

m : Slope of the linear part of the curve (load - deflection).

s : The distance between the footboards (mm).

b : Sample width (mm).

d : Sample thickness (mm).



Figure 3.7: Bending test device.

3.5.3 Tensile Test

A hydraulic press was used to test the tensile strength of prepared samples of standard dimensions according to the International Standard Specifications (ASTM 538) as it is showed in Figure 3.8, whereby the sample is attached to the device by a holder installed on the top table and another holder installed on the lower table for the press, after which a tensile strength is shed on the sample with a projected load rate of 500 kg. The sample is well fixed by the upper and lower jaws of the device, after which the tensile strength is applied to the sample until it is broken and

the highest tensile strength borne by the sample is recorded before it is broken, and the device includes a drawing that draws the relationship between the force and elongation of the sample as a result of pregnancy as tensile strength, according to the graph. This test was carried out for the four samples separately.

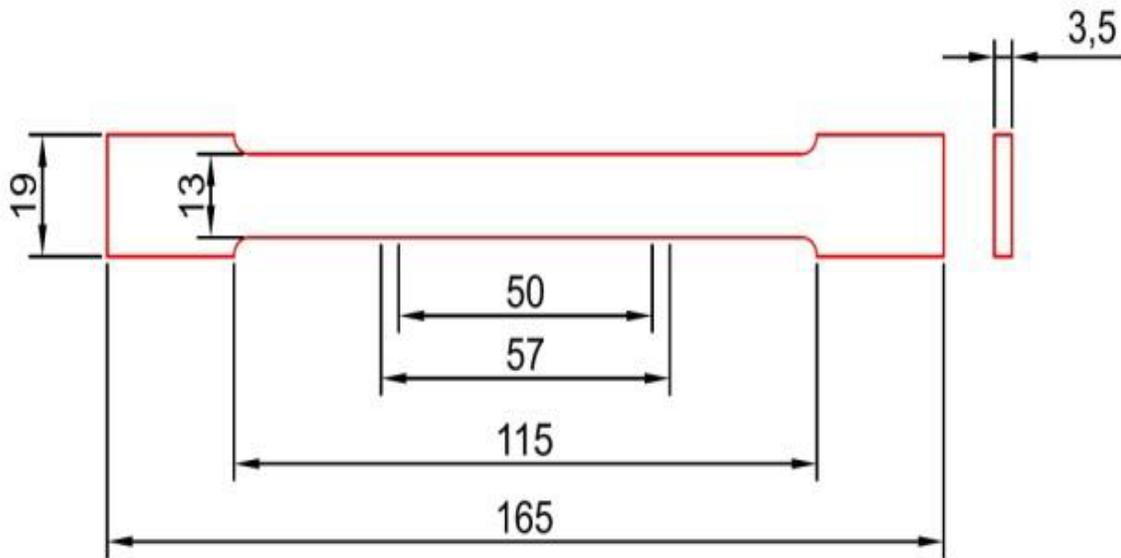


Figure 3.8: Standard dimensions of tensile samples [ASTM].



Figure 3.9: Tensile testing device.

3.5.4 Impact test

The impact test device used in this research is shown in Figure 3.10 and using the Charpy impact test method, the dimensions of the samples used in the impact test are 55 x 12.5 x 6 mm, as the device consists of a pendulum in which the hammer is used to break the samples, and the device contains hammers of different sizes, so that the hammer can be replaced with another and according to the required energy to break. The energy required for breakage is calculated by means of which the impact resistance of the material can be calculated.

At the start of the test, the pendulum with the hammer is raised to the maximum height so that it is well fixed by a stabilizer on the device. And the sample is placed on the device rests and in the place designated for them. And the power meter is zeroed first.

Then the pendulum is released using the lever installed on the scale. And with a swing motion the potential energy turns into Kinetic energy when it collides with the sample, part of it loses the sample fracture. And the scale indicator reads the sample breaking energy.

Note that a hammer with its capacity of 5J was used to perform an impact test in a Charpy way, and the impact resistance is calculated from the following relationship:

$$I.S = \frac{U_c}{A} \quad (3.3)$$

Where: -

I.S: Impact resistance to the material (J/m²).

U_c : Impact energy (J).

A: The area of the cross section of the sample (m²).



Figure 3.10: Impact test device.

4. RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter includes the presentation and discussion of the results of mechanical tests (tensile, Impact, bending resistance and hardness) for samples which prepared from epoxy reinforced by glass fiber samples before and after exposure to certain environmental conditions, which are immersed in water for one month, as well as exposing the samples to temperatures such as 50, 70 °C and for one month.

4.2 WATER ABSORPTION

After weighing the sample by a sensitive balance and then submerging the sample in water and leaving it for one day, the sample was taken out from the water and then suspended water was removed from the sample and then weighed again once after which was calculated the percentage of water absorption using the Equation 3.1. This process was done repeatedly for six days, when the sample reached a saturation state on the sixth day and there was no change in the sample weight. It was found out that the sample increases its weight due to its absorption of water until it reaches the saturation state as shown in Table 4.1 and Figure 4.1.

Figure 4.1 shows the relationship between the percentages of absorbance with the number of days of immersion the sample in the water, as the mass of absorbed water increases with the increase in the number of days of sample immersion in water until finally reaching saturation, after which the amount of absorbed water will be constant over time.

Throughout the figure, the percentage of absorbance increases with increasing time until it begins to settle on the fifth and sixth days respectively. The increase becomes slight and this means that the water increases during penetration through the open pores of the external surface of the samples, with increasing time until it reaches the saturation state. This leads to weakening the connections between the base material and fibers, and this corresponds to the results obtained by the researcher Abd al-Hussein [62]. As for the reason for not taking the weight values of immersion time more than six days, it is the stability of the results obtained and their almost constant stability, as we note a slight increase in days 5 and 6, which means fill open pores and saturate the sample with water.

Table 4.1: Water absorption percentages for 6 days.

Day	Sample weight	Weight Gain (%)
1	5.482	4.62
2	5.5742	6.37
3	5.6011	6.89
4	5.6108	7.07
5	5.611	7.08
6	5.611	7.08

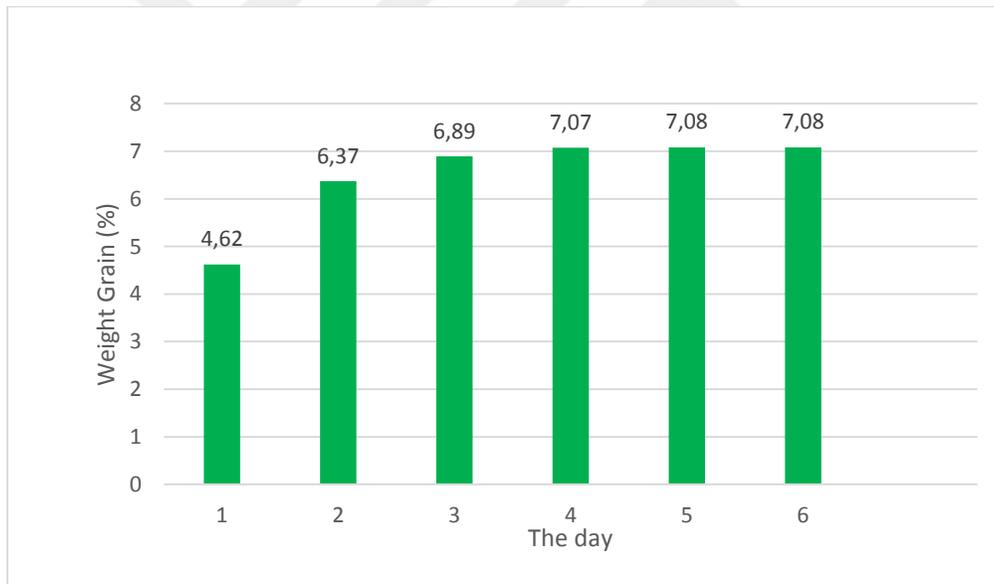


Figure 4.1: Water absorption percentages for 6 days.

4.3 MECHANICAL TEST RESULT

4.3.1 Hardness Test Result

The hardness test was done on the samples 1, 2, 3 and 4 by a shore device, and it was found that the hardness of sample 1 that was not exposed to any environmental conditions was 76, and the hardness of sample 2 that was immersed in water for one month equals to 71, and the hardness of

Sample 3 that was exposed to a temperature of 50°C for one month equals to 66.5, and the hardness of Sample 4 that was exposed to a temperature of 70 °C for one month equals to 65 as shown in Figure 4.2.

It was found out that the hardness of polymeric composites reinforced with glass fibers decreases when exposed to environmental conditions such as moisture and heat, and it was also found that the temperature is more effective on these composite materials. Due to the hardness in the sample 3 is less than the hardness in the sample 2, it was also found that the hardness decreases whenever the temperature to which the samples were exposed. It was found that the hardness in the sample 3 is greater than the hardness of the sample 4, that means the hardness in the composite material that it consists from the epoxy as a base material reinforced by glass fiber decreases with increasing temperature.

Table 4.2: Shore hardness in prepared samples.

Samples Number	Shore Hardness
1	76
2	71
3	66.5
4	65

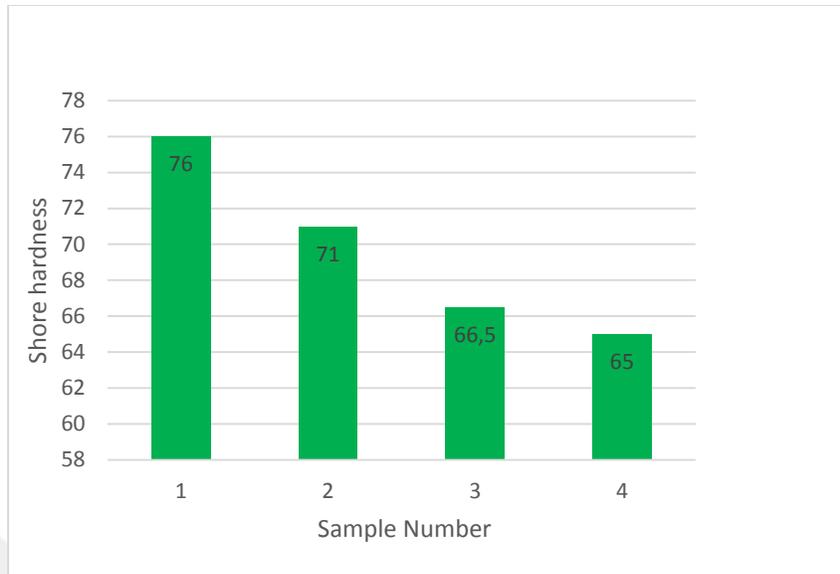


Figure 4.2: Shore hardness in prepared sample.

4.3.2 Bending Test Results

Figure 4.3 shows the relationship between bending stress and samples 1, 2, 3 and 4 that have been prepared and exposed to certain environmental conditions such as the humidity and a different temperature. It is noted from the relationship that the bending stress in sample 1 that was not subjected to environmental conditions was tested in the room temperature is 144 MPa, and the bending stress in sample 2 which has been immersed in water for one month is 140 MPa, meaning that there is little effect of the moisture absorbed in the sample on the bending stress. As well as a decrease in the bending stress in sample 3, which was exposed to a temperature 50 °C for one month when it was found that the bending stress was equal to 96 MPa, and also a decrease in the bending stress in sample 4 which has been exposed to a temperature of 70 °C for one month, where we found that the bending stress is equal to 92 MPa.

These results showed that the effect of moisture is less than the effect of heat on the bending stress in the composite material consisting of epoxy as the base material reinforced by glass fibers, as well as the bending stress of the composite material decreases when the temperature increases and this corresponds to many studies and research that have been mentioned in the first chapter.

From equation 3.3, the bending elastic modulus was found for the samples 1, 2, 3 and 4, it was found that the bending elastic modulus value is equal to 9600 MPa, 8640 MPa, 5440 MPa and 4880 MPa for the samples 1, 2, 3 and 4 respectively, which means that the bending elasticity modulus of the samples decreases when exposed to environmental conditions such as humidity and temperature, as well as its value is lower in the samples that have been exposed to heat, this means the effect of heat on the bending elastic modulus is greater than the effect of moisture on it.

Likewise, the bending elastic modulus of the sample 4 that was exposed to a temperature of 70 °C is less than the sample 3 that was exposed to a temperature of 50 °C. This means that the bending elasticity modulus decreases when the temperature increases, as shown in Figure 4.4.

Figure 4.5, Figure 4.6, Figure 4.7 and Figure 4.8 are relationship between the load and extension in samples 1, 2, 3 and 4 respectively in bending test, they are showed that the highest load bearing samples 1, 2, 3 and 4 are 360 N, 350 N, 240 N and 230 N respectively.

Figure 4.9, Figure 4.10, Figure 4.11 and Figure 4.12 are relationship between the stress and strain in samples 1, 2, 3 and 4 respectively in bending test, they are showed that the highest stress bearing samples 1, 2, 3 and 4 are 144 MPa, 140 MPa, 96 MPa and 92 MPa respectively.

Table 4.3: Bending stress and bending elastic modulus in prepared samples.

Sample number	Bending stress (MPa)	Bending elastic modulus (MPa)
1	144	9600
2	140	8640
3	96	5440
4	92	4880

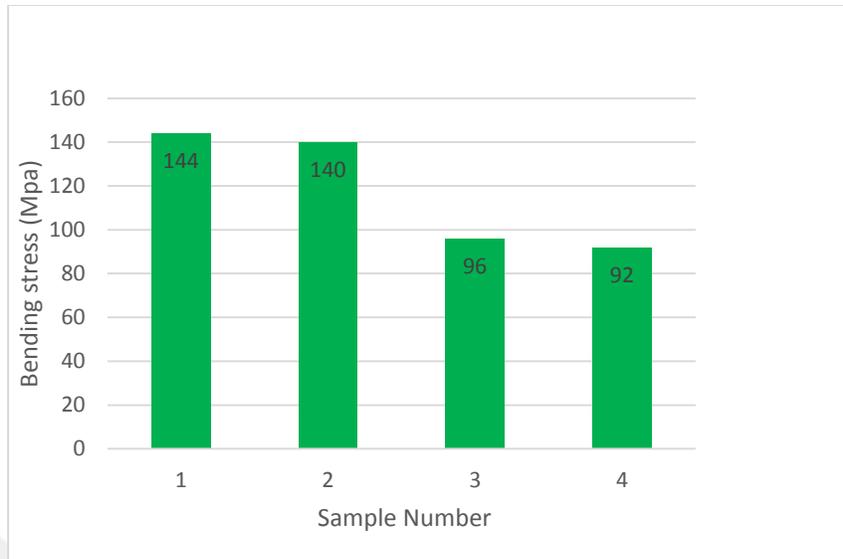


Figure 4.3: Bending stress in prepared samples.

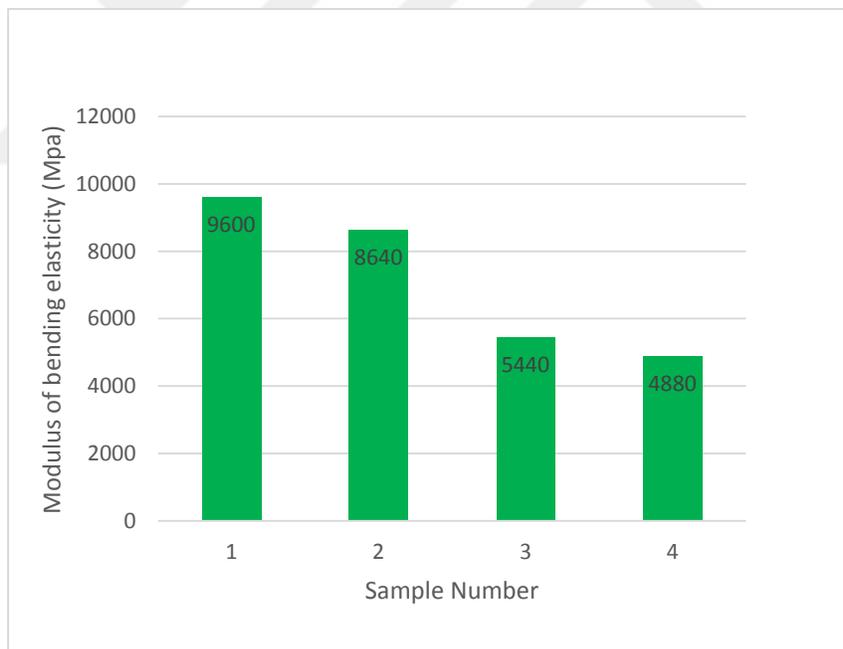


Figure 4.4: The modulus of bending elasticity in samples.

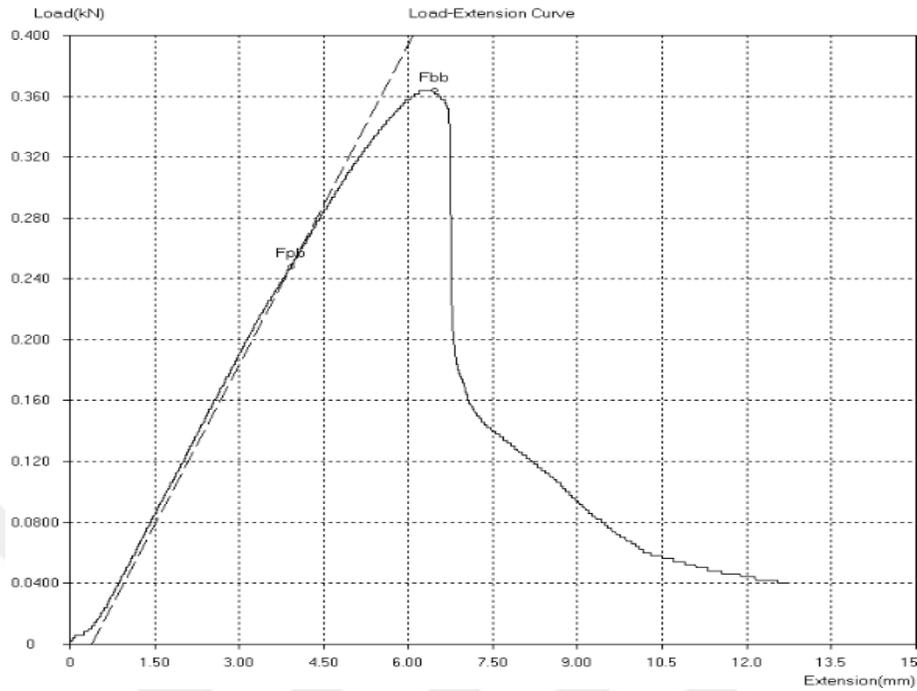


Figure 4.5: Relationship between the load and extension in sample1 in bending test.

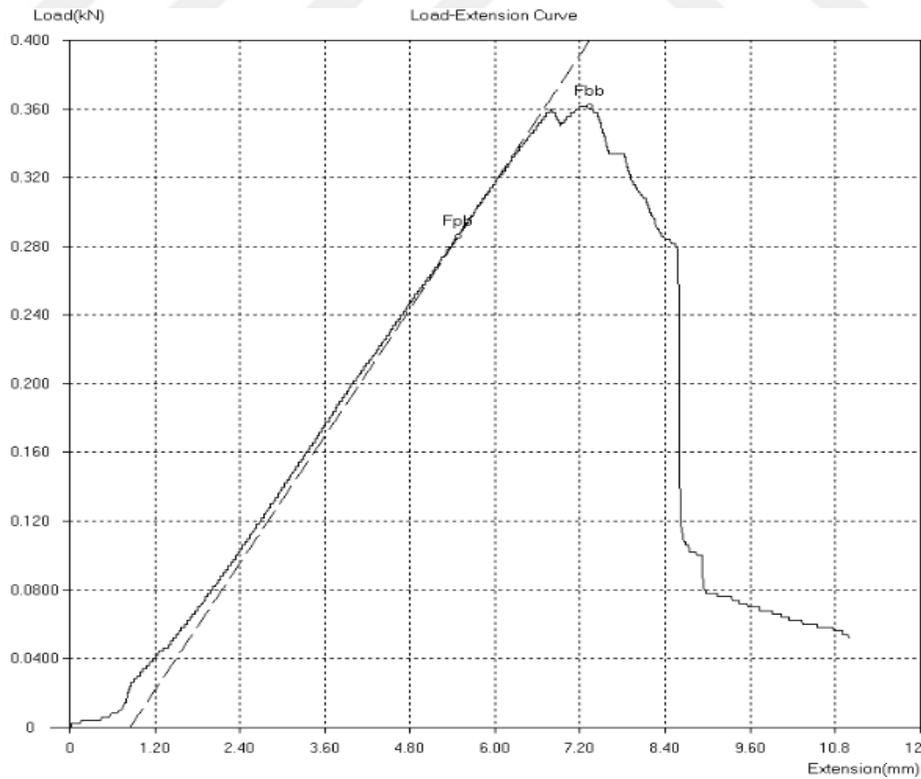


Figure 4.6: Relationship between the load and extension in sample2 in bending test.

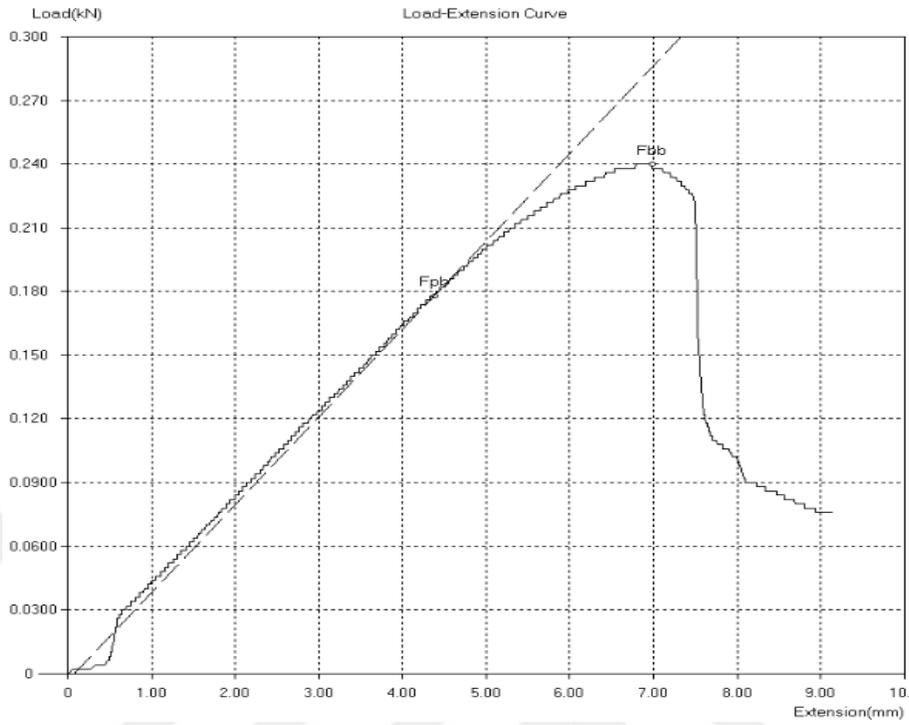


Figure 4.7: Relationship between the load and extension in sample 3 in bending test.

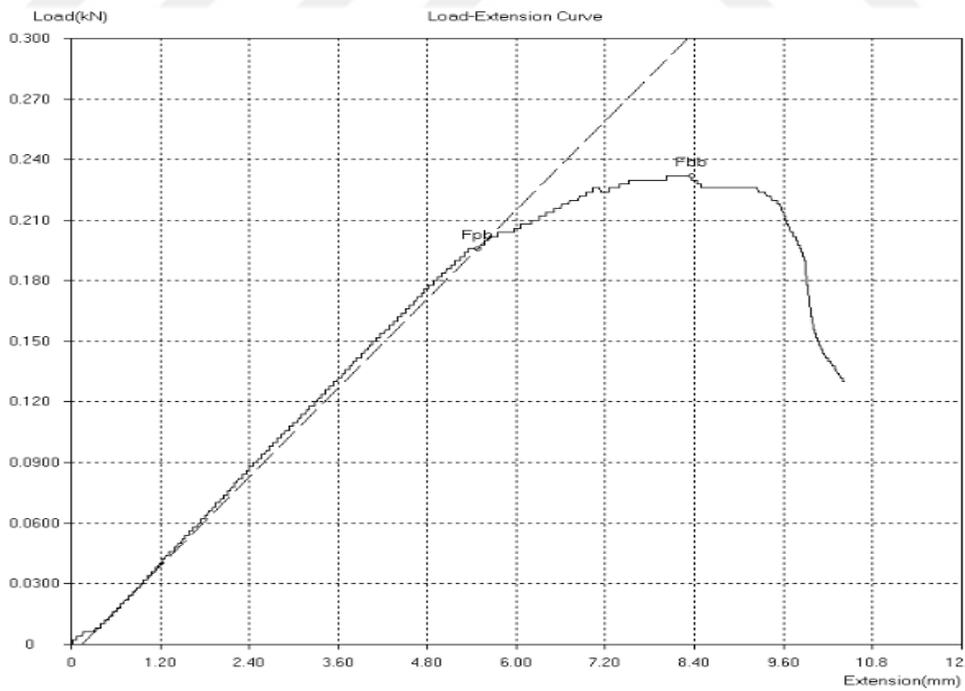


Figure 4.8: Relationship between the load and extension in sample 4 in bending test.

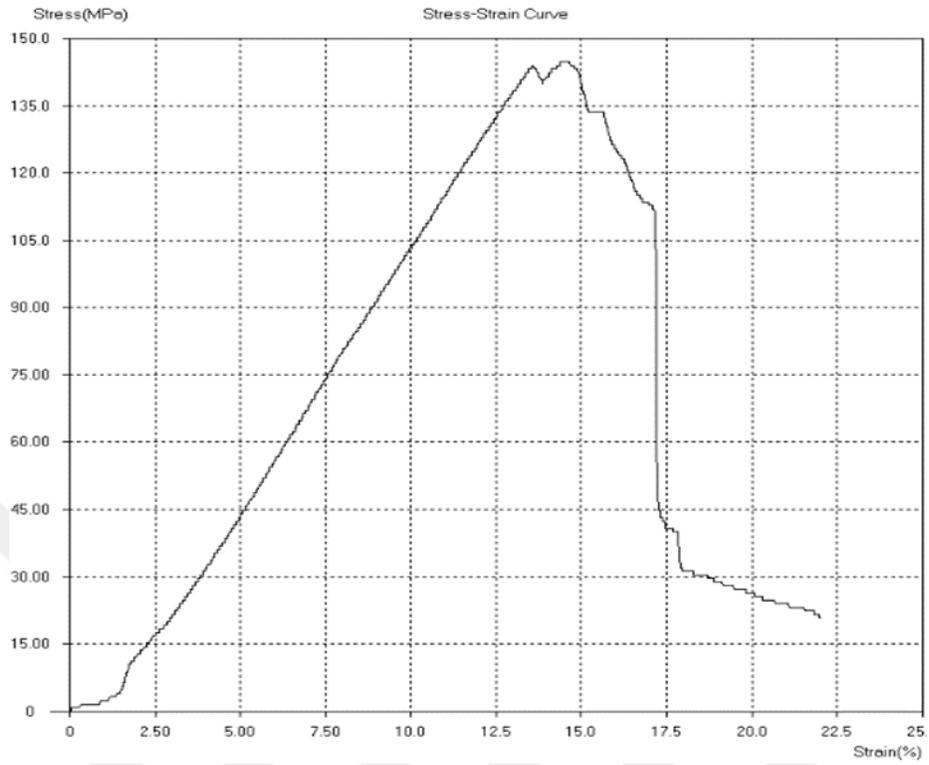


Figure 4.9: Relationship between the stress and strain in sample 1 in bending test.

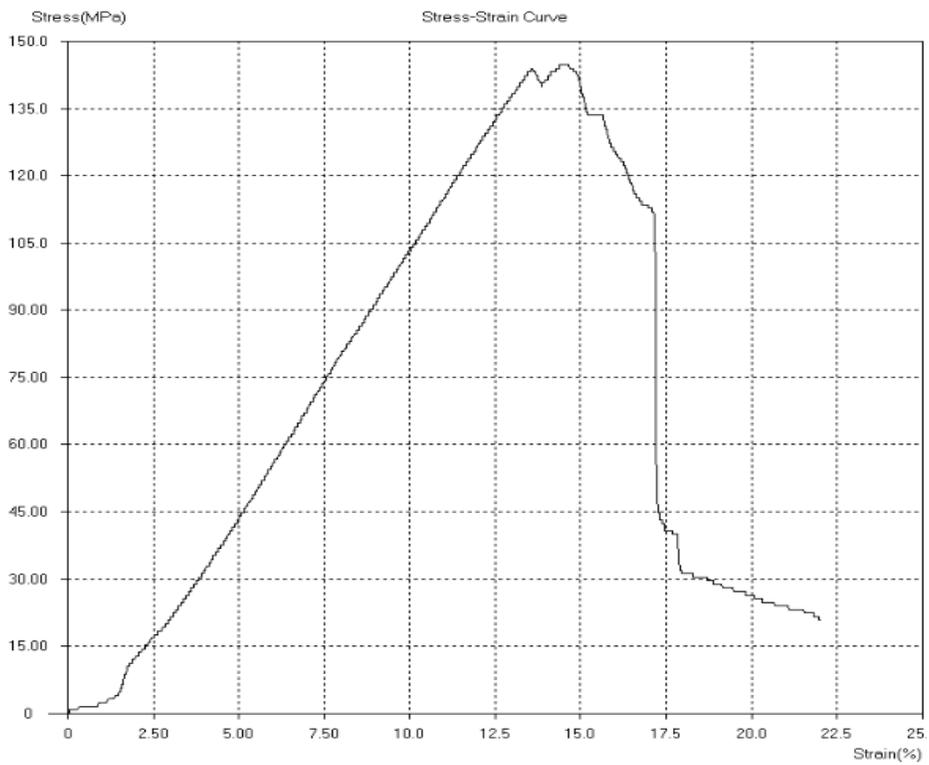


Figure 4.10: Relationship between the stress and strain in sample 2 in bending test.

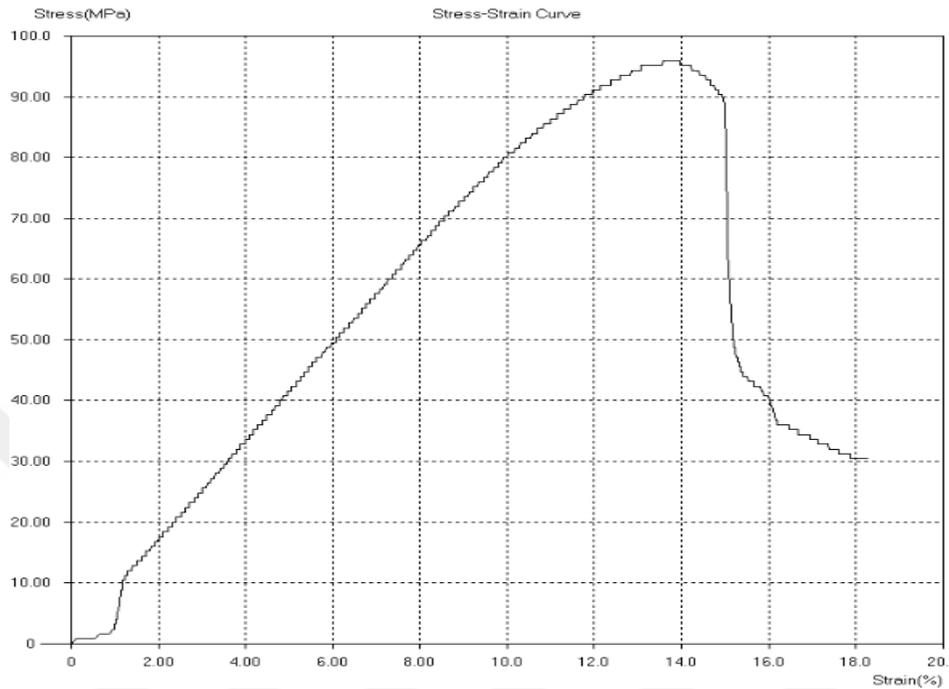


Figure 4.11: Relationship between the stress and strain in sample 3 in bending test.

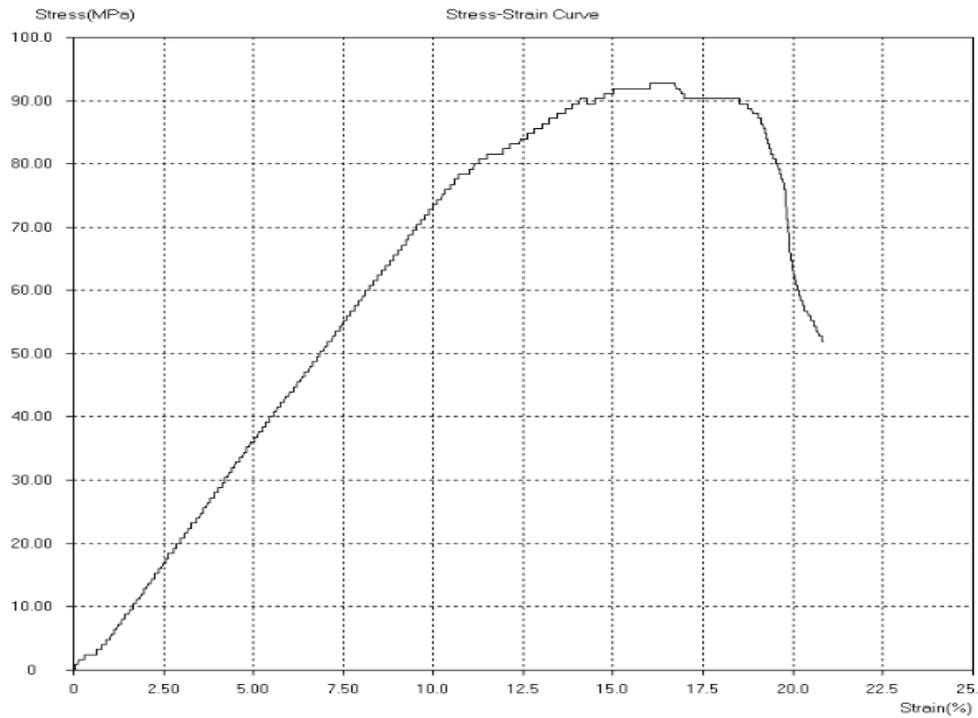


Figure 4.12: Relationship between the stress and strain in sample 4 in bending test.

4.3.3 Tensile Test Results

Figure 4.13 shows the relationship between the tensile strength and the samples 1, 2, 3 and 4 that have been prepared and exposed to environmental conditions, such as humidity and temperatures 50 and 70 °C. It is noted that the tensile strength in sample 1 that has not been subjected to environmental conditions equal to 49MPa. Also, it is found a decrease in the tensile strength in sample 2, which was immersed in water for one month, where it was found that the tensile strength was 41MPa. And it is noted a decrease in the tensile strength in sample 3, which was exposed to a temperature of 50 °C where it was found that the tensile strength is 41MPa. As well as a decrease in the tensile strength of the sample 4, which was exposed to a temperature of 70°C where it was found that the tensile strength was 30MPa.

These results showed that, the immersion of the composite material consisting of epoxy as a base material reinforced by glass fibers in water for one month leads to a decrease in tensile strength. Also it was found that exposure of the composite material to temperatures leads to a decrease in tensile resistance, and it was found that the tensile strength in the sample 4 was less than the tensile strength in the sample 2. Therefore, the effect of heat on the tensile strength of the composite material consisting of epoxy and glass fibers is greater than the effect of moisture on the same material. It is also concluded that the tensile resistance in the composite material decreases when the temperature to which it is exposed increases, and these results correspond to many of the studies mentioned in the first chapter.

Figure 4.14, Figure 4.15, Figure 4.16 and Figure 4.17 are relationship between the load and extension in samples 1, 2, 3 and 4 respectively in tensile test, they are showed that the highest load bearing samples 1, 2, 3 and 4 are 3642 N, 3112 N, 3048 N and 2278 N respectively.

Figure 4.18, Figure 4.19, Figure 4.20 and Figure 4.21 are relationship between the stress and strain in samples 1, 2, 3 and 4 respectively in tensile test, they are showed that the highest stress bearing samples 1, 2, 3 and 4 are 49 MPa, 41 MPa, 41 MPa and 30 MPa respectively.

Table 4.4: Tensile strength in prepared samples.

Sample Number	Tensile Strength
1	49
2	41
3	41
4	30

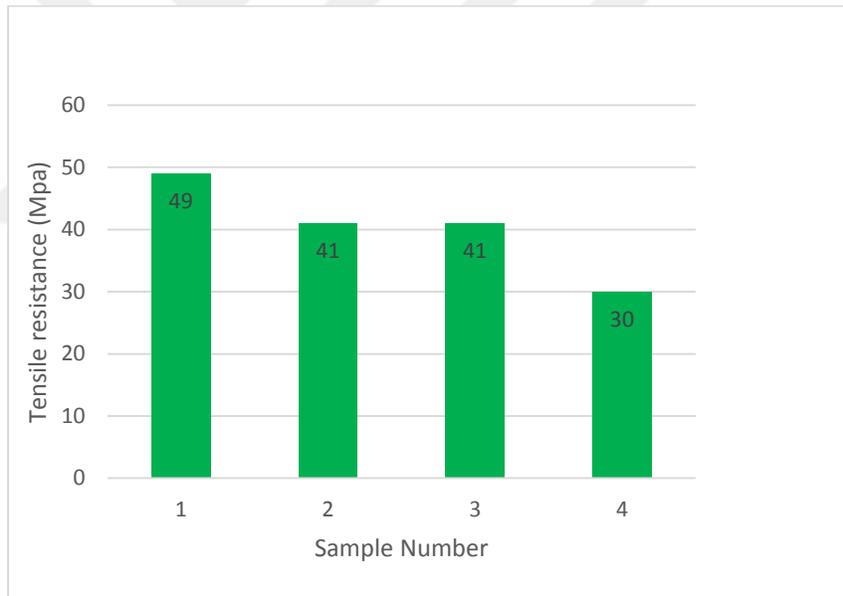


Figure 4.13: Tensile strength in prepared samples.

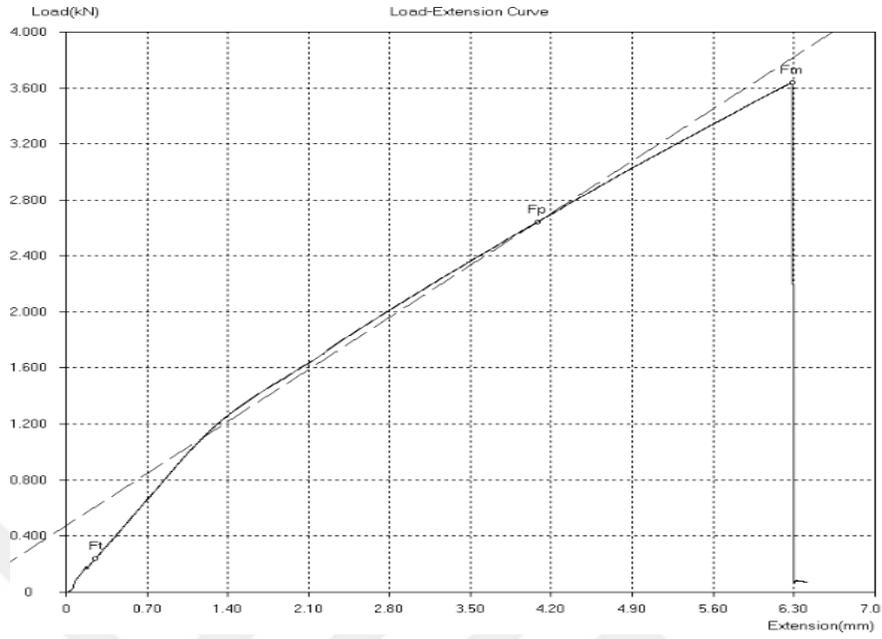


Figure 4.14: Relationship between the load and extension in sample1 in tensile test.

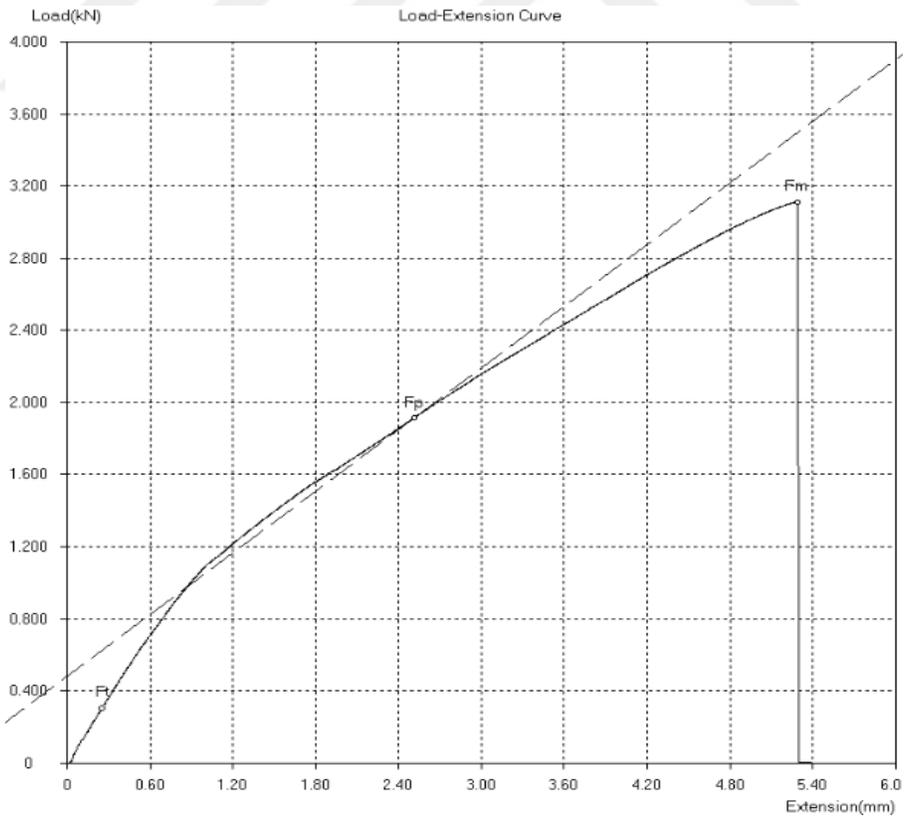


Figure 4.15: Relationship between the load and extension in sample2 in tensile test.

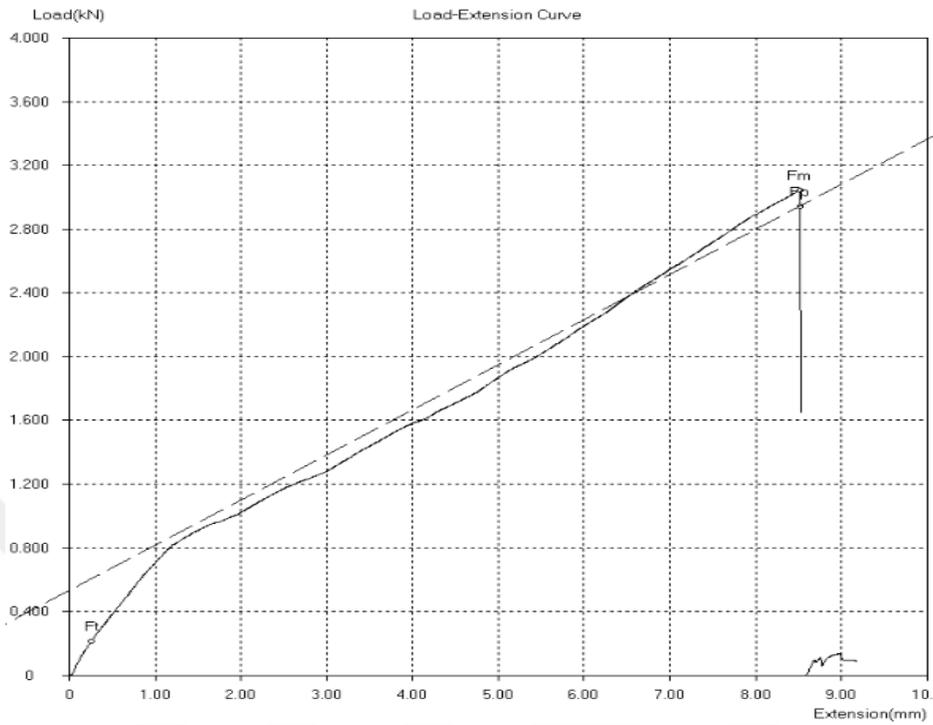


Figure 4.16: Relationship between the load and extension in sample3 in tensile test.

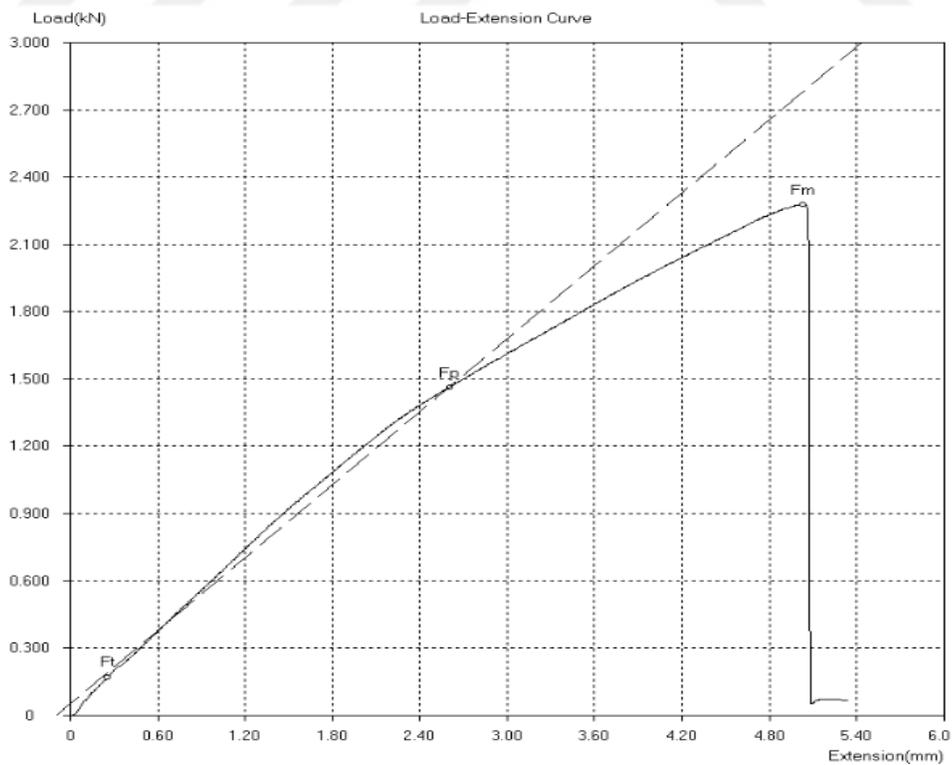


Figure 4.17: Relationship between the load and extension in sample 4 in tensile test.

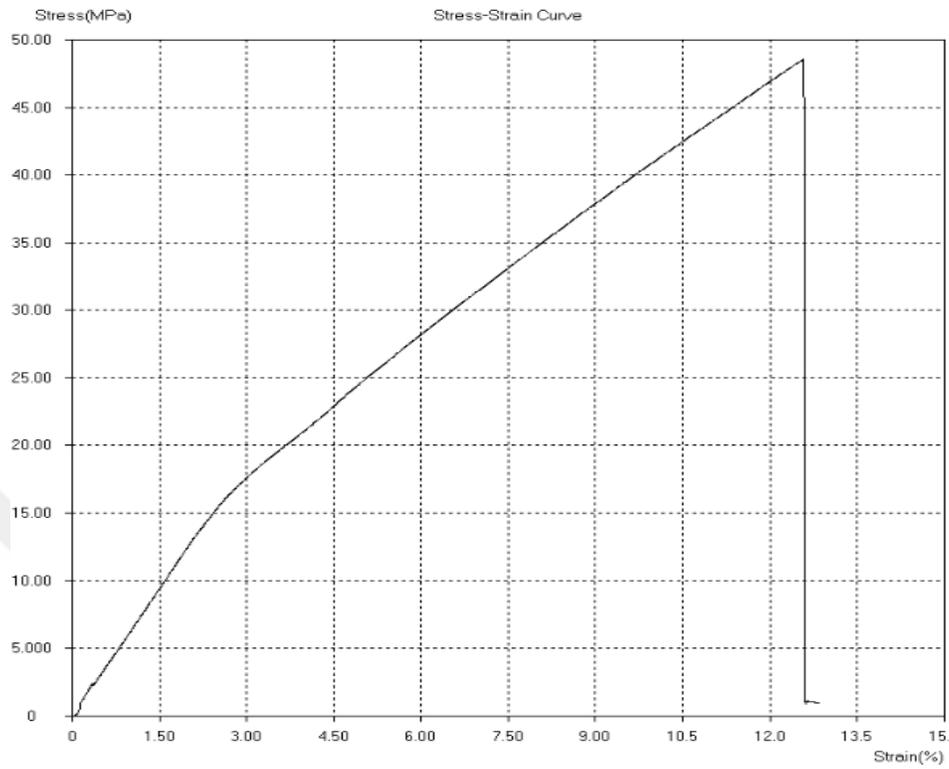


Figure 4.18: Relationship between the stress and strain in sample 1 in tensile test.

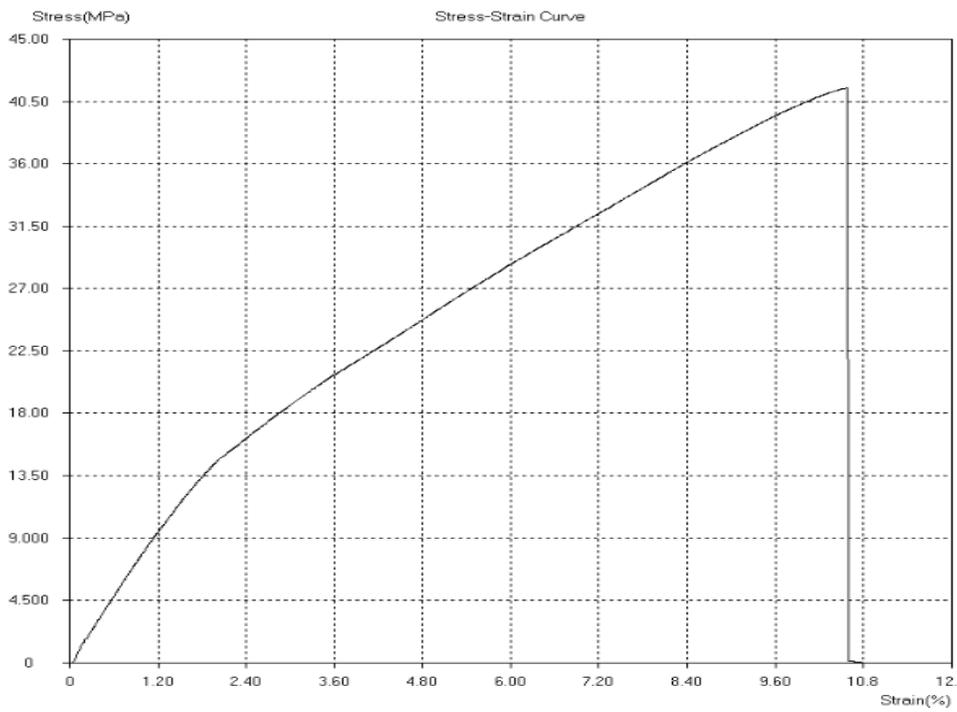


Figure 4.19: Relationship between the stress and strain in sample 2 in tensile test.

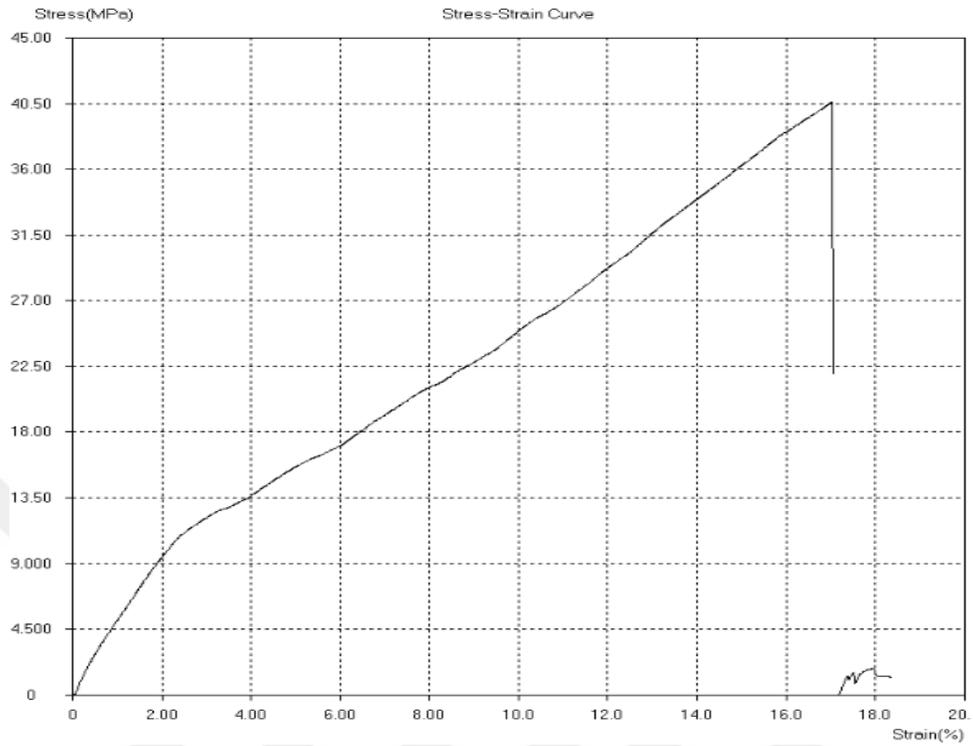


Figure 4.20: Relationship between the stress and strain in sample 3 in tensile test.

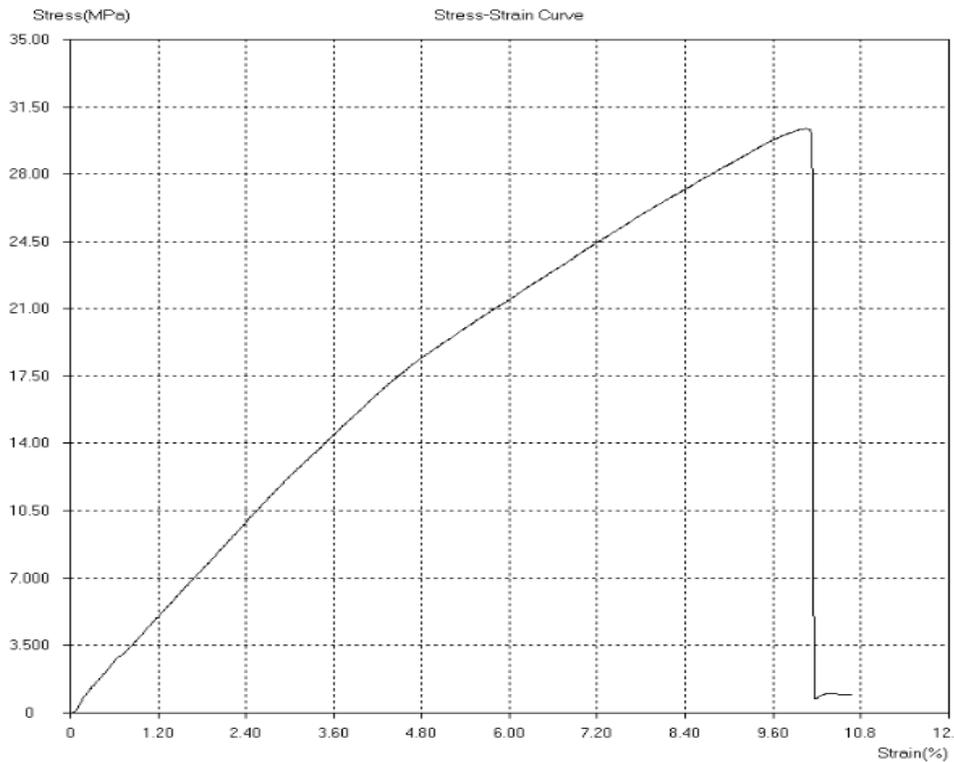


Figure 4.21: Relationship between the stress and strain in sample 4 in tensile test.

4.3.4 Impact Test Results

The impact test was done on the samples 1, 2, 3 and 4 by the impact test device and found that the impact resistance of sample 1 is 64 kJ / m^2 , the impact resistance of the sample 2 which was submerged in water is 61 kJ / m^2 , and the impact resistance of the sample 3 is 55 kJ / m^2 , and the impact resistance of Sample 4 is 33 kJ / m^2 as shown in table 4.5 and Figure 22.

It was found that the impact resistance in the prepared samples is less when exposed to environmental conditions such as submerge it in water and exposed to heat, and that the effect of heat on the impact resistance in the samples is greater than submerged it in water for same the time period where it was found that the impact resistance of the sample 3 is less than the impact resistance of the sample 2. It was also found that the impact resistance decreased with increasing temperature, where it was found that the impact resistance in sample 3 is greater than the impact resistance in sample 4, and these results correspond to many studies that have been mentioned in the first chapter.

Table 4.5: The impact resistance in prepared samples.

Sample Number	Impact resistance (kJ/m ²)
1	64
2	61
3	55
4	33

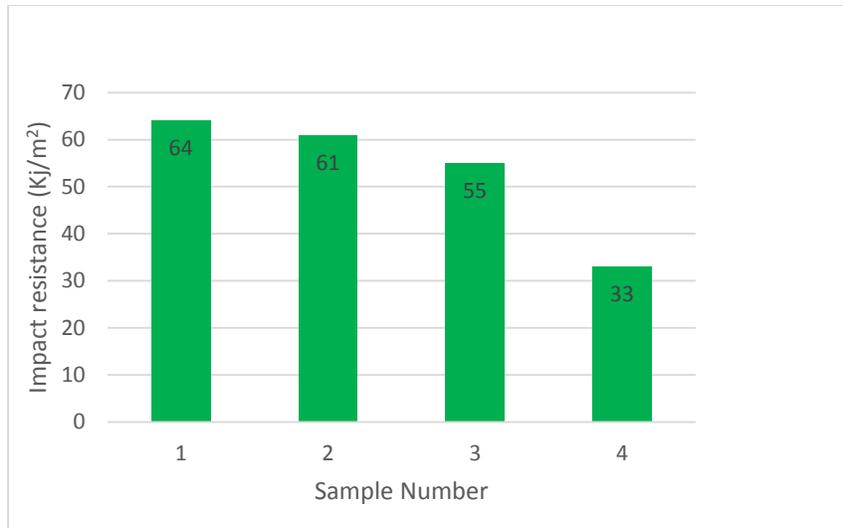


Figure 4. 22: The impact resistance of prepared samples.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Through the results obtained from mechanical tests such as hardness, bending resistance, tensile strength, and impact resistance in the samples 1, 2, 3 and 4 that were prepared and which were exposed to certain environmental conditions such as humidity and temperatures 50 and 70 °C. As conclusion it was found that the mechanical properties decrease when the samples are exposed to moisture and heat, and it was also found that the effect of heat on mechanical properties is greater than the effect of moisture.

Likewise, the mechanical properties such as hardness, bending resistance, tensile strength, and impact resistance decrease when increasing the temperature to which the samples are exposed, as shown in Table 5.1.

Table 5.1: Results of mechanical tests in the prepared samples.

Sample/Mechanical Tests	Shore hardness	Bending stress (MPa)	Tensile resistance (MPa)	Impact resistance (kJ/m²)
Sample 1	76	144	49	64
Sample 2	71	140	41	61
Sample 3	66.5	96	41	55
Sample 4	65	92	30	33

As a result of performing mechanical tests on the prepared samples in this research, the following conclusions were reached:

- The mass of water absorbed in the sample immersed in water increases with the increase in the number of days until it reaches the saturation state on the sixth day.

- The hardness in samples 1, 2, 3 and 4 are 76, 71, 66.5 and 65, respectively. This means that the hardness decreases when the samples are exposed to environmental conditions such as moisture and temperature, and that the effect of temperature is greater than the effect of moisture on the hardness in the samples, and that the effect of temperature on hardness in samples increases with increasing temperature.
- The bending resistance of the samples 1, 2, 3 and 4 are 144 MPa, 140 MPa, 96 MPa and 92 MPa respectively, which means that the bending resistance in the prepared samples decreases when the samples are exposed to environmental conditions such as moisture and temperature. The effect of temperature greater than the effect of moisture on the bending resistance in the prepared samples, and the effect of temperature on the bending resistance in the prepared samples increases with increasing temperature.
- The tensile strength of the samples 1, 2, 3 and 4 are 49 MPa, 41 MPa, 41 MPa and 30 MPa respectively, and this means that the tensile strength in the prepared samples decreases when the samples are exposed to environmental conditions such as moisture and temperature. It is concluded that the effect of moisture is equal to the effect of the temperature of 50 °C on the tensile strength in the samples, but the effect of the temperature of 70 °C is greater than the effect of moisture on the tensile strength, and that the effect of the temperature on the tensile strength increases with increasing temperature.
- The impact resistance of the samples 1, 2, 3 and 4 are 64 kJ / m², 61 kJ / m², 55 kJ / m² and 33 kJ / m² respectively, which means that the impact resistance in the prepared samples decreases when the samples are exposed to environmental conditions such as moisture and temperature, and the effect of moisture on the impact resistance in the prepared samples is less than the effect of temperature, and the effect of temperature on the impact resistance in the samples increases with increasing temperature.

From the above results it was found out that the mechanical properties such as hardness, tensile strength, bending resistance, and impact resistance decrease in the prepared samples when exposed to moisture and temperature, and that the effect of temperature is greater than the effect of moisture on the mechanical properties of the prepared samples, and that the effect of

temperature on the mechanical properties of the prepared samples increases with increasing temperature.

5.2 FUTURE STUDY RECOMMENDATIONS

The following are some recommendations for future studies:

- Studying the effect of other environmental conditions on composite materials such as ultraviolet rays and immerse them in chemical solutions.
- Studying the effect of environmental conditions on composite materials that consist of other polymeric materials such as unsaturated polyester.
- Studying the effect of environmental conditions on polymeric composites reinforced with other types of fibers or reinforced with particles as fillers.
- Studying the effect of environmental conditions on other mechanical properties such as creeping and fatigue.

REFERENCES

- [1] R. J. Crawford, "Plastic Engineering", 2nd ed., Pergamon press, V. K., (1987).
- [2] Theodore J. R., "Engineering Materials Hand Book", Vol. 1, 1987.
- [3] Lames Ali, "Study of mechanical and physical properties of unsaturated polyesters reinforced by glass and nylon fibers", Department of Materials Engineering, University of Technology, Iraq, 2006.
- [4] Mei Li, "Temperature and moisture effects on composite materials for wind turbine blades", Montana state university-Bozeman bozeman, Montana, 2000.
- [5] Cestmir David Herak, Petr Herbe and Abraham Kabutey, "Effect of temperature and moisture content on tensile behaviour of false banana fibre", Czech University of Life Sciences Prague, Kamycka 129, Prague, Czech Republic, 2017.
- [6] Shahram Eslami and Abbas Honarbakhsh-Raouf, "Effects of moisture absorption on degradation of E-glass fiber reinforced Vinyl Ester composite pipes and modelling of transient moisture diffusion using finite element analysis", Dalhousie University, Halifax, Nova Scotia, Canada, 2015.
- [7] Waruna P. Seneviratne, PhD, and John S. Tomblin, PhD, "Environmental Compensation Factor Influence on Composite Design and Certification", Wichita State University, Wichita.
- [8] Sanghamitra Sethi, Bankim Chandra Ray, "Environmental effects on fibre reinforced polymeric composites: Evolving reasons and remarks on interfacial strength and stability", Rourkela 769008, India, 2015.
- [9] B.Senthil Kumar, "Comparative Study of Moisture Diffusion Behavior of Textile Structured Nano Composite with Varying Nano Clay Composition", Gandhigram Rural Institute –Deemed university, 2016.
- [10] Hossein Ramezani Dana, Annick Perronnet, "Identification of moisture diffusion parameters in organic matrix composites", Lunam Université, France, 2013.
- [11] R.T.D. Prabhakaran, "Influence of moisture on properties of fiber reinforced polyamide 6 composites".
- [12] K.L. Pickering, M.G. Aruan Efendy, "A review of recent developments in natural fibre composites and their mechanical performance", Hanoi University of Science and Technology, Hanoi, 2016.
- [13] Chi-Hung Shen and George S. Springer, "Moisture absorption and desorption of composite materials", The University of Michigan Ann Arbor, Michigan 48109, 1975.

- [14] Akawut Siriruk, Y. Jack Weitsman, "Polymeric foams and sandwich composites: Material properties, environmental effects, and shear-lag modeling", The University of Tennessee, 223 Perkins Hall, Knoxville, TN 37996, USA, 2009.
- [15] Abdul Moudood, Anisur Rahman, Hossein Mohammad Khanlou, "Environmental effects on the durability and the mechanical performance of flax fiber/bio-epoxy composites", National University of Mar del Plata, J. B. Justo, 4302, B7608FDQ, Mar del Plata Argentina, 2019.
- [16] Dionsios E. Mouzakisa, Dimitrios G. Dimogianopoulosb, "Acoustic emission detection of damage induced by simulated environmental conditioning in carbon fiber reinforced composites", University of West Attica, 12244, Greece, 2019.
- [17] N.H.Nash, A.Portela, C.I.Bachour-Sirerol, I.Manolakis, A.J.Comer, "Effect of environmental conditioning on the properties of thermosetting- and thermoplastic-matrix composite materials by resin infusion for marine applications", 2019.
- [18] Fernand Ellyin, "Environmental effects on the mechanical properties of glass-fiber epoxy composite tubular specimens", 2004.
- [19] P.V.Joseph, Marcelo SRabello, L.H.CMattoso, "Environmental effects on the degradation behaviour of sisal fibre reinforced polypropylene composites", 2002.
- [20] Anand Venkatachari, Sundararajan Natarajan, "Mechanical buckling of curvilinear fibre composite laminate with material discontinuities and environmental effects", India, 2015.
- [21] Samuel C.R. Furtado, Aurélio L. Araújo and Arlindo Silva, "Inverse characterization of vegetable fibre-reinforced composites exposed to environmental degradation", Manchester, UK, 2018.
- [22] Lobanov Dmitriy S., "Research of temperature aging effects on mechanical behavior and properties of composite material by tensile test with used system of registration acoustic emission signal", Perm National Research Polytechnic University, 29 Komsomolsky AVE, Perm 614000, Russia, 2019.
- [23] Anxin Ding, Jihui Wang, Aiqing Ni, Shuxin Li, "Ageing of sandwich composites with E-glass fibre/vinylester skins and PVC foam core in synergistic environmental agents", University of Bristol, Bristol BS8 1TR, UK, 2018.
- [24] Schwartz, M.M. "The influence of Environmental Effects," Composite Materials, Properties, Nondestructive, Testing and Repair, 1996, pp. 117-119.1- R. J. Crawford, "Plastic Engineering", 2nd ed., Pergamon press, V. K., (1987).
- [25] D. Hall, "Introduction to Composite Materials", Cambridge University Press, 1981.

- [26] Martin Grayson , " Encyclopedia of Composite Materials and Component " , (1983) .
- [27] F.W.Billmeyer , " Text book of polymer science " , Wiley , Inc.New York,1971.
- [28] D.R.Paul and S.Newman , "Polymer Blends " , Vol.1,Academic press , Inc,New York , 1978.
- [29] Autar K. Kaw, "Composite Materials", Taylor & Francis Group, LLC, 2006.
- [30] Lawrence H. Van Vlack "Materials For Engineering Concepts And Application" ,1982 .
- [31] J.M.Kelvey,"Polymer processing "John Wiley and son, New York (1962).
- [32] A. Harper, "Plastic Handbook" Technology Seminars, Inc., Lutherville, Maryland, (2000).
- [33] Martin Hollman , " Composite Aircraft Design " , (1993).
- [34] W. J. Work and K. Horie , " Pure Appl. Chem. " , Vol. 76 , No. 11, PP.(1985-2007), (2004).
- [35] Launikitis, M.B., "Vinyl Ester Resins," Handbook of Composites, Edited by Lubn,G., 1981, pp. 38-50.
- [36] N. G. McCrum, et al "principle of polymer Engineering" Edition John Wiley and son, New York (1992).
- [37] Dr. Qahtan Khalaf Al-Khazraji, "Principles of Non-Metallic Materials Engineering", University of Babylon, Faculty of Engineering, 1994.
- [38] James P.Schaffer , Ashok Saxena , " The science and Design of engineering materials " , Richard D.Irwin,Inc,1995.
- [39] Kirk Othmar, "Encyclopedia of Chemical Technology", Tom Wiley & Sons Inc., Canada, 1982.
- [40] Dr. Akram Aziz Mohamed, "Chemistry of Plastics", Dar Al Kotob for Printing and Publishing, 1993.
- [41] D.Callister,JR., "Materials Science and Engineering An Introduction" 6th ed., John Wiley and Sons,Inc., New York, (2003).
- [42] J.G.Morley , "High Performance of Fiber Composites " , University of Nottingham , U.K , (1987) .
- [43] G.Piatti , "Advances in Composite Materials " , Applied Science Publisher /TD , (1978) .
- [44] J.Steppek and H.Daust," Additive for Plastic", New York , 1983.

- [45] L. Holliday, "Composite Material", Elsevier Publishing, London, (1966).
- [46] Andrea Prota, Kah Yong Tan, Antonio Nanni, Marisa Pecee and Gaetano Manfreeli, "Performance of Shallow RC Beams With Externally Bonded Steel Reinforced Polymer", 2004.
- [47] E. Paul De Garmo, J. T. Black, Ronald A. Kohser and Barney E. Klamecki, "Materials and Processes in Manufacturing", 9th Edition, John Wiley and Sons, Inc., 2003.
- [48] James P.Schaffer , Ashok Saxena , " The science and Design of engineering materials " , Richard D.Irwin,Inc,1995.
- [49] A. A. Berlin and , S. A. Volfson” Principle of Polymer Composite”, Springer verlag, New York (1986).
- [50] Shen, C., Springer, S.G., “Moisture Absorption and Desorption of Composite Materials,” Journal of Composite Materials, Vol.10, 1976, pp.2-20.
- [51] Buxton, A., Baillie, C., “A Study of the Influence of the Environment on the Measurement of Interfacial Properties of Carbon Fiber/Epoxy Resin Composites,” Composites, Vol. 25, No. 7, 1994, pp. 604-608.
- [52] M.D.Baijal , " Plastic Polymer Science and Technology " , Applied Science Publishers" , 1978.
- [53] R-K Mattham “Rubber Engineering” Tata McGraw -Hill publishing company,Delhi 1998.
- [54] Groover M.P. , “Fundamentals of Modern Manufacturing Material” , Processes , (1996) .
- [55] Ragad, “ Study of tensile and fatigue tests for epoxy and its hybrid composites”, The Iraqi Journal For Mechanical And Material Engineering, Vol.13, No.1, 2013.
- [56] Shaki La Umair "Environmental Impacts of Fiber Composite" Material Master in Environmental Stategese Research in Royal Institute of Technology in Kanada, 2006.
- [57] Anderson J.C., Leaver K.D., Leever P. & Rawlings R.D. "Materials Science For Engineers" 5th edition, Ltd, 2003.
- [58] Fadhil BM and Ahmed PS. Improving mechanical properties of epoxy by adding multi-wall carbon nanotube. Journal of Theoretical and Applied Mechanics. 54(2); 2016: 551–560.
- [59] Dr.. Abdul Latif Rashad al-Samarrai, “ Plastics and composite materials”, Iraq, 2010.
- [60] American Society for Testing and Materials, ASTM D 570 – 98, Standard test method for water absorption of plastics; 2009.

- [61] Hodgkinson. J.M., "Mechanical Testing Of Advance Fiber Composites" Wood head Publishing Ltd & CRC Cambridge, England press LLC, 2000.
- [62] Abdel-Hussein, Hoda Jabbar, "the effect of immersion in solutions Chemical has mechanical and physical properties for polymeric composites reinforced by nano-alumina particles", the journal Iraqi Science, Volume 56, No. 3; 2015.

