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ALTINBAŞ UNIVERSITY

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# INVESTIGATION OF MECHANICAL PROPERTIES OF UNSATURATED POLYESTER – GLASS FIBER COMPOSITES USED FOR BOAT STRUCTURE

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Master's Thesis

Supervisor

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# INVESTIGATION OF MECHANICAL PROPERTIES OF UNSATURATED POLYESTER – GLASS FIBER COMPOSITES USED FOR BOAT STRUCTURE

by

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Anmar Abdulazeez Owaid

# DEDICATION

I would like to dedicate this work to my first teacher, my mother, and to my dear father, who gave his dearest things in order to reach this scientific stage, and to my brothers without you, this dream has never been fulfilled.

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# ABSTRACT

## INVESTIGATION OF MECHANICAL PROPERTIES OF UNSATURATED POLYESTER – GLASS FIBER COMPOSITES USED FOR BOAT STRUCTURE

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Mechanical properties are important to choose the suitable material in the manufacturing of boats. In this research, the effect of glass fiber orientations and the fillers weight fraction on the Mechanical properties of composite materials that contain unsaturated polyester as a base material were studied in two cases, the first case is test the samples at room temperature, while in the second case the samples are tested after immersed it in sea water for 14 days. Tensile strength, impact resistance and water absorption tests were performed. The glass fibers were used at (0/0, 0/90, 45/45) angles with 30% wt. The carbon and the aluminum oxide Nano be used as fillers with (2.5%, 5%, 7.5%) and (0%, 1%, 3%) weight fraction respectively. The standard Taguchi's array L9 ($3^3$) was used. The analysis of mean, the signal to noise ratio and analysis of variance were introduced to analyze and estimate the optimal combination parameters. The results show that the mechanical properties improved by rather than that of pure unsaturated polyester.

The glass fibers orientations angle presents the most parameter effect than the other parameters on the elasticity modulus, tensile resistance and impact resistance with a contribution of 81.8%, 83.39% and 96.75% respectively. Followed by carbon and aluminum oxide Nano filler. Carbon

filler is the most parameter effect in the water absorption test than the other parameters with a contribution of 44.31%, followed by fiber orientation angle and aluminum oxide Nano filler. The optimum parameter with their levels for the highest elastic modulus was obtained at (0/90 fiber orientation, 2.5% carbon and 1% Nano aluminum oxide filler). While the highest tensile resistance and impact resistance present with using (0/0 fiber orientation, 5% carbon filler and 1 aluminum oxide nanofiller). It was found that the lowest value of water absorption was at (0/0 fiber orientation, 2.5% carbon filler and 0% aluminum oxide Nano filler).

In the case of samples that were immersed in sea water for 14 days, it was found that the most parameter effect than the other parameters on the modulus of elasticity and water absorption was the aluminum oxide Nano filler with a contribution of 36.53% and 40.58% respectively, followed by the carbon filler and finally the direction of the fiber. And it was found that the parameter most influence on tensile resistance and impact resistance is the direction angle of the fiber, where its contribution was 78.6% and 91.42% respectively, followed by alumina oxide Nano filler and finally carbon filler. It can be noticed that the sea water will influenced the parameters and their level effects on the composite properties.

**Key word:** composite material, Mechanical properties, Taguchi technique.

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# LIST OF ABBREVIATIONS

ANOM : Analysis of means

ANOVA : Analysis of variance

ASTM : American Society for Testing Material

CMCs : Ceramic Matrix Composites

DOE : Design of experiment

E : Modulus of elasticity

$G_c$ : Impact resistance

GF : Glass Fiber

I.S : Impact Strength

MMCs : Metal Matrix Composites

PMCs : Polymer Matrix Composites

S/N : Signal to noise ratio

$U_c$ : Impact energy

UP : Unsaturated polyester resin

$V_c$ : Volume of composite material

VF : Volume fraction

$V_f$ : Volume of fiber

$W_c$ : Weight fraction of composite material

$W_m$ : Weight fraction of base material

$W_p$ : Weight fraction of reinforcing material

$\rho_c$ : Density of composite material

# 1. INTRODUCTION

## 1.1 GENERAL

Human history has been directly related to the use of materials. This concept is still valid until the present time with a close relationship between the properties of the material and the purpose for which it is used. Often the need for a specific application and in specific circumstances calls for the exploitation of an important feature of the material. At other times, knowledge of a material's properties and behavior prompts its use in a specific application or prompts the development of an appropriate application for this property.

A composite material consists of two or more materials and different physical or chemical properties that result in new properties completely different from the properties of the basic components. To prepare a composite material, two important components should be provided: The matrix material and reinforcing material.

The properties of a composite material are determined by depending on these two elements, as well as the interaction occurring or overlapping between them.

Composite materials are classified into three types, according to the base material contained in the composite material, which are mineral composite materials, ceramic composite materials, and polymeric composite materials.

Polymeric composite materials consisting of polymer as base material, as for polymer, it is a Latin word consisting of two sections, *poly* which means multiple and *mer* which means part, meaning that it means multiple parts [1]. The polymer molecule is a large molecule that consists of small chemical molecules linked together by chemical bonds, or the polymeric molecule may be branched and it is called the branched polymer, and sometimes these branches are intertwined with each other and the polymer is called a cross linked polymer [2].

Polymers can be divided into two categories such as thermoplastic polymer and thermosetting polymer. Where plastic polymers are known as linear molecular chains that are not linked to cross-linking, but there are attractive forces between the chains, which are weak secondary bonding forces called van der Waals Forces, which transform from a solid state to molten material under the influence of heat. Examples include polyethylene, nylon, and polystyrene [2].

As for the thermosetting polymers, they are transformed by the effect of heat from the melted state to a solid that is not melting by the formation of covalent cross-linking [3]. These materials are in liquid form, so they can be poured into any desired shape. Epoxy resins and unsaturated polyester are examples of this type.

Many technological processes require an incorporation of properties that do not exist in metallic, ceramic and polymeric materials alone. These properties can only be achieved by using composite materials [4].

Composite materials have been used in many industries such as aircraft, automotive and marine vessels. Glass fiber reinforced unsaturated polyester has been used in the manufacture of boats and large ships due to its light weight, strength, durability and ease of production.

## 1.2 OBJECTIVE

The main aim of this research is to find the effect of mechanical and physical properties of composite material reinforcement. To achieve this objective, the following steps be required:

A. Selecting the matrix and reinforcement material that (Unsaturated polyester, glass fiber, carbon filler and aluminum oxide nano filler).

B. Manufacturing the test specimen required for tensile test, impact test and absorption.

C. Using the Taguchi method to find the effect of the best parameters on the mechanical properties.

## 1.3 LITERATURE REVIEW

In 1999, Mouritz and Mathys [5], studied the mechanical properties of composite materials used in marine applications, where the changes in the tensile properties of polyester reinforced with glass fiber and vinyl ester and phenolic composites were studied after exposure to heat, where the mechanical properties of the composite material were tested at room temperature once, and the properties were examined. It was found that the tensile resistance of all three composites receded rapidly with the increase in temperature and time due to the deterioration of the base material for the composite material.

In 2009, Muhammed et al. [6], using Taguchi's method in studying the effect of stirring time, stirring speed and volume fraction of reinforce materials on the mechanical and physical properties of the composite material. The preparation of composite materials from Al–Si /$Al_2O_3$. The experimental results showed that the Taguchi method was successful in predicting the parameters that give the best properties of the prepared composite material. Also found the volume fraction is the parameter most influencing tensile strength and hardness of the prepared composite materials.

In 2009, Anaam Wadi [7], studied the mechanical and thermal properties of unsaturated polyesters reinforced with ceramic particles. The composite material consisting of polyesters as a base material reinforced with ceramic alumina material with weight fractions of (5%, 10%, 15%, 20%, 25%). The microscopic photos of the internal structure were taken using the microscope to know the distribution of particles inside the base material. The results of the impact and hardness test showed an increase in impact resistance and hardness with an increase in the weight fraction of the ceramic particles. The thermal conductivity in the composite material reinforced with ceramic alumina particles reached at (20%), reaching (0.319 ° c w / m).

In 2010, Saleh et al. [8], had studied the mechanical and physical properties of polymeric composites reinforced with fibers and fillers. In this research, hybrid polymeric-based materials were manufactured by hand lay-up, and the composite materials were prepared from unsaturated polyester resin as a base material reinforced with glass fibers with volume fraction (10%) and graphite particles as the first group of samples, and the second group of samples are reinforced by Kevlar fibers alternative of glass fibers. The results showed that the value of (tensile stress, compression stress, tensile elastic modulus, fracture toughness, and hardness) increases when the volume fraction increase in graphite particles. Compression elasticity coefficient, bending strength and shear stress are increases at the low volume fractions of the graphite and for both samples of the two groups, while the values of impact resistance decrease when the volume fraction increase in graphite particles and for both samples of the two groups. The results also showed that the values of (tensile stress, tensile elastic modulus, coefficient compression elasticity, impact resistance, and fracture toughness) are higher in hybrid composite materials reinforced with graphite particles and Kevlar fibers than their counterparts in composite materials supported with Kevlar fiber instead of glass fibers.

In 2010, Al-Mousawi and Kazem [9], show the effect of reinforcing with different weight fraction of glass fibers on the mechanical properties of phenyl ester, where composite materials prepared containing phenyl ester as a base material reinforced with glass fibers with different weight fraction and angle (0□), then mechanical tests were performed on the prepared samples. The results showed that the mechanical properties of phenyl ester increased with the increase in the weight fraction of the glass fiber.

In 2011, Anter and Hasan [10], present the influence of water absorption on the mechanical and physical properties of epoxy reinforced with glass fiber. Where epoxy composites are prepared as a base material and reinforced with glass fibers, with a volume fraction of 25%. The samples are immersion in water. Samples were tested before and after immersion in water. The results showed that the hardness decreased with increasing the time of immersion in the water. And the amount of water absorption increases when the time of immersion increase, especially in the first week.

In 2012, Hussain et al. [11], investigate the mechanical properties of polyester material reinforced with chip and copper powder. It was found that the absorbing impact energy required for the occurrence of the fracture of the polyester without reinforcement is a few compared with the copper- reinforced samples of different chip forms and powder, and different weight fractions.

In 2012, Muhannad et al. [12], demonstrate the effect of nanoparticles and micro-additives of silica on the mechanical properties of bending strength and elastic modulus of epoxy, and they found that the strength of durability the elastic modulus increases by increasing the additions ratios to the nanoparticles, then the improvement decreases with the mechanical properties of the composites remaining higher than the mechanical and physical properties of the epoxy material, while the addition of the micro-particles leads to a reduction in the mechanical specifications of the composites with an increase in the elastic modulus of the micro composites.

In 2012, Hamad [13], studied the influence of distilled water on the impact resistance of unsaturated polyester composites reinforced by glass fibers and with a volume ratio of (35%) used an unsaturated polyester resin as a base material that includes synthetic glass fibers with directionality (0,90). Impact tests were performed on samples at laboratory temperature. By

observing the results and the tests of the samples, we found that there is an improvement in the impact resistance of the samples after adding glass fibers to them, and for the purpose of clarifying the effect of water on impact resistance, the samples were immersion in distilled water for a period of (50) days. By observing the results also, we find that the more time the samples are exposed to water, the shock resistance increases as well.

In 2012, Sultan et al. [14], An evaluation study of glass-fiber reinforced polyester and Kevlar by using the Taguchi method, where two types of fiber-reinforced polymeric composite were prepared using three different parameters (treatment temperature, pressure, and the fractional volume of the fiber). The first group was prepared from polyester as a base material reinforced with glass fiber, and the second group was prepared of polyester reinforced with Kevlar fiber, and both contain different volume fractions (4%, 8%, 12%) of the fibers. Tensile strength and impact resistance tests were performed on the prepared samples. The Taguchi method was used to predict the best parameters that give the best tensile resistance and impact resistance. The results showed that the Taguchi method succeeded in improving the parameters that give the best tensile strength and impact resistance. It was also found that the volume ratio has the most effect on tensile strength and impact resistance, and that the composite is reinforced with Kevlar fibers it has the highest tensile strength and impact resistance.

In 2012, Mohammed and Smait [15], investigate the effect of the amount of graphite particles on the mechanical and tribological behavior of the polyester resin reinforced with glass fiber, where samples were prepared from polyester as a base material reinforced with glass fibers, then mechanical tests were done on the samples such as (tensile resistance, elasticity modulus, compression, and wear rate), the results showed that the mechanical and tribological properties increased with an increase in the amount of graphite to its highest value at 7.5% and then decreased with the increase of graphite.

In 2013, Salman [16], studied the tensile strength of hybrid composite materials. Hybrid composite materials containing glass fibers and Kevlar fibers were prepared with specific volume fraction. Tensile testing was performed on samples prepared using a special tensile testing device. From the results it was found that the number of layers and the type of fibers had the greatest influence on the mechanical and physical properties of the prepared samples. It has

been found that the tensile strength increases in the prepared hybrid composite materials, especially for samples that consist of more than one layer and contain two types of fibers.

In 2013, Ikram et al. [17], Studied the mechanical properties of the epoxy reinforced by micro and nanoscale titanium dioxide, and the results showed that the bending strength of an epoxy composite reinforced by nanoscale titanium dioxide increases with the increased weight ratios of the nanoparticles, and this results from the reduction of the distance between the chains and the formation of van der Waals bonds between the chains and the particles, and this conclusion leads to an increase in the restriction between the polymeric chains and the particles and between the polymeric chains themselves.

In 2014, Antar and Hassan [18], demonstrate the mechanical properties of unsaturated polyester reinforced with glass fibers. The volume fraction of the fiber is (25%). The fatigue property of an unsaturated polyester sample reinforced by one, two and three layers of glass and random fibers were studied in the dry and wet conditions. The results showed that the number of fatigue cycles to the limit of failure decreases when the number of fiber layers reinforced glass increase and for all dry samples or submerged samples in water, and the number of cycles in the submerged samples is less than in dry samples.

In 2015, Ali et al. [19], had studied the mechanical and physical properties of composite materials of unsaturated polyester reinforced by glass fibers and filler. The effect of adding fillers, sodium aluminum silicate and talc, was studied on unsaturated polyesters not reinforced by glass fibers, and the results showed that the best values were obtained, when adding a mixture of sodium and talc aluminum silicate according to the ratio (5% Talc, 10% SAS), the value of tensile strength increased 6%, and the value of the elastic modulus also increased 88%, and the value of bending strength also increased 21.8%.

In 2015, Dr. Maysa Shash [20], investigate the mechanical and physical properties of a composite material consisting of unsaturated polyester reinforced with glass fibers randomly. Samples were prepared from composite materials consisting of unsaturated polyester as a base material reinforced with glass fibers with different weight ratios, and some mechanical tests were done on the prepared samples, such as the tensile resistance, hardness and impact resistance test, the study showed that the best results with 40% glass fibers, where the tensile strength increased

by about 70%, the hardness increased by 30%, and the impact resistance also increased by 43%. The study also showed that increasing the percentage of the glass fiber to 60% leads to a decrease in its mechanical properties.

In 2015, Raju B et al. [21], studied the mechanical and physical properties of a composite material of polyester reinforced with glass fiber and ZnO nanoparticles, where the ZnO nanoparticles were mixed with polyester with different weight ratios of (1%, 2%, 4%, 6%). And glass fibers weight ratios of (70/30, 60/40, 50/50). It was found that the mechanical properties improve in the composite material that contains ZnO nanoparticles in weight ratio of 2%, and it was also found that the mechanical properties are better in the composite that contains 50/50 glass fiber.

In 2015, Abdul-Hussein [22], demonstrate the effect of a nano powder on the mechanical and physical properties of the epoxy composite reinforced with glass fibers, and samples were prepared from epoxy reinforced by glass fiber, with a volume fraction of 3%, and (2%, 4%, 6%) volume fraction of nano powder ($Al_2O_3$ aluminum oxide, $SiO_2$ silicon oxide, And $TiO_2$) as a filler. After that, bending tests, strength, density and water absorption tests were done on the prepared samples. The results showed that the non-reinforced composite materials had lower mechanical properties than the composite materials reinforced with nano powder. The measured density results showed increase when the volume fraction increase, and water absorption and stiffness and flexion showed increase when the volume fraction increase.

In 2015, Sihama et al. [23], studied of strengthening the whole set of prosthetic denture, upper and lower, of the type of polymethyl resin, which was prepared and treated as a base material. And they were reinforced with two different types of particles, including hydroxyapatite nanoparticles and zirconia were added with different size fractions (1- 2-3%) and two types of bi-directional fibers are E glass fiber and kevlar fibers type. The composite materials were added with a volumetric fraction (5%), and many mechanical tests were performed such as bending, greater shear stress and impact resistance. The results showed that the values of most of the properties increased with the increase in the volumetric fraction of the hydroxyapatite nanoparticles and zirconia particles, while the impact resistance decreased. And that the zirconia particales and the kevlar fibers gave the highest values of the properties of the composite materials and for all samples used in the preparation except for bending strain.

In 2016, Abdul-Hussein et al. [24], studied the effect of nano powder on a composite material consisting of epoxy reinforced with glass fibers, $Al_2O_3$, $SiO_2$ and $TiO_2$ as nanoparticles were added to the epoxy compound reinforced with glass fibers to improve the mechanical and physical properties. The results found that the hardness and bending strength were increased in the composite material containing $SiO_2$ as compared with the results of tests in other composite materials. The physical properties such as density and water absorption were improved in composites containing $TiO_2$. Because the silica particles are smaller as compared to other materials used.

In 2016, Muhammad [25], investigate the mechanical properties of composite materials under the influence of different parameters. The experimental plan was designed by using the Taguchi method. The most influential parameters on mechanical properties were found by S / N ratio and ANOVA analysis. The results showed that the practical and expected results are very convergent. It was found that the type of fiber most influenced the mechanical properties, followed by the filler, followed by the volume fraction of the fiber. And he found the best parameter components are ((glass fiber + carbon fiber), 7.5% graphite, 30% fiber volume fraction) in terms of good mechanical properties.

In 2016, Hashim et al. [26], investigate the mechanical and physical properties of polyester composite with multiple layers. A composite material consisting of unsaturated polyester was prepared as a base material reinforced with Kevlar fibers in a different number of layers, the glass fiber is added by replacing one of the Kevlar layers with a layer of glass fiber, the mechanical properties of the prepared samples were tested (tensile strength test, impact resistance test, and optical microscope test). The test results showed that the samples prepared from polyester reinforced with Kevlar fibers, that the mechanical properties (tensile resistance, elasticity modulus, impact resistance, and hardness) increase with the increase in the number of layers. And it was found that the mechanical and physical properties of samples that contain three layers reinforced with Kevlar fiber are higher than samples in which one of the layers of Kevlar fiber was replaced with glass fiber.

In 2016, A. Gnanavelbabu et al. [27], studied the effect of mechanical reinforcement with different shapes and the different orientation of glass fibers on polymeric composites material, where a composite material containing polyester reinforced with glass fiber was prepared, and

the glass fibers are various shapes such as Chopped Strand Mat (CSM 450), Woven Roving Mat (WRM 610) and Combinational Mat (COMBO MAT 910), this composite material is widely used in marine applications, and the composite material is prepared from polyester and glass fibers with different volume fractions (60% - 40%, 50% - 50%). , 40% - 60%), and the composite material was prepared by hand casting and processed in a furnace at a temperature of 80 °C, and the hardness test, tensile test, bending test and water absorption test were carried out in the samples. And it was found that the best sample in terms of mechanical properties is the sample that contains glass fibers in the form of COMBO MAT 910.

In 2017, Hamid [28], studied the effect of the bending resistance of a polymeric material and another reinforced with fibers, by conducting the three-point and four-point bending tests with a volume fraction of (20%) of the fiber. The epoxy was reinforced with glass fibers. The tests were done at room temperature, and the test results showed that epoxy reinforced with glass fibers has a higher bending strength than that of pure epoxy, as well as the least strain. In a four-point test, it was found that the strength required for failure of the sample of pure epoxy was higher than that required for the failure of the sample subjected to the three-point test.

In 2017, Sanjay and Yogesha [29], studied hybrid polymer composite materials reinforced with natural glass fibers, and hybridization of natural glass fiber reinforced polymer composite material was developed for use in engineering and technology. In this research was studied the recent developments of hybrid polymer composites reinforced with natural fibers made by manual molding and compression techniques. This study aims to understand and study the reasons that lead to the results presented regarding the incorporation of natural fibers with polymeric composites reinforced with glass fibers. Where emphasis was placed on the physical and mechanical properties of hybrid composites, previous relevant studies were cited. And he found that hybrid composites made from two different types of natural fibers with glass fibers were less prevalent compared to natural glass fibers.

In 2018, Muhammad et al. [30], demonstrate the effect of adding aluminum powder on the bending and combustion properties of the unsaturated polyester polymer, where aluminum powder was added as fillers with weight ratios (0.5%, 0.8%, 1%, 1.5%, 2%, 2.5%). The results showed that the maximum bending resistance of the polymeric material reinforced with aluminum powder is 140 MPa at the weight ratio of 0.8%. After which the bending strength

values decrease when the percentage of the additive is increased until it reaches its lowest value at the weight ratio of 2.5%, which is 84.3 MPa, and because the behavior of the polymeric composite material the rate of burning time begins with a strong effect at the ratio of 0.5%, as its value reaches 168 Sec, after which it begins to decrease when the weight percentage of the additive increases and then increases until it reaches the maximum value at the ratio is 2.5%, as its value reaches Sec 195, and this behavior is anomalous at the weight ratio of 1%.

In 2019, Mohammed et al. [31], by studying the effect of independent factors such as filler (3%, 6%, 9%, 11% fraction weight), normal load (5N, 10N, 15N), and time sliding (5,7, 9 min) on the corrosion behavior of unsaturated polyester resin it is reinforced with jute fiber, eggshell, and rice husk powder. Samples were prepared consisting of unsaturated polyester as a base material reinforced with jute fiber by weight (4%), eggshell powder by weight (3%, 6%, 9%, 11%), and rice husk powder, the samples were prepared using the method taguchi method. The results showed that 11% by weight of eggshell, rice husk and 4% jute fiber improves the wear resistance of unsaturated polyester composite materials significantly. It was found that filler is the main factor affecting the wear rate followed by sliding time and normal load.

In 2019, Guobys et al. [32], studied cavitation erosion in the polymeric composite materials reinforced by glass fiber, due to the increasing use of polymeric composites in marine applications where they are exposed to severe environmental effects, one of which is cavitation. This study investigates the behavior of unidirectional GFRP compounds subject to cavitation erosion. The results of the research indicated that the denudation process was affected by several parameters including sample thickness, distance between fiber bundles and bundle shape.

In 2020, Kumar et al. [33], studied the mechanical and physical properties a composite material consisting of epoxy reinforced with glass fibers and cellulose nanocrystals (CNC). The results showed that the mechanical and physical properties were significantly improved, as the addition of 2% of the nanocrystals of cellulose led to a 50% increase in the bending modulus, 14% in the tensile modulus, 24% in tensile strength.

## 1.4 CONCLUDING REMARKS

There are many researchers who have used unsaturated polyester as a base material and reinforced by glass fiber and filler materials. And they studied the influence of glass fibers and

fillers on the mechanical and physical properties, and it was noticed that the mechanical and physical properties of the prepared samples increased sometimes and sometimes decreased according to the mixing ratios.

While others studied the influence of nano powder on the mechanical and physical properties of epoxy composite reinforced with glass fibers, samples were prepared from epoxy as base material reinforced with glass fiber, and nano powder ($Al_2O_3$ aluminum oxide, $SiO_2$ silicon oxide, and $TiO_2$ titanium oxide) as filler. After that, the bending test, strength, density and water absorption tests were done on the prepared samples. The results showed that the non-reinforced composite materials had lower mechanical properties than the composite materials reinforced with nano powder.

In this research, the effect of the direction of the glass fiber (0/0, 0/90, 45/45) and the volume fraction of carbon filler (2.5%, 5%, 7.5%) and aluminum oxide nano filler (0%, 1%, 3%) was studied on the mechanical and physical properties of composite materials that consist of unsaturated polyesters as a base material and Taguchi's theory was used to obtain the optimum composition.

# 2. THEORETICAL ASPECTS

## 2.1 INTRODUCTION

Composite materials appeared as a result of industrial and technical development and due to the need for new materials that have special properties which is used as a substitute for other materials. Therefore, composite materials have an advanced position in various industries since their first discovery, and as the main type in the group of composite materials, they possess the base materials the polymeric is of particular importance in many industries depending on the mechanical and physical properties of the polymer base and reinforcing material [34].

## 2.2 POLYMERS

They are organic materials composed of long molecules consisting of repetition of one type or several types of small units called the monomer, which represents the basic unit for building the polymer. These small units combine with each other to form multiple forms of the large molecule, so they are linear, branched, or tangled in each other, and they may have similar or different units in composition [35,36]. Polymeric industries depend mainly on petrochemicals, and these materials are modified into a more useful material. This modification is represented by the production of polymers used in the industry such as polyethylene, polypropylene and other polymeric materials [37,38]. Compared to metals and alloys, polymers possess lower density and lower durability. It is not solid, has low thermal conductivity and has a much higher thermal expansion coefficient than metals. Polymers also have high electrical insulation capacity with resistance to most acids and basicity, but at the same time they suffer from deterioration in properties when exposed to the atmosphere as well as to sunlight, as this leads to breakage of bonds secondary is slow and becomes more fragile, and this effect can be controlled with use some additives [38].

Polymers are important materials for use in many industrial applications, and the reason is due to [39,40]:

A. Easy to mold, even for complex parts. It also does not require subsequent treatments.

B. Polymers are very important for applications that do not require very high mechanical resistance because of their advantages of low density, high specificity and high resistance to corrosion.

C. It requires less energy for manufacturing compared to other engineering materials, as it is originally formed at low temperatures.

D. Some types are transparent, so it is used as an alternative to glass in some applications.

E. It has a lower cost than other engineering materials and is widely available.

F. Do not react chemically with the mold.

G. Low moisture absorption.

H. Good electrical qualities.

Despite all these advantages, it suffers from some disadvantages and limitations in its uses, the most important of which are [39]:

A. It has less mechanical resistance than other engineering materials.

B. It has low creep resistance.

C. Low elastic modulus.

D. Low durability.

E. Low thermal resistance.

## 2.3 COMPOSITE MATERIALS

They are the solid systems resulting from the participation of two or more substances, so that each material represents a separate phase in the system, and its purpose is to obtain new materials with appropriate properties that combine the properties of the raw materials involved in the preparation of the composite material and exceed the undesirable properties to be more suitable for industrial applications. That the composite material consists of [41]:

A. Matrix material.

B. Reinforcement materials.

Therefore, the composite material can be defined as a link between two or more substances to form a new substance that has better qualities and differs from its original components [42].

### 2.3.1 Matrix Material

The basic material is one of the components of the composite material and its basic function is [43,44]:

A. Link reinforcement material.

B. You transfer the load to the reinforcement material.

C. Preserving the reinforcement materials from weather conditions, temperature changes, oxidation and corrosion.

The choice of the base material may be based on improving electrical or thermal properties, or for ease of formation.

The base material is often characterized by being low in density and with low hardness and resistance compared to the reinforcement materials [42].

### 2.3.2 Reinforcement Materials

They are the materials that work to strengthen the base material, and they may be ceramic, metallic, or polymeric materials and are generally characterized by high resistance, while their ductility is different, they may be high or low depending on the type of material and the purpose for which it is used, and it is classified depending on the shape and dimension to Fibers, Particles, Flakes, or in the form of a network of materials [45,46], as shown in Figure 2.1.

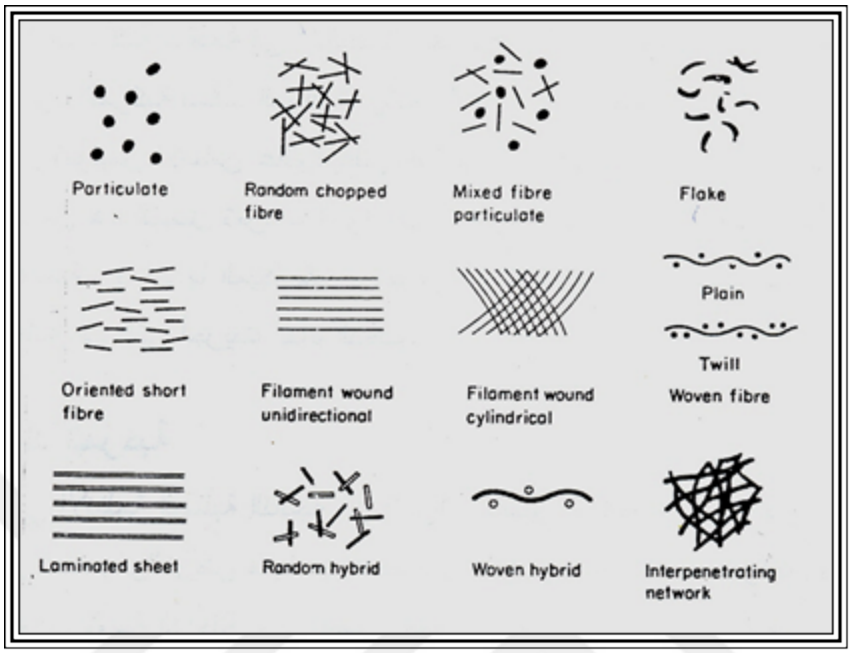



**Figure 2.1:** The different forms of mono and hybrid reinforcement materials [46].

Depending on the shape of the reinforcement materials, they were classified into three categories as follows:

### 2.3.2.1 Particulate reinforcement

The materials for this type of strengthening can be classified into two main types according to the particle size:

**Composite materials reinforced by dispersion**

Reinforcement materials in this type are small particles whose size does not exceed (0.1 μm). They work to strengthen the base material by impeding the movement of dislocations during the plastic deformation process [47,48], and the percentage of weight fractions in them ranges between (1- 15%). This type of reinforcement is used in the manufacture of pistons and connecting rods [49].

**Composite materials reinforced by particles**

They are particle composite materials, but they differ from the composite materials reinforced by dispersion in the particles size, which is always bigger than (1 μm) and the percentage of weight ratio in them may reach (90%) in the highly additive composite materials, Figure 2.2 illustrates some forms the particles and their distribution [41,47].

The strengthening occurs when the particles act as obstacles to deforming the base material due to their high hardness and non-distortion during loading. They are of several types and shapes, such as the spherical, needle and filamentous, as the particles increase the hardness and the impact strength of the base material. [49], and Figure 2.3 shows the reinforcement by particles [50].

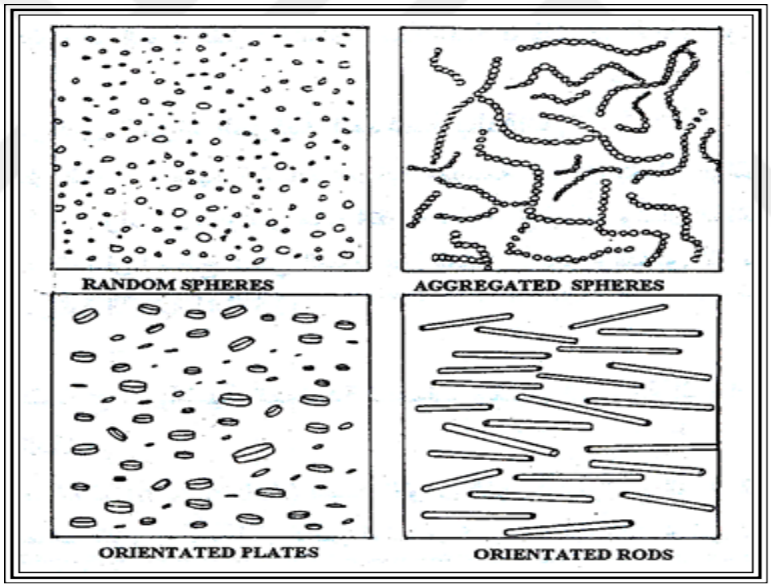



**Figure 2.2:** Different types of particle reinforcement materials [50].

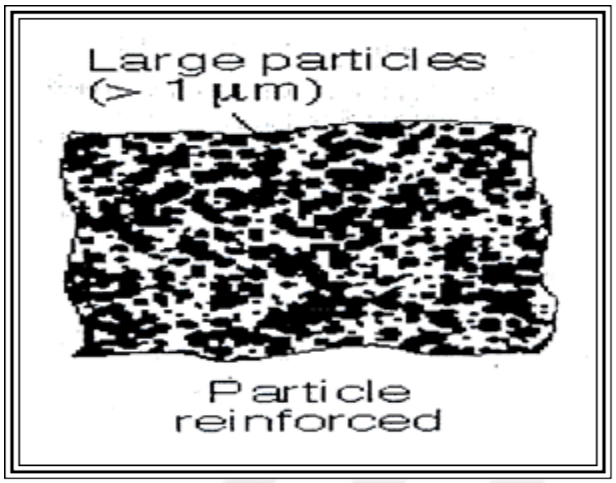



**Figure 2.3:** shows the reinforcement by particles [50].

The mechanical and physical properties of the particle-reinforced composite material are affected by several factors, some of which are related to the properties of the base material and others to the properties of the reinforcing material such as the type, size, shape of the particles and their distribution within the base material, and the bonding force between the base material and the particles has a great influence on the composite material properties [51,52]. This type of reinforcement is used in the manufacture of cutting tools head [49].

### 2.3.2.2 Reinforcement Fibers

The fiber has a great role in improving the mechanical properties in general and in increasing the tensile strength in particular, and the reason is due to the fibers bearing the bulk of the external impacted load because of their high resistance, while the base material will transfer the stress and its delivery to the fibers. The properties of the composite material reinforced by fibers depend on the properties of the fiber itself, such as the diameter and length of the fiber, the volume fraction (*Vf*) and the arrangement of the fiber, as the fibers may be continuous (long) or short (cut) and randomly distributed or directed in a specific direction. Fiber-reinforced composite materials have directional properties, so the direction of stress effect relative to the direction of fiber arrangement is an important factor affecting the properties.

The fiber material may be ceramic such as (glass fibers or silicon carbide) and it may be polymeric, such as Kevlar fibers, or as for metallic fibers they are used in the form of wires such as steel or copper wire [45].

### 2.3.2.3 Laminates Reinforcing

The laminate composite material consists of phases arranged according to a geometric layout designed according to its goal, for example in the form of an alternating series of layers or in the form of another pattern called a sandwich, where these materials can give a significant improvement and difference in the resulting properties compared to the properties of their internal phases and may the single layer contains the same components as the other layer, as it may be completely different [45].

## 2.4 RULE OF MIXTURE

The mixing rule can predict the properties of the composite materials reinforced with (particles, fibers, or laminates) depending on the volume fraction or weight fraction and the properties of the materials used in the manufacture of the composite materials [53].

The density can be calculated by the following law:

$$_{c} \quad V_{i}.\ _{i} \quad V_{1}.\ _{1} \quad V_{2}.\ _{2} \ \ldots\ldots\ldots\ldots \quad V_{n}.\ _{n} \qquad 2.1$$

Whereas:

$\rho_c$: Composite material density.

$\rho_1$, $\rho_2$, $\rho_n$ : Component density.

$V_1$, $V_2$, $V_n$ : Volume fraction of each component.

The weight fraction for each of the reinforcing material and the base material is calculated as follows:

$$V_p = \frac{vp}{vc} \times 100\% \qquad 2.2$$

$$V_m = \frac{vm}{vc} \times 100\% \qquad 2.3$$

Whereas:

$V_p$, $V_m$ : Volume fraction of both the reinforcing material and base material.

$v_c$ , $v_m$ , $v_p$ : The volume of the composite material, the base material, and the reinforcing material.

$$V_p \quad \frac{^{c}}{_{p}} W_p\% \quad 100\% \tag{2.4}$$

$$V_m \quad \frac{^{c}}{_{m}} W_m\% \quad 100\% \tag{2.5}$$

Whereas:

$_m$, $_p$, $_c$ : Density of each base material, reinforcing material, and composite material.

$W_m$, $W_p$ : Weight fraction of both the base material and the reinforcing material.

$$W_p \quad \frac{w_p}{w_c} \quad 100\% \tag{2.6}$$

$$W_m \quad \frac{w_m}{w_c} \quad 100\% \tag{2.7}$$

Whereas:

$w_c$, $w_m$, $w_p$ : The composite material weight, the base material, and the reinforcing material.

$$W_p \quad W_m \quad 1 \tag{2.8}$$

$$V_p \quad V_m \quad 1 \tag{2.9}$$

The mathematical relationship between the components of the composite material reinforced in particles for any characteristic under study will depend on the volume fraction or the weight fraction of the phases formed the composite material in addition to the values of that characteristic for each component separately. Researchers in this field have concluded that there is an upper bound and a lower bound for the values of each characteristic shown in Figure 2.4,

which represents the reinforced in tungsten particles, whose values are represented by the two relationships (2.10) and (2.11) respectively [49].

$$E_{c=}E_mV_m+E_pV_p \qquad 2.10$$

$$E_c \quad \frac{E_m E_p}{V_m E_p \quad V_p . E_m} \qquad 2.11$$

Whereas:

*E*: Modulus of elasticity.

*V*: Volume fraction.

*c*, *m*, *p*: Represents the composite material the base and the particles, respectively.

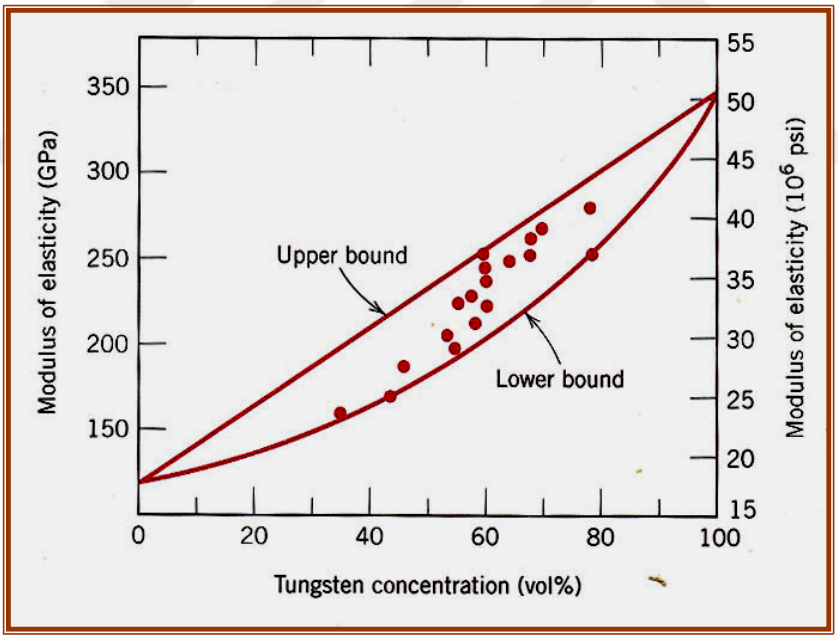



**Figure 2.4:** Represents the reinforcing in tungsten particles and its effect on elastic modulus [49].

## 2.5 THE COMPOSITE MATERIALS REINFORCED WITH PARTICLES

The mechanical behavior of the composite materials reinforced with particles results from the interaction or the mutual influence of the properties of the materials that make up the composite material, represented by [54]:

A. Base material.

B. Reinforcing material.

As for the resistance and durability of the composite material reinforced with particles, it depends on several variables [54]:

A. Volume fraction of particles.

B. The size of the particles.

C. Modulus of elasticity and durability of particles.

D. The aspect ratio of particles.

E. Correlation between base material and particles.

F. The durability of the base material.

### 2.5.1 Volume Fraction of Particles

The change in the volume fraction leads to the improvement of the mechanical properties of the particle compositions as both the resistance to bending, tensile strength and hardness as well as the elasticity depend on the volume fraction of the reinforcing material, and the content of the optimal reinforcing material depends on [55]:

A. The location of the use of the composite material.

B. The desired characteristics of the product.

C. The size of the particles.

D. The type of surface treatment.

That in most experimental systems, the maximum volume fraction of the reinforcement material is (50%), which mixes to avoid the presence of gaps. As for volume fractions of low to the extent (30%) precipitation occurs. Therefore, in order to produce a homogeneous cast, the mold must be rotated, or Pour the mixture before it becomes gelatinous [54].

### 2.5.2 Particles Size

The change in the size of the reinforcing particles at a fixed volume fraction does not have a clear and important influence on the modulus of elastic in the composite material. The researchers in the report [56] used glass balls with two diameters (4.5, 62 μm). They found that the modulus of elasticity increases a little for the composite material which contain particles with a diameter (4.5 μm), but in experiments on resin reinforced with silica particles with a size of (60, 300 μm), it appeared that there is no appreciable or perceptible change in relation to the modulus of elasticity or stress tensile factor at a fixed volume fraction.

In general, small particles give high and important mechanical properties, while large particles lead to lower properties.

### 2.5.3 Modulus and Strength of Particles

The particle phase may cause an increase or decrease in the elasticity modulus of the composite material, depending on the modulus of elasticity for particles, being lower or higher than the elasticity modulus of the base material [57], and when increasing the modulus of elasticity for particles, this causes an increase in the modulus of elasticity of the resulting composite material, but if it is used weak particles such as micro-spherical particles as in the case of silica and dolomite particles, the strength of the resulting material is not obtained, meaning that these particles will causes a decrease in the strength of the cast because it represents a source of defects or cracks, so when choosing the reinforcement material it must be of the same Sufficient durability to be effective in the composite material [54].

### 2.5.4 Resin – Filler Adhesion

The resistivity properties of the composite material reinforced in particles depend to a large extent on the adhesion and contact of the interface between the two materials [58], as the bonding between the reinforcing material and the base material is the main factor in determining the mechanical behavior of the composite material during loading [59].

The interface can be defined as the connecting surface between the reinforcing material and the base material, as there is a kind of instability in the mechanical, physical and chemical properties, and the instability means the presence of a difference in the crystalline structure, elastic modulus, density, thermal expansion coefficient from one side to the other [60]. The

mechanism for transferring strength from the base material to the reinforcing material is the basic principle for reinforcing the base material with materials with a high modulus of elasticity and resistance depending mainly on the strength of the bonding between the resin and the particles and the lack of this bonding will lead to the non-transfer of strength, thus the reinforcing materials in this case act as gaps within the base material [43], that the properties of the interface and how it behaves depends on the ability of the base material to wet the reinforcement material (in the event that the base material is liquid during the manufacture of the composite material). This property is called wettability and can be defined as the diffusion of a liquid on a solid surface. Increasing this property between the matrix and the reinforcing material provides an increase in the interface contact area between these two materials through which the force is transferred [60,61].

### 2.5.5 Matrix Toughness

The durability of the base material has a great effect on the properties of the composite material and for all types of reinforcing because it binds the reinforcement material. In addition, in the case that a load is placed on the composite material, it deforms and distributes the stresses on the reinforcement material [43].

The durability of the base material also has an important influence on the durability of the particles-composite material through several mechanisms, the most important of which are: crack bowing, separation between the matrix and the particles, and the occurrence of micro-cracking [62].

## 2.6 FIBER

### 2.6.1 Glass Fiber

Glass fiber is one of the most common materials used to reinforced resins in general, because these fibers are easy to manufacture and have good mechanical and physical properties and low costs.

Glass fibers are made by mixing the glass and dry components of silica, limestone, Boric Acid, and some materials such as clay. Long, thin glass fibers are obtained on a fast-moving roller, Rotation pulley whenever the diameter of the fiber glass product is less, so that A fiber can be

produced with a diameter of about 2 microns using a rotation speed of 500-300 m/s [63]. It is then cooled and spun to obtain the final forms of glass fibers. Chemical surfaces of these fibers are usually chemically treated to be bonded with resinous materials They are treated with chemicals called linking coefficients [64].

#### 2.6.1.1 Glass fiber properties

A. Glass fiber characterized a high durability and when added to the middle of the plastic will produce a composite material with high resistance.

B. It does not burn and does not help combustion due to its chemical nature and has a high melting point.

C. It does not absorb liquids and therefore does not experience stretching.

D. Glass fiber has low coefficient of expansion and low thermal conductivity.

E. Glass fiber is not a conductor of electricity, so it is considered an insulating material [65].

#### 2.6.1.2 Glass fiber types

Fiberglass is manufactured in different types, each with different and distinct properties. And the basic oxide of all kinds is silica, $SiO_2$. Other oxides are added according to the required properties of glass fibers and the most important types of glass fibers [66]: -

A. Glass fiber type E

B. Glass fiber type C

C. Glass fiber type S

Glass fiber E-symbol for electrical properties, E-glass is the most widely used form due to its ease of manufacture, high durability, hardness and electrical insulating and weather-resistant properties.

**Table 2.1:** The most important types of glass fibers and their chemical composition [67].

| | E glass | C glass | S glass |
|---|---|---|---|
| $SiO_2$ | 52.4 | 64.4 | 64.4 |
| $Al_2O_3.Fe_2O_3$ | 14.4 | 4.1 | 25.0 |
| CaO | 17.2 | 13 | - |
| MgO | 4.6 | 3.3 | 10.3 |
| $Na_2O.K_2O$ | 0.8 | 9.6 | 0.3 |
| $Ba_2O_3$ | 10.6 | 4.7 | - |
| BaO | - | 0.9 | - |

### 2.6.2 Effect Fiber on the Composite Behavior

#### 2.6.2.1 Direction of fiber

The following figure shows the influence of fiber direction on tensile strength, where different tensile strength values are observed with angle difference between fibers (tensile direction) [68,69].

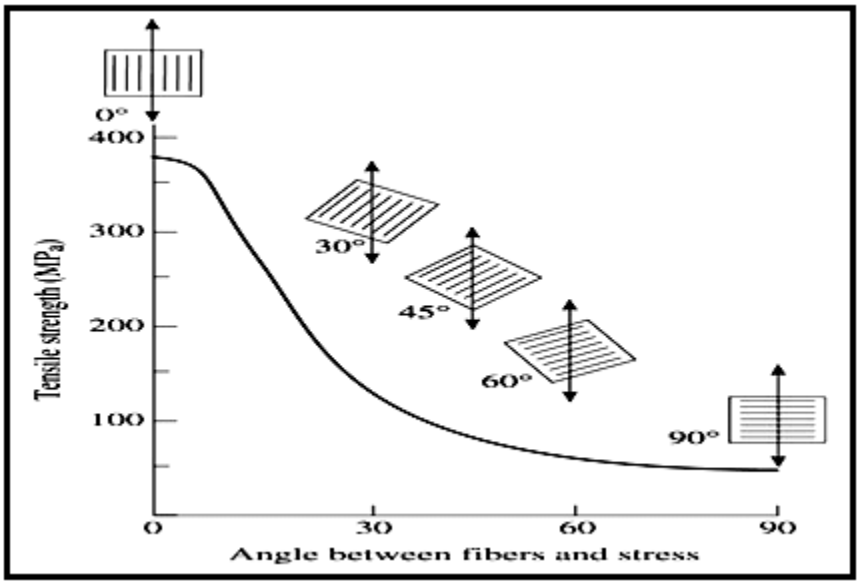


**Figure 2.5:** The effect of fiber orientation on the tensile strength of a composite polymer-reinforced material with continuous fibers [69].

### 2.6.2.2 Length of the fiber

The mechanical and physical properties of composite materials reinforced by the fiber also depend on the amount of load transfer from the matrix to the fiber. [70] When the composite material reinforced with short fibers is subjected to tensile stress, the short fibers in the base matrix will suffer tension due to shear stress at the interface Which operate on the fiber surfaces and these shear stresses are of big value at the fiber ends that are experiencing bigger tension. The value of the shear stresses begins to decline as we approach the middle of the fiber. The tensile stresses in the fibers are zero at the ends and begin to increase with decreasing shear stress as shown in Fig. 2.6 [71].

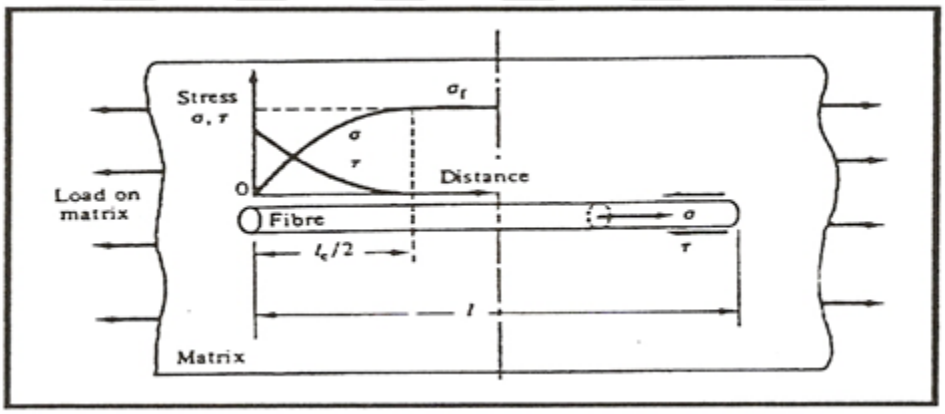



**Figure 2.6:** shows the distribution of tensile stress and shear stress to the surface along the short fibrous surface in the base material [71].

### 2.6.2.3 Geometric shape and cross sectional area

The properties of the geometric shape of the fiber are related to the form and cross section area, where they can be circular, pyramidal, flat or square. Figure 2.7 shows different forms of the cross-sectional area of the fibers, where they can be circular, square or triangular.

The ring or cylindrical fiber called Dumbbell is the shape of the preferred cross-sectional area [72].

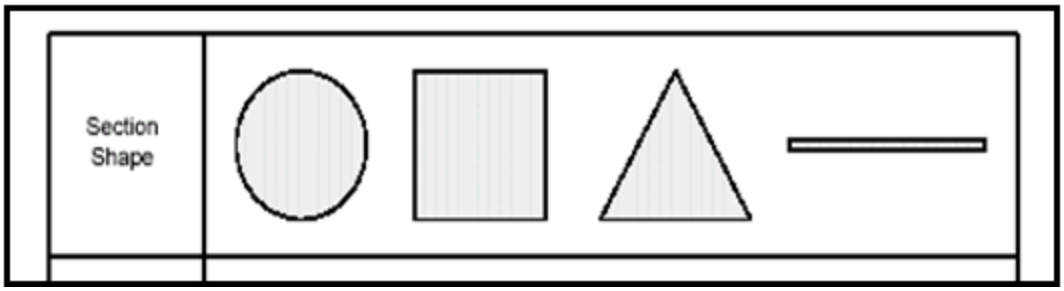



**Figure 2.7:** shows the different shapes of cross-sectional area of fibers [72].

### 2.6.2.4 Volume fraction (Vf)

Volume fraction influences the mechanical and physical properties of the composite materials [73]. When the volume fraction is increased, the tensile strength increases and continues to increase to a reach to a peak value and then starts to reduce as a result of the low resin efficiency to absorb the fiber. The amount of fiber in the composite material is known as volume fraction (*Vf*), where the ratio between the volume of fibers (*Vf*) and the volume of composite material (*Vc*) [69]:

$$Vf = \frac{\mathrm{Vf}}{\mathrm{Vc}} \qquad 2.12$$

Where (*Vf*): the volume fraction of fiber, (*vf*) and the volume of fiber and (*vc*) the size of composite material.

### 2.6.2.5 The link between the fiber and the matrix

The perfect conditions for composite material applications are to be reinforced with continuous fibers, which results in a strong bond between the fibers and the matrix. This is necessary for the transfer of pregnancy from the base material to the fiber. Without this interconnection, the composite material system does not function [68].

### 2.6.2.6 Properties of the base material

Base material should be strong, durable and ductile, to transfer the load to the fibers and prevent the growth of the cracking during the composite material [69].

## 2.7 RESINS

They are complex polymers that are amorphous organic materials, which may be natural or synthetic, consisting of small molecules called monomers. Large numbers of these molecules are linked chemically to form polymeric chains that are arranged in amorphous form when solidified, and are divided into two parts [74]:

### 2.7.1 Thermoplastic Resin

They are a little branched polymer that can be easily converted into a plastic dough easy to form or liquid according to the temperature used without change in their chemical properties or composition and when cooling they harden easily and this type of polymer changes its shape due to the effect of the impacted load due to the sliding of the particles on each other due to the weakness of the bonds between its molecules (van der Waals), such as polyethylene, polypropylene, vinyl [75,76].

### 2.7.2 Thermosetting Resin

They are materials that cannot be reformulated with heat, and a chemical change occurs in their composition upon heating and pressure. Its molecules are bound by a strong covalent bond, for example, polyester, epoxy, phenol [75,77].

## 2.8 POLYESTER RESIN

Polyester resins are the most preferred system in the work due to their low cost, high properties, and rapid operation rates. Polyester reactions are one of the heat-emitting reactions so this temperature must be overcome and controlled during the forming process. The high temperature exceeding the limit is critical and leads to cracks. It is caused by thermal stress in the final product and affects the mechanical properties to some extent, as well as the physical and electrical properties.

Good electrical and physical properties are among the most important features of polyester, and this material, in addition to the above, is distinguished by good stability in dimensions, resistance to corrosion and resistance to the influences of light and severe weather conditions. Also, the development of this material made it possible to form products of indefinite sizes at an

economical price, which was not possible in the past, But polyester resins are not suitable for use alone because they are not strong and do not have high hardness, but by introducing them in groups with the material, some of the reinforcements have good properties that make them suitable for use and have high bearing capacity [78].

Polyester resins have the advantage of being luminous in color as well as being transparent, solid, and resistant to water and chemicals. They are used up to 790 °C or more depending on the reinforcing particles and they shrink in size between (4-8%). In addition, polyester resin is characterized by high electrical insulation, so it is used in many industries such as the manufacture of various plastics, the manufacture of films, the preparation of some types of protective coatings and in the manufacture of insulators, and as a composite material in the manufacture of structures for small boats, planes, structures and bridges [79, 80,81].

## 2.9 POLYESTER RESIN TYPES

Polyester resins can be divided into two types, which are [82]:

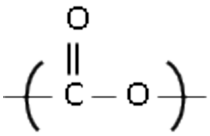
### 2.9.1 Saturated Polyester Resin

They are those materials prepared from multi-active monomers so that the crosslinking process occurs during the multi-esterification reaction, and this type is called (saturated cross-linked polyesters) and is used in the manufacture of fibers and films (82).

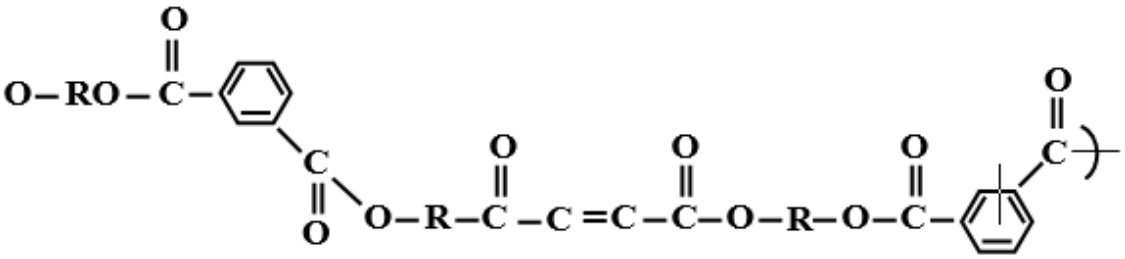
### 2.9.2 Unsaturated Polyester Resin

They are those materials that undergo a crosslinking process by an additional independent polymerization reaction through the double active bonds present in the main structure of the polyester, and this type is known as unsaturated polyesters [82].

Unsaturated polyester resins consist of polymeric chains, these chains are dissolved in effective organic solvents, and suitable accelerators and auxiliaries are added to the resin (polyester) when it is in the liquid state in order for a chemical reaction to occur in the cold state without pressure and then a solid composition is formed in dimensions three. In addition to the above, polyester resins can be defined as synthetic polymers in which the repeating units of the molecular chain are of the ester type and their chemical formula [83]:



The polyester resin is prepared from the reaction of its raw materials (saturated and unsaturated dibasic acid) with dihydroxyl alcohol (glycol) and by displacing the water between the acid and glycol, so the ester will bind in a cyclic form and the result will be a long chain of molecules containing alternating units of acid and glycol as in the following chemical equation:



After the completion of the reaction and the addition of the monomer or solvent that represents the crosslinking agent such as (styrene) with the appropriate inhibitor the mixture is cooled to room temperature and the added Styrene content ranges from (30-40%) [82].

## 2.10 APPLICATIONS OF UNSATURATED POLYESTER RESINS

Unsaturated polyesters are used in many general fields such as the building materials industry, marine ships, electrical materials, industrial materials, transportation, as well as the medical materials industry. In the field of construction, it is used for roofing slats, air conditioning ducts, partitions, window and door frames, swimming pools, as well as waterproof cladding.

As for furniture, it is used for the manufacture of decorative and decoration panels, furniture parts, frames, school desks, blackboards, the interior parts of the cars, semi-transparent windows and statues.

They are used in the manufacture of pleasure boats, fish preservation boxes, fishing boats, containers, car bodies, inner linings of subway cars, caravans, propeller blades, radar screens, racing car drivers' helmets, parts of aircraft and helicopter bodies, electrical insulators, industrial tanks, and fishing rods. Fish and its various tools [84].

## 2.11 CLASSIFICATION OF COMPOSITE MATERIAL

Most of the composite materials developed to date have been specifically designed to improve mechanical properties such as strength, toughness, and use at high temperature, and the ownership of composite materials for a specific property is due to the nature of the material or the type of reinforcement and therefore the composite materials can be classified according to the nature of the base material or the type of reinforcement used [85].

A. Metal Matrix Composite (MMCs).

B. Ceramic Matrix Composite (CMCs).

C. Polymer Matrix Composite (PMCs).

Is one of the common composite materials where polymer is a base material containing fiber (the reinforced material) that can be made of glass or carbon.

Either the base material can be thermostat, thromboplastic, elastomer.

These materials are considered of the best types because they have high mechanical and physical properties commensurate with their density and ease of manufacture [85]

Polymer composite materials are among the most widely used types of materials. It has been used in many industries such as the manufacture of molds and aircraft parts due to its light weight and durability which has led to ideal materials of low cost and low energy consumption. As a result, resins have gained wide popularity as a modern material entering many industries. [86,87]

Polymer composites contain excellent properties at room temperature and at low cost. The base material contains various thermally rigid polymers, and later thermoplastic polymers reinforced by fiberglass, carbon, boron, organic fiber and polymeric base material are often reinforced by fibers due to its properties and features Different from other reinforcing materials.

Because polymers are characterized by low density but lack strength and durability, so some other components are added to the homogeneous polymer and the formation of polymers

composite in order to change some of its properties and the introduction of new qualities, including [85].

A. Increase polymer stiffness, strength and dimension stability.

B. Increase the shock resistance of the polymer.

C. Improved tensile and elasticity.

D. Increase the distortion temperature.

E. Reduce polymer permeability to gases and liquids.

F. Reduce the cost of polymer.

Finally, the reason for the increase of polymer-containing composites is due to several reasons, the most important of which are:

A. It can be shaped into different shapes and sizes.

B. Do not rust and corrode.

C. It has good resistance to chemical solutions and moisture.

D. Light weight and high durability.

E. It is considered one of the electrical insulating materials.

The characteristics of the polymer-based composites are determined by the characteristics of polymer additives, the nature of their minutes, the nature of the overlap between the polymer and the additives, and the weighted proportion of additives that play a large role in determining the mechanical properties of polymeric composite materials.

## 2.12 MECHANICAL PROPERTIES

The choice of materials is often based on the material's mechanical properties, which means the behavior of engineering materials under the influence of forces and loads and under various conditions, and the mechanical properties of resistance, stiffness, hardness, and susceptibility to deformation.

The general and engineering uses of polymers depend to a large extent on their good mechanical properties, especially their relatively high strength and their ability to deform by the effect of stresses. This duality in the properties of the polymer arises from the nature of its composition, since the presence of two types of forces, chemical bonds and secondary bonds between molecules that affect one way or another on its mechanical properties [88,89].

### 2.12.1 Tensile Test

The tensile test is widely used to provide the designer with information about the resistance of the material and the maximum elongation and other engineering information. The tensile test of a sample is performed by applying a continuous increasing axial force with a successive instantaneous observation of the elongation in the sample, and then creating the geometric curve between stress and strain which is derived from the values of the impacted load and the amount of elongation obtained. Figure 2.8 shows the stress - strain that occurs in polymeric materials [45].

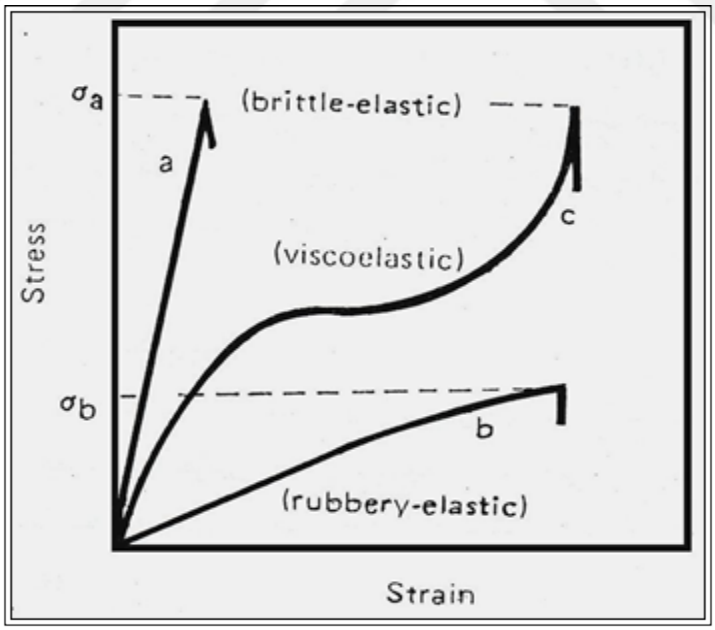



**Figure 2.8:** General strain-strain diagram of polymers [45].

The stress that is used in such a curve is the average longitudinal stress in the tensile sample, which is obtained by dividing the load by the original cross - sectional area of the sample.

$$\sigma = \frac{P}{A} \qquad 2.13$$

whereas:

$\sigma$: the mean longitudinal stress of the sample (MPa.).

$P$: Impressive load (N).

$A$: The cross-sectional area of the original sample prior to testing ($m^2$).

The strain used in the geometric (stress - strain) curve is the linear strain rate, which is obtained by dividing the elongation obtained for the sample by the original length of the sample, as in the following equation:

$$\varepsilon = \frac{\delta}{L_O} \qquad 2.14$$

whereas:

$\varepsilon$: Strain.

$\delta$: the elongation in the model (m).

$L_0$: original length (m).

And that ($\delta$) is equal to the difference between the terminal length ($L$) and the original length ($L_o$)

$$L \quad L_o \qquad 2.15$$

The shape and values of the stress-strain curve depend on several factors such as temperature, strain rate, and stress position during the test. The values extracted from the (stress - strain) curve are:

A. Tensile Strength.

B. Yield strength.

C. Modulus of elasticity.

D. Poisson ratio

E. Percentage of elongation.

F. The amount of decrease in area.

The two values (1,2) represent resistance formulas, while the two values (5,6) represent ductility. The general shape of the Engineering Stress - Strain Curve for polymeric materials, represented in Figure 2.8, consisting of a straight line at the beginning, which represents the elastic region, at which the stress is proportional to the strain, that the slope of this part of the curve The elastic modulus (E) represents, when stress is removed from the model within the boundaries of this part of the curve, the sample returns to its original dimensions because the energy expended on it is stored in the form of elastic energy and bypassing this part, either the sample is broken if it is brittle or submissive at a point called the Yield Point which represents the end of flexible behavior. After this point, a plastic deformation occurs, because the energy expended here leads to the disengagement of the physical entanglement between the chains of the material and may lead to the breaking of some of the main bonds in the material and elongation of the sample. After this stage, a gradual increase is observed due to the arrangement of the material chains towards the drag axis, thus increasing the sample strength [88,45].

### 2.12.2 Impact Test

When the material is exposed to a sudden load (a kinetic load), that is, at a high rate of strain, it will behave differently from its behavior when exposed to a static load (Tensile test, bend test) but when exposed to a kinetic load (impact test) it may behave brittle. From the impact test, the following can be obtained:

A. The impact resistance of the material, and its value is extracted from the following relationship [45]: -

$$G_c = \frac{Uc}{A} \qquad 2.16$$

whereas:

*Gc*: the impact resistance of the material (J / $m^2$).

*Uc:* Impact energy (J).

*A*: The cross-sectional area of the sample ($m^2$).

B. The fracture toughness of the material, which can be obtained from applying the following relationship [45,90]: -

$$K_c = \sqrt{GcE} \qquad 2.17$$

whereas:

*Kc*: The toughness strength of the material (MPa.$m^{0.5}$).

*Gc*: The impact resistance of the material (J / $m^2$).

*E*: Elastic modulus of the material (MPa).

## 2.13 THE WATER ABSORPTION TEST

Submerging any material in water causes the absorption of a percentage of water, which may be large or may be small, depending on the material properties. Also, the composite materials, when they remain in the water for a long time, causes the absorption of a percentage of water and that this absorbed amount of water leads to an effect on the properties. For example, it causes a reduce in the temperature of the glass transition when increasing the humidity rate, as well as causes a reduce in the tensile resistance and elastic modulus with an increase in humidity in the composite materials. Moreover, the absorption of water causes a bulging in the composite materials and also causes an increase in weight, therefore, it is necessary to study the influence of absorbing liquids such as water on the mechanical and physical properties of composite materials [91].

## 2.14 TAGUCHI METHOD

Taguchi design, developed by Dr. Genichi Taguchi, is a set of methodologies by which variables in materials and manufacturing processes have been taken into account in the design stage. The use of this technology became widespread in many American and European industries after the 1980s. The beauty of Taguchi's design is that several factors can be considered simultaneously. Also, it looks for nominal design points that are not affected by changes in production environments and are used to improve the accuracy of product performance. Therefore, not only the controlled factors, but also the noise factors can be taken into account. Although similar to Design of Experiment (DOE), the Taguchi design only performs balanced (orthogonal) experimental groups, making the Taguchi design more efficient than the partial proxy design. By using Taguchi technologies, industries are able to significantly reduce product development time for both design and production, thus reducing costs and increasing profits. Furthermore, Taguchi's design allows consideration of variance caused by noise factors, which are typically ignored in the DOE approach. Plus, the Taguchi method is a form of DOE with special application principles. For most experiments conducted in the industry, the difference between the DOE approach and the Taguchi approach is in the method of application [92].

The Taguchi method is a technique for designing and executing experiments to find processes in which the output depends on many factors without operating the process uneconomically using all possible combinations of values. Thanks to certain combinations of specific variables, it is possible to separate their individual effects [93]. In the Taguchi method, the desired design is finalized by selecting the best performance under certain conditions. The tool used in the Taguchi method is the orthogonal matrix. An orthogonal matrix is a set of numbers arranged in columns and rows. The Taguchi method uses the signal-to-noise ratio (S/N) to determine the difference. Signal-to-noise ratios (S/N) are used as measures of the effect of noise factors on performance characteristics. S/N ratios take into account the amount of variance in the response data and the proximity of the average target response. There are types of signal-to-noise analysis:

A. Lower is better: Usually this ratio (S/N) is used for all undesirable characteristics such as defects for which the optimum value is zero. The signal to noise ratio can be calculated by the following equation:

$$\frac{S}{N} = -10\,Log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad 2.18$$

B. Larger the better: Usually this ratio (S/N) is used for all desired qualities for which the optimum value is the highest. The signal to noise ratio can be calculated by the following equation:

$$\frac{S}{N} = -10\,Log\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{y_i^2}\right) \qquad 2.19$$

Table 2.3 shows nineteen orthogonal regular matrix along with the number of columns for such matrices in different levels. The name of the matrix indicates the number of rows and columns it contains, as well as the number of levels in each column. The orthogonal array of rows represents the necessary number of experiments. The number of rows must be at least equal to the degree of freedom of the control variables related to the factors. In general, the number of degrees (the control variable) equals the number of levels minus one for that factor.

**Table 2.2:** Standard orthogonal arrays.

| Orthogonal arrays | Number of rows | Max. number of factors | Maximum number of columns at levels | | | |
|---|---|---|---|---|---|---|
| | | | 2 | 3 | 4 | 5 |
| L4 | 4 | 3 | 3 | - | - | - |
| L8 | 8 | 7 | 7 | - | - | - |
| L9 | 9 | 4 | - | 4 | - | - |
| L12 | 12 | 11 | 11 | - | - | - |
| L16 | 16 | 15 | 15 | 1 | - | - |
| L16 | 16 | 5 | - | - | 5 | - |
| L18 | 18 | 8 | 1 | 7 | - | - |
| L25 | 25 | 6 | - | - | - | 6 |
| L27 | 27 | 13 | - | 13 | - | - |
| L32 | 32 | 31 | 31 | - | - | - |
| L32 | 32 | 10 | 1 | - | 9 | - |
| L36 | 36 | 23 | 11 | 12 | - | - |
| L36 | 36 | 16 | 3 | 13 | - | - |
| L50 | 50 | 12 | 1 | - | - | 11 |
| L54 | 54 | 26 | 1 | 25 | - | - |
| L64 | 64 | 63 | 63 | - | 21 | - |
| L64 | 64 | 21 | - | - | - | - |
| L81 | 81 | 40 | - | 40 | - | - |

## 2.15 ANALYSIS OF VARIANCE (ANOVA)

Parameter construction is affected to varying degrees by multiple influences. The decomposition of variance, which is commonly referred to as variance analysis (ANOVA), provides a better sense of the relative influence of the various variables. This is obtained by calculating the number of squares first [93].

$$Total\ sum\ of\ squares = \sum_{i=1}^{0} \eta_i^2 \qquad 2.20$$

The effect of any of the parameters on any factor depends on the level, for example the level A1 (Experiments 1, 2, 3) is calculated as a difference in the mean S/N ratio for these experiments and the overall mean.

The effect of the parameter at level A

$$m_{A1} - m = \frac{1}{2}(\square_1 + \square_2 + \square_3) - m \qquad 2.21$$

The average for each factor level is calculated by using the S/N ratio. This average with a separate effect for each factor is called the main effects.

$$m = \frac{1}{9}\sum_{i=1}^{9} \eta_i = \frac{1}{9}(\square_1 + \square_2 + \ldots\ldots \square_9) \qquad 2.22$$

## 2.16 DEGREES OF FREEDOM

A. The degree of freedom related to the total number of squares is proportional to the number of rows.

B. The degree of freedom that is related to the average quantity of squares one.

C. The degree of freedom associated with the total number of squares is minus one for the number of rows in the template matrix.

D. The degrees of freedom that are related with the component are equal to the minus one number of stage. For the complete number of squares minus the sum of the degrees of freedom for the separate variables, the degrees of freedom for the mistake would be equal to the degrees of freedom [93].

## 2.17 CONFIRMATION TEST

In the final step, the comparison between the experimental and expected values is done using the confirmation test, which is a validation test at the optimum levels. The following equations can be used to obtain a better prediction of the S / N ratio under ideal conditions [93]:

$$\zeta_{opt} = \zeta_m + \sum_{n=1}^{9} ( \zeta_i + \zeta_m ) \quad 2.23$$

Where:

$\zeta_{opt}$ : Is the optimal ratio of S/N.

$n$ : Is the number of implementation variables.

$\zeta_m$ : Is the total mean S/N ratio.

$\zeta_i$ : Is the S/N mean ratio at optimum condition.

The expected S/N ratio and confirmatory test results are estimated. The experimental results are closer to the expected results with an error ratio not exceeding a little less than the specified value.

# 3. EXPERIMENTAL WORK

## 3.1 INTRODUCTION

In this chapter, the practical aspect is explained and the definition of the raw materials used in the preparation of the polymeric composite material with an explanation of its properties, general characteristics, and the importance of its role within the composite material, and how to prepare samples for the tests that have been conducted, and the method of preparing molds for the manufacture of the composite materials, as well as showing some pictures for the test samples and illustrations of these samples and their dimensions, with reference to the information on the equipment used in the study with the photographs. Figure 3.1 shows the graphical technological pathway for the experimental fractions that have been used in the present work.

## 3.2 MATERIALS USED

The materials used in the research are divided into:

### 3.2.1 Matrix Materials

#### 3.2.1.1 Unsaturated polyester resin (UP)

In this research, unsaturated polyester resin (UP) is used, which is a thermosetting material that is used as an adhesive in industries, and for cross-linked chains. It is in the form of a transparent, pink liquid with a strong and distinctive smell. In solid mode, this is by adding a hardener (methyl-ethyl ketone peroxide) and symbolized by the symbol (MEKP) of the type of methyl ethyl ketone peroxide and with mixing proportions (2: 100) and upon completion of adding the hardener to the resin, the mixing process begins directly by manual mixing for a period (3 - 5) minutes, and the mixture is stirred by a glass rod until the mixture is homogeneous.

The reaction causing solidification of the mixture is of the exothermic reaction (heat is released during the cross-linking process), so the mixing must be done inside containers with an appropriate surface area, and the material of the container is not insulating to ensure the heat transfer of the reaction to the periphery. Unsaturated polyester resin has good mechanical

properties, dimensional stability, good interconnection ability with various other materials, good electrical and thermal insulation, and surface quality after hardening. Table 3.1 shows some properties of unsaturated polyester resin in this research.

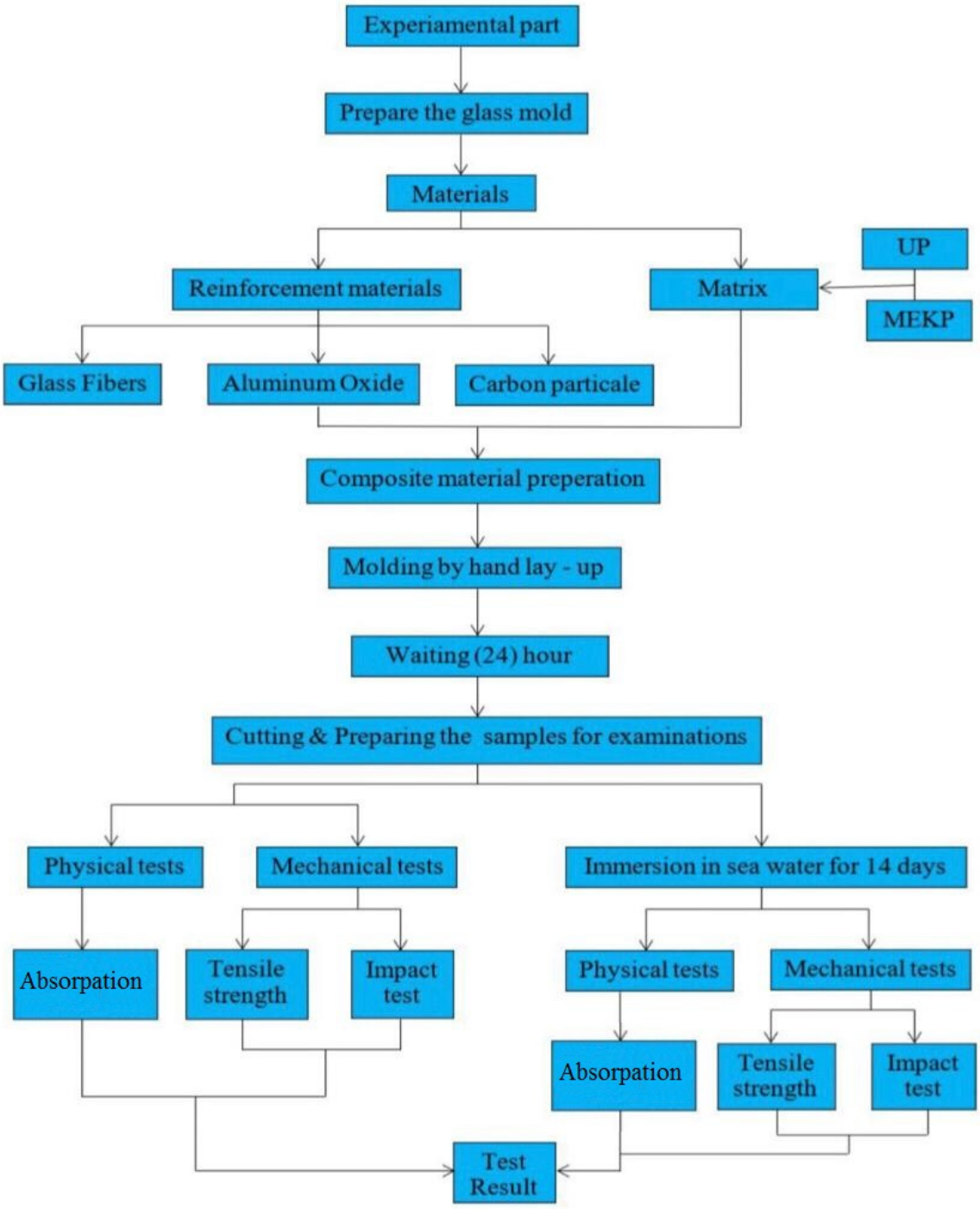


**Figure 3.1:** The methodology path diagram of the experimental.

**Table 3. 1:** Physical and mechanical properties of (UP) resin [94].

| Properties | Value |
|---|---|
| Density | 1268 kg/m$^3$ |
| Tensile strength | 50 MPa |
| Modulus of elasticity | 3 GPa |
| Elongation | 2.5% |
| Hardness | 40 |

### 3.2.2 Reinforced Materials

#### 3.2.2.1 Glass fiber

In this research, E-glass fibers were used as a reinforcing material for the unsaturated polyester resin in the form of a continuous glass fiber mat with a filament diameter rate (13 µm) for the glass fiber mat. Table 3.2 shows the mechanical and physical properties of E- glass fiber.

**Table 3.2:** Physical and mechanical properties of E-glass fiber [95].

| Properties | Value |
|---|---|
| Density | 2580 kg/m$^3$ |
| Tensile strength | 3450 MPa |
| Modulus of elasticity | 72 GPa |
| Poisson’s ratio | 0.22 |

#### 3.2.2.2 Carbon filler

Carbon particles were used as fillers to reinforce unsaturated polyesters. Table 3.3 shows the mechanical and physical properties of carbon grains.

**Table 3.3:** Physical and mechanical properties of carbon particles [96].

| Properties | Value |
|---|---|
| Density | 1780 kg/m$^3$ |
| Tensile strength | 40 MPa |
| Modulus of elasticity | 11.7 GPa |
| Thermal conductivity | 118 w/m.K |
| Practical size | 100 µm |

### 3.2.2.3 Aluminum Oxide Nanoparticles Filler

It is one of the industrially important ceramic oxides due to its mechanical and thermal properties such as resistance, high thermal stability, high hardness and high mechanical resistance, so it is used in many industrial applications such as the manufacture of refractories, skimmers and electrical insulators.

Aluminum oxide powder (Al2O3) German originating from (RIEDEL - DE HAEN AG) was used with a particle size (50 nm) and Table 3.4 shows some properties of aluminum oxide [54].

**Table 3.4:** Some properties of aluminum oxide powder [54].

| | |
|---|---|
| Thermal conductivity (W/m $^oC$) | 39 |
| Fracture toughness (MPa. m$^{0.5}$) | 4.2- 5.9 |
| Tensile strength ( MPa) | 282- 551 |
| Modulus of elasticity (GPa) | 304 |
| Density (kg/m$^3$) | 3720 |

## 3.3 PREPARATION OF SAMPLES

Samples were prepared for the composite material using the hand lay-up technique, where samples were prepared from unsaturated polyester as the base material reinforced with glass fibers at different angles (0/0, 0/90, 45/45) and adding carbon particles and aluminum oxide as

fillers, and with different weight ratios (2.5%, 5% and 7.5%) and (0%, 1% and 3%) respectively. Taguchi method was used where the control factor was chosen in the design of the experiment where three parameters were used with three levels, the orthogonal design L9 ($3^3$) was used, Table 3.5 shows the samples that were prepared.

**Table 3.5:** The prepared composite.

| Exp. No | Fiber angle (degree) | Carbon Filler (wt %) | Nano Aluminum Oxide Filler (wt %) | Polyester Weight fraction % |
|---|---|---|---|---|
| 1 | 0/0 | 2.5 | 0 | 67.5 |
| 2 | 0/0 | 5 | 1 | 64 |
| 3 | 0/0 | 7.5 | 3 | 59.5 |
| 4 | 0/90 | 2.5 | 1 | 66.5 |
| 5 | 0/90 | 5 | 3 | 62 |
| 6 | 0/90 | 7.5 | 0 | 62.5 |
| 7 | 45/45 | 2.5 | 3 | 64.5 |
| 8 | 45/45 | 5 | 0 | 65 |
| 9 | 45/45 | 7.5 | 1 | 61.5 |

### 3.3.1 Configuration of the Mold

This process includes preparing a special mold for the casting process, which is a sheet of glass with dimensions of 25 x 25 cm that represents the base of the mold and is covered with thermal transparent paper to prevent resin adhesion to the glass plate and ease of casting out, so that the plate is placed at a high degree of flatness and the surface is made sure that the surface is flat by the leveling scale, either the sides of the mold are made of glass rulers with a height of 5 mm covered with a transparent thermal adhesive, as it is an insulating material to ensure that the resin does not adhesion to the glass rulers as shown in Figure 3.2.

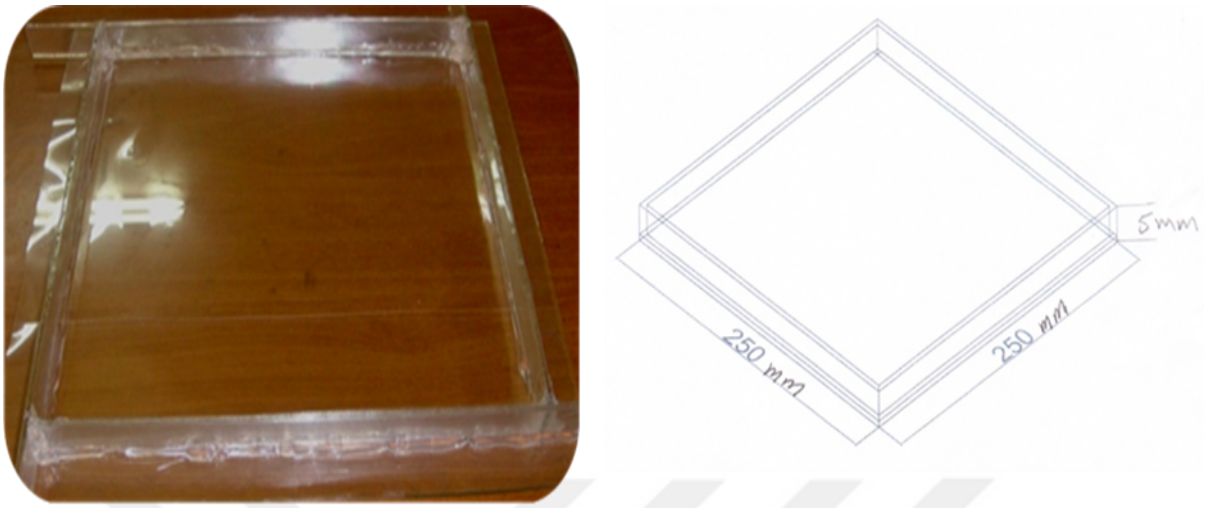



**Figure 3.2:** The glass mold.

### 3.3.2 Sample preparation

We can summarize the process of preparing and pouring samples in the following steps:

A. A quantity of unsaturated polyester material is weighed according to the size of the designed mold, and a hardener is added where the hardener is added to the polyester with a ratio of (2: 100).

B. A quantity of the reinforce material, which is the E-glass fiber, is weighed with a weight fraction of 30%. The fibers are weighed on the sensitive scale.

C. A quantity of carbon is weighed according to the percentages specified in Table 3.5 and added to the samples to be prepared.

D. Weighing a quantity of aluminum oxide nanoparticles and according to the proportions specified in Table 3.5 and adding them to the samples to be prepared.

E. In order to fully harden, the casting must be left in the mold for a period of (24) hours before removing it from the mold.

F. Samples are cut according to the standard specifications and dimensions adopted in each test using a CNC cutting machine as shown in Figure 3.4.

G. The mechanical and physical properties of the samples are tested (tensile strength, impact resistance, and water absorption). The sample is tested in two cases, the first case is at room temperature, and in the second case the sample is immersed in sea water for 14 days, then the sample is taken out of the water and the water is removed from the surface, the sample is then tested for the mechanical properties.

**Figure 3.3:** Composite plate.

**Figure 3.4:** The CNC cutting machine in which the samples were cut.

## 3.4 EXPERIMENTAL TESTS

### 3.4.1 Tensile Testing Device

A special device was used in the tensile strength test on the samples with certain dimensions according to international standards (ASTM 638M- 78b) [97, 98], Where the sample is placed in the device by a clamp installed in the upper table and another clamp installed in the lower pressure table, then a tensile force is applied to the sample. With a load rate of (500) Kg and a test speed of (1 mm / min), The specimen is well clamped in the device, after which a tensile force is applied to the specimen until it is broken and the highest tensile strength the specimen can withstand before it is broken, the device includes a plotter that plots the relationship between stress and elongation obtained by the sample as a result of the tensile load, on a special plotter's graph. This assay was performed for the nine samples separately.

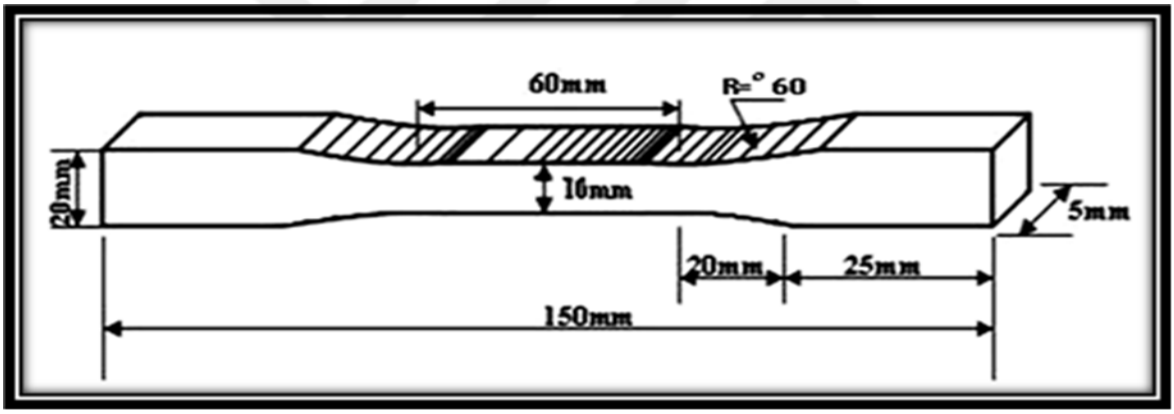



**Figure 3.5:** Tensile test sample according to ASTM (638M- 78b).

**Figure 3.6:** Tensile strength test device.

### 3.4.2 Impact test

In this research, the impact test device shown in Figure 3.6 was used, and using the Charpy method to impact test, the device contains a pendulum in which the hammer is fixed. The dimensions of the samples are (55 × 10 × 5) mm according to ISO 179 [99]. The device has the hammers with different sizes, so that the hammer can be changed according to the energy required. Where the energy required to break is calculated and through which the impact resistance of the material can be calculated.

At the beginning of the test, the pendulum is raised with the hammer to the maximum height so that it is properly fixed by the installer on the device, the sample is placed on the two supports of the device and in the designated place, and the power meter is reset first, then the pendulum is released using the lever mounted on the balance and in a oscillating motion, the potential energy

is converted into kinetic energy when it hits the sample, and part of it is lost in the sample fracture, so the scale pointer reads a sample of the fracture energy, knowing that a 5J card hammer was used for testing Shock The shock resistance is calculated from the following relationship:

$$G_c = \frac{Uc}{A} \qquad 3.1$$

whereas: -

*Gc*: the impact resistance of the material (J / $m^2$).

$U_c$ : Impact energy (J).

*A*: The cross-sectional area of the sample ($m^2$).

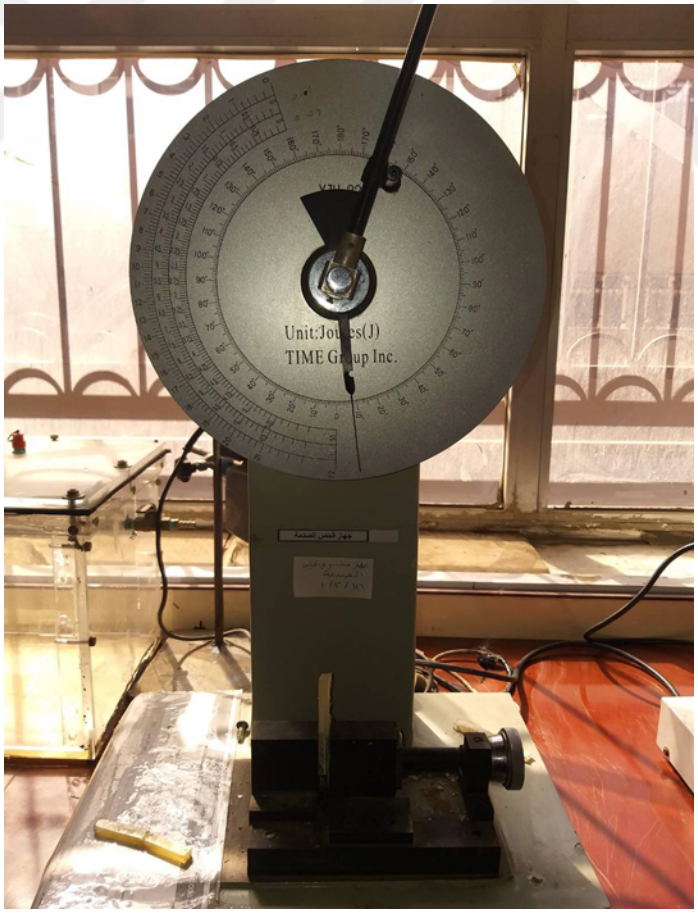



**Figure 3.7:** Impact test device.

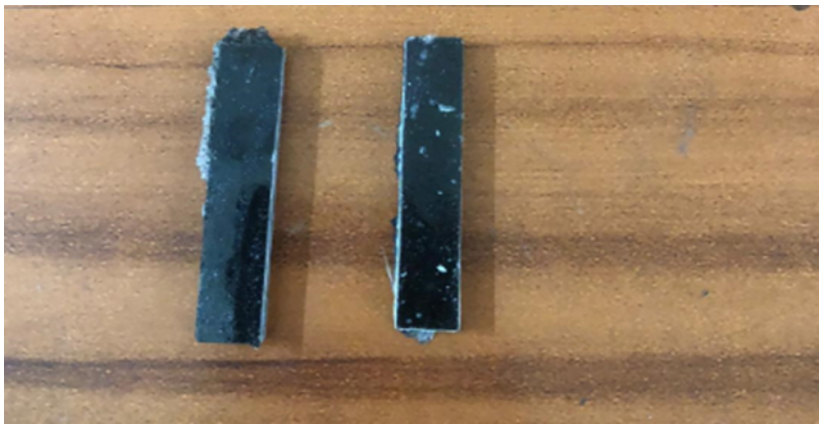


**Figure 3.8:** Impact test sample according to ISO 179.

### 3.4.3 Water absorption test

The water absorption test, or swelling test, is performed in accordance with ASTM D570. In this test, the sample was completely submerged in distilled water. A set of samples were immersed in a container of distilled water for a period of (24 hours), and another set of samples was immersed in sea water for 14 days. After removing the sample from the water, the water was cleaned from the surfaces with a soft dry cloth and then weighed with an accurate digital scale. The water absorption percentage was found using the following equation:

$$\text{Water absorption percentage} = ((ws - wd) / wd) \times 100\% \quad (3.2)$$

Whereas:

$W_d$: The mass of sample before immersion.

$Ws$: The mass of the sample after immersion.

# 4. RESULTS AND DISCUSSION

## 4.1 INTRODUCTION

In this chapter, discuss the experimental results obtained from the tests. Each test will be analyzed separately. Experiments were carried out using the Taguchi technique to find the optimum combination that has the best mechanical properties.

## 4.2 DESIGN EXPERIMENTS

There are three parameters that are (fiber orientation A, carbon filler B, aluminum oxide nano-filler C).

Each parameter has three levels, the three parameters and their levels are shown in Table 4.1. From the collection of control factors and studying the influence of these factors on the results, the orthogonal array is L9 ($3^3$). Nine experiments were presented as shown in Table 4.2.

**Table 4.1:** Parameters with their levels.

| Parameters | Symbol | Levels of Parameter | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| Fiber arrangement | A | 0/0 | 0/90 | 45/45 |
| Carbon filler | B | 2.5% | 5% | 7.5% |
| Nano Aluminum Oxide filler | C | 0% | 1% | 3% |

**Table 4.2:** Experimental factors and levels using L9 orthogonal array.

| Exp. No. | Parameters and level | | | | | | Polyester Weight fraction% |
|---|---|---|---|---|---|---|---|
| | Fiber arrangement-A | | Carbon Filler-B | | Nano Aluminum Oxide Filler-C | | |
| | Level | Angle | Level | Value | Level | Value | |
| 1 | 1 | 0/0 | 1 | 2.5% | 1 | 0% | 67.5% |
| 2 | 1 | 0/0 | 2 | 5% | 2 | 1% | 64% |
| 3 | 1 | 0/0 | 3 | 7.5% | 3 | 3% | 59.5% |
| 4 | 2 | 0/90 | 1 | 2.5% | 2 | 1% | 66.5% |
| 5 | 2 | 0/90 | 2 | 5% | 3 | 3% | 62% |
| 6 | 2 | 0/90 | 3 | 7.5% | 1 | 0% | 62.5% |
| 7 | 3 | 45/45 | 1 | 2.5% | 3 | 3% | 64.5% |
| 8 | 3 | 45/45 | 2 | 5% | 1 | 0% | 65% |
| 9 | 3 | 45/45 | 3 | 7.5% | 2 | 1% | 61.5% |

## 4.3 TENSILE TEST RESULTS

The nine samples were tested according to ASTM (D638M-87b). Each test was repeated three times and the average results were taken, Table 4.3 shows the results of the tensile and elastic modulus with their S / N ratio, using bigger is better. Figure 4.1 shows the relationship between the strain and stress for experiments number (1, 3 and 7).

In Table (4.3) it was found that Exp. No.4 present the maximum value of the elastic modulus of (1.013 GPa) that consists from (0/90 fiber orientation, 2.5 % carbon filler, and 1 % Nano aluminum oxide).

It was found that the maximum value of tensile strength is 62 MPa in experiment No. 2, which consists of (0/0 fiber orientation, 5% carbon filler and 1% nano aluminum oxide).

It was found the value of the elastic modulus and tensile strength in the pure unsaturated polyester are 0.4 GPa and 8 MPa respectively.

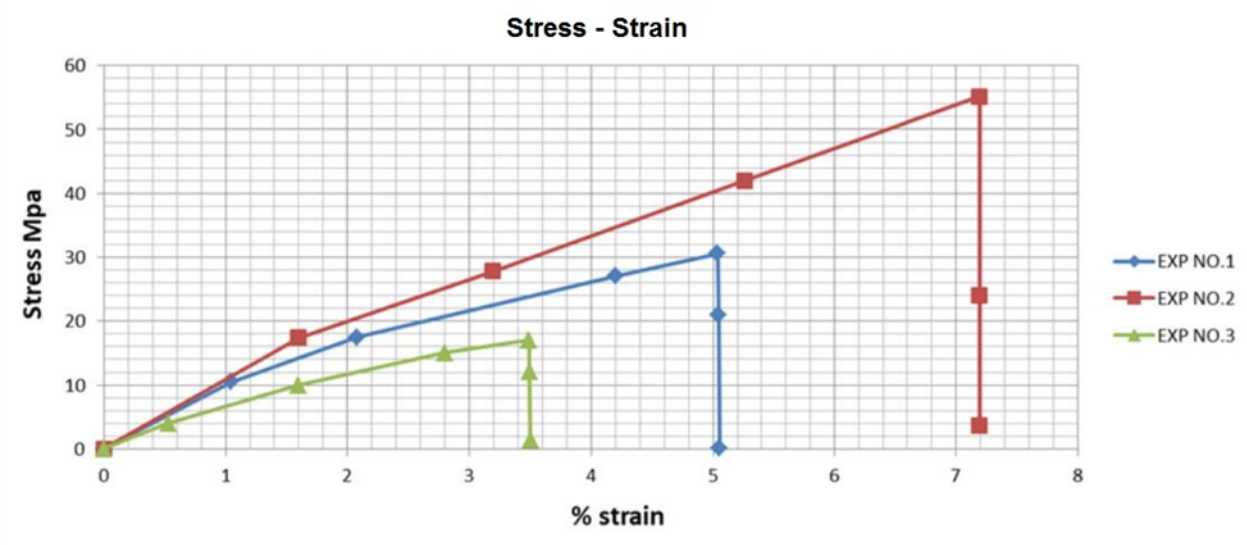



**Figure 4.1:** Stress-strain curve for the three experiments.

**Table 4.3:** Experimental results and their signal –to-noise ratio.

| Exp. No. | Modulus of Elasticity | | Tensile strength | |
|---|---|---|---|---|
| | Gpa | S/N | Mpa | S/N |
| 1 | 0.67 | -3.478 | 31 | 29.827 |
| 2 | 0.8 | -1.9382 | 62 | 35.847 |
| 3 | 0.7 | -3.098 | 55 | 34.807 |
| 4 | 1.013 | 0.1121 | 24 | 27.604 |
| 5 | 1 | 0.00000 | 26 | 28.299 |
| 6 | 0.88 | -1.1103 | 22 | 26.848 |
| 7 | 0.55 | -5.1927 | 17 | 24.609 |
| 8 | 0.68 | -3.349 | 18 | 25.10 |
| 9 | 0.47 | -6.558 | 19 | 25.575 |

### A. Analysis of Means (ANOM)

The analysis of mean is a statistical approach in which the optimal level of the process parameters is calculated based on the result of the average factor. The average value of the experimental results at different levels (1, 2, 3) was obtained for each parameter (the fiber orientation A, carbon filler B, aluminum oxide Nano-filler C), and clarified in Table 4.4 the value of 0.7233 GPa is obtained through ((0.67 + 0.8 + 0.7) / 3). The angle effect is the most effective (Rank 1) in the elastic modulus, followed by carbon filler and finally aluminum oxide Nano filler in Rank 3.

The tensile strength value of 49.33 MPa is also obtained from ((31 + 62 + 55) / 3) where the results of ANOM show the effect of angle is the most effective on the tensile strength (Rank 1) followed by carbon filler and Nano aluminum oxide filler.

**Table 4.4:** Mean for each factor level.

| Parameter | Symbol | Average of different level | | | Max-Min | Rank |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | | |
| **Modulus of Elasticity, Gpa** | | | | | | |
| **Fiber arrangement** | A | 0.7233 | 0.9643 | 0.5667 | 0.3977 | **1** |
| **Carbon filler** | B | 0.7443 | 0.8267 | 0.6833 | 0.1433 | **2** |
| **Nano Aluminum Oxide filler** | C | 0.7433 | 0.761 | 0.75 | 0.0177 | **3** |
| **Tensile Strength, Mpa** | | | | | | |
| **Fiber arrangement** | A | 49.33 | 24 | 18 | 31.33 | **1** |
| **Carbon filler** | B | 24 | 35.33 | 32 | 11.33 | **2** |
| **Nano Aluminum Oxide filler** | C | 23.67 | 35 | 32.67 | 11.33 | **3** |

**B. Signal to Noise Ratio Analysis**

The signal-to-noise ratio is required to achieve the best parameter combination levels to get the maximum mechanical. The results of S / N ratio show in Table 4.5 and the optimal levels were predicted by estimating factors for three different levels. The levels of the factors were determined as shown in Table 4.5. Figure 4.2 show the distributions of mean S / N ratios. From Table 4.5 and Fig. 4.2 it can be seen that the optimal combination of the parameters with their levels of the higher elasticity modulus is ($A_2B_2C_1$) equivalent to (0/90 fiber orientation, 5% carbon filler and 0% Nano aluminum oxide filler) with 65% unsaturated polyester. For the tensile strength, the optimum parameters with their levels are ($A_1B_2C_2$) equivalent to (0/0 fiber orientation, 5% carbon filler and 1% Nano alumina oxide filler) with 64 % Of unsaturated polyester.

**Table 4.5:** Average signal to noise ratio of different parameter levels.

| Parameter | Symbol | Average of S/N (dB) of different level | | | Max-Min | Optimum level |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | | |
| **Modulus of Elasticity, GPa** | | | | | | |
| **Fiber arrangement** | A | -2.838 | -0.332 | -5.033 | 4.7008 | $A_2B_2C_1$ |
| **Carbon filler** | B | -2.853 | -1.762 | -3.588 | 1.8261 | |
| **Nano Aluminum Oxide filler** | C | -2.646 | -2.794 | -2.763 | 0.1485 | |
| **Tensile Strength, MPa** | | | | | | |
| **Fiber arrangement** | A | 33.49 | 27.58 | 25.1 | 8.4 | $A_1B_2C_2$ |
| **Carbon filler** | B | 27.35 | 29.75 | 29.08 | 2.4 | |
| **Nano Aluminum Oxide filler** | C | 27.26 | 29.68 | 29.24 | 2.42 | |

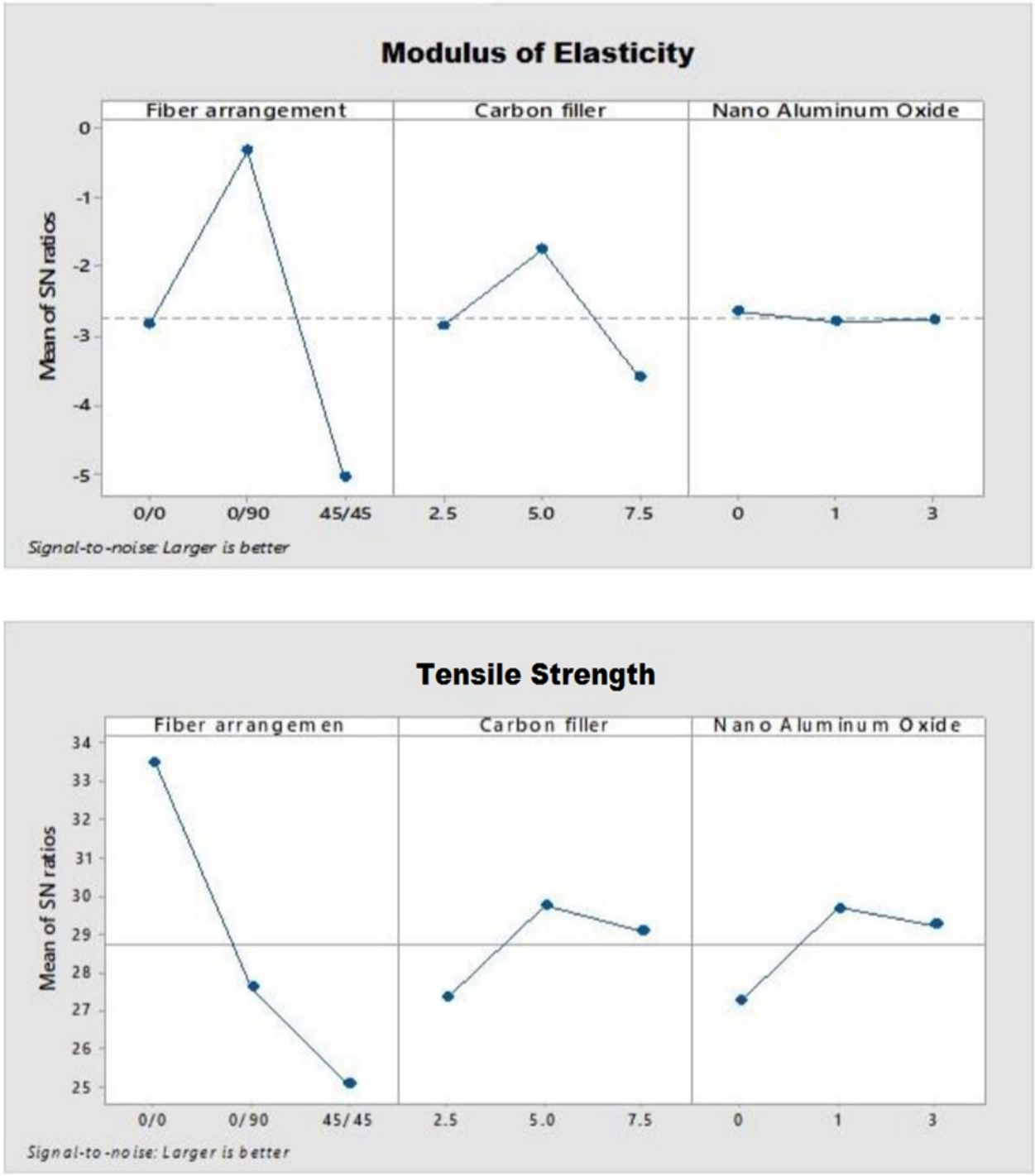



**Figure 4.2:** Average signal to noise ratio of different parameter levels.

**C. Analysis of Variance (ANOVA)**

The results were analyzed by analysis of variance (ANOVA), which is used to study the effect of factors (fiber orientation, carbon filler, Nano-aluminum oxide filler) on the mechanical properties. By conducting an analysis of variance, It is possible to determine the independent factor that dominates the other and the proportion of the contribution of that particular independent variable. Table 4.6 show the dominant factor is the direction of the fiber. Which indicates that the direction of the fiber is the most important factor among other factors on the modulus of elasticity and tensile strength. It is noticed from the table that the direction of the fibers had the highest effect, as the contribution of (81.8%) to the elastic modulus, followed by carbon filler (12.4%) and finally the third contribution of aluminum Nano-oxide, which was the least effective (0.09%). The tensile strength, contribution of the fiber direction was (83.39%), followed by the filler of Nano aluminum oxide with a contribution (7.42%) and finally the carbon filler with a contribution (6.89%). It can be concluded that the direction of the fiber has a greater influence than the rest of the factors on tensile strength and elastic modulus. The results from (ANOVA) are compatible with that of (ANOM) by consider in the most effect parameters than other.

**Table 4.6:** ANOVA results of mechanical properties.

| Parameters | Sum of Squares | Degree of Freedom | Mean Squares | Contribution (%) |
|---|---|---|---|---|
| **Modulus of Elasticity, GPa** | | | | |
| Fiber arrangement | 33.1947 | 2 | 16.5973 | 81.8 |
| Carbon filler | 5.0650 | 2 | 2.5325 | 12.4 |
| Nano Aluminum Oxide filler | 0.0368 | 2 | 0.0184 | 0.09 |
| Error | 2.2834 | 2 | 1.1417 | 5.71 |
| Total | 40.5799 | 8 | | 100 |
| **Tensile Strength, MPa** | | | | |
| Fiber arrangement | 111.636 | 2 | 55.818 | 83.39 |
| Carbon filler | 9.227 | 2 | 4.614 | 6.89 |
| Nano Aluminum Oxide filler | 9.938 | 2 | 4.969 | 7.42 |
| Error | 3.065 | 2 | 1.533 | 2.3 |
| Total | 133.867 | 8 | | 100 |

## 4.4 IMPACT AND ABSORPTION TESTS RESULTS

The impact resistance test was carried out according to (ISO-179) and the water absorption test according to the standard (ASTM D570). Each test was repeated three times and the average results be listed in Table 4.7 with S / N ratio, using the bigger is the better for the impact test. While using the smaller is the best in the water absorption test. In Table 4.7 it was noticed that the maximum value of the impact resistance test was equal to (2.325 J/mm$^2$) in experiment No. 2

which consisted of (0/0 fiber orientation, 5% carbon filler and 1% Nano aluminum oxide filler) with 64% unsaturated polyester, the water absorption test has the lowest value equal to (0.471) in experiment No. 1 which consists of (0/0 fiber orientation, 2.5% carbon filler and 0% Nano aluminum oxide filler).

It was found the value of the impact and absorption in the pure unsaturated polyester are 0.2 J/cm$^2$ and 0.846 g respectively.

**Table 4.7:** Experimental results and their signal –to-noise ratio.

| Exp. No. | Impact | | Absorption | |
|---|---|---|---|---|
| | J/mm$^2$ | S/N | g | S/N |
| 1 | 1.725 | 4.735 | 0.471 | 6.539 |
| 2 | 2.325 | 7.3285 | 1.062 | -0.522 |
| 3 | 1.775 | 4.984 | 1.080 | -0.668 |
| 4 | 1.35 | 2.606 | 0.820 | 1.719 |
| 5 | 1.45 | 3.227 | 1.266 | -2.048 |
| 6 | 1.225 | 1.762 | 1.716 | -4.690 |
| 7 | 0.45 | -6.935 | 1.162 | -1.304 |
| 8 | 0.325 | -9.762 | 1.093 | -0.772 |
| 9 | 0.3 | -10.457 | 1.156 | -1.259 |

**A. Analysis of Means (ANOM)**

The average value of the experimental results was obtained at different levels (1, 2, 3) of the factors (fiber orientation, carbon filler and Nano-aluminum oxide filler) as shown in Table 4.8. The value of (1.09417 J/mm$^2$) is obtained from ((1.725 + 2.325 + 1.775) / 3) for the impact resistance. The results of ANOM in Table 4.8 show that the fiber direction is the most effective (Rank 1) in the impact resistance test, followed by the carbon filler and finally the aluminum oxide Nano filler. As for the water absorption when the smaller is the best, a value of (0.871) is obtained from ((0.471 + 1.062 + 1.080) / 3). ANOM results showed that the carbon filler is the

most effective (Rank 1) in the absorption test, followed by the direction of fiber and alumina oxide Nano filler.

**Table 4.8:** Mean for each factor level.

| Parameter | Symbol | Average of different level | | | Max-Min | Rank |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | | |
| **Impact, (J/mm$^2$)** | | | | | | |
| **Fiber arrangement** | A | 1.9417 | 1.3417 | 0.3583 | 1.5833 | 1 |
| **Carbon filler** | B | 1.175 | 1.3667 | 1.1 | 0.2667 | 2 |
| **Nano Aluminum Oxide Filler** | C | 1.0917 | 1.325 | 1.225 | 0.2333 | 3 |
| **Absorption ( g)** | | | | | | |
| **Fiber arrangement** | A | 0.871 | 1.2673 | 1.137 | 0.396 | 2 |
| **Carbon filler** | B | 0.817 | 1.140 | 1.317 | 0.499 | 1 |
| **Nano Aluminum Oxide filler** | C | 1.093 | 1.012 | 1.169 | 0.156 | 3 |

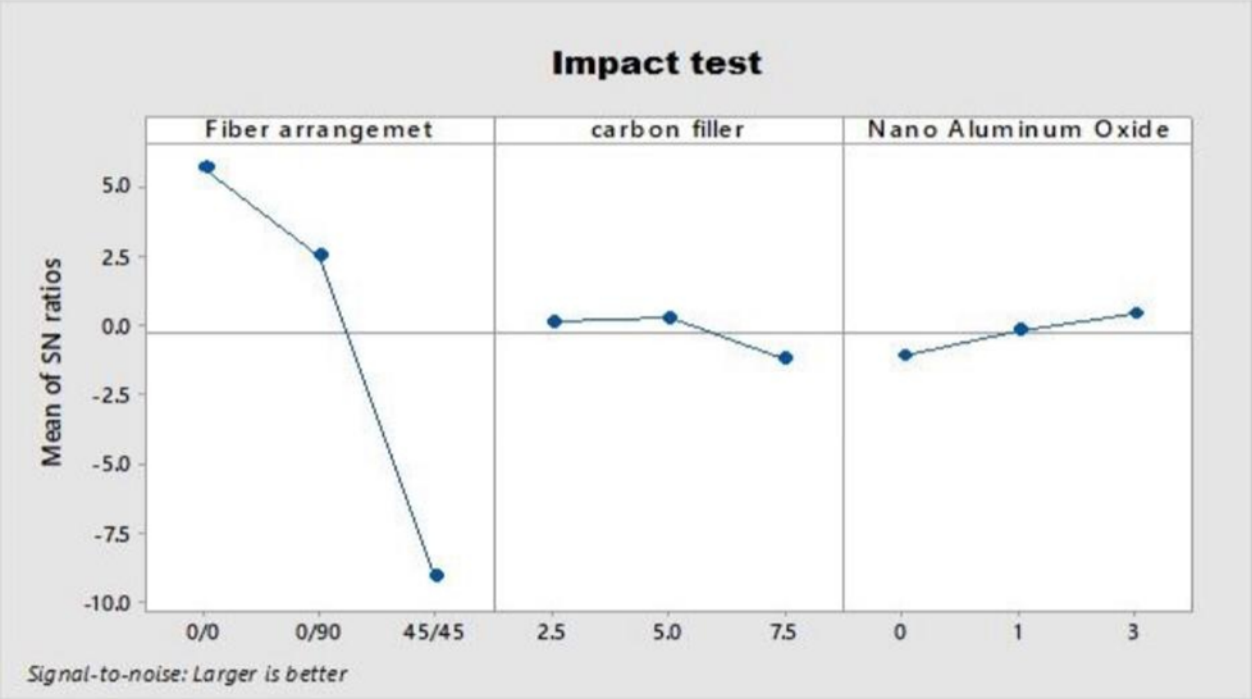
## B. Signal to Noise Ratio

Signal to noise ratio is required to achieve optimum mechanical properties. Where the use of a larger S / N ratio is the best for the impact resistance. As for water absorption, a smaller S / N ratio is the best will be used, as shown in Table 4.9. The optimal levels were predicted by estimating the factors of the three different levels. The levels of the control factors were identified and listed in Table 4.9. Figure 4.3 shows the distributions of the average ratios of S/N. From Table 4.9 and Fig. 4.3 combines the optimal parameters of higher impact resistance is $A_1B_2C_3$, equivalent to (0/0 fiber orientation, 5% carbon filler and 3% Nano-aluminum oxide filler) with 62% unsaturated polyester, while the optimal parameters for the absorption test is

$A_1B_1C_1$, equivalent to (0/0 fiber orientation, 2.5% carbon filler and 0% Nano-aluminum oxide filler) with 67.5% unsaturated polyester.

**Table (4.9):** Average signal to noise ratio of different parameter levels.

| Parameter | Symbol | Average of S/N (dB) of different level | | | Max-Min | Optimum level |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | | |
| **Impact strength ($J/mm^2$)** | | | | | | |
| **Fiber arrangement** | **A** | 5.687 | 2.5323 | -9.051 | 14.7346 | $A_1B_2C_3$ |
| **Carbon filler** | **B** | 0.1356 | 0.2645 | -1.237 | 1.5015 | |
| **Nano Aluminum Oxide filler** | **C** | -1.087 | -0.174 | 0.4252 | 1.5131 | |
| **absorption test (g)** | | | | | | |
| **Fiber arrangement** | **A** | 1.782 | -1.671 | -1.111 | 3.454 | $A_1B_1C_1$ |
| **Carbon filler** | **B** | 2.319 | -1.114 | -2.205 | 4.525 | |
| **Nano Aluminum Oxide filler** | **C** | 0.358 | -0.019 | -1.340 | 1.699 | |



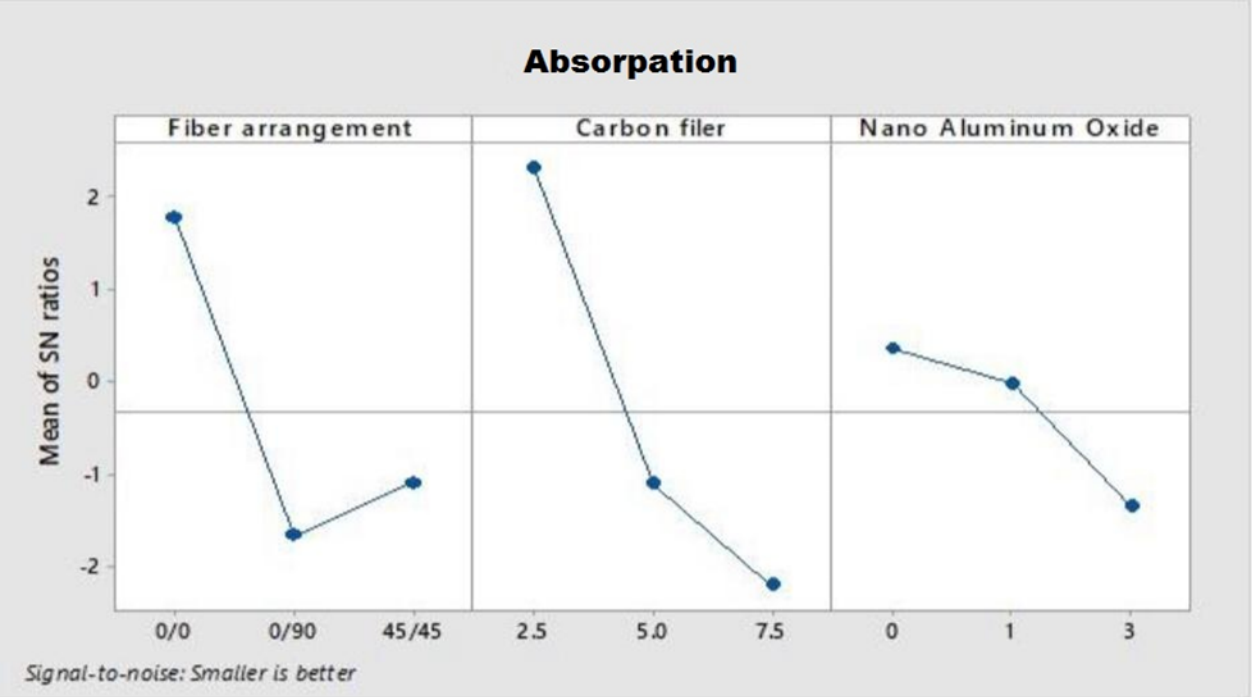




**Figure 4.3:** Average signal to noise ratio of different parameter levels.

### C. Analysis of Variance (ANOVA)

The experimental results were analyzed using ANOVA, which is used to study the effect (fiber orientation, carbon filler and Nano-aluminum oxide filler) on the impact and absorption properties. From the analysis of variance, it is possible to determine the independent factor that dominates the other, from Table 4.10 that shows the results of the ANOVA analysis, found that the dominant and most important factor on impact resistance is the direction of the fibers, where its contribution was 96.75%, followed by the carbon filler with a contribution of 1.11% and finally the filler of Nano aluminum oxide with a contribution of 0.93%. For the water absorption test, the main contribution was carbon filler, with contribution 44.31%, followed by the direction of the fibers with a contribution of 27.31%, and finally the filler of Nano aluminum oxide with a contribution of 6.32%.

**Table 4.10:** ANOVA results of mechanical properties.

| Parameters | Sum of Squares | Degree of Freedom | Mean Squares | Contribution (%) |
|---|---|---|---|---|
| **IMPACT TEST (J/mm$^2$)** | | | | |
| **Fiber arrangement** | 361.227 | 2 | 180.613 | 96.75 |
| **Carbon filler** | 4.155 | 2 | 2.077 | 1.11 |
| **Nano Aluminum Oxide filler** | 3.484 | 2 | 1.742 | 0.93 |
| **Error** | 4.494 | 2 | 2.247 | 1.2 |
| **Total** | 373.36 | 8 | | 100 |
| **ABSORPTION TEST (g)** | | | | |
| **Fiber arrangement** | 20.628 | 2 | 10.314 | 27.31 |
| **Carbon filler** | 33.468 | 2 | 16.734 | 44.31 |
| **Nano Aluminum Oxide filler** | 4.776 | 2 | 2.388 | 6.32 |
| **Error** | 16.660 | 2 | 8.332 | 22.06 |
| **Total** | 75.53 | 8 | | 100 |

## 4.5 EFFECT OF SEA WATER ON THE COMPOSITE PROPIRTEIS

Tests of mechanical and physical properties were repeated for a second group of samples after being immersed in sea water for 14 days, to know the effect of sea water and salts on the composite material because the composite material was manufactured for the purpose of use in the boat structure.

### 4.5.1 Tensile Test Results

The tensile test was performed for the second group immersed in sea water for 14 days, each test was repeated three times and the average results were found as shown in Table 4.11 with their S/N ratio. Fig. 4.4 show the relation between stress and strain curve for samples 1, 3, and 7. It was noted that the value the maximum elastic modulus is 0.97GPa in experiment No. 6 which consists of (0/90 fiber orientation, 7.5 % carbon filler and 0% Nano aluminum oxide filler). The maximum value of tensile strength is 60MPa in experiment No. 2, which consists of (0/0 fiber orientation, 5% carbon filler and 1% Nano aluminum oxide filler).

It was found the value of the elastic modulus and tensile strength in the pure unsaturated polyester are 0.4 GPa and 7 MPa respectively.

**Table 4.11:** Experimental results and their signal –to-noise ratio.

| Exp. No. | Modulus of Elasticity | | Tensile strength | |
|---|---|---|---|---|
| | Result Gpa | S/N | Mpa | S/N |
| 1 | 0.5 | -6.0205 | 27 | 28.627 |
| 2 | 0.87 | -1.209 | 60 | 35.563 |
| 3 | 0.67 | -3.478 | 50 | 33.979 |
| 4 | 0.74 | -2.615 | 23 | 27.234 |
| 5 | 0.45 | -6.935 | 25 | 27.958 |
| 6 | 0.97 | -0.264 | 21 | 26.444 |
| 7 | 0.54 | -5.352 | 17 | 24.609 |
| 8 | 0.53 | -5.514 | 16 | 24.082 |
| 9 | 0.77 | -2.2701 | 18 | 25.105 |

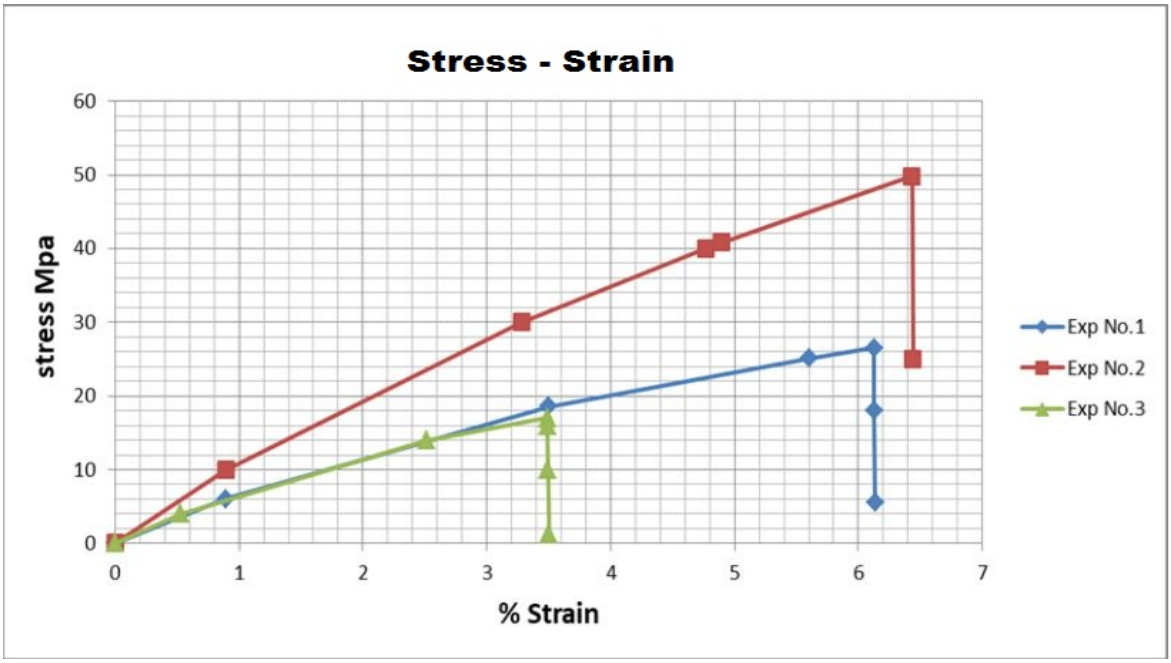



**Figure 4.4:** Stress-Strain Curve**.**

## A. Analysis of Means (ANOM)

The average value of the experimental results was obtained at different levels (1, 2, 3) for each factor and summarized in Table 4.12. ANOM results show that Nano-aluminum oxide filler is the most effective (Rank 1) in the elastic modulus, followed by carbon filler and finally the direction of the fiber. As for the tensile strength, the direction of the fiber is the most effective (Rank 1), followed by the Nano-aluminum oxide filler and finally the carbon filler.

**Table 4.12:** Mean for each factor level.

| Parameter | Symbol | Average of different level | | | Max-Min | Rank |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | | |
| **Modulus of Elasticity, Gpa** | | | | | | |
| **Fiber arrangement** | **A** | 0.68 | 0.72 | 0.6133 | 0.1067 | 3 |
| **Carbon filler** | **B** | 0.59 | 0.6167 | 0.8033 | 0.21 | 1 |
| **Nano Aluminum Oxide filler** | **C** | 0.6667 | 0.7933 | 0.5533 | 0.24 | 2 |
| **Tensile Strength, MPa** | | | | | | |
| **Fiber arrangement** | **A** | 45.67 | 23 | 17 | 28.67 | 1 |
| **Carbon filler** | **B** | 22.33 | 33.67 | 29.67 | 11.33 | 3 |
| **Nano Aluminum Oxide filler** | **C** | 21.33 | 33.67 | 30.67 | 12.33 | 2 |

## B. Signal to Noise Ratio Analysis

Signal-to-noise ratio analysis is required to achieve the best mechanical properties (elasticity modulus and tensile resistance). Therefore, larger S / N is better. The results of the tensile test with its S / N value for the samples submerged in sea water are shown in Table 4.13. The optimum levels were predicted as shown in Table 4.13. Figure 4.5 shows the distributions of mean S/ N ratios. From Table 4.13 and Fig. 4.5 that the optimum combination of parameters with their levels of elasticity modulus is $A_2B_3C_2$, which is equivalent to (0/90 the fiber orientation, 7.5% carbon filler and 3% Nano alumina oxide filler) with 59.5% unsaturated polyester. While

in terms of tensile strength, it was found that the optimum parameters that combine with their levels of tensile resistance are $A_1B_2C_2$, which is equivalent to (0/0 fiber orientation, 5% carbon filler and 1% Nano aluminum oxide filler) with 64% unsaturated polyester.

**Table 4.13:** Average signal to noise ratio of different parameter levels.

| Parameter | Symbol | Average of S/N (dB) of different level | | | Max-Min | Optimum level |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | | |
| **Modulus of Elasticity, GPa** | | | | | | |
| **Fiber arrangement** | **A** | -3.57 | -3.272 | -4.379 | 1.107 | $A_2B_3C_2$ |
| **Carbon filler** | **B** | -4.663 | -4.553 | -2.004 | 2.658 | |
| **Nano Aluminum Oxide filler** | **C** | -3.933 | -2.032 | -5.255 | 3.224 | |
| **Tensile Strength, MPa** | | | | | | |
| **Fiber arrangement** | **A** | 32.72 | 27.21 | 24.6 | 8.12 | $A_1B_2C_2$ |
| **Carbon filler** | **B** | 26.82 | 29.2 | 28.51 | 2.38 | |
| **Nano Aluminum Oxide filler** | **C** | 26.38 | 29.3 | 28.85 | 2.92 | |

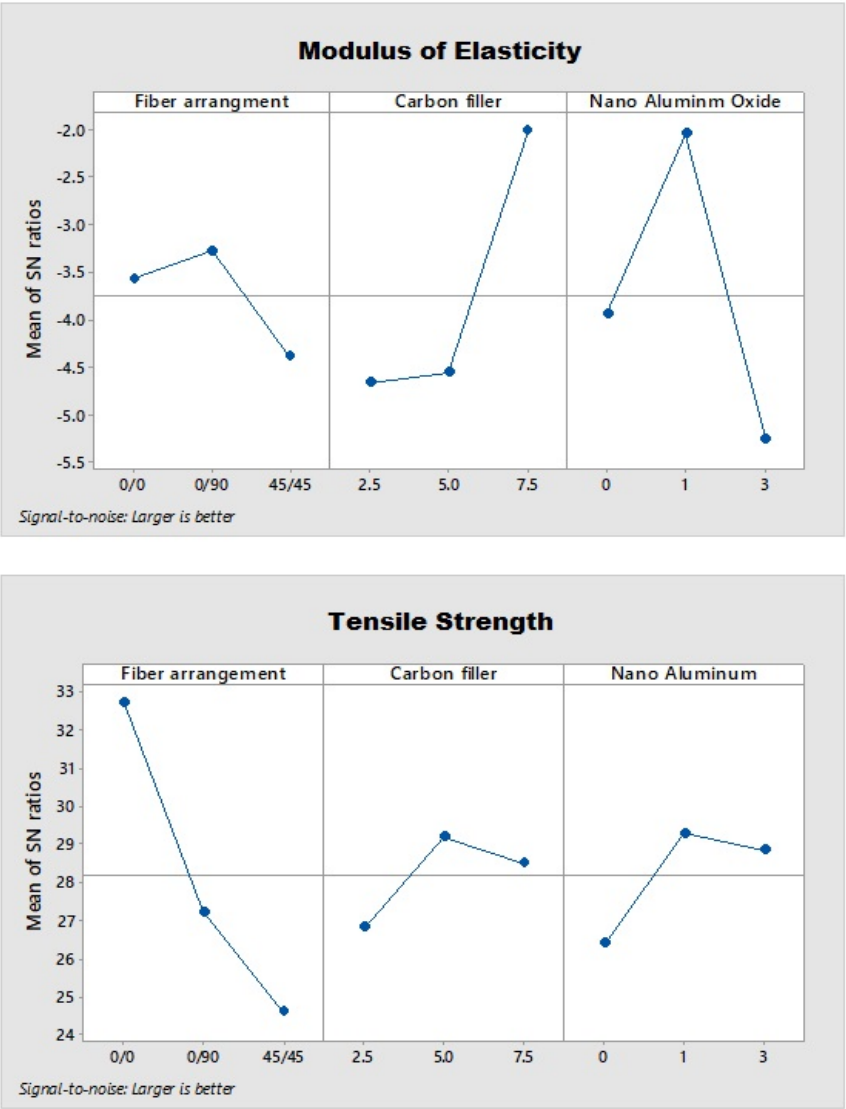



**Figure 4.5:** Average signal to noise ratio of different parameter levels.

### C. Analysis of Variance (ANOVA)

The experimental results of the samples immersed in sea water were analyzed by ANOVA. Table 4.14 shows that the dominant factor and the more effective is Nano aluminum oxide for the elastic modulus, where its contribution was 36.53%, followed by carbon filler with a contribution of 31.47% and finally the direction of fiber with a contribution of 4.57%. As for

tensile strength, the direction of fiber is the dominant one and the more effective, as its contribution was 78.6%, followed by Nano aluminum oxide filler, where its contribution was 11.26%, and finally carbon filler, where its contribution was 6.84%.

**Table 4.14:** ANOVA results of mechanical properties.

| Parameters | Sum of Squares | Degree of Freedom | Mean Squares | Contribution (%) |
|---|---|---|---|---|
| **MODULUS OF ELASTICITY (GPa)** | | | | |
| **Fiber arrangement** | 1.969 | 2 | 0.9846 | 4.57 |
| **Carbon filler** | 13.575 | 2 | 6.7876 | 31.47 |
| **Nano Aluminum Oxide filler** | 15.556 | 2 | 7.8782 | 36.53 |
| **Error** | 11.836 | 2 | 5.9179 | 27.44 |
| **Total** | 43.137 | 8 | | 100 |
| **TENSILE STRENGTH (MPa)** | | | | |
| **Fiber arrangement** | 103.202 | 2 | 51.601 | 78.6 |
| **Carbon filler** | 8.975 | 2 | 4.488 | 6.84 |
| **Nano Aluminum Oxide filler** | 14.782 | 2 | 7.391 | 11.26 |
| **Error** | 4.332 | 2 | 2.166 | 3.3 |
| **Total** | 131.293 | 8 | | 100 |

### 4.5.2 The Impact and Absorption Results Tests

The impact resistance test and water absorption test were carried out for the nine samples submerged in sea water for 14 days, impact resistance in accordance to (ISO 179) and water absorption according to (ASTM D790). Each test was repeated three times and the average results are shown in Table 4.15 with their S/N ratio. In Table 4.15 it is noticed that the maximum value of the impact resistance test is equal to 1.45 J/mm$^2$ in Experiment No. 2 which consists of (0/0 fiber orientation, 5% carbon filler and 1% Nano aluminum oxide filler). While the water absorption test showed that the lowest value was 1.109 gr in Experiment No. 1, which consisted of (0/0 fiber orientation, 2.5% carbon filler and 0% Nano aluminum oxide filler) as the minimum is the best.

It was found the value of the impact and absorption in the pure unsaturated polyester are 0.19 J/cm$^2$ and 1.16 gr respectively.

**Table 4.15:** Experimental results and their signal –to-noise ratio.

| Exp. No. | Impact | | Absorption | |
|---|---|---|---|---|
| | J/mm2 | S/N | g | S/N |
| 1 | 1.2 | 1.583 | 1.109 | -0.8986 |
| 2 | 1.45 | 3.227 | 2.168 | -6.721 |
| 3 | 1.4 | 2.922 | 1.563 | -3.879 |
| 4 | 0.65 | -3.741 | 1.671 | -4.459 |
| 5 | 0.85 | -1.411 | 1.998 | -6.011 |
| 6 | 0.45 | -6.935 | 1.622 | -4.201 |
| 7 | 0.35 | -9.118 | 1.578 | -3.962 |
| 8 | 0.25 | -12.041 | 1.488 | -3.452 |
| 9 | 0.35 | -9.118 | 1.631 | -4.249 |

### A. Analysis of Means (ANOM)

The average value of the experimental results was obtained for samples submerged in sea water as shown in Table 4.16. The ANOM results show that the fiber orientation is the most effective (Rank 1) in the impact resistance test, followed by the Nano aluminum oxide filler and finally the carbon filler, and for water absorption showed that carbon filler was the most effective (Rank 1), followed by Nano alumina oxide filler and finally the direction of fiber.

**Table 4.16:** Mean for each factor level.

| Parameter | Symbol | Average of different level | Max-Min | Rank |
|---|---|---|---|---|

| | | 1 | 2 | 3 | | |
|---|---|---|---|---|---|---|
| **Impact J/mm$^2$** | | | | | | |
| **Fiber arrangement** | **A** | 1.35 | 0.65 | 0.3167 | 1.0333 | 1 |
| **Carbon filler** | **B** | 0.7333 | 0.85 | 0.7333 | 0.1167 | 3 |
| **Nano Aluminum Oxide filler** | **C** | 0.6333 | 0.8167 | 0.8667 | 0.2333 | 2 |
| **Absorption g** | | | | | | |
| **Fiber arrangement** | **A** | 1.613 | 1.764 | 1.566 | 0.198 | 3 |
| **Carbon filler** | **B** | 1.453 | 1.885 | 1.605 | 0.432 | 1 |
| **Nano Aluminum Oxide filler** | **C** | 1.406 | 1.823 | 1.713 | 0.417 | 2 |

B. **Signal to Noise Ratio Analysis**

Signal to noise ratio is required to achieve optimum mechanical properties. Levels of control factors were found and listed in Table 4.17, and Figure 4.6 shows the mean distributions of S / N ratios. The set of optimal parameters for higher impact resistance are $A_1B_2C_3$ equivalent to (0/0 fiber orientation, 5% carbon filler and 3% Nano aluminum oxide filler) with 62% unsaturated polyester. The optimal parameters for the absorption test are $A_1B_1C_1$, equivalent to (0/0 fiber orientation, 2.5% carbon filler and 0% Nano aluminum oxide filler) With 67.5% polyunsaturated polyester.

**Table 4.17:** Average signal to noise ratio of different parameter levels.

| Parameter | Symbol | Average of S/N (dB) of different level | | | Max-Min | Optimum level |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | | |
| **Impact strength (J/mm$^2$)** | | | | | | |
| **Fiber arrangement** | **A** | 2.578 | -4.030 | -10.09 | 12.671 | $A_1B_2C_3$ |
| **Carbon filler** | **B** | -3.759 | -3.408 | -4.377 | 0.969 | |
| **Nano Aluminum Oxide filler** | **C** | -5.798 | -3.211 | 2.536 | 3.262 | |
| **Absorption test (g)** | | | | | | |
| **Fiber arrangement** | **A** | -3.833 | -4.891 | -3.888 | 1.058 | $A_1B_1C_1$ |
| **Carbon filler** | **B** | -3.107 | -5.395 | -4.11 | 2.282 | |
| **Nano Aluminum Oxide filler** | **C** | -2.851 | -5.143 | -4.618 | 2.293 | |

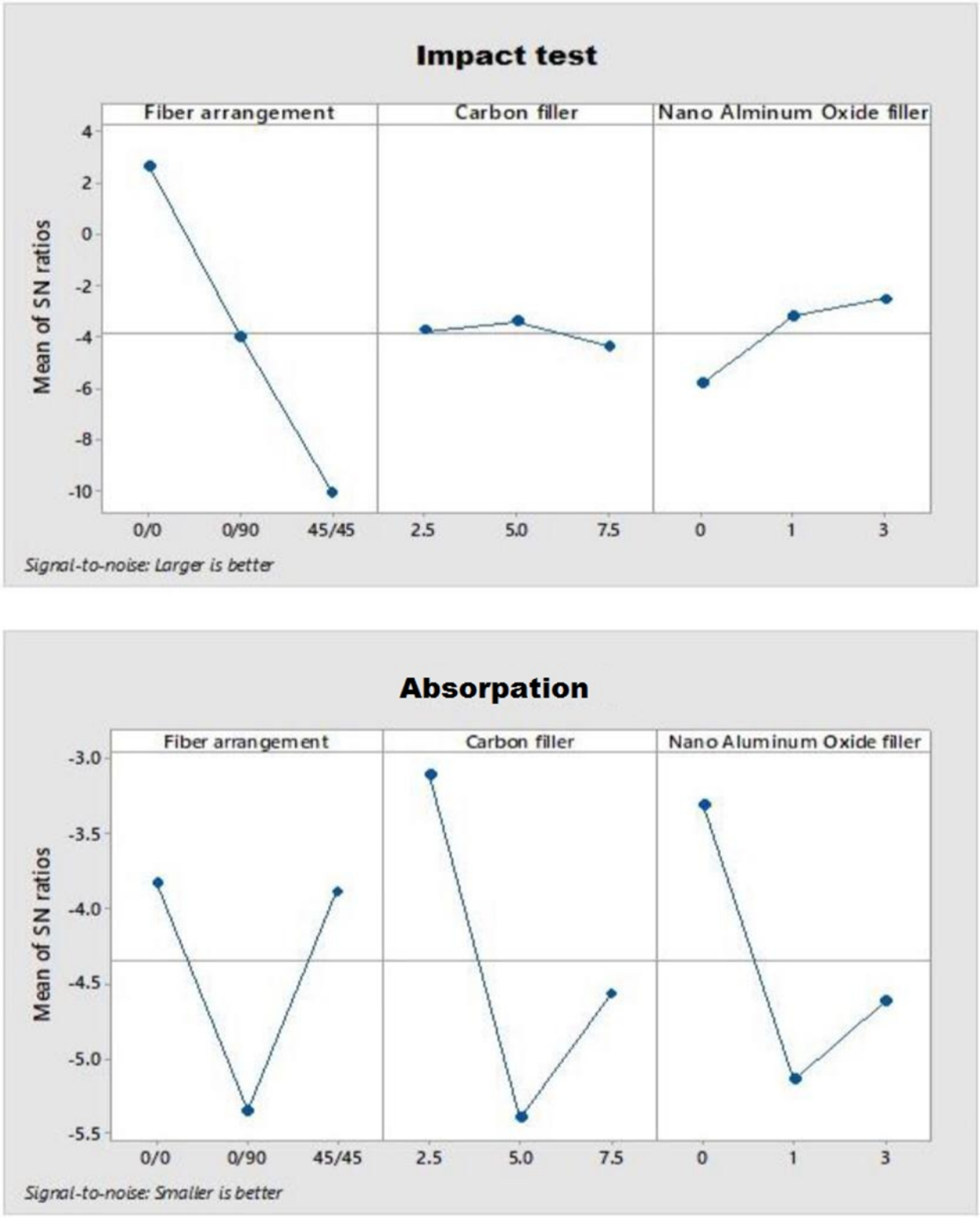



**Figure 4.6:** Average signal to noise ratio of different parameter levels.

## C. Analysis of Variance (ANOVA)

From Table 4.18, it can be seen that the prevailing factor is the direction of the fibers in impact resistance, with its contribution of 91.42%. This indicates that the fiber orientation is the most important among the other parameters, followed by the Nano aluminum oxide filler with a contribution of 6.75% and the carbon filler with a contribution of 0.55%. The Nano aluminum oxide filler was the most effective in the water absorption among other parameters, with its contribution of 40.58%, followed by carbon filler, where its contribution with 37.02% and finally the fiber direction, where its contribution with 9.98%.

**Table 4.18:** ANOVA results of mechanical properties.

| Parameters | | Degree of Freedom | Mean Squares | Contribution (%) |
|---|---|---|---|---|
| **IMPACT STRENGTH (J/mm$^2$)** | | | | |
| **Fiber arrangement** | 240.967 | 2 | 120.484 | 91.42 |
| **Carbon filler** | 1.444 | 2 | 0.722 | 0.55 |
| **Nano Aluminum Oxide filler** | 17.787 | 2 | 8.893 | 6.75 |
| **Error** | 3.375 | 2 | 1.688 | 1.28 |
| **Total** | 263.573 | 8 | | 100 |
| **ABSORPTION TEST (g)** | | | | |
| **Fiber arrangement** | 2.128 | 2 | 1.064 | 9.98 |
| **Carbon filler** | 7.894 | 2 | 3.947 | 37.02 |
| **Nano Aluminum Oxide filler** | 8.656 | 2 | 4.328 | 40.58 |
| **Error** | 2.649 | 2 | 1.325 | 12.42 |
| **Total** | 21.327 | 8 | | 100 |

## 4.6 CONFIRMATION TEST

Taguchi's method confirms the results of the analysis [16]. The optimum levels of practical parameters obtained by analyzing the signal to noise ratio and laboratory results of mechanical and physical properties were used for the purpose of developing the confirmation test. The values of the optimum levels were used together with the mean value of each of the signal to noise ratio. The confirmation test done using equation (2.28).

Elastic modulus, tensile strength, impact strength and water absorption were obtained by combining the optimal parameters and their levels which are $A_2B_2C_1$, $A_1B_2C_2$, $A_1B_2C_3$ and $A_1B_1C_1$ respectively. The tensile strength value of group $A_1B_2C_2$, which is equivalent to experiment No. 2, as well as the lowest value of water absorption in group $A_1B_1C_1$, which is equivalent to experiment No. 1, while the other two combinations not have experiment test. So, the combinations of $A_2B_2C_1$ and $A_1B_2C_3$ sample sets are prepared and the experimental test done. Table 4.19 shows the results of the confirmation test. The experimental and expected results are very close with an error not exceeding 5%. This results from the fact that the result of the experiment is related with the expected result.

**Table 4.19:** Confirmation results for samples without immersion in water.

| characteristic | Optimum Parameter | | | |
|---|---|---|---|---|
| | Level | Experiment | Predication | Difference (%) |
| Modulus of elasticity (GPa) | $A_2B_2C_1$ | 1.03 | 1.04 | 0.96 |
| Impact strength (MPa) | $A_1B_2C_3$ | 2.225 | 2.325 | 4.3 |

In the case of samples that were immersed in sea water for 14 days, the elastic modulus, tensile strength, impact strength and water absorption were obtained by combining the optimum parameters and their levels which are $A_2B_3C_2$, $A_1B_2C_2$, $A_1B_2C_3$ and $A_1B_1C_1$ respectively. The tensile strength value of group $A_1B_2C_2$, which is equivalent to experiment No. 2, and the water absorption in group $A_1B_1C_1$, which is equivalent to experiment No. 1 are presented, while the other two combinations not have experiment test. So, the combinations of $A_2B_3C_2$ and $A_1B_2C_3$ sample sets were prepared and the pilot test performed. Table 4.20 shows the results of the confirmation test as it was found that the experimental and expected results are very close with an error not exceed than 4%.

**Table 4.20:** Confirmation results for samples immersion in water.

| Characteristic | Optimum Parameter | | | |
|---|---|---|---|---|
| | Level | Experiment | Predication | Difference (%) |
| Modulus of elasticity (GPa) | $A_2B_3C_2$ | 0.96 | 0.98 | 2 |
| Impact strength (MPa) | $A_1B_2C_3$ | 1.51 | 1.45 | 3.9 |

# 5. CONCLUSIONS AND RECOMMENDATIONS

## 5.1 CONCLUSIONS

The effect of reinforcement on the mechanical and physical properties of composite material had been experimentally investigated using Taguchi technique.

The following conclusion be drawn:

A. The glass fibers orientation angle presents the most parameter effect than the other parameters on the elasticity modulus, tensile resistance and impact resistance with a contribution of 81.8%, 83.39% and 96.75% respectively, followed by carbon and aluminum oxide Nano filler. This is because the reinforcement with fibers gives greater resistance to the forces applied to the samples than the reinforcement with the particles because the fibers bear the largest part of the forces applied to the samples. As well as this resistance depends on the direction of the fibers.

B. Carbon filler is the most parameter effect on the water absorption test than the other parameters with a contribution of 44.31%, followed by fiber orientation angle and aluminum oxide Nano filler. This is probably due to the hydrophilic nature of the composite in the given composition.

C. The sea water influences the parameter and their level effect on the composite properties in which the most parameter effect than the other parameters on the modulus of elasticity and water absorption is the aluminum oxide nano filler, followed by the carbon filler and finally the direction of the fiber. The most parameter influence on the tensile resistance and impact resistance is the direction angle of the fiber, because the fibers bear the largest part of the forces applied to the samples, as well as this resistance depends on the direction of the fibers.

D. The optimum parameter with their levels for the highest elastic modulus was obtained at (0/90 fiber orientation, 2.5% carbon and 1% Nano aluminum oxide filler). While the highest tensile resistance and impact resistance present with using (0/0 fiber orientation, 5% carbon filler and 1 aluminum oxide nano filler).

E. The lowest value of water absorption was at (0/0 fiber orientation, 2.5% carbon filler and 0% aluminum oxide Nano filler).

F. The experimental and expected results are very close, with error not exceeding 5%.

## 5.2 FUTURE RECOMMENDATIONS

A. Studying other mechanical characteristics such as (wear, fatigue, creep, dynamic fracture strength and stability of dimensions).

B. Studying using other polymeric materials such as epoxy.

C. Examining other types of fibers such as Kevlar or nylon fibers.

D. The prepared samples were immersed for a longer period in sea water, then mechanical and physical properties tests were performed on them.

E. Studying the effect of other types of natural reinforcing powder fillers with different sizes and different weight ratios.

F. Studying the effect of other solutions on composite materials such as acidic solutions.

G. Observing the effect of coating the prepared composite material to reduce water absorption and maintain mechanical properties.

# REFERENCES


[1] G. G. Mecrum, C. P.Buckley , & C. B. Bucknall, "Princples of polymer engineering", 2nd Ed., Oxford University Press, (1997).

[2] G. Abd Al Adam, H. A. Kashif, “Technology and Polymers Chemistry”, Basra University Press, Basra, (1981).

[3] H. A. Wichman., "Materials science and metallurgy", 3rd Ed., Reston Publishing Company, Inc., (1981).

[4] W. D. Callister, Jr., "Materials science and engineering an introduction", 5th Ed., John Wiley & Sons, Inc., (2000).

[5] A.P. Mouritz, Z. Mathys. “Post-®re mechanical properties of marine polymer composites”, DSTO, Aeronautical and Maritime Research Laboratory, P.O. Box 4331, Melbourne, Vic. 3001, Australia, 1999.

[6] O. S. Muhammed, H. R. Saleh and Hussam L. Alwan, “Using of Taguchi Method to Optimize the Casting of Al–Si /Al2 O3 Composites”, Eng. & Tech. Journal, Vol.27, No.6, 2009.

[7] A. Wadi, “Studying Some of the mechanical &thermal properties of polyester reinforced with ceramic particles”, Diala Journal, Vol. 37, 2009.

[8] S. E. Saleh, K. M. Shabib and Q. A. Hamad, “Studying Mechanical Properties For Polymer Matrix Composite Material Reinforced By Fibers And Particles”, Journal of Engineering and Technology, Vol. 28, Issue 4, 2010.

[9] A. I. Al-Mousawi and F. J. Kazem, “Effect of reinforcing by different percentage of fibers on mechanical properties of vinyl ester resin”, Iraq, 2010.

[10] F. H. Anter and H. S. Hasan, “Effect of Water Absorption on Hardness Property for Epoxy Reinforced by Glass Fibers”, Journal of university of Anbar for Pure science, Volume 5, Issue 3, Pages 23-28, 2011.

[11] A. Hussein, L. Waddah, A. Muhammad, “Studying some properties the mechanism of a polymeric material reinforced with copper brushes and powder", Journal of Engineering, Volume 18, Issue 5, 2012.

[12] M. M. Abd, H. I. Jaffer and E. A. Al-Ajaj, "Comparison study of some mechanical properties of micro and nano silica EP composites",Iraqi Journal of Physics, Vol. 10, No.18, )º50º( PP. 62-68.

[13] M. G. Hamad, “Effect of water on the impact resistance of unsaturated polyester composites reinforced with glass fibers”, College of Science, Anbar University, Iraq, Anbar Journal for Engineering Sciences, 2012.

[14] O. S. Muhammad, M. H. Abdul Majeed, I. A. Kazim, “Evaluation Study of Glass Fiber Reinforced Polyester and Kevlar Reinforced Polyester by Taguchi Method”, Department of Materials Engineering, University of Technology, Iraq, Al-Khwarizmi Engineering Journal, Vol. 8, No.4, PP 53 -61(2012).

[15] F. M. Mohammed and D. A. Smait, “Mechanical and Tribological Behavior of Glass-Polyester Composite System Under Graphite Filler Content”, Electromechanical Engineering Department, University of Technology /Baghdad, Iraq, Eng. &Tech. Journal, Vol. 30, No.4, 2012.

[16] S. D. Salman, “Experimental Measurements of the Mechanical Behavior of the Composite Materials and Hybrid Materials Subject to Tensile Test”, Al-Mustansariya University, College of Engineering Materials Engineering Department, Iraq, Journal of Engineering and Development, Vol. 71, No.1, Mar. 2013, ISSN 1813- 7822, 2013.

[17] Al-Ajaj , Ikram A., Abd, Muhannad M. and Jaffer, Harith I.," Mechanical Properties of Micro and Nano TiO2/Epoxy Composite ", International Journal of Mining, Metallurgy & Mechanical Engineering (IJMMME) Volume 1, Issue 2 ISSN 2320–4060, 2013.

[18] F. H. Antar and H. S. Hassan, “Study the mechanical properties of rglass fiber reinforced unsaturated polyester resin” Anbar University Journal of Pure Sciences, 2014.

[19] A. M. Ali, H. M. Mahmoud and N. S. Ibrahim, “The mechanical properties of the Composites (unsaturated polyester/ filling material) reinforced by fiberglass”, Tishreen University Journal for Research and Scientific Studies - Engineering Sciences Series Vol. (73) No. (1) 2015.

[20] M. chache, “Studying the mechanical properties of composite material based on unsaturated polyester reinforced with random fiberglass”, Al-Baath University Journal, Volume 73, Number 10, 2015.

[21] B. Naga Raju, K. Ramji and V. S. R. Prasad, “Mechanical Properties of Glass Fiber Reinforced Polyester ZnO NanoComposites”, Materials Today: Proceedings 2 (2015) 2817 – 2825, India, 2015.

[22] A. B. Abdul-Hussein, F. A. Hashim and T. R. Kadhim, “Effect of Micro Powder on Mechanical and Physical Properties of Glass Fiber Reinforced Epoxy Composite”, Materials Engineering Department, University of Technology/Baghdad, Iraq, Eng. &Tech.Journal, Vol.34, Part (A), No.7,2015.

[23] Sihama. J. H.  Studying the Flexural Properties and max shear stress of self cure pmma resin for denture application”, the Iraqi Journalfor materials Engineering , Vol.17, Dec. (2017).

[24] A. B. Abdul-Hussein, F. A. Hashim and T. R. Kadhim, “Effect of Nano Powder on Mechanical and Physical Properties of Glass Fiber Reinforced Epoxy Composite”, Department of Materials Engineering/ University of Technology, Al-Khwarizmi Engineering Journal,Vol. 12, No. 3, P.P. 72- 79, 2016.

[25] F. M. Mohammed, “Mechanical properties investigation of composite material under different parameters variations”, Al-Khwarizmi Engineering Journal,Vol. 13, 2016.

[26] F. A. Hashim, M. S. Hamza, and R. R. Abdulla, “Study the Mechanical and Physical Properties of Polyester Composite Reinforced by Multi Layers”, Materials Engineering Department, University of Technology/Baghdad, Iraq, Engineering and Tech. Journal, E Vol.34, Part (A), No.9, 2016.

[27] A.Gnanavelbabu, P.Saravanan, K.Rajkumar, P.Sabarinathan and S.Karthikeyan, “Mechanical strengthening effect by various forms and orientation of glass fibre reinforced isopthalic polyester polymer composite”, Materials Today: Proceedings 5 (2018) 26850–26859, India, 2016.

[28] A. H. Muhammad, “Comparison of the bending strength of a polymeric and fibrous composite material by two methods of triple and quadruple point bending”, Journal of college of education, No1, Department of Applied Sciences / University of Technology, Iraq, 2017.

[29] M R Sanjay and B Yogesha, “Studies on Natural/Glass Fiber Reinforced Polymer Hybrid Composites: An Evolution”, Visvesvaraya Technological University, Belagavi, Karnataka, India, 2017.

[30] A. J. Muhammad, A. Abbas and I. K. Ibrahim, “The effect of adding aluminum powder on the bending and burning resistance properties for unsaturated polyester polymer”, University of Aden Journal of Natural and Applied Sciences, Vol. (22), No. (2), 2018.

[31] Reem Alaa Mohammed, Ruaa Haitham Abdul Raheem and Shaymaa Hasan Khazaal, “Wear Behavior Performance of Polymeric Matrix Composites Using Taguchi Experiments”, Al-Khwarizmi Engineering Journal, Vol. 15, No. 4, December, 2019.

[32] R. Guobys, A. Rodríguez and L. Chernin, “Cavitation erosion of glass fibre reinforced polymer composites with unidirectional layup”, 2019.

[33] S. Kumar, B. G. Falzon, J. Kun, E. Wilson, G. Graninger and S. CHawkins, “High performance multiscale glass fibre epoxy composites integrated with cellulose nanocrystals for advanced structural applications”, Monash University, Clayton, Victoria 3800, Australia, 2020.

[34] D.R.Askeland, “The Science and Engineering of Materials”, Wadsworth, Inc., California, 1984.

[35] Department of Defense Hand Book, "Composite Material Hand Book", Polymer Matrix Composites, Vol. 1, U.S.A, 2002.

[36] D. Jasterzebski,"The Nature and Properties of Engineering Materials", 2nd ed., John Wiely, New York, 1977.

[37] F. Rodriguez, "Principle of Polymer System" 2nd ed., McGraw - Hill, New York, 1985.

[38] E. England and D. Lother, "Atlas of Polymer Damage" John Wiely, New York, 1981.

[39] M. Mickel & P. Groover, "Fundamental & Modern Manufacturing" Published by McGraw - Hill, New York, 1996.

[40] G. S. Misra, "Introductory Polymer Chemistry", New Age International LTD, Publishers, New Delhi, 1993.

[41] L. Holliday, "Composite Material", Elsevier Publishing, London, 1966.

[42] S.M. Lee Editer," International Encyclopedia of Composite" VCH Publishers, Inc., (1990).

[43] G. Piatti,"Advances in Composite Materials", Applied Science Publishers LTD, 1978.

[44] M. M. Schwartz "Composite Materials Hand Book", McGraw Hill Company, New York, 1984.

[45] R. J. Crawford," Plastic Engineering", 2nd ed., Pergamonl Press, U.K, 1987.

[46] R. P. Sheldon," Composite Polymeric Material" School of Materials Science Publishing, London, 1982.

[47] L. J. Broutman & R. H. Krock, "Modern Composite Material", Eddison Wisely, London, 1967.

[48] A. D. Jayatilaka, "Fracture of Engineering Brittle Materials", Applied Science, London, 1979.

[49] W.D.Callister,JR., "Materials Science and Engineering An Introduction", 6th ed., John Wiely and Sons,Inc., New York, 2003.

[50] J. W. Phillips "Behavior of Engineering Materials", the Board of Trustees of the University of Illinois at Urbana-Champaign, 1997.

[51] J. A. Manson, "Polymer Blends and Composite", Leaslie H. Speling, New York, 1978.

[52] L. J. Broutman and R. H. Krock, "Composite Materials", Vol.5, Academic Press, Inc., London, 1970.

[53] R. Kleinhdz & J. Molinir, " Vetrotex Fiber Work ", Journal of Materials Science, Vol.22, 1986.

[54] A. C. Moloney, H. H. kausch and H. R. Beer, " Review Parameters Determining the Strength and Toughness of Particulate Filled Epoxide Resins", Journal of Materials Science, Vol.22, No. 2, 1987.

[55] J. Stepek and H. Daoust, "Additives for Plastics", Springer- Verlag New York Heidelberg, Berlin, 1983.

[56] J. Spnoudakis and R. J. Young, "Crack Propagation in a Glass Particle- Filled Epoxy Resin", Journal of Materials Science, Vol.19, 1984.

[57] L. J. Broutman, "Composite Materials, Fracture & Fatigue", Academic Press, Inc., London, 1974.

[58] L. Mascia, "The Role of Additivesin Plastics", Edward Arnold Publishers LTD, London, 1974).

[59] D. Hull, "Introduction to Composite Materials", Cambridge University Press, U.K, 1981.

[60] K. K. Chawla," Composite Materials", Springer Netherlands Inc., New York, (1987).

[61] W. N. Findley, J. S. Lai &Kasifonaran,"Creep and Relaxation of Nonlinear Viscoelastic Material", Published by North- Holland Publishing Company, Amsterdam, New York, Oxford, 1976.

[62] A. G. Evans, S. Williams & P. W.R. Beaumont, "On the Toughness of Particulate Filled Polymers", Journal of Materials Science Vol.20, No.10, 1985.

[63] Q. Al-Khazraji, “Principles of Non-Metallic Engineering”, Babylon University, Faculty of Engineering, 1994.

[64] H. Ali, “Polymer Technology and Chemistry”, College of Science, University of Basra, Iraq, 1983.

[65] A. A. Rajab, "Study of Mechanical Properties of Composite Materials and Hybrid Composite Materials", Master Thesis, University of Technology, 1996.

[66] J. P. Schaffer, A. Saxena, " The science and Design of engneering materials ", Richard D.Irwin,Inc,1995.

[67] K. Othmar, “Encyclopedia of Chemical Technology”, Tom Wiley & Sons Inc., Canada, 1982.

[68] A. M. Abdulla, "Study of the Effect of Shear Stress on the Mechanical Properties of an composite material with a polymeric basis and Reinforced by Steel Fibers", Master Thesis, Materials Engineering, University of Technology, 2006.

[69] E. P. Garmo, J. T. Black, R. A. Kohser and B. E. Klamecki, "Materials and Processes in Manufacturing", 9th Edition, John Wiley and Sons, Inc., 2003.

[70] J. Stepek and H. Daust," Additive for Plastic", New York , 1983.

[71] Z. A. Ismail, "Study of Physical Properties of Reinforced Polymers", Master Thesis, Mustansiriya University, 2004.

[72] A. Prota, K. Y. Tan, Antonio Nanni, Marisa Pecee and Gaetano Manfreeli, "Performance of Shallow RC Beams With Externally Bonded Steel Reinforced Polymer", 2004.

[73] J.E. Mark " The science and technology rubber",Third edition, New york ,2005.

[74] M. Morton, "Rubber Technology", Van Nestrand Reinhold, New York, 1973.

[75] L. Robert & P. E. Mott," Applied Strength of Materials", 3th ed. University of Dayton, Ohio, U.S.A, 1996.

[76] B. Segmour & S. Raymond," Modern Plastic Technology", Publishing Company, Inc., London, 1975.

[77] N. G. Mccrum, C. P. Buckley & C. B. Bucknall "Principles of Polymer Engineering", 2nd ed., John Wiley & Sons, New York, 1997.

[78] M. I. Omar, Technology for the manufacture of reinforced plastic", House of Scientific Books for Publishing and Distribution, Baghdad, 2001.

[79] C. Abd Al Adam and D. M. Aziz, “The Chemistry of Large Molecules”, Basra University printing house, Iraq, 1980.

[80] H. F. Mark and J. I. Kroschwitz, "Encyclopedia of Polymer Science and Engineering", John Wiley and Sons, New York, 1988.

[81] G. Lubin, "Hand – Book of Composite", Van Nostrand Reinhold, New York , (1982).

[82] M. B. Sevensen, translated by K. G. Al-Lami and Q. A. Ibrahim, “Polymerase Chemistry”, Department of Chemistry, College of Science, Basra University, iraq, 1984.

[83] Q. K. Jabouri, “Study of the Mechanical Properties of Composite Materials Reinforced with Metal Wire”, Master Thesis, Engineering of Machinery and Equipment, University of Technology, Iraq, 1998.

[84] M. I. Omar, "Encyclopedia of Plastic Raw Materials", Dar Al-Kutob of the scientific for Publishing and Distribution, Iraq, 2002.

[85] F. W. Billmeyer ," Text book of polymer science ", Wiley , Inc.New York,1971.

[86] Z. A. Ismail, "Study of Physical Properties of Reinforced Polymers", Master thesis, Mustansiriya University, Iraq, 2004.

[87] D.R.Paul and S.Newman ,"Polymer Blends ", Vol.1,Acadimic press , Inc,New York , 1978.

[88] S. Goodman, "Plastic Materials & Processes", Van Nostand Reinhold, New York, 1982.

[89] T. J. Reinhart, "Engineering Material Hand Book", Vol.1, ASM International, U.S.A, 1988.

[90] D. R. Askeland & P. P. Phule, “The Science & Engineering of Materials", 4th ed., 2003.

[91] M. Li, “Temperature and moisture effects on composite materials for wind turbine blades”, Montana state university-Bozeman bozeman, Montana, 2000.

[92] S. Thamizhmanii, “Analysis of surface roughness by turning process using Taguchi Method”, Journal of Achievement in Materials and manufacturing engineering, vol. 20, 1-2, pp. 503–506, 2007.

[93] B. Berginc, Z. Kampus, B. Sustarsic, “The use of the Taguchi Approach to determine the influence of injection-moulding parameters on the Properties of green parts”, Journal of Achievements in Materials and Manufacturing Engineering, 15,pp. 63-70, 2006.

[94] "Technical Data Sheet", Industrial chemicals & resins Co. Ltd, Dammam, Saudi Arabia, 2009.

[95] G. Lubin, "Handbook of Composites", Van Nostrand Reinhold, USA, 1982.

[96] W. D.Callister, “Materials science and engineering an Introduction”, 6th ed., John Wiely and Sons, Inc., New York, 2003.

[97] ASTM Designation: D 638-03, “Standard test method for tensile properties of plastics”, ASTM international.

[98] Annual Book of ASTM Standard, "Standard Test Method for Plastics Properties-Durometer Hardness", D 2240-03, PP. (1-12), 2003.

[99] ISO 179-1982 (E),” Plastics-Determination of Charpy impact strength of rigid material”, International standard.