زانکۆی پۆلیتەکنیکی هەولێر
ERBIL POLYTECHNIC UNIVERSITY

An Experimental and Numerical Investigation of Mechanical Properties of Unidirectional Fiber Epoxy Composite.

A Thesis

Submitted to the Council of the Erbil Technical Engineering College at Erbil Polytechnic University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

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DECLARATION

I declare that the Master Thesis entitled ***An Experimental and Numerical Investigation of Mechanical Properties of Unidirectional Fiber Epoxy Composite*** is my own original work, and I hereby certify that unless stated, all work contained within this thesis is my own independent research and has not been submitted for any other degree at any institution, except the acknowledgement which made in the text.

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DEDICATION

This dissertation is for my most beloved Mother (Mrs. Fawzia) Thank you for giving me all your supports, endless prayers and encouragement for finishing up my dissertation and reach to my dream.

To my father's purest soul (Engineer Jalal) RIP.

To my beloved husband (Ramar) who has been a constant source of support and encouragement during my studies. I am truly thankful for being a part of my life.

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ABSTRACT

The composite of carbon fiber and fiber glass received enormous attention from research communities in the field of epoxy layers of composite. In this study, the mechanical properties of the epoxy and Unidirectional Carbon with fiberglass composite in different volumes of fraction in fibers were experimentally and computationally investigated. American Society for Testing and Materials (ASTM) used in this study for preparing the composite samples. Tensile, impact and flexural tests were conducted to investigate the mechanical properties of the new produced of epoxy Unidirectional Carbon and Epoxy Fiberglass composites. The outcome of the experimental demonstrated that the strength of the produced samples increased with the increase in the number of Unidirectional Carbon layers and the maximum rate was % 15 of lower density of epoxy resin and other was % 5.5. In addition, four different composites were utilized: (1) woven carbon composite with glass fiber (2) woven carbon with epoxy resin composite. (3) Fiber glass with epoxy resin composite (4) Epoxy resin only. While the process of comparing the result in computational way by using Finite Element Method and using ANSYS 2022 R1 Work bench noted that the computational samples are stronger than experimental tested samples, because of the inter face reactions between and bonding in actual situation don’t takes place completely for the purpose of using hand lay-up method for conducting samples in experimental. When comparing the strengthen of two reinforcement fibers the results explained that woven carbon composite has higher mechanical resistance. While in tensile and impact tests the strength of samples increased with adding layers of wight percentage (1.5% UDC by 3% fiber glass), (3% UDC by 1.5% fiber glass) and (3% UDC by 3% fiber glass) of mixture of and epoxy resin. Meanwhile, in flexural test the most strengthen sample was with the one that contains highest layer of percentage which was 15% of fiber glass for the first group of

Master Protect 180, while in the second group Master Brace ADH 1406 the most strengthen sample was with the one which contains unidirectional carbon fiber layers.

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LISTS OF ABBREVIATION

UDC	Unidirectional Carbon
F.G	Fiber Glass
CMC	Ceramic Matrix Composite
MMC	Metal Matrix Composite
PMC	Polymer Matrix Composite
CF	Carbon Fiber
FEA	Finite Element Analysis
ITER	Thermonuclear Experimental Reactor
ASTM	American Society for Testing and Materials
CNC	Computerized Numerical Control
RVE	Representative Volume Element
J	Joule
N	Newton
MPa	Mega Pascal
µm	Micro meter
PEEK	Polyether ether ketone
℃	Celsius
gm	gram

cm	Centimeter
ε	Strain
μ	Micro
σ	Stress

CHAPTER ONE

INTRODUCTION

1.1 Introduction

The composite material or (Composites for short) consist of two or different material in different physical and mechanical properties, the mixture gives a single compound material with different properties. In general, there are two components of composite Matrix and Reinforcement. About reinforcement material transports their properties to improve the matrix's mechanical and physical properties. Due to their strength and lightweight advantages over traditional materials, composite materials provide a wide range of possible applications. For instance, certain sectors are creating "smart" composite materials, which may be able to sense, act, calculate, communicate, and have other qualities. Engineers need to have a good grasp of these materials' behavior before they can be used to design composite structures (Soami, 2018).

Over the recent decades, the demand for using composite and the trend of mixing materials have been widely increased. As a result of high stiffness, low density, cost and wight that leads composite materials being progressively used. Especially in aerospace and transportation industry the reinforcement fiber and the plastic epoxy were upgraded. Moreover, the strength and stiffness of the composite material is

high compared to its cost that leads to be more economical which is strength to – cost ratio and strength – wight ratio (Tabatabaei, 2016). As well as, making a small comparison between metal, ceramic and polymer composite materials, it can be seen that polymer composite have a large variety, because they have properties which is different from metals, typically soft and flexible (THE and SCIENCE, 2022).

To address the issues of high-performing material qualities aimed at engineering and for structural applications, composite materials have been well developed. Composite materials provide engineers with various mechanical, thermal, chemical, and damage-tolerance advantages with few downsides, such as brittleness, due to their higher capacity to absorb stresses and disperse strain energy compared to other materials, such as polymers and ceramics (Low and Dong, 2021).

For mass reduction, carbon fiber reinforced polymers are becoming more and more popular in the luxury and sporting goods sectors. These materials are expensive and are better suited for low volume manufacturing because of the long molding cycle durations. They may also be reinforced with glass or other fibers. In the past few years, new technology to lower the cost of fiber and panel processing has been in the news, and the rising use is a promising sign that progress is being achieved. Over in the coming years, more updates and applications are anticipated to be announced. Application to other popular, less expensive vehicle sectors is not anticipated to happen anytime soon, though (Fekete and Hall, 2017).

Due to their superior strength and low specific weight, composite materials are made of carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP), among other fiber reinforced materials, are displacing conventional materials more and more. These materials are a great choice for engineering applications due to their high fatigue, toughness, high temperature wear, and

oxidation resistance qualities, as well as their ability to be manufactured in a variety of combinations with specific strength properties (Karataş and Gökkaya, 2018).

1.2 Classification of Composite material

There are three different kinds of composite materials: Ceramic-Matrix Composites, Polymer Matrix Composites, and Metal Matrix Composites. As illustrated in Figure 1.1, these materials are widely used in a variety of technical applications.

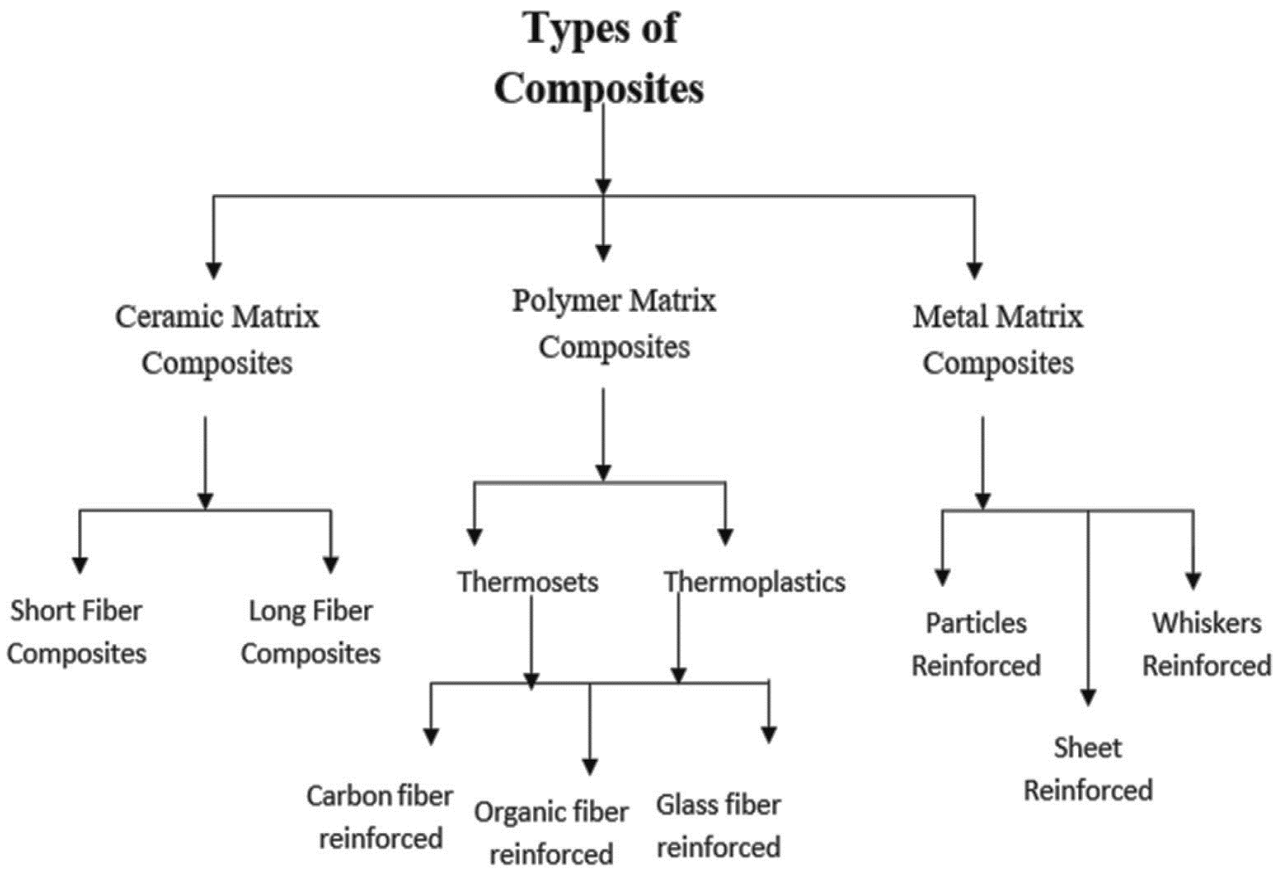


Figure 1. 1 composite materials classifications (Singh et al., 2020a)

1.2.1 Ceramic Matrix Composite (CMC)

Technical ceramics and composite materials are combined to create a ceramic matrix composite (CMCs). They are made of ceramic fibers that are tangled in a ceramic matrix to create a material that reinforced with ceramic fibers. CMCs are strong despite having brittle elements because of the fiber matrix interface's excellent design, which deflects and arrests matrix cracks to keep the fibrous reinforcement from failing (Zhang, 2014). A distinctive and relatively recent class of structural materials are CMCs. A considerable variety in mechanical and thermophysical properties can be achieved, leading to the new applications, depending on the method of processing and the type of inner phase or interface (Krenkel and Reichert, 2018). Ceramic matrix composites (CMCs) have created and used for components that operate in tough corrosive conditions with high temperatures because they are among the most promising thermos structural materials for ultra-high-temperature applications (above 1300 °C), in the aerospace industry as well as the automotive and energy technologies including ultra-high temperatures and extreme loads. The primary goal of both oxide and non-oxide CMC development is to make ceramics are more durable. The basic function of ceramic matrix reinforcements is to support brittle ceramic matrix that has toughness in order to stop crack growth and avoid catastrophic failure (Zivic et al., 2021) and (Mutin, 2003).

1.2.1.1 Ceramic Fibers Composite

From the last few decades, the utilization of ceramic fibers in composite applications has attracted great attention. Because of its excellent thermal tolerance and resistance to corrosion, continuous ceramic fibers and filaments are frequently used in high-temperature applications instead of metals. Depending on the application area,

ceramic fibers can be generated in a variety of ways, including blankets, felts, bulk fibers, vacuum-formed or cast shapes, paper, and textiles (Yalamaç et al., 2017). Because organic, polymeric fiber materials degrade at temperatures below 500 ° C, they cannot be standard in CMCs. Additionally, standard glass fibers with melting or softening temperatures under 700 °C temperatures are unsuitable for using as a reinforcement with CMSs. Amorphous inorganic fibers, as well as carbon fibers are good candidates for the use as reinforcement in ceramic materials. With the exception of fibers produced by the solidification of glass melts, all non-metallic, inorganic, oxide or non-oxide fibers are referred to as "ceramic fibers" (Clauß, 2008). Numerous components are utilized in the automotive and aerospace sectors, for instance, are made from short fiber-reinforced composites. Modeling the fatigue behavior of injection-molded, fiber glass-reinforced PEEK thermoplastic polymer composite laminates allowed researchers to assess the hybrid formulation's applicability ((Vassilopoulos, 2015). Despite having significant poorer mechanical characteristics than long fiber reinforced ceramic matrix composites, short fiber reinforced ceramic matrix composites (SF-CMCs) offer, a compelling alternative. This kind of ceramic matrix composite has found success in lightweight components for frictional applications like brake disks, pads, and gear linings as well as in combustion conditions like nozzles and burners, telescopes, heat treatment, and aerospace (CMC) (Krenkel et al., 2021).

1.2.2 Polymer Matrix Composite (PMC)

Different kinds of organic polymers make the continuous phase of the polymer matrix composites (PMC), whereas reinforced fibers compensate the dispersed phase. In order to effectively transfer load between the fibers, the continuous phase acts as a matrix to hold the fibers together. The matrix serves as a vital framework for evenly distributing the fibers throughout the structure. Because of this, the

matrix, reinforcing fibers, and the interphase contents of PMC affect its mechanical and the physicochemical properties. The PMC's fracture toughness, tensile strength, and stiffness are modified by the reinforcing fibers. Scientists around the world is interested in polymer matrix composites (PMCs) as high performance unique engineering materials (Mirzaei et al., 2021). Due to their low cost, straightforwardness , and adaptability fabrication procedures, PMCs are widely used in modern life in the form of items Ranging from device components to an enormous collection of car components (Devaraju et al., 2021). The applications that use PMC are in the branches of automobile , aerospace, marine , bio medical and electrical, as well, used in sports equipment ,industrial and protective equipment (Jose and Joseph, 2012) , (Wang et al., 2011). Glass fibers, carbon fibers, aramid fibers, or even natural fibers like grass or flax are the principal pack fibers. Polyester resin, epoxy resin, and thermoplastics like polylactide are the related matrix materials. Typically, low viscosity matrix is infused into fiber preforms such as multilayers, 2D, or 3D reinforced fabrics, or felts.

Due to their inherent mechanical behavior, chemical stability, physicochemical versatility, and functional tunability, thermoplastic and thermosetting polymers are a good option. Additionally, plastics have desirable and undeniable qualities that make them ideal for this particular application, such as easy processing, high production, cost-effectiveness, impressive sterilization susceptibility, and the capacity to induce or improve biomaterial-related functionality (Bîrcă et al., 2019). One of the most adaptable thermoset materials is epoxy resin. As well thermosets are a particular class of polymers that form well-defined, irreversible, chemical networks that tend to grow in three-dimensional directions. There are many other applications for them as well, including high performance composites for the aerospace and automotive industries, etc. (McKenna and Simon, 2002) and

(AlMaadeed et al., 2020). thermoplastics are addition polymerized polymers that are straight or slightly branched. Due to the weak intermolecular forces of attraction holding the polymer chains together, thermoplastic polymers can soften when heated and harden when chilled (Deb et al., 2019). In next sections both thermoset and thermoplastic will defined and more deeper.

1.2.2.1 Thermosets

For the purpose of their high cross-linking density, Thermoset reins are particularly adaptable for industries that require qualities like their high modulus, strength, durability, and resistance to heat and chemicals. The reason is that after curing or polymerizing, thermosetting resins have very little impact resistance and cannot be reshaped. There are many thermosets available, including polyesters, polyurethanes, epoxy resins, and phenol formaldehyde resins. Additionally, thermosets are used in industrial applications like building materials and transportation to improve performance and impact resistance (Asim et al., 2017). As well, epoxy resin composites have light weight, desirable mechanical qualities, and ability to be molded into complex shapes. Researches have seen increasing application in the aerospace industry in recent years. Epoxies have a wide range of uses in composites due to their chemical and because of its high thermal resistance, as well as good thermomechanical qualities such as strength, modulus of elasticity and glass transition temperatures, which can be changed by modification through chemical composition and kinetic manipulation (Thakre et al., 2011a, Thakre et al., 2011b). The thermoset composites, particularly in high-performance materials, can utilize the epoxy matrix the most. To increase their resistance and for identify the reason of deformation, and it is therefore highly recommended to investigate the deformation of composites based on this matrix (Abdellaoui et al., 2019).

1.2.2.2 Thermoplastics

Thermoplastic matrix composites have been studied for use in aerospace applications since the 1970s, which is a long time ago (Pemberton et al., 2018).

Here are the most well-known thermoplastics that are famous

- The Polyethylene is used the most, accounting for 39% of all identified thermoplastics for the three major areas (modeling , extrusion and others) (Biron, 2015). Application (uses for plastic parts, containers for shampoo and other cleaning goods in the cosmetics industry, films, laminates, tubes, etc. (Sharada et al., 2022).
- Polypropylene has a smaller market share but a rapid annual growth rate (Biron, 2015). When exposed to the majority of solvents, cleaners, lipids, and bleaches, polypropylene displays high chemical resistance. The polymer's clarity and chemical resistance is used in medicine delivery, lure components, connections, syringes, and lab equipment applications (Mitrano and Wagner, 2022).
- Polyvinylchloride (PVC) is the third-largest material, has limitations due to external pressure. It has the lowest annual growth rate, primarily because of China (Biron, 2015). PVC has a variety of uses in the home in addition to its usage in medicine. Contractors may utilize PVC-made plumbing, siding, flooring, or roofing materials when constructing a home (MATERIALS, 2022).

1.2.3 Metal Matrix Composite (MMC)

Subsequently of its superior qualities, such as its light weight, increased ductility, and increased strength, etc. Metal Matrix Composites (MMCs) are replacing traditional metallic materials in the automotive and aerospace industries. Despite the

fact that many different MMC types have been created over the years, including aluminum (Al) and magnesium (Sreekala et al.) MMCs have emerged as the most promising materials in the automotive and aerospace sectors due to their light weight, superior mechanical qualities, and improved tribological performance (Katiyar et al., 2021). As well as, metal matrix composites are emerging materials that can exhibit enhanced strength, wear, and creep resistance, excellent damping, reduced thermal expansion, and other properties that make them suitable for a variety of applications in the transportation, electronic goods, cutting tools, aerospace, defense, marine, and packaging industries. Metal matrix composites can unifying continues metallic matrix and carefully selecting metallic/ceramic reinforcements, reinforcements, especially in fibers and particles (Seetharaman and Gupta, 2021). Table 1.1 shows the difference between Metal Matrix Composite, Ceramic Matrix Composite and Polymer Matrix Composite.

Table 1.1 Different between composite types (Sarkar, 2018)

Properties	**Metals**	**Ceramics**	**Polymers**
High temperature strength (Ramakrishnan and Sampath)	Moderate	High	Very poor
Ease of fabrication	Good	Poor	Very good
Conduction (Thermal or electrical) (W/m.K or S/m)	Good	Insulator	Insulator
Resistance to chemical attack (mm/year)	Poor	Inert	Inert
Dimensional stability (stiffness)(N/m)	High	High	Poor
Density (gm/cc)	Very high	Low	Very low
Luster (GU)	Excellent	Poor	Poor

Elastic Modulus (Ramakrishnan and Sampath)	High	Very high	Low
Melting point (^{O}C)	Moderate	High	Low
Heat capacity (J/K)	High	Moderate	Low
Hardness	Moderate	High	Low
Toughness (Ramakrishnan and Sampath)	High	Moderate	Low
Coefficient of thermal expansion (K^{-1})	Moderate	Low	High
Compressive strength (Ramakrishnan and Sampath)	Moderate	High	Low
Tensile strength (Ramakrishnan and Sampath)	High	Moderate	Low
Dielectric constant (unit-less)	Infinity	High	Very low
Magnetism (T)	High	Low-high	Very low
Band gap (eV or J	Very low	Moderate	High
Wear rate (mm/Nm)	Moderate	Low	High
Coefficient of friction (unit-less)	High	Low	Very low

1.2.4 Reinforcement

In reinforced composites, the virgin resin also contains a high-strength additive. Typically, the addition is a fiber made of glass, carbon, or kevlar. The arrangement of these fibers might be random, aligned, or mat-like. Fine metal shavings may occasionally be used (Cantor and Watts, 2011). The polymer would have relatively low mechanical characteristics without these reinforcements. Numerous research studies have looked at related topics such as pre-treatment as well as the impact of

the type of reinforcing material employed on the qualities of the finished composite. The reinforcing material can be integrated in three main ways: as particulates (or particle material), as fiber (in the form of individual fibers embedded in the matrix) and as layers (fibers woven into mats that are laid on top of one another to create a laminate) (Bai, 2022). As presented in figure (1.2) there are two types of reinforcements fibers and particles. Carbon fiber has been widely adopted as an essential structural and functional material in high performance lightweight structural applications due to its superior mechanical and thermal properties, woven carbon fabric composites have advantages such as good integrity, compatibility, and balance properties at the fabric level. Although layers of woven fabric are preferred in practice, additional layers are required to achieve the desired design strength. This results in a larger nominal size, which increases the weight of the component/structure, making it more popular in structural applications such as vehicles, aircraft, yachts, and civil structures (Ramakrishnan and Sampath, 2017). Because they have a higher specific strength than traditional metallic materials, carbon fiber reinforced polymer (CFRP) composites are being employed more and more in the aerospace sector. However, these composites' higher susceptibility to damage is a serious drawback (Sonat, 2021). However, Glass fibers are made by adding various amounts of raw materials to melts in order to make fibers with various compositions, such as sand for silica, clay for alumina, calcite for calcium oxide, and colemanite for boron oxide. As a result of the various quantities of silica or other sources used, different glass fiber variants have a variety of characteristics, such as alkali resistance or superior mechanical capabilities. The classification of glass fiber products is based on the type of composite at which they are employed (Cevahir, 2017). The class of materials known as glass fibers is exceedingly diverse. For polymeric resins like epoxy and unsaturated polyester, they are often employed as a reinforcement fiber. Although glass fiber has less stiffness than other reinforcing

fibers, it has the particular benefit of combining a very high strength with a low density and, most importantly, a relatively affordable price. Long into the future, glass fiber will be a significant reinforcement fiber (Sereni, 2016).

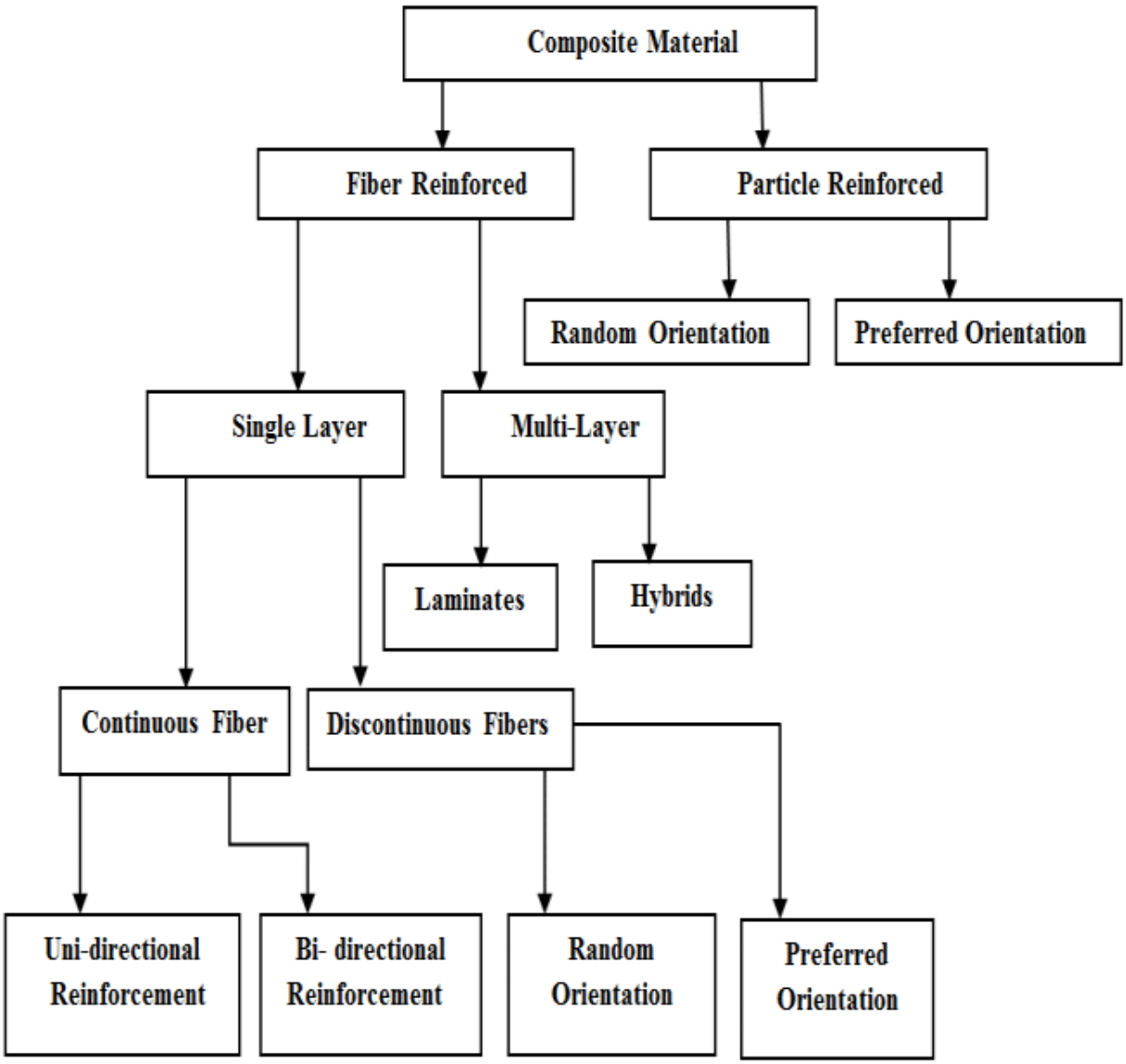


Figure 1. 2 Reinforcement types (Arumugam et al., 2020)

1.3 Simulation

Different design goals are served by Finite Element Analysis FEA-based simulations. Design analysis and design synthesis are two fundamental design processes. The FEA model is used to determine the system state or reaction to external loads after all the design variables and system parameters have been provided in the design study. It is the task for design analysis, sometimes known as what-if simulation. Some design variables must be chosen for design synthesis depending on the given design criteria. In other words, even if design variables might vary within a design space, they are provided as changeable ranges rather than values, and FEA models are used to assess the reactions of a system. FEA results are analyzed for multiple situations in order to optimize the solution in accordance with the stated design criteria (Bi, 2018). Now adays, Finite element analysis is the best and most reliable tool for engineers to design and analyses projects. The finite element method is the way for solving experimental results by using hand manual or computer program such as ABAQUS, ANSYS and etc. Due to its benefits of accuracy, time savings, and the display of a thorough stress distribution, the finite element method is increasingly used to examine the properties of fibrous materials as computer hardware and CAD programs advance quickly (Shen, 2013).

1.4 Problem statement

Composites have become more popular as a result of the demand for better materials with high specific mechanical properties, high stiffness-to-weight ratios, and high strength-to-weight ratios. Advanced composites have been employed for a wide range of purposes, particularly in the military, for items which includes airplanes,

tanks, and bulletproof armor. However, high specific stiffness and strength values, stability at high temperatures, and resistance to abrasive external conditions are all characteristics of carbon and graphite fibers (Madke and Chowdhury, 2019).

Fiber-reinforced composites constitute the majority of the composite parts and structures utilized in material removal applications. In order to understand the mechanical properties of fiber reinforced composites, a significant deal of study has been done. By using fiber glass and Unidirectional Carbon as two reinforcements and two types of epoxies resin a matrix.

As well as, glass and carbon fiber where the two main types of fiber were used in most applications.

1.5 Research objective

- ✓ To analyze the mechanical properties of two types of reinforcements fiber glass and Unidirectional Carbon with epoxy composite individually in different layers using two kinds of epoxy resin.
- ✓ To analyze the mechanical properties of triple composite fiber glass, Unidirectional Carbon using epoxy composite in different layers and two type of epoxy resin.
- ✓ To improve the sample's structures of Unidirectional Carbon and fiber glass with epoxy composite.
- ✓ To compare the experimental results with computational finite element analysis.

1.6 Scope of the study

In order to achieve the objective, the scope of the study was to analyze the mechanical properties of Unidirectional Carbon, fiber glass and both of them with epoxy composite with different layers to improve the combination of composite of the sample's structures of Unidirectional Carbon and fiber glass with epoxy. Epoxies use in this research was two types in order to achieve optimum mechanical properties of the composite of Unidirectional Carbon, fiber glass and epoxy resin.

1.7 Research outline

This research's focus has been narrowed down to the main points, and efforts have been made to rationally elaborate the works below chapters.

Chapter 2

Discusses the composite structure and the main components that belongs to composite materials such as Unidirectional Carbon, Fiber glass and epoxy resin. Another point is the fabrication process which have been explored and done by previous authors is reported briefly. As well, the finite element formula and computational programs which have used is also discussed.

Chapter 3

Specifically deals with experimental work and selecting a composite components material. Thus, discussing steps of fabrication process of composite structure and the ratios of fiber to matrix that used. As well as, three mechanical tests Tensile, Impact and Flexural was done and presenting their standards and all specifications.

Chapter 4

Deals with finite element modeling using ANSYS as a computational program and also the way of numerical formulas about finite element method for triple tests (tensile, impact and flexural) that were done experimentally.

Chapter 5

Presents the results and discussion of experimental and computational work form chapter 3 & 4. And it contains discussion about comparison between either using Unidirectional Carbon or Fiber glass as a fiber with matrix as an epoxy resin by illustration of charts and result tables. As well the comparison between both experimental and finite element method is compared and discussed in deep.

Chapter 6 Conclusion and future work with recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Nowadays one of the most demands are in more strengthen and less cost and weight composite materials. In this chapter, the known as the gap of a scientific failure will be introduced and the ways of reaching it will be specified. The purpose of this study is to identify good information about composite materials and their structure components. Another point which was discussed is the mechanical property of each component with the combination too. Moreover, discussing the way of other researchers that used for numerical and finite element analyses for composite materials.

2.2 Composite Materials

A composite is a combination of two or more components, materials, or phases with variable macroscopic or microscopic physical/chemical properties. Fiber and matrix are often two or more of the elements of composites. Composites are divided into two types those by the type of reinforcement , flake, fiber reinforcement, and

those by type of matrix, metal, ceramic, and carbon (Singh et al., 2013). Hence low cost is the primary benefit of composite materials (Velu et al., 2021). The utilization of fiber-reinforced composite structures are expanding exponentially across a variety of societies due to its qualities, which include a relatively high strength-to-weight and stiffness-to-weight ratios, the effects for increasing these two properties are molecular structure, temperature and composite structure, as well as superior corrosion resistance, and adaptable mechanical properties (Su and Ye, 2008).

(Cherif et al., 2016) used fiber reinforced composite as a structure of wind blade turbines for the purpose of minimizing risks and maximizing use, damage-sensing or structural health monitoring (SHM) is very essential for materials that are subject to repeated complicated loading or straining which used in. The behavior of the laminated fiber-reinforced composite structures have been a major source of concern in many modern engineering structures and components because they are vulnerable to damage from an accidental impact. Monitoring fiber-reinforced composite constructions and the development of material health condition are becoming more and more important (Meo and William Andrew Publishing: Oxford, 2015).

2.3 Composite Structure Scales and Fiber Orientations

Composites structures can be divided into three different sizes: micro (**μ**), meso (m), and macro (M). The Meso-scale describes the internal structure of the unit cell, fiber orientation, and the volume percentage inside a yarn, according to the fundamental component of woven textile composites at the mesoscale, yarn is made up of fiber and matrix and defines the weaving pattern. Whilst the micro-scale specifically determines the distribution of fibers in the yarn which relates to the size

of the fiber and contains represent volume element (RVE) information on the fiber level, such as fiber arrangement. The macro level deals with the component's overall mechanical properties under various loading circumstances as well as the composite's 3D shape, curvatures, and global mechanical properties and woven textile composites are typically considered as equivalent continuous materials at the macro-scale, which is generally referred to as the structure scale as shown in figure (2.1) (Tabatabaei, 2016) and (Liang et al., 2019). As well, the physical qualities of composite materials depend on fiber orientation. To estimate the behavior of the material, the theoretical characteristics of a certain reinforcement is often well understood and frequently employed. However, production processes like weaving or needling might cause variations in the predicted primary orientations of the fibers. These variations can lead to unexpected behavior from the material and should be considered when evaluating its quality (Blanc et al., 2006). (Radhakrishnan and Mathialagan, 2022) provide evidence that the from composite's fiber orientation has a major impact on the composite's mechanical behavior and used three different orientation for the purpose of fabricating such as /90°/ , /45°/, or /0°/ . While (Mrazova, 2013) said fibers frequently have lower fiber length to diameter ratios which is aspect ratio and are treated in a random X orientation. During production, these fibers are either processed into sheets with the fibers randomly arranged and overlapped, or they are chopped into short strands as presented in Figure (2.2).

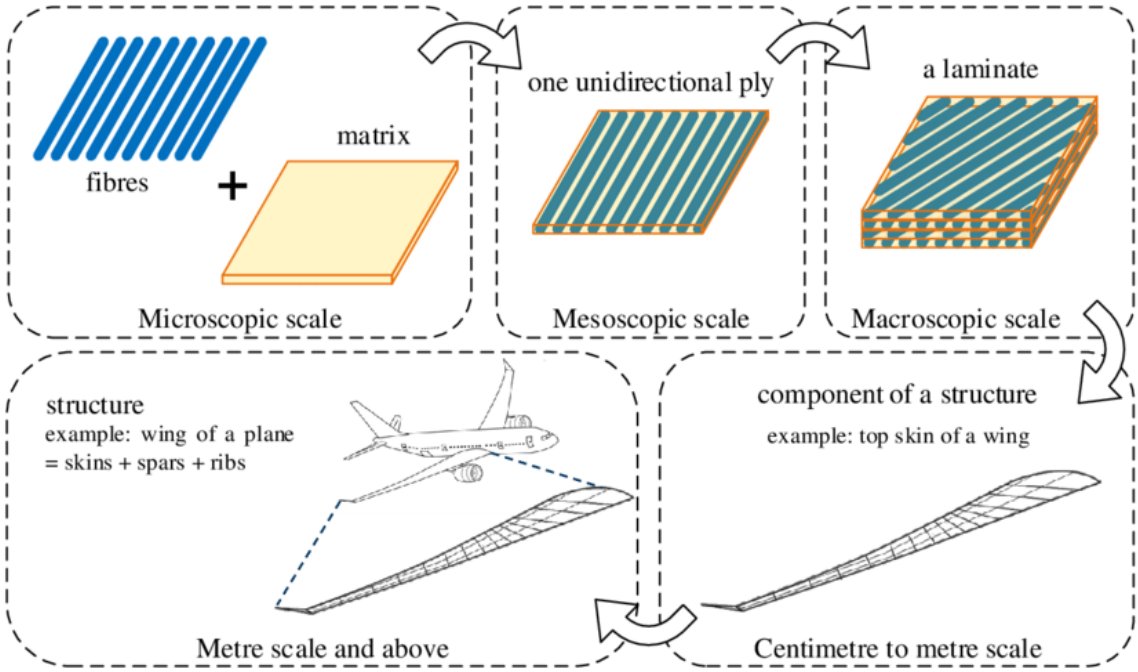


Figure 2. 1 Scales of Composite (FEDON, 2021)

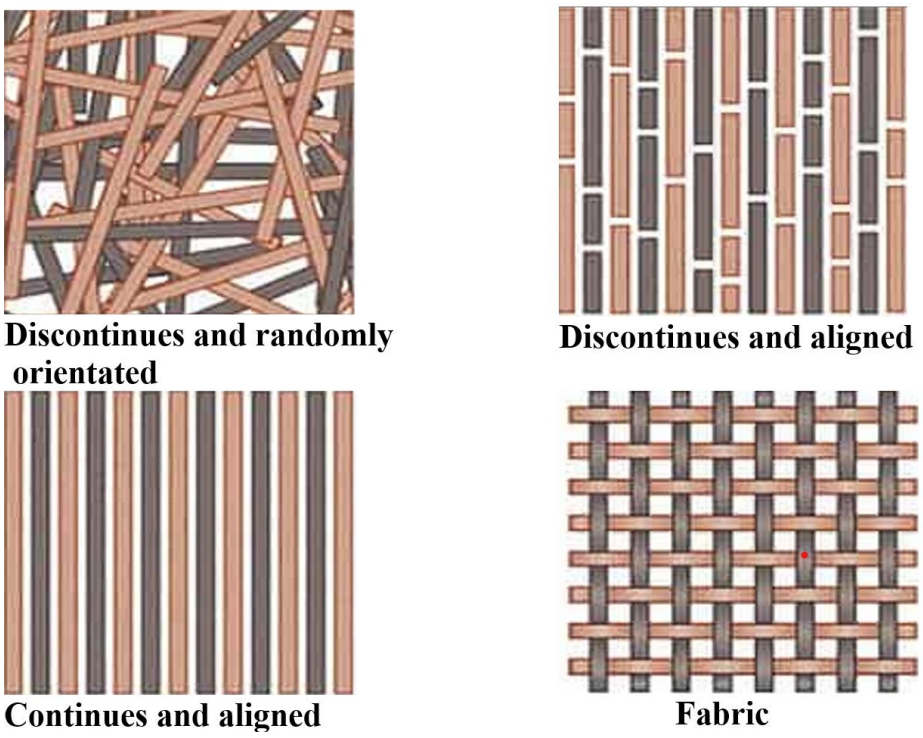


Figure 2. 2 Plastic composite structure types (Mrazova, 2013)

2.4 The Advantages and Disadvantages of Composite Materials

Regarding to the widely use of composite materials obviously it has many advantages and disadvantages by using on its own applications can be reduce the disadvantages.

2.4.1 The Advantages of Composite Materials

In comparison to traditional metallic materials, composite materials have many benefits. The following are a few of the main advantages:

- high ratio of strength to weight (Soami, 2018)
- Corrosion resistance is improved.
- Better fatigue strength (Chokshi and Gohil, 2018)
- Production cost reduced (Armstrong et al., 2020)
- The composite density is lower and has good specific mechanical properties such as reinforced plastics.
- The human risks change (Mohd Bakhori et al., 2022).

2.4.2 The Disadvantages of composite materials

There are several difficulties with utilizing composite materials because they are

- include the high cost of raw materials and processing (Soami, 2018)
- Thermal resistance and water resistance are low (Mohd Bakhori et al., 2022).
- Curing time will take time ; it's either hot or cold curing (Armstrong et al., 2020).
- They are difficult to analyze since they also contain anisotropic materials. (Soami, 2018)

- Tools and pressure are required for repairing within the original curing time. (Deepak et al., 2020).

2.5 Composite Materials Applications

The main consideration in composite applications is weight reduction. Speaker cones, which combine low weight, fast sound speed, and enough internal dampening, randoms, ground-based and low-speed aircraft, helicopters, and boats are just a few examples of the many composite applications that use it (due to the low dielectric constant, negligible absorption of radar energy, no water uptake, and high impact and penetration resistance). Additionally, bobbins for conductor's magnet coils (high strength, electrical insulation, low coefficient of friction, toughness at very low temperatures, and the negative thermal expansion coefficient), sonar domes (due to the high transmission of sound waves, low reflection and impact properties, and its suitability in a marine environment), and motor helmets (for its weight savings down to 40% of the original shell weight).below table 2.1 is the main application of composite materials in all fields (Vlasblom, 2018).

Table 2. 1 Industrials applications of composite materials (Soami, 2018)

Application	**Components**
Air craft	Wings and fuse legs
Defense	Tanks and submarine
Wind turbine	blades
Construction and installation	Doors, panels, frames, and bridges
Engineering in chemical	Pressure, vessels, storage tanks, piping and reactors

Transportation and automobile	Bicycles and automobiles components
Travelling by rail and water	Boat hulls and rail components
Sports and consumer products	Tennis rackets and golf club shafts
Electronics	Distribution pillars and connection boxes

2.6 Fiber Reinforcements

2.6.1 Unidirectional Fibers

Tapes, tows, unidirectional tow sheets, and roving are examples of unidirectional reinforcements which are collections of fibers or strands. The highest mechanical qualities are offered by these fibers since they are uncrimped and all parallel in one direction. Composites made with unidirectional tapes or sheets have a high degree of strength parallel to the fiber direction. Since most structural applications need for numerous layers ; unidirectional sheets are thin ; see figure (2.3) (Karataş and Gökkaya, 2018). It could be randomly or longitudinally oriented; randomly (chopped) oriented fibers provide isotropic properties, meaning they have the same mechanical properties in all directions. While, the longitudinally oriented fibers, such as those found in: (a) unidirectional continuous fiber laminates, provide an anisotropic effect. Meaning they have different properties in different directions; this type of laminate exhibits the highest strength and stiffness in composites, but only in the direction of the fibers. (b) Bidirectional discontinuous short and long fiber or textile textiles (woven, knitted, and braided fabrics) laminates that exhibit the orthotropic effect, that is, the same qualities in two directions with differing properties in the third, orthogonal direction (Safwat et al., 2021).

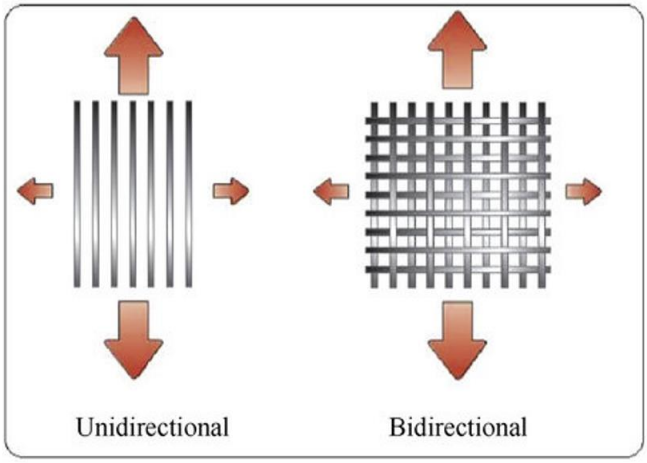


Figure 2. 3 Types of unidirectional fibers (Karataş and Gökkaya, 2018)

2.6.2 Unidirectional Carbon (UDC)

Carbon fibers are incredibly strong, robust, and rigid. A component made of carbon fiber has properties comparable to those of steel and weighs approximately the same as plastic. In a nutshell, carbon fiber components have much higher strength to weight and stiffness to weight ratios than plastic or steel. In addition, toward being excellent, and carbon fiber composite also has an attractive style. It is assumed that the composite will achieve greater power the more carbon fiber there is in it (Singh et al., 2020b).

Woven fabric reinforced plastic composites, as compared to traditional laminated composites, have superior delamination resistance and make it easier to produce complicated advanced structures with less labor expense.(Hayat et al., 2018) Because of their excellent mechanical properties such as high specific strength high specific stiffness, and high energy absorption efficiency, carbon fiber-reinforced composites have found extensive use in the domains of aviation, transportation, and maritime(Jiang et al., 2019). Automobile, aerospace, and other industries frequently

use carbon fiber reinforcement polymer composites (CFRP). Since those woven structures were initially employed to create fabrics from fibers (Cao et al., 2020). "Taxonomy" of damage for complicated mix of longitudinal, transverse cracks, and delamination in 3D woven fabric has been presented by (John et al., 2001). The progression of damage is related to the alteration in sample stiffness, and optical microscopy is used to examine the microstructure of cracks on cross-sections. Transverse cracking first appears in the damage, followed by longitudinal cracks and then debonding on the boundaries impregnated yarn matrix. Future lightweight technologies like carbon fiber reinforced plastic (CFRP) are preferred above other lightweight materials since they are well-liked across all industries, including the automotive industry. However, the cost of CFRP-based products is a result of the carbon fiber used as a raw material. Due to the continued usage of the current steel-based automotive manufacturing facilities by industry, there are additional industrial challenges (Moon et al., 2019).

As well, Carbon fiber reinforced polymers are composite materials that depend on the carbon fiber to give strength and stiffness while the polymer offers a cohesive matrix to safeguard and hold the fibers together and offers some toughness. The highly directed characteristics of carbon fibers are very different from those of the metals that are most frequently used in these automobile applications. They can be manufactured to achieve mass reductions that metals cannot. Due to the fact that these materials are artificially composited, it is possible to adapt their attributes and performance to the particular application by changing the strength, length, directionality, and quantity of the reinforcing fibers as well as the choice of the polymer matrix. The production of fibers is expensive, and manufacturing components at low throughput rates is one of the biggest difficulties. The total amount of time required to insert the fibers into a mold, inject the polymer, and wait

for the part to harden is only a few minutes (Fekete and Hall, 2017). (Kim et al., 2000) proved that woven fabric composites had better fracture toughness than unidirectional laminates, which is roughly 4-5 times higher. The woven carbon fiber-reinforced plastic material's characteristics under static and fatigue loading. Between expected and experimental outcomes, they discovered strong relationships (Wicaksono and Chai, 2015).

The high mechanical properties of carbon fiber make it a viable choice for applications, but its high cost forces designers to look for hybrid alternatives (Velu et al., 2021).Composite laminates failure can occur in composite material, especially when continuous carbon or glass fibers are placed into a relatively weak polymer matrix (Zabala et al., 2015).

However, woven composites have recently gained more attention because industry-wide restrictions on manufacturing with less price and time. They are a great option for building principal load-carrying structures due to their high specific energy absorption, superior damage tolerance, and significant manufacturing advantages over conventional composites (Wehrkamp-Richter et al., 2018). Moreover about plastic composite as shown in figure (2.4) (Hasan et al., 2021) said several multidirectional fabric-reinforced composite performs showing the models design on the left and made product on the right (a); interlock weave 3-D across the thickness; (b) an interlock weave 3-D layer by layer; (c) an orthogonal weave (3-D); (d) a 4-step braided weave (2-D triaxial); (e) a plain weave (2-D); (f) a weave (2-D triaxial); (g) a honeycomb (hexagonal cells); (h) a multilayered sandwich (Z-pinned).

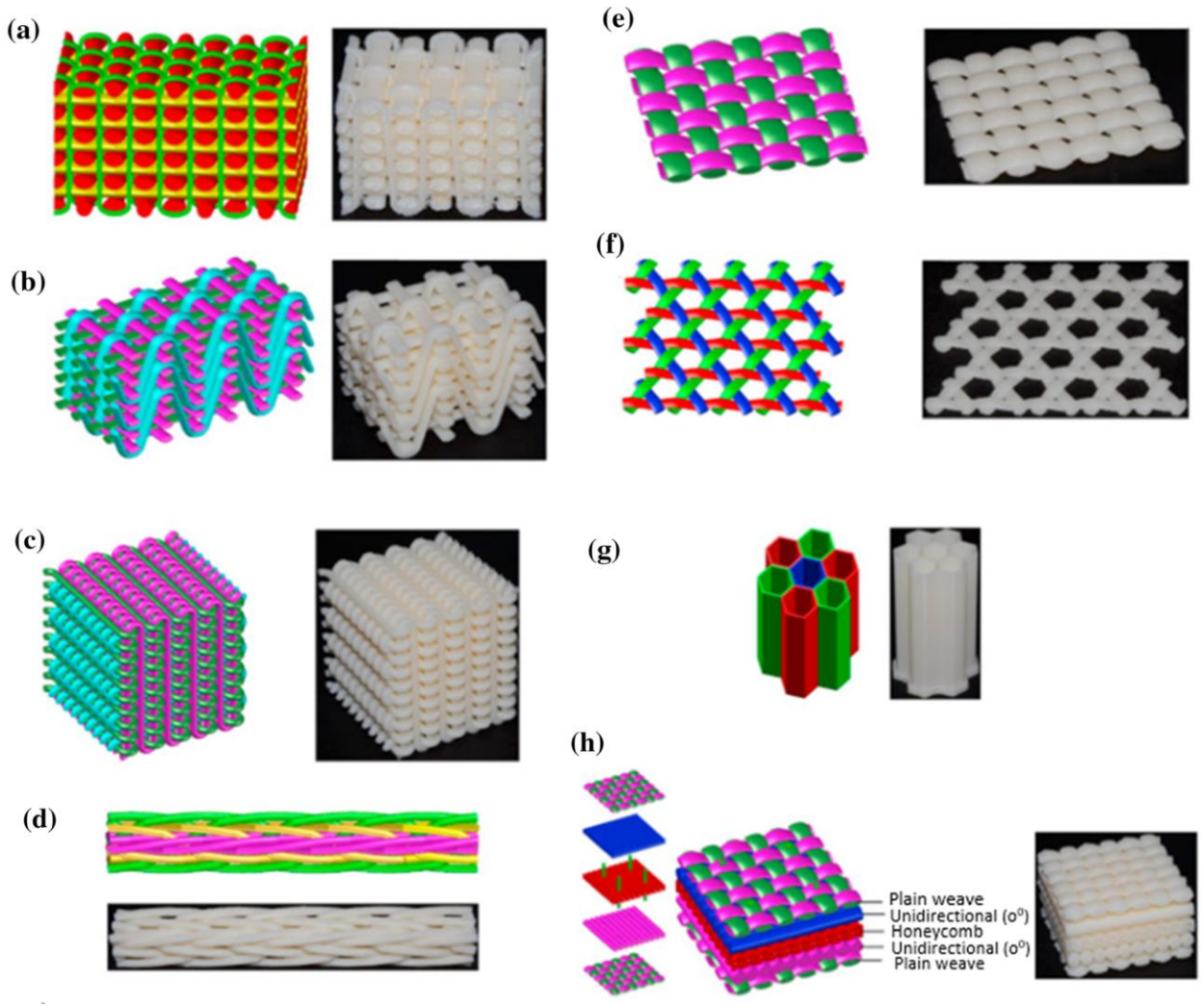


Figure 2. 4 Multi direction carbon types (Hasan et al., 2021)

2.6.3 Woven Fiber Orientation Structure

The simplest woven structure is a plain weave, in which the warp yarns alternately lift and cross one weft strand, and vice versa (Figure 2.5a). A fabric with a twill the weave will have diagonal lines on the surface (Figure 2.5b). When viewed along in the warp direction, the diagonal lines can be either upward and to the right or left, creating a Z- or S-twill. Comparing the plain weave of the same fabric specifications to twills, longer floats, fewer crossings, and more open construction are present.

Although there are numerous twill construction variations (the least repeat is three in the warp and weft directions), only simple twills are used technically. Satin is a weave where the interlacing points are distributed as randomly as possible to prevent twill lines, as opposed to a weave where the binding sites are chosen to produce a smooth cloth surface devoid of twill lines (Figure 2.5c) (Özaslan et al., 2019).

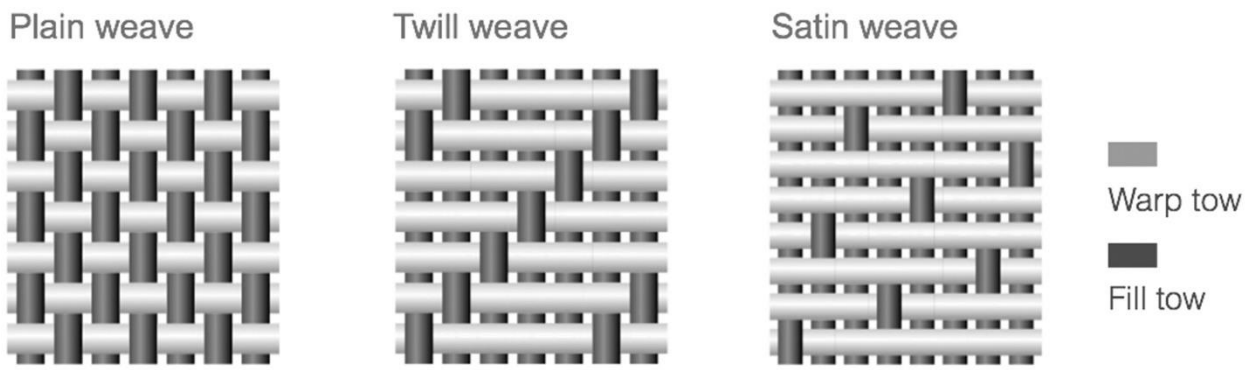


Figure 2. 5 Woven orientation structure types (Özaslan et al., 2019)

2.6.4 Fiber glass

There are various glass fiber kinds available (E-glass, S-glass). The type of glass fiber known as "E-glass" has an elastic modulus of 70 to 73 GPa and a failure strain of 2.5%. S-glass fibers exceed other kinds in terms of mechanical performance and resilience to high temperatures and corrosives. However, there are disadvantages to using glass fiber. Low fatigue strength and poor adherence to polymeric matrices are characteristics of glass fiber. Physical treatments or the use of linking chemicals, such as maleic anhydride, are used to get around these restrictions (Yılmaz and Khan, 2019). In many different industries, especially in aerospace, wind energy, and automotive applications, lightweight design is gaining significance. Due to its exceptional stiffness and strength paired with a low density, fiber-reinforced

composites are becoming more popular for these weight-sensitive applications (Swolfs et al., 2014). Composite materials made of fiber-reinforced polymer (FRP) are heterogeneous, anisotropic materials that do not deform plastically. They have been utilized in a variety of modern applications, including aerospace, automotive, maritime, and the production of sporting goods (Karataş and Gökkaya, 2018) .

Silica serves as the matrix for glass fiber, which is inorganic and non - combustible. Glass fibers may absorb a lot of heat because of their extremely high melting temperatures (1225–1360°C). Glass fibers come in a variety of shapes and chemical types, including the A, AR, C, E, HS, and S types. Glass fibers are always utilized as fillers in thermoplastic polymers to increase stiffness and heat resistance (Fei, 2018) . Meanwhile, Glass fibers are mostly utilized as reinforcement for polymers. E-glass and S-glass fibers are the most popular types of glass fibers for mechanical engineering applications. Due to its affordability and comparably low elastic moduli to other reinforcements, E-glass fibers are the most often employed of all fibrous reinforcements. S-glass fibers are stronger, stiffer, and more resistant to fatigue and creep than E-glass fibers (Tanzi et al., 2019).

(Mortazavian and Fatemi, 2015) conducted experimental and analytical research to investigate the effect of anisotropy on the tensile properties of two short glass-fiber reinforced thermoplastics. Good predictions of elastic modulus and tensile strength were made using the laminate analogy. The polymer matrix contains glass fibers in a variety of orientations, each of which offers a unique set of characteristics and strengthening effects. Table 2.2 shows more details about manufacturing, composition, characteristics and applications of fiber glass types.

Table 2. 2 Fiber glass types (Zhang and Matinlinna, 2012)

Type	Manufacturing	Composition	Characteristics	Application
A-glass	Produced from cullet glass (often a bottle) to fiber	Alkali-lime with little or no boron oxide	Not very resistant to alkali	When alkali resistance is not required
AR-glass			Resistant to alkali	When alkali resistance is required
C-glass (T-glass)	From used glass staple fibers	Alkali-lime with high boron oxide content	Resistant to chemical attack and most acids which dissolve E-glass	When higher chemical resistance to acid is required, for glass step fibers
D-glass		Borosilicate	High Dielectric constant	When high dielectric constant is preferred
E-glass		Alumino-borosilicate with less than 1 % alkali oxides	Not chloride-ion resistant; E-glass surface is soluble	Mainly for glass-reinforced plastics:originally for electrical applications
E-CR-glass		Alumino-lime borosilicate with less than 1 % alkali oxides	High acid resistance	When high acid resistance is required
R-glass		Alumino silicate without MgO or CaO	Good mechanical properties	With high mechanical requirements

S-glass		Alumino silicate without CaO but with high MgO content	Highest tensile strength among all types of fiber	Aircraft components and missle casing, when high tensile strength required.

2.5 Properties and Specification of Matrices

The thermoset plastic most frequently employed in polymer matrix composites is the epoxy resin. Epoxy resins are a class of thermoset plastic polymers with low cure shrinkage because they do not produce reaction products during the curing process. Further, they offer excellent chemical and environmental stability, excellent chemical properties, and high insulating competence. It also attach well to other materials (Singla et al., 2010).

Thermosets are crosslinked polymers that cannot be remelted or reconfigured after being cured or set by using heat or heat and pressure. They create a three-dimensional molecular chain known as crosslinking during the curing process. The materials will be stiffer and more thermally stable the more cross links there are. While heated, cured thermoset resins may soften but do not melt or flow. In general, they are more heat resistant than thermoplastics. Since thermosets are brittle by nature, filler materials like powders or fibers are employed with them to improve strength and/or stiffness (Park and Seo, 2011).

Because of its strong corrosion resistance and great chemical stability, epoxy resin is a frequently utilized matrix in fiber reinforced composites at medium and low temperatures (Jin et al., 2015).The framework was made from out epoxy resin. In

fact, they provide the finest execution even at higher temperatures (Ramakrishnan and Sampath, 2017). Epoxy resins have been used more frequently in supercritical engineering technologies as injecting materials, adhesives, or matrices for fiber-reinforced composites as a result of the fast developments in spacecraft and superconducting cable technologies, as well as large cooling engineering projects like the International Thermonuclear Experimental Reactor (ITER) and others (Yang et al., 2007).

Due to their high Young's modulus, strong bonding force toward large substrates, and high solvent resistance, low production cost, numerous epoxy resins under various trademarks have been used as matrix materials for hybrid potting adhesives. To simultaneously achieve the desired high fluidity and high mechanical strength in composite potting adhesives, it have been discovered to be very useful to mix various epoxy resins as matrices. In addition, many curing agents generated from acid-anhydrides, such as methyl tetrahydro phthalic anhydride, have been used in hybrid potting adhesives due to the curing agents' excellent high electric insulation property and relatively wide temperature application range. Potting adhesives have accomplished various desirable properties, such as an easy perfusion procedure, high curing mechanical properties and low curing volume-shrinkage. In addition, it has been discovered that amine-derived curing-agents cause the properties cured adhesives to fail at high temperatures but not at low temperatures low curing temperatures, by using those acid-anhydride derived curing-agents (Hu, 2020).

2.6 Fabrication process

To process composite materials, several manufacturing techniques are available, including: hand molding, distillation, filament winding, vacuum bag forming, and

resin transfer molding. The hand position technique is preferred for this work due to its simplicity and robustness. One of the most popular procedures for combining resin and fabric components is the hand position technique (Davim et al., 2004).This method involves manually inserting the fiber reinforcement into a one-sided mold, then forcing the resin through the fiber mats using hand rollers. The ability to produce very large and complex parts with shorter manufacturing times are a major advantage of the hand-to-hand approach. Simple equipment and tools, which are much less expensive, than other production methods, are also the advantages of the drawing technique. A manual fitting procedure was used to generate all composite samples (Singh and SK Jain, 2013).

The composite is prepared from epoxy as well as strong jute fibers (oriented 0/90) with 760 GSM titanium dioxide and TiO2 filler particles. Woven jute mat, Araldite LY556 epoxy resin and HY951 hardener based on Triethylenetetramine Ltd (TETA). (Bhargav and Babu, 2021b) Used hand lay technology, and this method was adopted by 10:1 epoxy for curing. For an ASTM D3039-79 tensile test performed on a UTM with a dumbbell-shaped specimen and a crossover speed of 2 mm/min, and for bending at testing, ASTM D790 is approved with 1.5mm/min.

S2-glass-woven/reinforced epoxy, woven IM7-graphite/reinforced epoxy, and woven S2-glass-IM7-graphite fiber/epoxy were used by (Wang et al., 2021) for research purposes. Vacuum Assisted Resin Transfer Molding (VARTM) technology used to stack weave woven warp fabrics and the composite was manufactured and designed by EDO Fiber Innovations in 101.6 mm 101.6 mm sheets , the samples were cured at 177 °C.

A 0.3 mm thick glass fabric as reinforcement and epoxy with R101, and H101 matrices respectively are used by (Singh and SK Jain, 2013), and also produced a

rectangular volume to perform tensile tests using ASTM D638 (165x19x4mm) or tensile testing and ASTM D790 (130x12x4mm) for bending testing.

WSR618 epoxy resin as matrix with benzene dimethylamine as the resin curing agent and butyl phthalate as hardener, as well unidirectional woven fabric glass as a reinforcement were used by (Zhou et al., 2017). The layer-by-layer manual stacking process using room temperature vacuum technology and magic pressure treatment is used to prevent cracks and cracks between layers.

Conductive glass fibers and carbon fibers were used as reinforcements and epoxy as the matrix material by (Jagannatha and Harish, 2015). Epoxy resin and Tri Ethylene Tetra Amine (TETA) hardener was supplied by Atul Ltd. % 15, %30 , 45% and 60% fiberglass and carbon fiber in a 40% epoxy matrix. It appears that the mechanical properties of carbon fibers were superior to others.

Aramid twill fiberglass, twill aramid fiber, single-shell carbon fiber, unidirectional glass, and unidirectional carbon fibers were used by (Ekşı and Genel, 2017). An epoxy resin (MGS L285) was mixed with a solid (HGS L285) in a volume ratio of 50/100. The compound was made by a manual laying process. The composites were cured at 75°C in an oven after curing at room temperature for 24 hours. Steel plates were stacked on the edges of some samples to prevent failure. The carbon fiber reinforced epoxy compound had much better performance than the glass fiber reinforced epoxy compound, due to the unidirectional fibers reinforcing the epoxy compound.

These are another type such as LY556, and HY591 epoxy resin matrix, 0.4mm thick bidirectional jute fiber reinforced, and woven S-glass fibers were used by (Bhargav and Babu, 2021a). And the manufacturing tests technique is to be applied by hand. For mechanical test specimens used in tensile with ASTM-D3039, for impact

testing, the Izod impact test was conducted according to ASTM-D256 and the three-point bend test according to ASTM-D790 with a sample size of 80×83mm×3. It is observed that in the field of automotive and some components of aerospace applications, high strength, durability and stiffness with the combination of two different levels of fibers play a critical role.

2.7 Finite Element Analysis

Described an indirect identification technique to predict the mechanical properties of composites that makes use of eigen frequencies, experimental analysis of a composite plate specimen, corresponding numerical eigen value analysis and optimization techniques has been used by (Madke and Chowdhury, 2019) to model debonding during interphase in order to analyze fiber-matrix debonding. The zone in the matrix phase known as the interphase, which has a finite thickness and is affected by fiber, as well, the surface between the fiber and the matrix, known as the interface, is considered to be fully bonded and has a thickness of zero. And using (ABAQUS) as a computational program for modeling and simulating.. (Lisle et al., 2017) used finite element method by ANSYS program to estimate bending stress and predict the design of gear teeth on ANSYS work bench. (Shohel et al., 2023) examined the laminate level and lamina level mechanical strength of glass fiber/resin polyester, glass fiber/resin epoxy, and glass fiber/PVC foam under tensile loading circumstances in Ansys and Ansys ACP. In comparison to glass fiber/resin polyester and glass fiber/PVC foam, this study's investigation has shown that glass fiber bonded with resin epoxy composite has a higher life cycle and high stress-bearing capacity. (Faizan and Gangwar, 2021) Prepared the carbon fiber reinforced polymer composite material, automobile roof panel and examined its mechanical strength.

The 3-D model of an automobile roof panel was created, then analyzed and simulated. Workbench for ANSYS 21. (Chandra et al., 2017) used ANSYS, Finite Element Analysis (FEA) is performed for each of the aforementioned tests, and experimental and FEM values are confirmed. Sandwich beams are constructed and tested in a three-point bending test with varying skin-to-core weight ratios and spanning-to-depth ratios, and several failure modes are noted during testing. The FEM is associated with these failure modes, failure criteria are applied according to each failure, and all values obtained are compared.

CHAPTER THREE

EXPERIMENTAL WORK

3.1 Introduction

In this chapter all information about the experiment works of this study will be shown and discussed accurately. During this chapter two groups of composites were produced by two types of epoxies as a matrix and reinforcements such as Unidirectional Carbon and fiber glass. Hence, standards will be presented for preparing specimens. Meanwhile three tests Tensile, Impact and Flexural were done for investigating the composite sample's mechanical properties.

3.2 Material selection

For conducting experimental work, and generating a composite material there were three types of material used.

- ✓ Epoxy resin
- ✓ Unidirectional Carbon
- ✓ Fiber glass.

3.2.1 Epoxy resin

Two types of epoxies Master Protect 180 and Master Brace ADH 1406 were used for preparing samples.

Master Protect 180 it is a high build epoxy resin protective coating specially developed to protect concrete see figure 3.1. It is provided as a two-component system that just needs to be mixed on site to create an easily applied and it's important to mix these two components with a thin stick for 2-3 minute and let them to mix well, the two components are a pigmented base A and a hardener B. When coating storage tanks for potable water or in locations where contact with foods is anticipated.

The primary uses for this type of epoxy resin are as a decorative and protective coating in labs, slaughterhouses, etc. Advantages of this type of epoxy resin are non-toxic, water proof, protective, thermally and chemically high resistance and simple to apply with a brush, roller, or airless sprayer. (Master Protect 180) can be used safely. Since it is solvent-free, it can be safely utilized in small spaces or tanks without the need for additional ventilation. Table 3.1 shows the most important physical and chemical properties of this type of epoxy resin (Soulution, 2021).

The chemical components of Master Protect 180 are:

- Formaldehyde, 40% solution
- Sopheric Acid, 50% solution
- Hydrochloric Acid, 50% solution.
- Hydrochloric Acid 5% solution.

- Lactic Acid, 50% solution.
- Nitric Acid, 10% solution.
- Sodium Hydroxide, 50% solution.
- Diesel oil.
- Wine.
- Sea and brackish water.
- Aviation hydraulic fuels (Sky droll).
- Vegetable oils.

Table 3. 1 chemical and physical properties of Master Protect 180 epoxy (Soulution, 2021)

Parameter	Epoxy
Mixing ratio	87.2%: 12.8%
Mixing density	1.5 gm/cm^3
Initial cure	24 H @ 25 ℃
Final curing	7 H @ 25 ℃
Working life	40 Minute
Young's Modulus	1.5 MPa

Figure 3. 1 First epoxy resin

As well as, Master Brace ADH 1406 is the second epoxy resin see Figure 3.2**,** that is pasty precision, simplicity of application, and a lack of sagging in overhead applications are created in buckets in accordance with the proper mixing ratio. Without leaving any material in the bucket behind, combine Part B a hardener with Part A pigmented base. For polymer mixing, it should be blended using a suitable mixer (300 rpm). Also, to create a homogeneous mixture, stir the components for at least 3 minutes.

The advantages of this type of epoxy resin are Perfect adhesive to concrete, steel, to surfaces on concert, solvent-free, resistance to chemicals, water, and gas. Moreover, some applications failed the results of it are bonding of various construction materials, including steel, concrete, and brick, pining of rods and deformed bars to concrete, stone, or brick, as well Repair and insulating of wide cracks, and etc. The main disadvantage of Master brace ADH 1406 is that it will cause toxic and make a sensitivity if its contacted with skin even in a very small amount. See table 3.2 for more information about this epoxy resin (Solution, 2021)**.**

Figure 3.2 Second epoxy resin

Table 3. 2 Master Brace ADH 1406 (Solution, 2021)

Parameter	Epoxy
Mixing ratio	75%: 25%
Mixing density	1.70 gm/cm^3
Compressive strength 1 day 7 days	30 MPa 60 MPa
Flexural strength 1 day 7 days	17 MPa 25 MPa
Pot life	40 Minute
Application temperature	5°-30° ℃
Fully cured at 20 ℃	7 days

3.2.2 Unidirectional Carbon (UDC)

The fiber type which used is SikaWrap-230 C, a Unidirectional Carbon fiber fabric with mid-range strengths, designed for installation using the dry application process. See Figure 3.3. And the main advantages are (it is made with weft fibers to maintain the fabric's stability (heat-set), a multipurpose material for use in a variety of strengthening applications, adaptable to various surface planes and geometrical structures (beams, columns, chimneys, piles, walls, soffits, silos etc.), low density to add a little extra weight, incredibly affordable compared to conventional strengthening methods (Woven unidirectional carbon fiber fabric et al., 2014). as well, table 3.3 shows properties of this type of reinforcement and here it’s application, such as: masonry walls' improved seismic performance

- Replacing any steel reinforcing that is lacking.
- Improving the ductility and strength of columns.
- Increasing the structural elements' loading capacity.
- Making possible changes in usage, modifications, and renovation.
- Repairing faulty structural design and/or construction.
- The resistance to seismic movement is getting stronger.
- Increasing durability and service life.
- Updating structures to meet modern standards.

Figure 3.3 Unidirectional Carbon (Woven unidirectional carbon fiber fabric et al., 2014)

Table 3. 3 Mechanical and physical properties of Unidirectional Carbon (Woven unidirectional carbon fiber fabric et al., 2014)

Parameter	UDC
Fiber density	1.82 g/cm^3
Filament diameter	21-22 µm
Tensile strength	4000 MPa
Tensile modulus	230000 MPa
Fiber orientation	0° rad
Limit temperature	5-35 ℃

3.2.3 Fiber glass

360 Direct Roving is coated with a silane based compatible with unsaturated polyester, vinyl ester, and epoxy resins. It is designed for filament winding, pultrusion, and weaving applications. By measuring the diameter via Vernier, as shown in Figure 3.4 the dimeters of the fiber glass known, for more information about this type of fiber glass see table 3.4.

Table 3. 4 Mechanical and physical properties of fiber glass.

Parameter	Fiber glass
Density	2.62 g/cm^3
Filament diameter	21-22 µm
Tensile strength	2673 MPa
Tensile modulus	81126 MPa
Shear strength	70 MPa
Limit temperature	15-35 ℃

(a) (b)

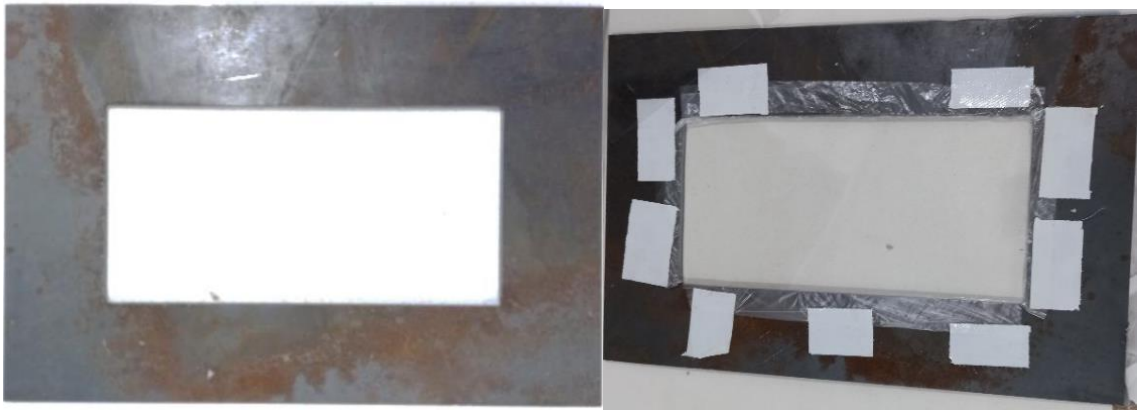
Figure 3. 4 (a) Fiber glass (b) Filament diameter of fiber glass by Micrometer

3.3 Steps of Experimental Work

The procedure of experimental works was done by utilizing five steps. All of them are listed below.

3.3.1. Preparing the Mold

The mold was prepared by a hollow plate with 3 mm and inside (200 mm x 100 mm), see Figure (3.5). The shape and volume of rectangular hole which it keeps prepared composite during curing time is non changeable. In addition, in the time of booting-out of the rigid composite the shape doesn't change at all. After that, using on backside of a transparent paper and adopting a stick for all sides, and the front of the mold is cased inside for ease of emerging and using sticks for adoption.

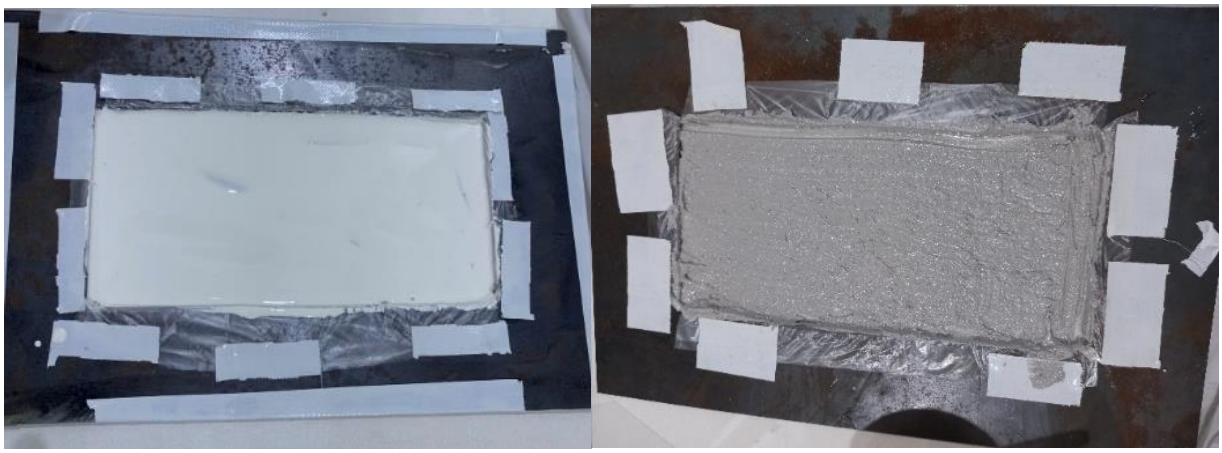


(a) (b)

Figure 3.5 (a) A hollow plate (b) The mold with covered backside

3.3.2 Composite Layers

The first layer is resin epoxy. Figure 3.6 (a) shows the Master Protect 180 first epoxy resin and (b) shows the Master Brace ADH1406 second epoxy resin. Further, the second layer were conducted, it is either UDC or Fiber glass for both epoxies as presented in figure 3.7. After that third layer was constructed by using epoxy resin as shown in figure 3.8, and by this way layers were repeated, and the maximum number of layers was 7 for the first group and 5 for the second group. For the purpose of full filling the hollow plate with composite layers of mixture calculation were done, and presented in appendix section.

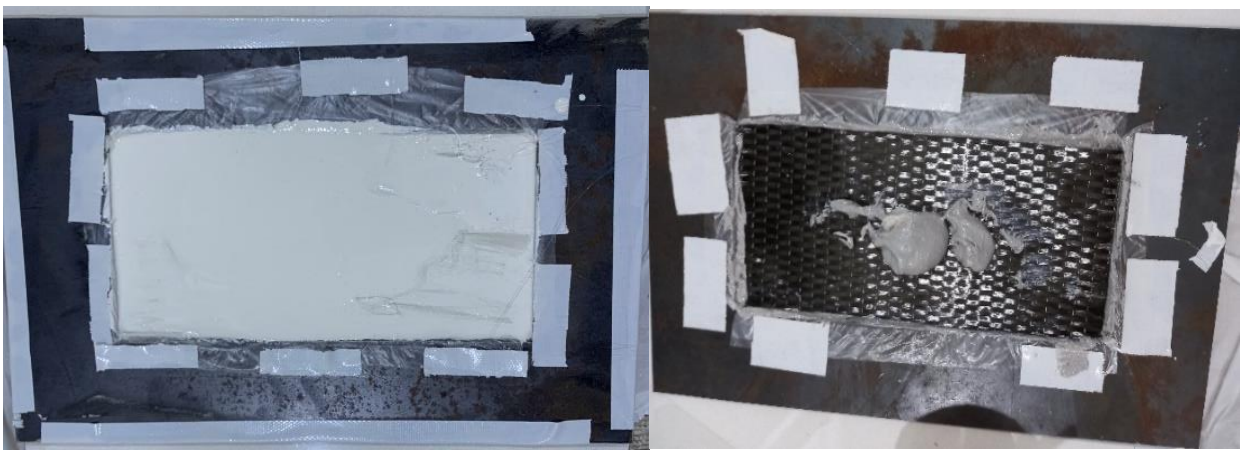


(a) (b)

Figure 3.6 (a) first composite (b) second composite

(a) (b)

Figure 3.7 Second layer (a) first composite (b) second composite



(a) (b)

Figure 3.8 Third layer (a) first composite (b) second composite

3.3.3. Drawing and Cutting Specimens and Preparing Test Requirements

Auto CAD 2023 is used to draw the samples, the dimension taken from ASTM with different parameters and boundary conditions were considered for each test. And three types tests were conducted (tensile, impact and flexural).

3.3.3.1 Tensile test

The tensile sample with ASTM D638 used for the tensile test and the design were prepared from Auto Cad 2023 in figure 3.9. The XHC-50 Ring Stiffness ran a sample slicer which had software showing all the test details. As well, the cross-head speed and the strain rate was 5mm/min, operating with a 5KN load cell with advanced control as shown in figure 3.10.

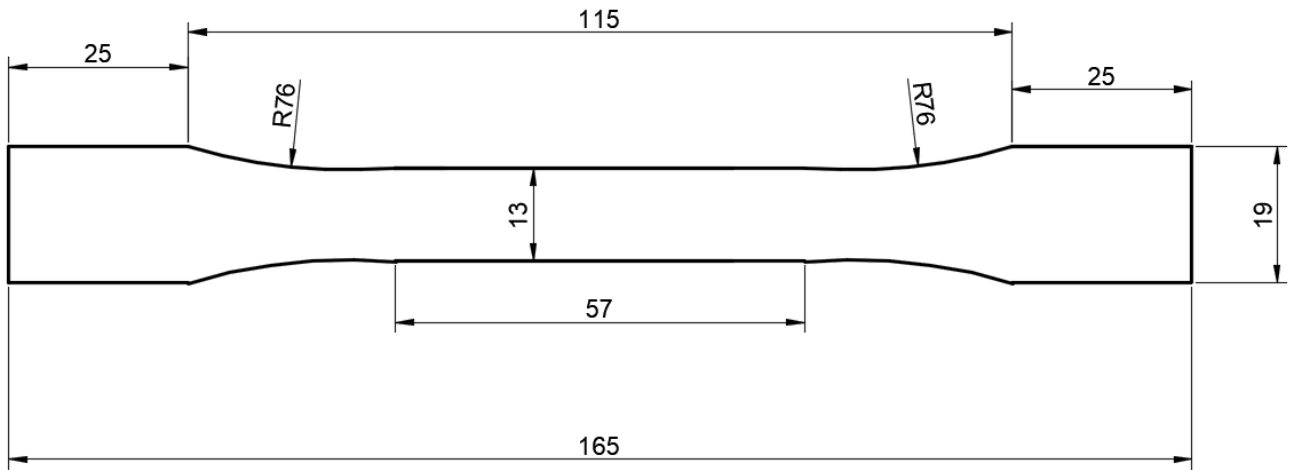
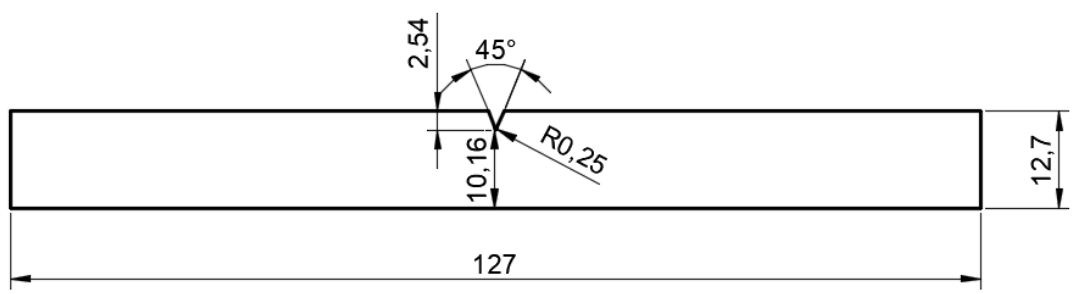


Figure 3.9 Tensile test sample (units are in mm)

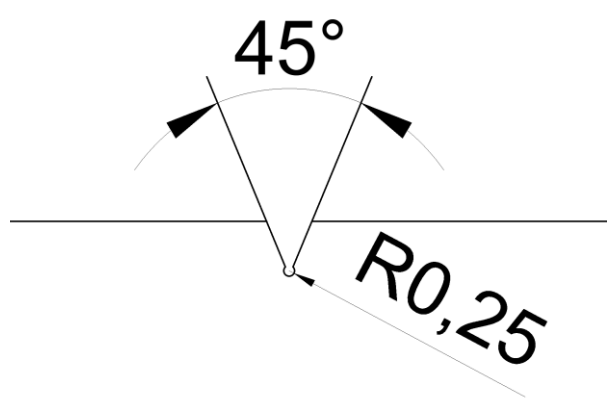
Figure 3.10 Tensile testing machine

3.3.3.2 Impact test

To perform this test, ASTM D256 was used. and the drawing was prepared from Auto Cad 2023 in Figure 3.11. As well as, the most important characteristic of this design is the quarter circle with radius of 0.25 that keeps helping to increase the samples toughness. The machine that performed the test was a special XJJD-50 series for Charpy impact testing on metal and plastic. By smart screen recorder, the energy that is necessary for cutting the sample were shown, the machine is shown in figure 3.12.



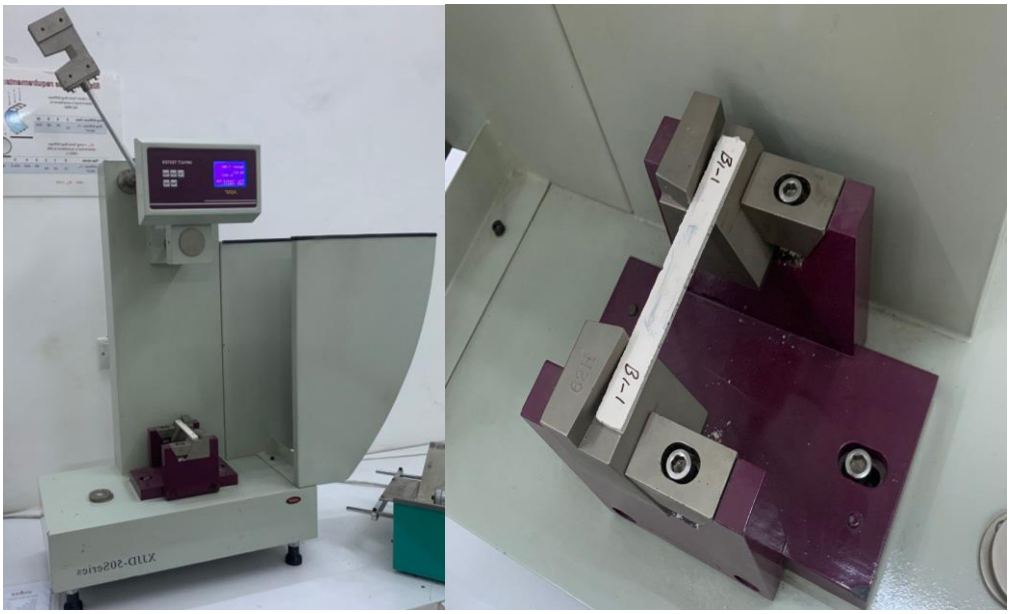
(a)



(b)

Figure 3.11 (a) Impact test sample (b) magnified port

(Units are in mm)



(a) (b)

Figure 3.12 (a) XJID series Charpy impact machine Impact test machine (b) Clamping sample procedure

3.3.3.3 Flexural test

This test was performed by ASTM D790 standard for flexural test and the drawing was prepared from Auto Cad 2023 in figure 3.13 below. As well as, this sample's characteristic is its main flat surface which leads to holding by three-point loads., and XWW-5KN INSTRON 5982 machine as shown in figure 3.14. This device can make either tensile and flexural test in the same time by using specific tools. As well, by software all details are known, the value of the bending units is determined. Two cross head rate and strain rate 5 mm/min and 10 mm/min for much ductile composite with the span length 80 mm for both.

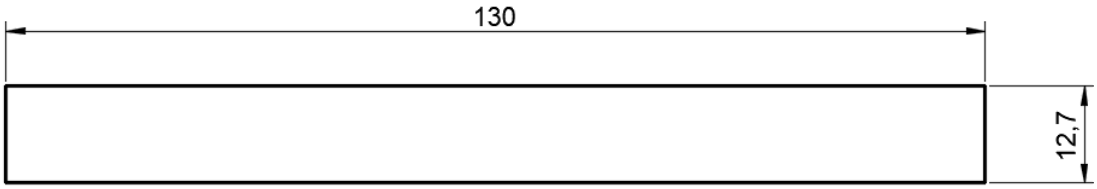
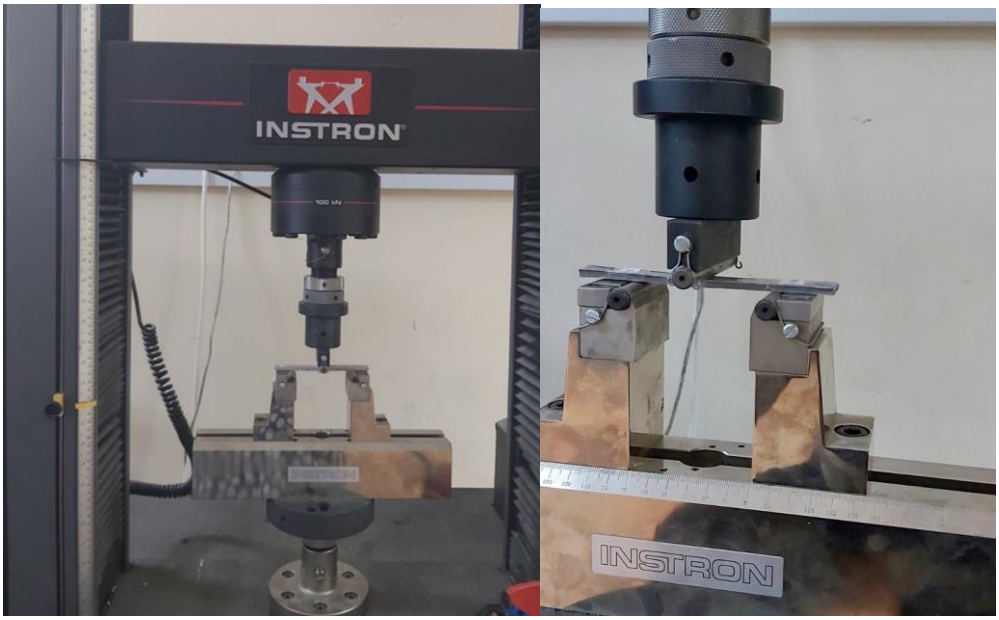


Figure 3.13 Flexural test sample (units are in mm)



(a) (b)

Figure 3.14 (a) XWW-5KN INSTRON 5982 machine (b) clamping sample procedure

Before testing of samples, all the samples of composite which cured 7 days and then, droughting cured composite to water jet the Computer Numerical Control (CNC) machine (X Optima 320) in the northern south industry in Erbil city, to cut them according to ASTM standards for each test, as indicated in figure 3.15. Additionally, waterjet cutting is a cold process, with no heat affected zones, hardened material, or material tensions are produced as a result of the cutting operation. Often, further surface polishing is not necessary with a clean, accurate, burr-free finish. The small

diameter, extremely accurate kerfs produced by the optima waterjet cutting technique ensure that the clean completed goods can be generated in a way that may not be achievable with other methods. Waterjet cutting makes it possible to rapidly and easily build, modify, and revise prototypes for items still in development. It is also suited for both short and lengthy production runs (MACHINE, 2021).

Figure 3.15 Water jet CNC machine

3.3.4 Grouping Coding and Testing Samples

In this step, all the specimens were prepared for testing. The tests were (Tensile, Impact and Flexural) and each test has its own standard on ASTM as mentioned on section (3.3.3). Tensile and Impact tests were done at Salaheddin University in Erbil city but Flexural was done at Koya University in Koya city. For the purpose of being more familiar with the samples that were produced, they allotted them to 2 groups, for first and second group of composites as a matrix base. As well, selecting codes for specimens were necessary for this purpose for each test two letters were chosen. For the tensile test letter (A and R), for impact test (B and M), and for flexural test (C and N) were chosen and all information about layers of epoxy, UDC, fiber glass, and the wight percentage of each composite are shown in tables 3.5 and 3.6. Moreover, samples are shown in Figure 3.16 for the first composite group with epoxy Master protect 180 which is a white color and in Figure 3.17 is the second group of composites with gray color epoxy Master brace ADH 1406.

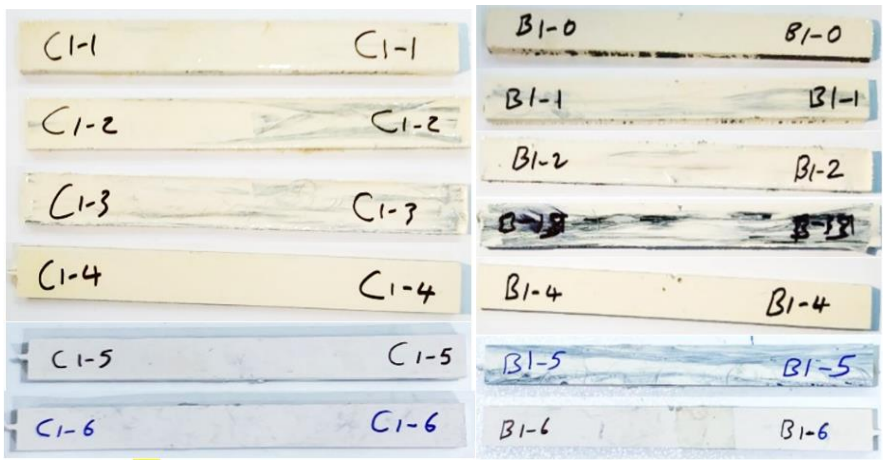
Table 3. 5 Specimen codes for first group of composite Master Protect 180

Code of composite	EP %	Carbon%	Fiber glass %	Layers of composite
A1-0, B1-0, C1-0	100	0	0	Ep*
A1-1, B1-1, C1-1	95	5	0	Ep-C*-Ep
A1-2, B1-2, C1-2	90	10	0	Ep-C-Ep-C-Ep
A1-3, B1-3, C1-3	85	15	0	Ep-C-Ep-C-Ep-C-Ep
A1-4, B1-4, C1-4	94	3	3	Ep-C-Ep-F.g-Ep
A1-5, B1-5, C1-5	95.5	3	1.5	Ep-C-Ep-F.g-Ep
A1-6, B1-6, C1-6	95.5	1.5	3	Ep-C-Ep-F.g -Ep
R1-1, M1-1, N1-1	95	0	5	Ep-F.g -Ep
R1-2, M1-2, N1-2	92.5	0	7.5	Ep-F.g-Ep-F.g
R1-3, M1-3, N1-3	90	0	10	Ep-F.g-Ep-F.g

Table 3. 6 Specimen codes for second group of composite Master Brace ADH 1406

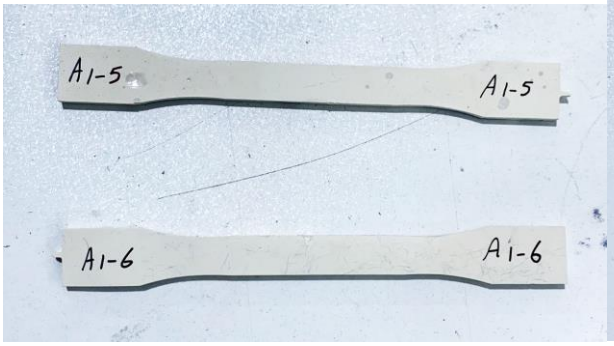
Code of composite	EP %	C %	F.glass %	Layers of composite
A2-0, B2-0, C2-0	100	0	0	Ep
A2-1, B2-1, C2-1	97	3	0	Ep-C-Ep
A2-2, B2-2, C2-2	94.5	5.5	0	Ep-C-Ep-C-Ep
A2-3, B2-3, C2-3	98.5	1.5	0	Ep-C-Ep
A2-4, B2-4, C2-4	94	3	3	Ep-C-Ep-F.g-Ep
A2-5, B2-5, C2-5	95.5	3	1.5	Ep-C-Ep-F.g-Ep
A2-6, B2-6, C2-6	95.5	1.5	3	Ep-C-Ep-F.g -Ep
R2-1, M2-1, N2-1	98.5	0	1.5	Ep-F.g -Ep
R2-2, M2,2, N2,2	96.7	0	3.3	Ep-F.g-Ep-F.g
R2-3, M2-3, N2-3	94.5	0	5.5	Ep-F.g-Ep-F.g

Note* Ep refers to the Epoxy C: refers to the Unidirectional CarbonF.g: refers to the Fiber glass

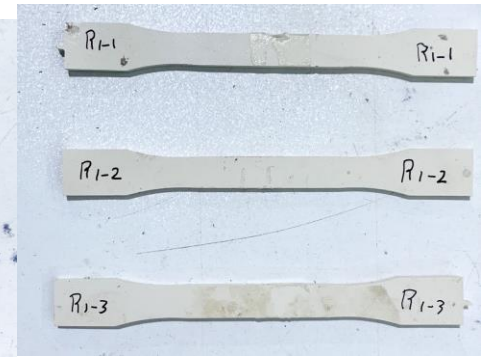


(a)

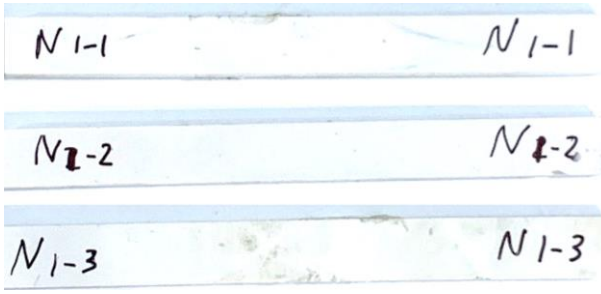
(b)



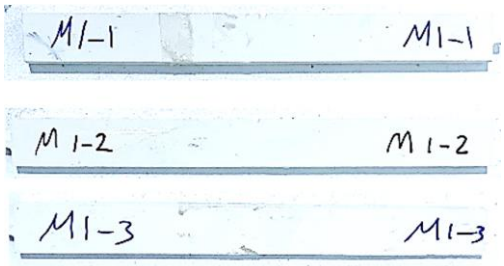
(c)



(d)

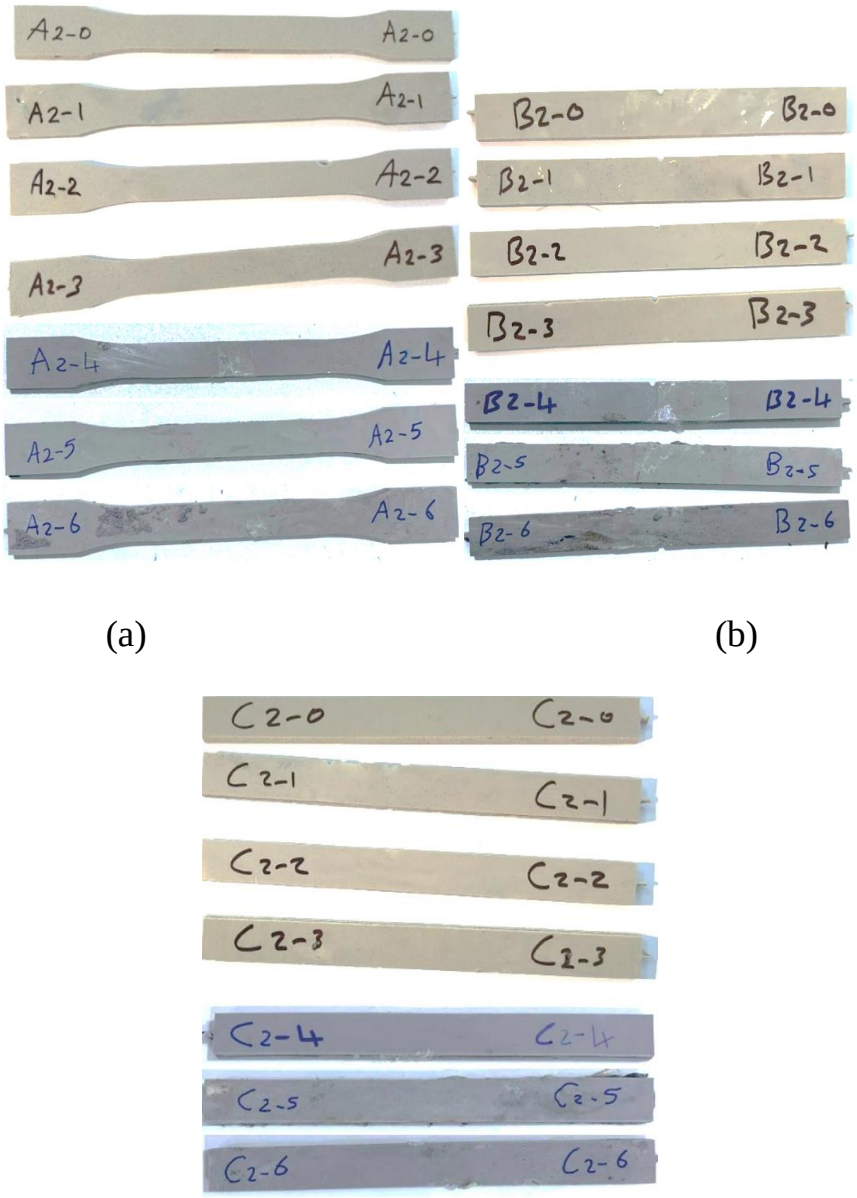


(e)



(f)

Figure 3.16 (a) and (e) Flexural (b) and (f) Impact (c) and (d) Tensile samples of first group Master Protect 180 of composites before testing



(a) (b)

(c)

Figure 3.17 (a) Tensile (b) Impact (c) Flexural samples for Second group Master Brace ADH 1406 of composites before testing

The results of three groups of the tests will be shown in chapter five , also discussing each samples results in a brief argument.

CHAPTER FOUR

FINITE ELEMENT ANALYSIS AND MODELING

4.1 Introduction

Through this chapter numerical analysis about Tensile, Impact and Flexural will be analyzed. As well formulas will show and discussed briefly. Furthermore, simulation and modeling of experimental work by the ANSYS Work bench 2022 R1 software will be presented, and how that effect of each layer of composite material has on the composite samples.

4.2 Formulation for the Tensile Test

For determining the micro-mechanical modeling, the description of the stress-strain curve and relationship are very useful. At the beginning of the engineering strain formula can be used, which is represented by

$$\varepsilon = \frac{L_f - L_i}{L_f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.\ 1)$$

Where L_f is represented as the length of the body sample after deformation and Li is before deformation. However, equation 4.1 is used much more for uniform deformation. And if there is non-uniform deformation, the above formula can be expressed as the following:

$$\varepsilon = \frac{P}{AB} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.\ 2\ )$$

Where u is the displacement vector and x is the orthogonal direction. Thus, the equation above can be expressed as three orthogonal directions as

$$\left.\begin{aligned} \varepsilon_x &= \frac{du}{dx} \\ \varepsilon_y &= \frac{du}{dy} \\ \varepsilon_z &= \frac{du}{dz} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.\ 3)$$

Moreover, the strain can be a distinct a function of stress as

$$\varepsilon = \frac{\sigma}{E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.\ 4)$$

As well, stress is relation between the load and the cross-section area in (N/mm^2), and E is Modulus of elasticity in (Ramakrishnan and Sampath).

$$\sigma = \frac{Load}{Cross\ section\ area} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.\ 5)$$

So, to conduct the finite element method nodes

$$\sigma = \varepsilon E \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.\ 6)$$

Above equations are from (Hosford, 2010)

4.3 Formulation for the Impact Test

$\Delta P = w.(h + \delta)$ ……. (4. 7)

$\Delta SE = \frac{1}{2}$ P δ …… (4. 8)

$= \frac{1}{2}\sigma$ A.$\frac{L}{E}$ σ

$= \frac{\sigma^2 \cdot}{2E}$ AL …… (4. 9)

(4.5) = (4.7)

W (h+δ) $= \frac{\sigma^2 \cdot}{2E}$ AL

w(h+$\frac{\sigma L}{E}$) $= \frac{\sigma^2 \cdot}{2E}$ AL

$\frac{\sigma^2 \cdot}{2E}$. AL - σ $\frac{W L}{E}$ – w.h = 0

$\sigma = \frac{w}{A}(1 \pm \sqrt{1 \pm \frac{2hAE}{wh}}$ ……. (4. 10)

Considering maximum stress

$\sigma_{i} = \frac{w}{A}(1+ \sqrt{1 + \frac{2AEh}{wh}}$

$\varepsilon = \frac{\sigma_i}{c}$

$\delta = \frac{\sigma L}{E}$

$\varepsilon = \frac{\sigma_{i\,2}}{2E}$. AL= $\frac{1}{2}\sigma\varepsilon$. wy

h=o

$\sigma_i = \frac{w}{A}(1+ \sqrt{1 + \sigma})$

$\sigma_i = \frac{2W}{A}$ …….. (4. 11)

Where :

ΔP =potential energy (Joules)

$w = weight\ of\ pandol\ (gram)$

h = hight of the pandol (mm)

δ= initial length (mm)

ΔSE = strain energy of the rod (unitless)

P= load (N)

A = area (mm^2)

4.4 Formulation for the Flexural Test

$\Delta x = \rho\ \theta$ ……..... (4. 12)

$\Delta S = (\rho - y)\Delta\theta$ ……. (4. 13)

Normal strain y from N.A

$$\varepsilon = \frac{\Delta S\prime - \Delta S}{\Delta S} = \frac{(\rho - y)(\Delta\theta - \rho\Delta\theta}{\rho\Delta\theta} = \frac{-y}{\rho}$$

$$\varepsilon_{max} = \frac{\varepsilon}{y}$$

$$\varepsilon = \frac{-y}{c}\,\varepsilon_{max}$$

From hooks low $\sigma = E\varepsilon$

$$\frac{\sigma}{E} = \frac{-y}{c}$$

$\sigma = \frac{-y}{c} \sigma_{\text{max}}$ ..... (4. 14)

Where:

$\Delta x =$ length of element (mm)

$\rho = radius\ of\ curveture$ (mm)

θ = angle od deformation (degree)

$\Delta S = \ change\ in\ length$ (mm)

$y =$ length from neutral axixs $(N.A)$the top (mm)

N.A = neutral axis

$\varepsilon =$ strain (unitless)

$\Delta S' =$ length after deformation (mm)

C= extreme distance from N.A to the top of element (mm).

Equations for impact and flexural were taken from (Yi et al., 2018)

4.5 Modeling and Simulation

The first step of simulating is entering data from hand manual for each component of experimental work. In addition, having a composite material must so there must be a hand manual entering a modeling an Representee Volume Element (RVE). Hence the steps are briefly shown in the next part.

4.5.1 Steps of Modeling RVE

First step: For conducting this work an ANSYS 2022 R1 work bench is used. As opening the program there were to be selected Material Designer in Analysis System

for the purpose of RVE modeling, see figure 4.1, then entering mechanical properties of each material as shown in figure 4.2.

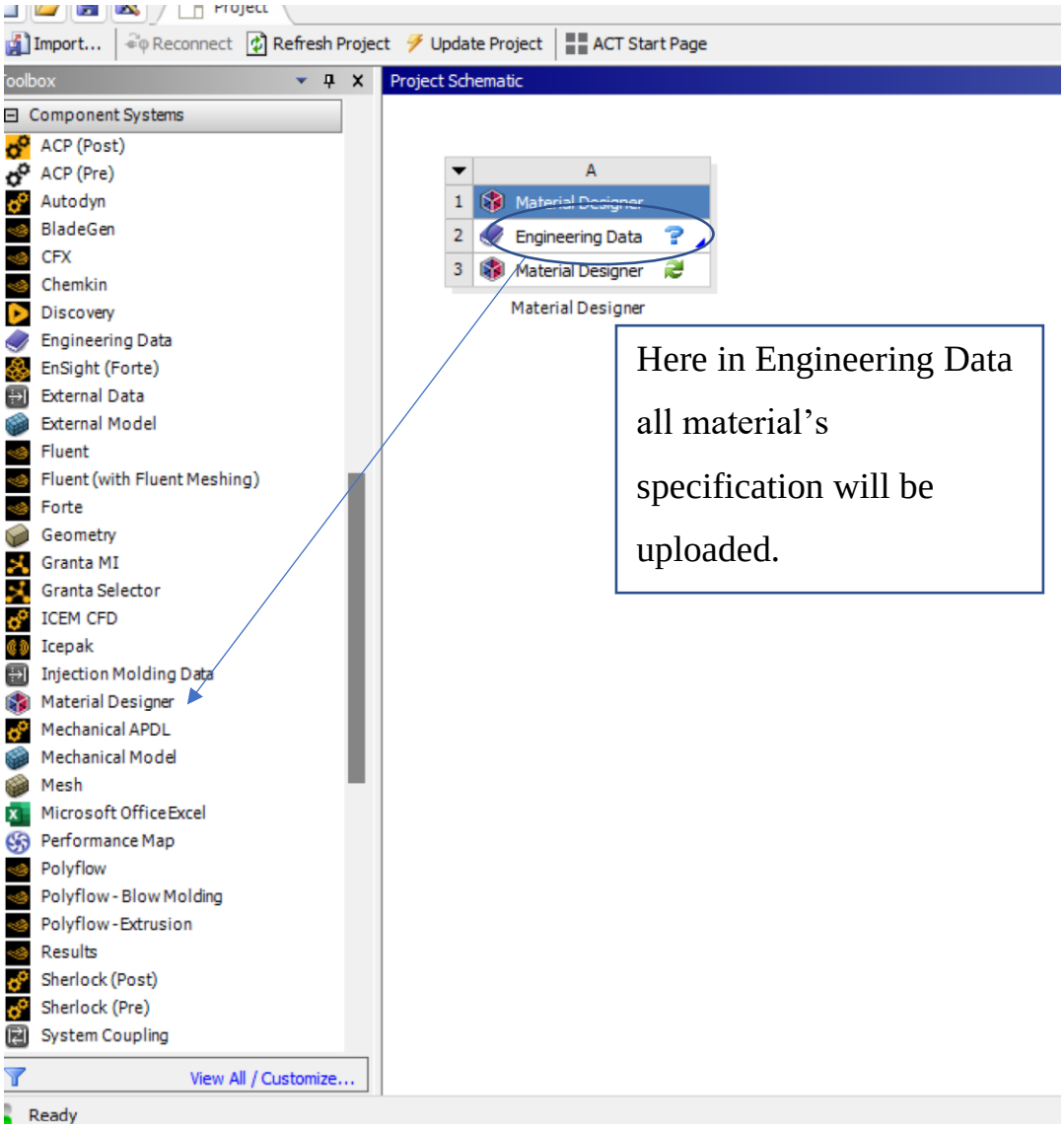


Figure 4. 1 First step of modeling RVE

Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Mat...				
3	Epoxy resin			C:\Users\BEST TECH	
*	Click here to add a new material				

Properties of Outline Row 3: Epoxy resin

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variable	Table			
3	Density	1.5	g cm^-3		
4	Isotropic Elasticity				
5	Derive from	Young's...			
6	Young's Modulus	1.5	MPa		
7	Poisson's Ratio	0.23			
8	Bulk Modulus	9.2593E+05	Pa		
9	Shear Modulus	6.0976E+05	Pa		

(a)

Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Mat...				
3	Epoxy resin			C:\Users\BEST TECH	
4	Woven carbon			C:\Users\BEST TECH	
*	Click here to add a new material				

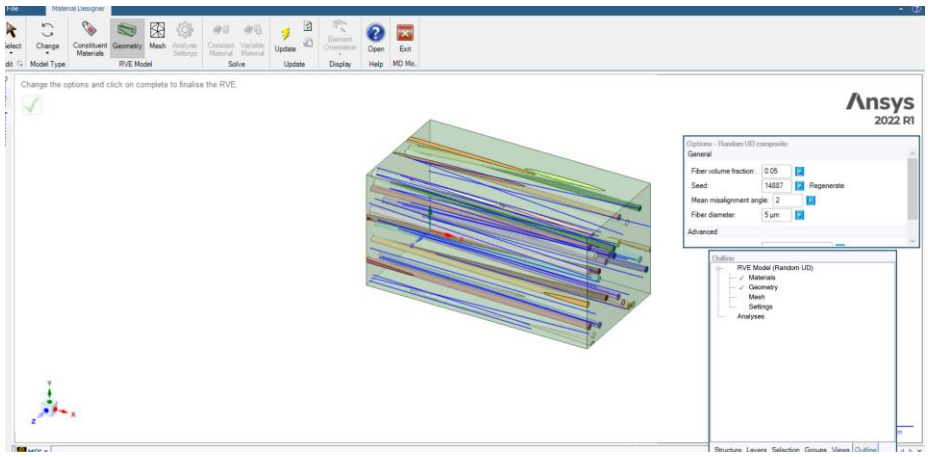
Properties of Outline Row 4: Woven carbon

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variable	Table			
3	Density	1.82	g cm^-3		
4	Isotropic Elasticity				
5	Derive from	Young's...			
6	Young's Modulus	2.3E+05	MPa		
7	Poisson's Ratio	0.25			
8	Bulk Modulus	1.5333E+11	Pa		
9	Shear Modulus	9.2E+10	Pa		

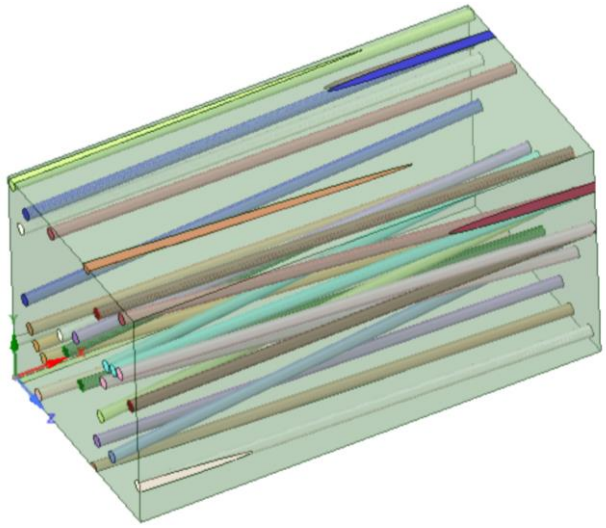
(b)

Figure 4. 2 Entering properties of (a) Matrix (b) reinforcement.

Second step: Generating RVE by introducing material types and fiber volume fraction.



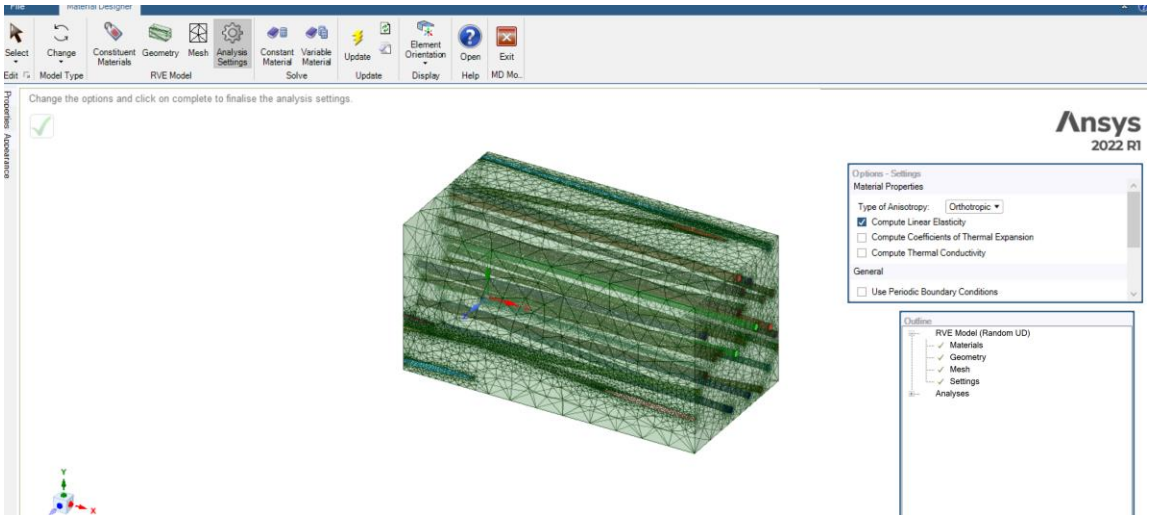
(a)



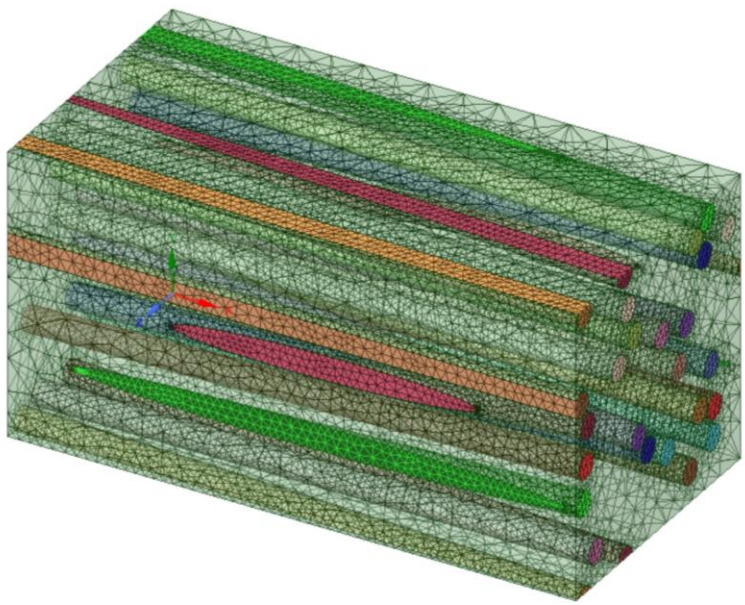
(b)

Figure 4. 3 (a) Entering volume fraction (b) RVE

Third step: Computing meshing and linear elasticity by using Constant Material settings.



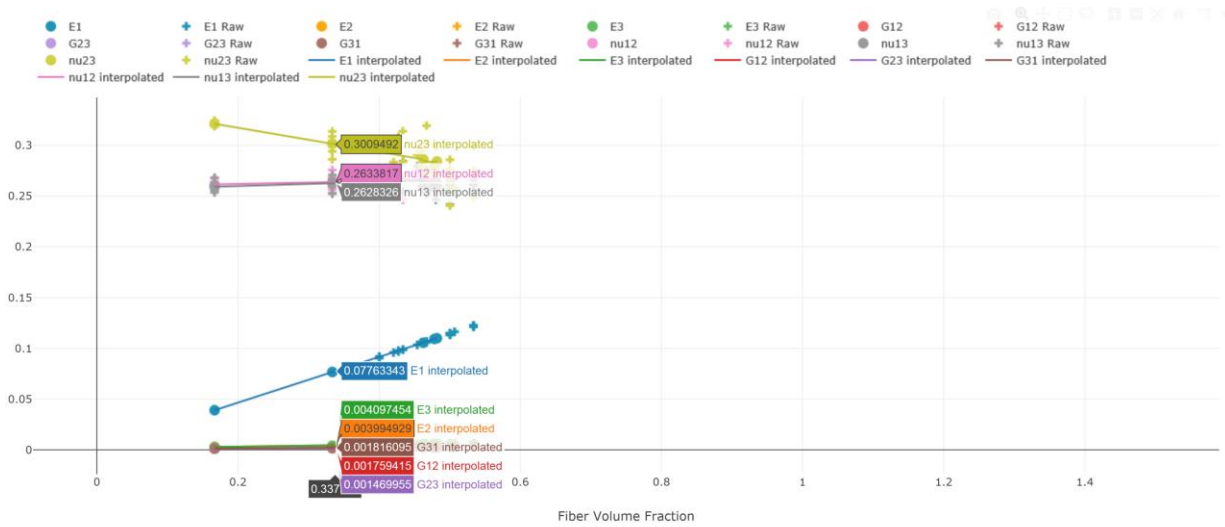
(a)



(b)

Figure 4. 4 (a) Compute of meshing (b) meshed RVE

Fourth Step: Adding charts and calculating the mathematical model for Variable Material also computing modulus of elasticity, rigidity and fiber volume fraction.



(a)

Name	Values[0]	Std. dev.[0]	Values[1]	Std. dev.[1]	Values[2]	Std. dev.[2]	Values[3]	Std. dev.[3]	Values[4]	Std. dev.[4]	Unit
Parameters											
Fiber Volume Fraction	0.16685	3.5882E-05	0.33364	6.8031E-05	0.47838	0.025755	0.4627	0.053323	0.48189	0.037675	
Engineering Constants											
E1	0.039083	0.00044273	0.076763	0.00044113	0.1094	0.0058158	0.10564	0.012354	0.11012	0.0088123	MPa
E2	0.0028154	1.306E-05	0.0039367	0.0001057	0.0059047	0.00051903	0.0058674	0.0010986	0.006193	0.0007342	MPa
E3	0.002797	1.3168E-05	0.0040395	0.00010456	0.0060156	0.00049449	0.0059615	0.0011291	0.0062659	0.00086439	MPa
G12	0.0011724	1.206E-05	0.0017286	5.6019E-05	0.0027175	0.0002623	0.0027514	0.00054989	0.0028948	0.0003164	MPa
G23	0.001044	3.1198E-06	0.001451	1.904E-05	0.0021333	0.00017431	0.002081	0.0003147	0.0022346	0.0002505	MPa
G31	0.001154	1.2461E-05	0.0017864	5.6011E-05	0.0027698	0.00024551	0.0027728	0.00052468	0.0029238	0.00042332	MPa
nu12	0.26154	0.004092	0.26329	0.00714	0.26451	0.0050156	0.26649	0.0065695	0.26076	0.0091862	
nu13	0.25915	0.0043667	0.26275	0.0056573	0.25914	0.0043243	0.26539	0.010879	0.26211	0.01335	
nu23	0.32124	0.0017635	0.30141	0.0085531	0.27958	0.012196	0.28619	0.021575	0.28411	0.024291	
Density											
rho	1.72E-09	4.5489E-15	1.74E-09	9.59E-15	1.7574E-09	3.0885E-12	1.7555E-09	6.4007E-12	1.7578E-09	4.5192E-12	t mm^-3

(b)

Figure 4. 5 (a) Chart of modulus of elasticity, rigidity and fiber volume fraction (b) results table

Fifth step: previous steps are the steps for composite which consists of two components one reinforcement and matrix as an epoxy. Meanwhile, if having three components: two reinforcements and a matrix as an epoxy then after meshing and setting. Adding another Material Designer including another one and making it as Matrix for the new reinforcement, as (Zachariah et al., 2021), (Johri et al., 2022) did, And then the steps will be repeated until computing Variable Material, as shown in figure 4.6.

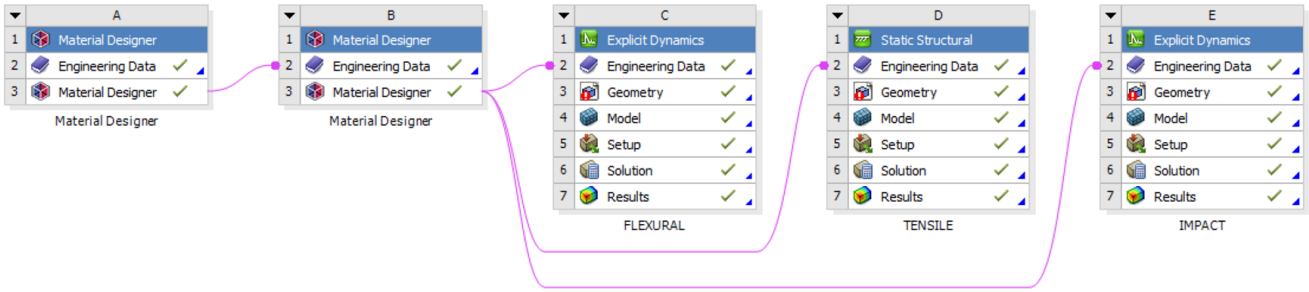


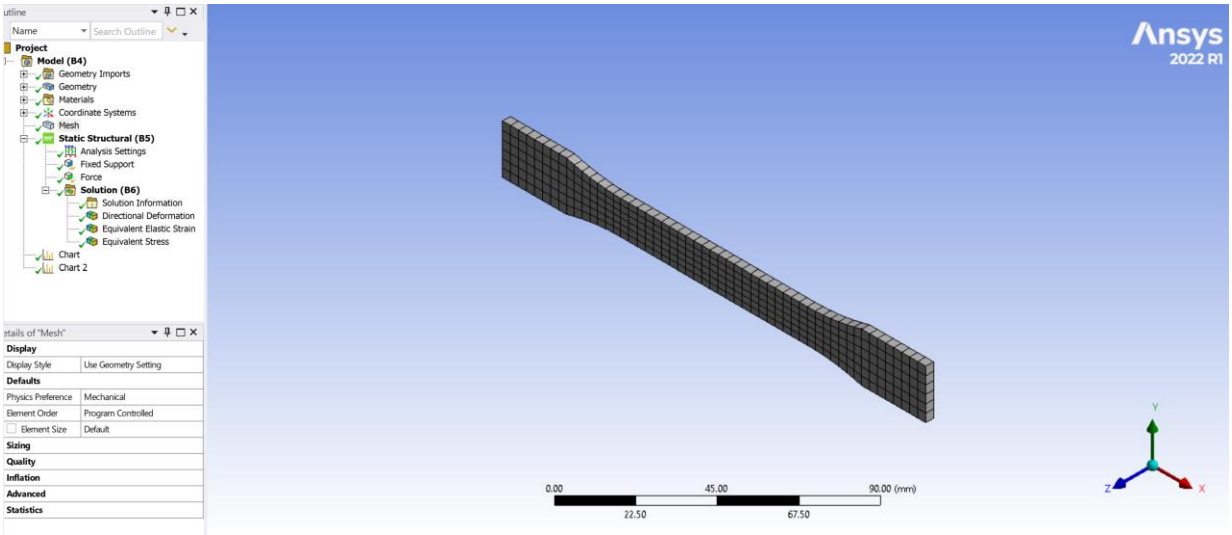
Figure 4. 6 Steps of simulation

4.6 Modeling of Samples

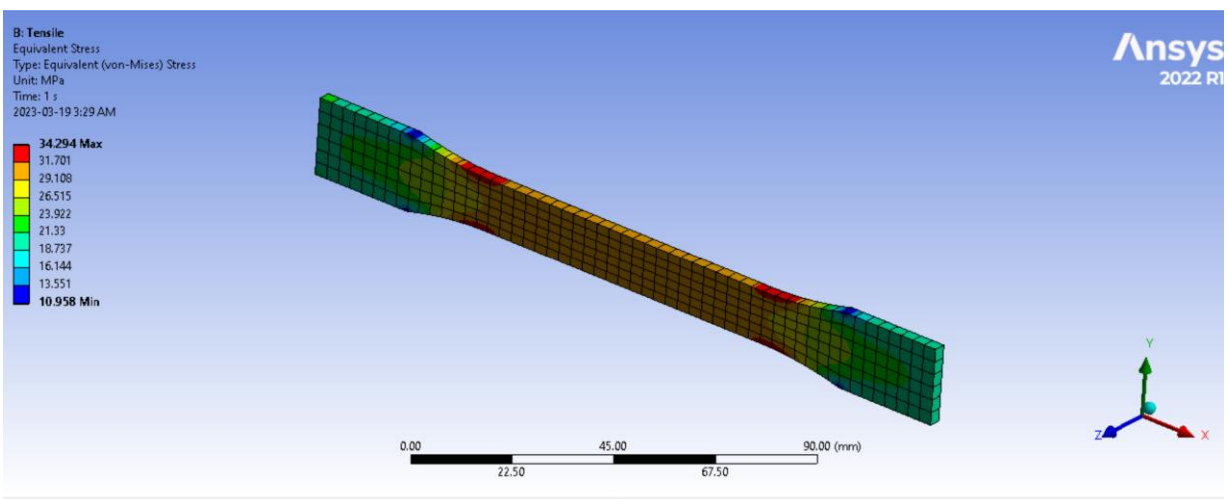
For creating the model simulation for three samples (tensile, impact and flexural) the ANSYS 2022 R1 used in the geometry part and then boundary conditions added for the purpose of computing results in a Finite Element Analysis way.

4.6.1 Modeling of the Tensile Test Samples

By using Static structure, the simulation of a tensile test was done. Hence, changing of the force was the most important part for conducting the numerical simulation because each sample hasn't got the same strength as another. For instance, sample A1-0 by only (390 N) while A1-5 needs (6000 N) and sample A2-0 by (180N) while A2-6 by (5000N) fracted for tensioning, this point shows that the strength of the sample after increasing layers of UDC and fiber glass. Figure 4.7 shows the simulation of tensile sample and table 4.1 and 4.2 presented results that obtained in first group Master Protect180 and second group Master Brace ADH 1406 of composites respectively.



(a)



(b)

Figure 4. 7 (a) Geometry model and (b) Simulation of Tensile sample

Table 4. 1 First group Master Protect 180 tensile results ANSYS

Code of composite	Stress (MPa)
A1-0	10.49
A1-1	79
A1-2	109.14
A1-3	122
A1-4	167
A1-5	24
A1-6	39
R1-1	11
R1-2	41.76
R1-3	41.79

Table 4. 2 Second group Master Brace ADH 1406 tensile results ANSYS

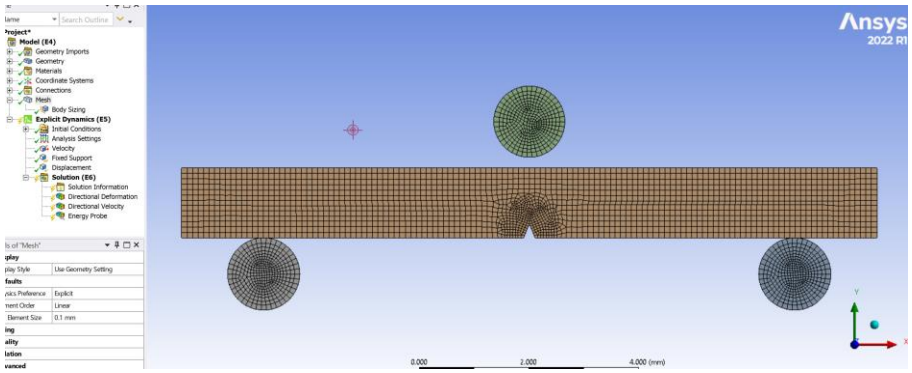
Composite code	Stress (MPa)
A2-0	4.83
A2-1	80.72
A2-2	129
A2-3	21
A2-4	154.09
A2-5	137
A2-6	13.9
R2-1	13.459
R2-2	12.651
R2-3	14.82

4.6.2 Modeling of the Impact Test Sample

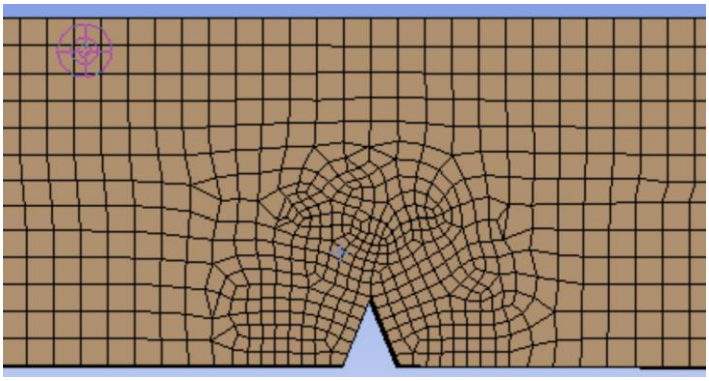
Explicit Dynamic was used for representing simulation of impact sample all variables were uploaded and the meshing section has more and specifications as shown in figure 4.8 by increasing number of element sizing in the location of the edge cutting by below procedures:

- ✓ Transferring the coordinate location to the middle of the edge.
- ✓ Adding meshing size in meshing section.
- ✓ Adding sphere sizing.
- ✓ Changing the sphere center in to coordinate system.
- ✓ Entering the sphere radius 0.5mm and element size of the sphere 0.05mm as shown in figure (4.9).

As well, by Energy probe in the solution result, the total impact energy was computed as shown in figure 4.10, table 4.3 and 4.4 presented results that obtained in first group Master Protect180 and second group Master Brace ADH 1406 of composites respectively.

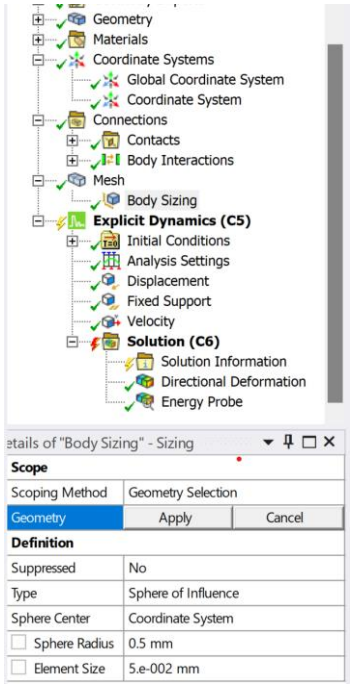


(a)

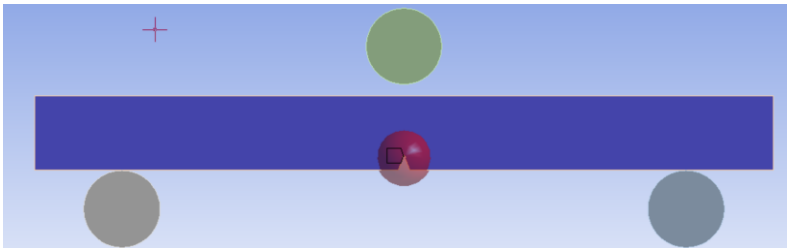


(b)

Figure 4. 8 (a) Modeling and (b) Size meshing of impact sample



(a)



(b)

Figure 4. 9 (a) procedure of element sizing (b) impact sample with sphere sizing

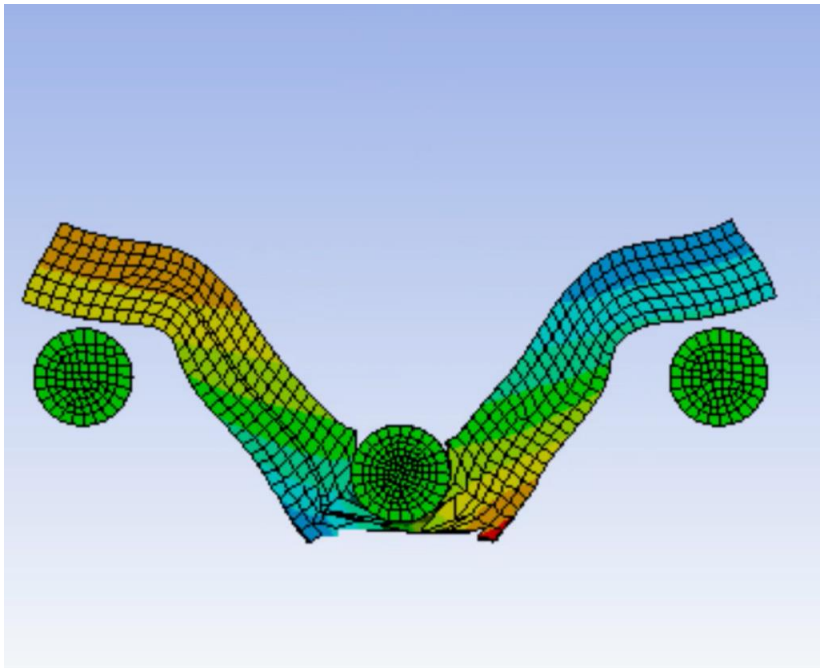


Figure 4. 10 Impact sample simulation

Table 4. 3 First group Master Protect 180 impact result ANSYS

Composite code	Energy (J)
B1-0	0.272
B1-1	1.41
B1-2	2.87
B1-3	6.412
B1-4	2.12
B1-5	1.573
B1-6	0.95
M1-1	0.1292
M1-2	0.722
M1-3	1.397

Table 4. 4 Second group Master Brace ADH 1406 impact result ANSYS

Composite code	Energy (J)
B2-0	0.047
B2-1	1.0116
B2-2	3.463
B2-3	1.4236
B2-4	4.334
B2-5	3.247
B2-6	0.7521
M2-1	2.542
M2-2	0.886
M2-3	2.12

4.6.3 Modeling of the Flexural test sample

As modeling of Impact test Explicit Dynamic to conduct a Flexural sample's finite element analysis. See this sample on Figure 4.10 after meshing. As well as, by using velocity rate, the stress and bending strength were found. The two cylinders that are located at the bottom of the sample create friction for the purpose of neglecting the fractional contact between the specimen and both cylinders the connection between them will be deleted. As shown in Figure 4.10. and Figure 4.11 shows the specimen while bending and table 4.5 and 4.6 presented results that obtained in first group Master Protect180 and second group Master Brace ADH 1406 of composites respectively..

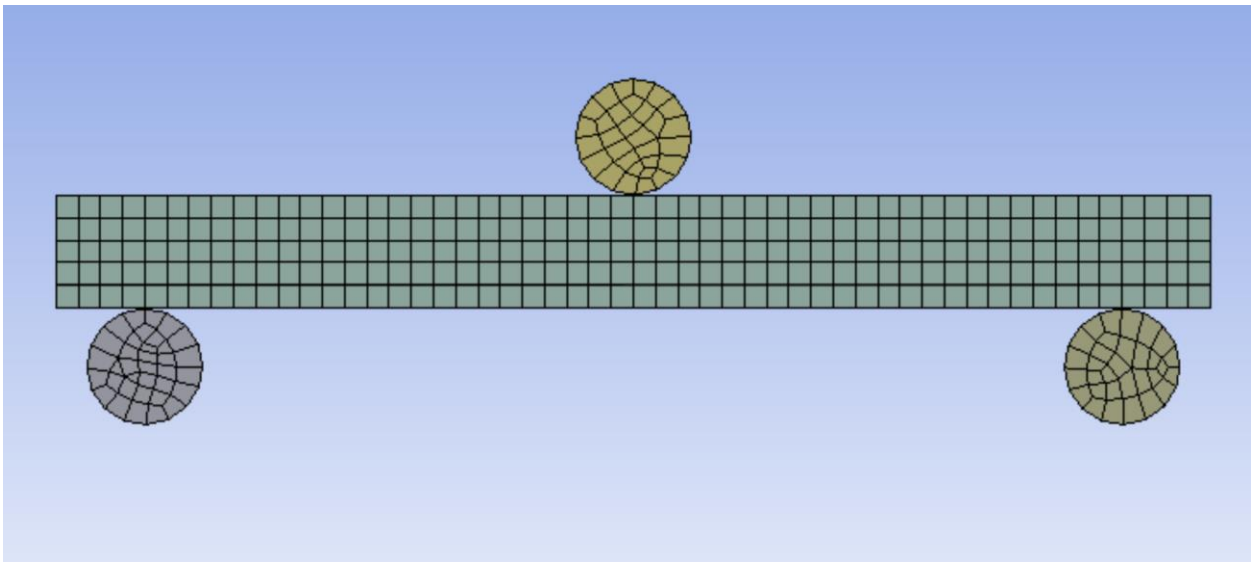


Figure 4. 11 Mesh of flexural sample

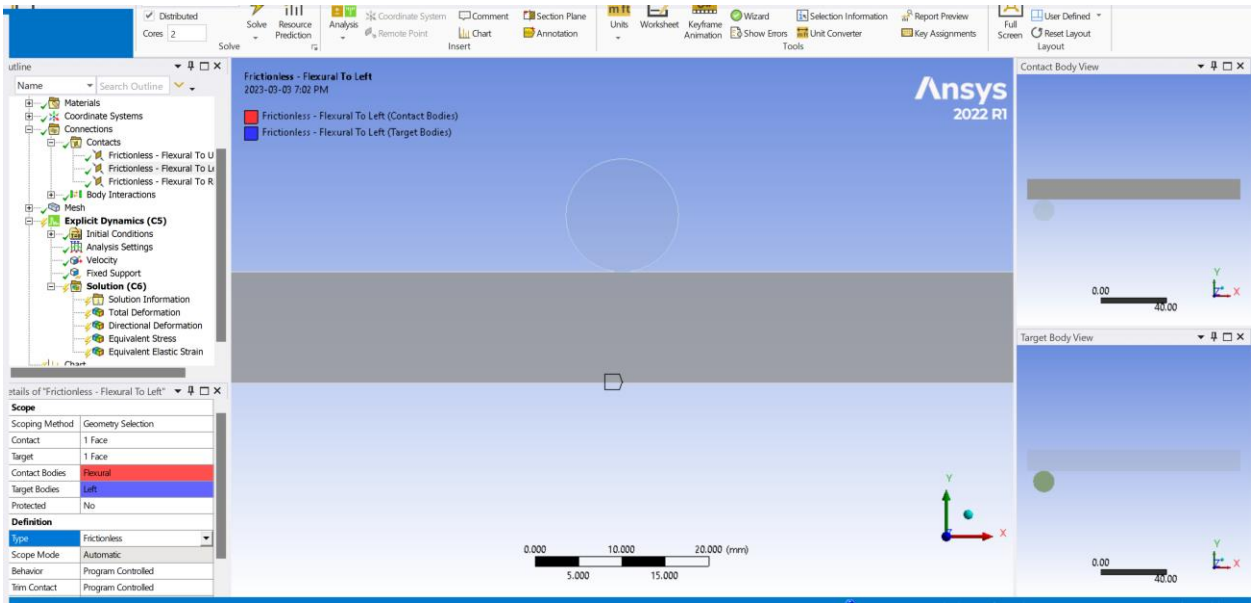


Figure 4. 12 Flexural connection ANSYS

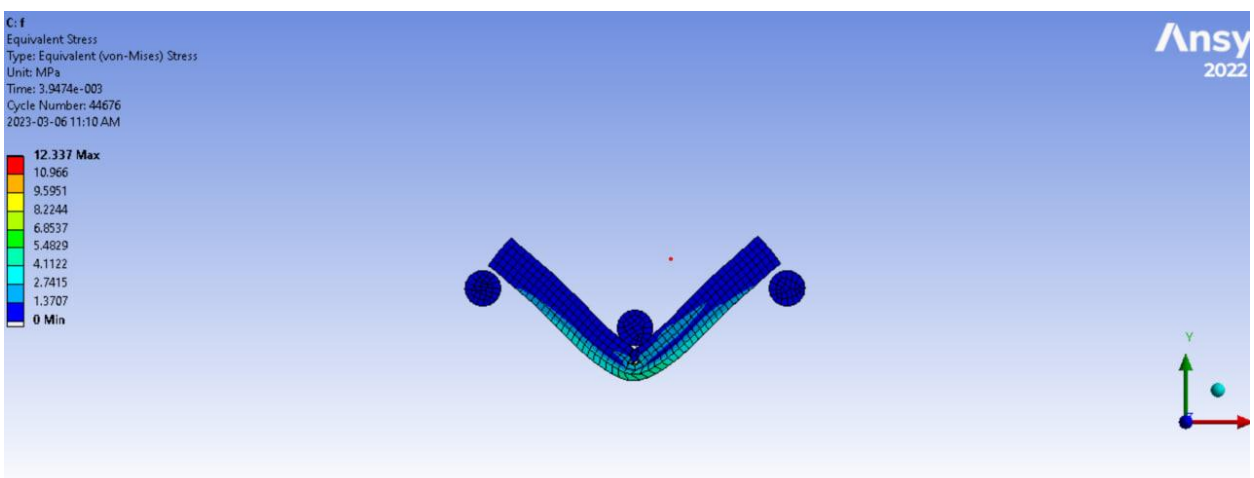


Figure 4. 13 Flexural sample bending process

Table 4. 5 First group Master Protect 180 Flexural result ANSYS

Sample codes	Stress (MPa)
C1-0	20.909
C1-1	56.071
C1-2	67.605
C1-3	100.67
C1-4	64.921
C1-5	29.156
C1-6	25.572
N1-1	34.76
N1-2	23.009
N1-3	109.516

Table 4. 6 Second group Master Brace ADH 1406 Flexural result ANSYS

Sample codes	Stress (MPa)
C2-0	17.075
C2-1	26.82
C2-2	113.18
C2-3	66.69
C2-4	33.96
C2-5	28.69
C2-6	45.55
N2-1	27.6
N2-2	31.116
N2-3	22.915

CHAPTER FIVE

DISCUSSION AND ANALYSIS OF EXPERIMENTAL WORK

5.1 Introduction

In this chapter, analysis of the results of experimental work is shown in a brief way, through tables, charts and samples after testing. Also, discussion and finding reasons of the results of each test are shown. As well, there are a comparison between the experimental and computational results by charts is presented.

5.2. Result and Discussion About Tensile Test

5.2.1 Tensile Test for the First Composite Epoxy Master protect 180

As shown in Table 5.1, and Figure 5.1, the results of the samples. Since the test was performed, the highest value of ultimate tensile strength (168 MPa) was reached for sample A1-4, which contains a mixture of fiberglass and UDC. On the other hand, by adding more layers of UDC to the sample, the tensile strength will also increase. This indicates that the difference in stacking sequence had little effect on the tensile strength. In addition, the table shows the modulus of elasticity for each sample and as we seen, the highest one is A1-4 which contains

tertiary epoxy, UDC, and fiberglass this is another indication which tells us that the rigid bond between this triple mixture is very high that leads to have the highest modulus of elasticity. Moreover, the minimum value is with R1-1 that contains fiber glass with rate of (%5) with epoxy resin which is less than A1-0 which contains only epoxy resin, this result shows as the fiber glass is not a suitable fiber for strengthen these samples, and another point is that While adding only fiber glass to the epoxy will not change any increase in tensile strength Figure 5.1 shows the relation between stress and strain, and Figure 5.2 shows some of samples after conducting testing. As well, from equation 4.6 Modulus of elasticity for samples can be found.

Table 5.1 Tensile test table result (first group Master Protect 180)

Composite code	**Load (N)**	**Stress (MPa)**	**Strain**	**Elongation (%)**	**Modulus of Elasticity (MPa)**
A1-0	415	1.046	18.019	7.5	0.55
A1-1	3460	74	5.8	0.83	12
A1-2	4260	107	13	1.23	8.2
A1-3	4620	112	23	1.18	5.2
A1-4	7670	168	5	11.77	33
A1-5	1130	23	3.8	9.6	6.05
A1-6	1380	32	2.9	7.89	11.03
R1-1	340	6	90	0.02	0.06
R1-2	1750	33	3.75	8.3	8.8
R1-3	242	36	4.4	8.72	8.18

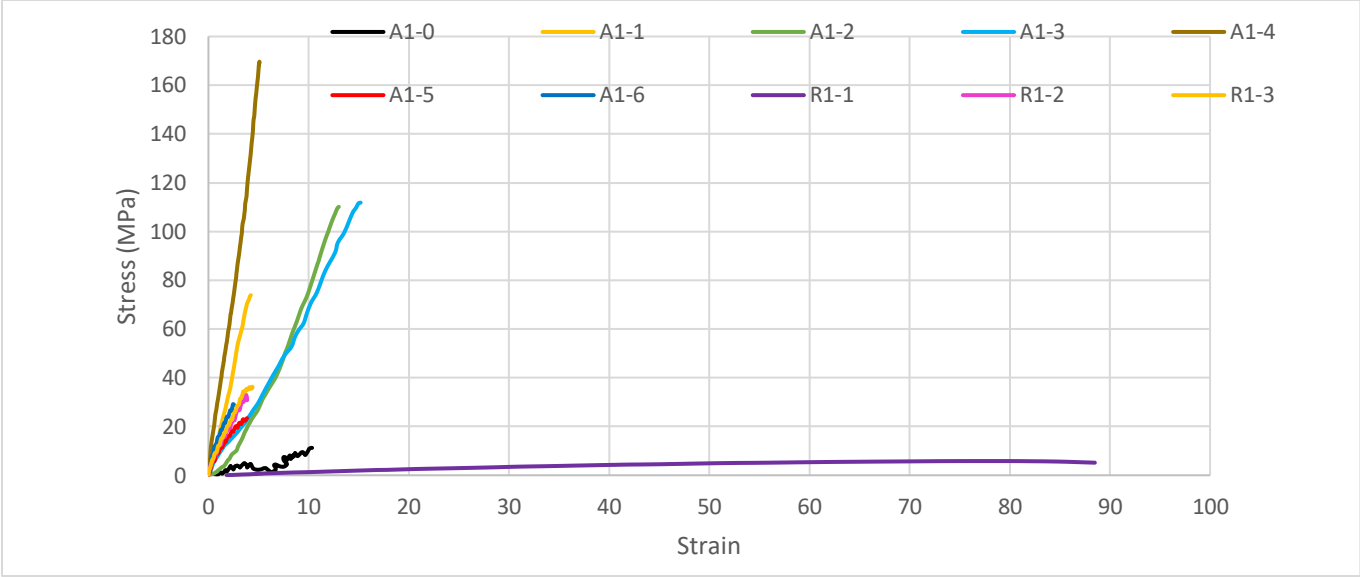


Figure 5. 1 Tensile test result chart (first group Master Protect 180)

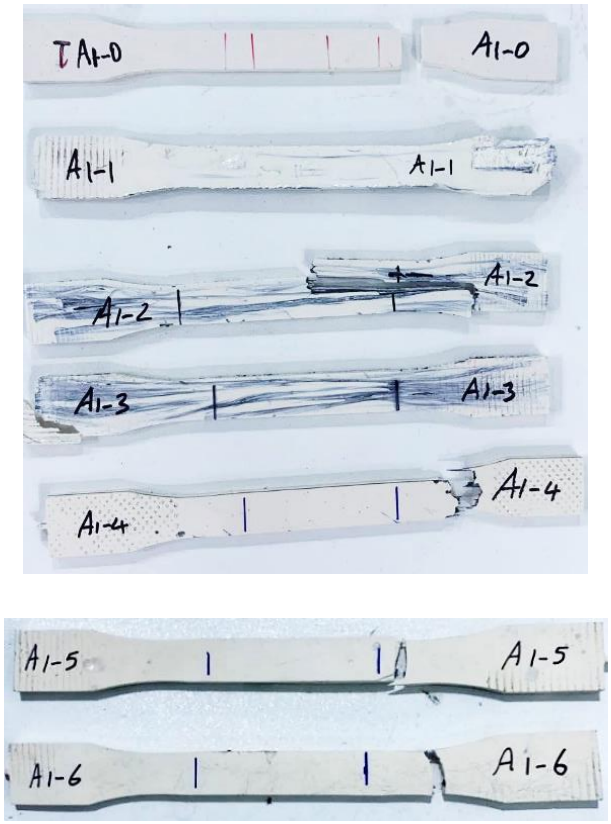


Figure 5. 2 Tensile samples after testing (first group Master Protect 180)

5.2.2 Tensile Test for the Second Composite Epoxy Master Brace ADH 1406

As can be seen in Table 5.2 the results achieved by this test. The achievement of the maximum pressure distribution in a mixture of UDC and fiber glass is 158 (Ramakrishnan and Sampath) due to the maximum resistance to elongation, ductility, and the very strong inter-composite bond leads to this. Also, the maximum loading in the bilayer carbon in sample A2-2 is due to the increased strength, which signifies a positive strain rate. However, A2-5 has a value of (135 MPa), which is also a high one compared to others the reason is that there are more layers of UDC compared to the A2-6 sample. Also, the minimum value of the tensile strength is in the A2-0 sample, and, it is clear for all the reasons that there is no layer of compound on it. And the addition of two layers of carbon. In addition A2-2 has a great value role for increasing strength and as can be seen on the graph, the stress value of this sample is even little lower than that of sample A2 -4 because the sudden drop down of the sample result reduces the area under the curve which affects the ductility of the specimen. Furthermore, samples have only fiber glass gain with this epoxy has low stress compared to those with only UDC. Thus, in these results, we can conclude that fiber glass gives more strength to the samples compared to a mixture of triple composite and UDC. The results of the tensile test were explained in Figure 5.3 as well as some sample in figure 5.4

Table 5.2 Results of tensile test (second group Master Brace ADH 1406)

Composite code	Load (N)	Stress (MPa)	Strain (%)	Elongation (%)	Modulus of Elasticity (MPa)
A2-0	190	4.25	9.1	6.2	0.46
A2-1	4050	76	7.3	0.75	10.41
A2-2	6650	126	9.2	3.5	13.69
A2-3	709	14	1.34	0.05	10.44
A2-4	6610	158	4.89	0.5	32.31
A2-5	2060	135	4.1	8.5	32.92
A2-6	620	14	1.06	7.2	13.20
R2-1	460	12	1	0.02	12
R2-2	490	11	0.31	0.4	35.48
R2-3	700	14	1.35	1	10.37

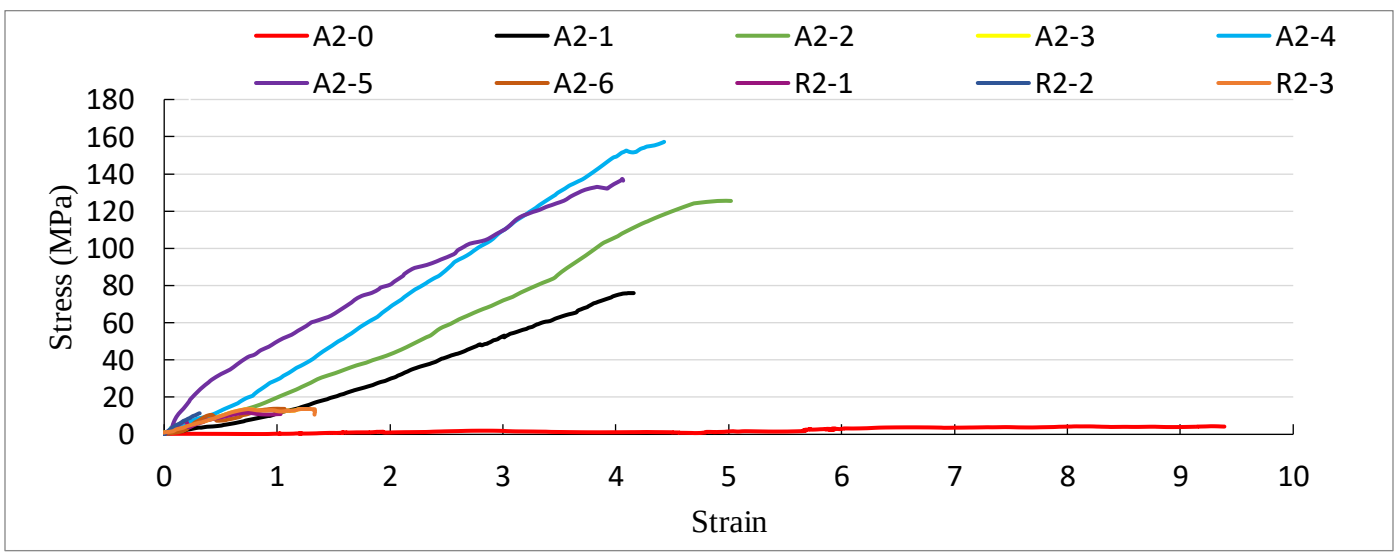


Figure 5. 3 Tensile test result chart (second group Master Brace ADH 1406)

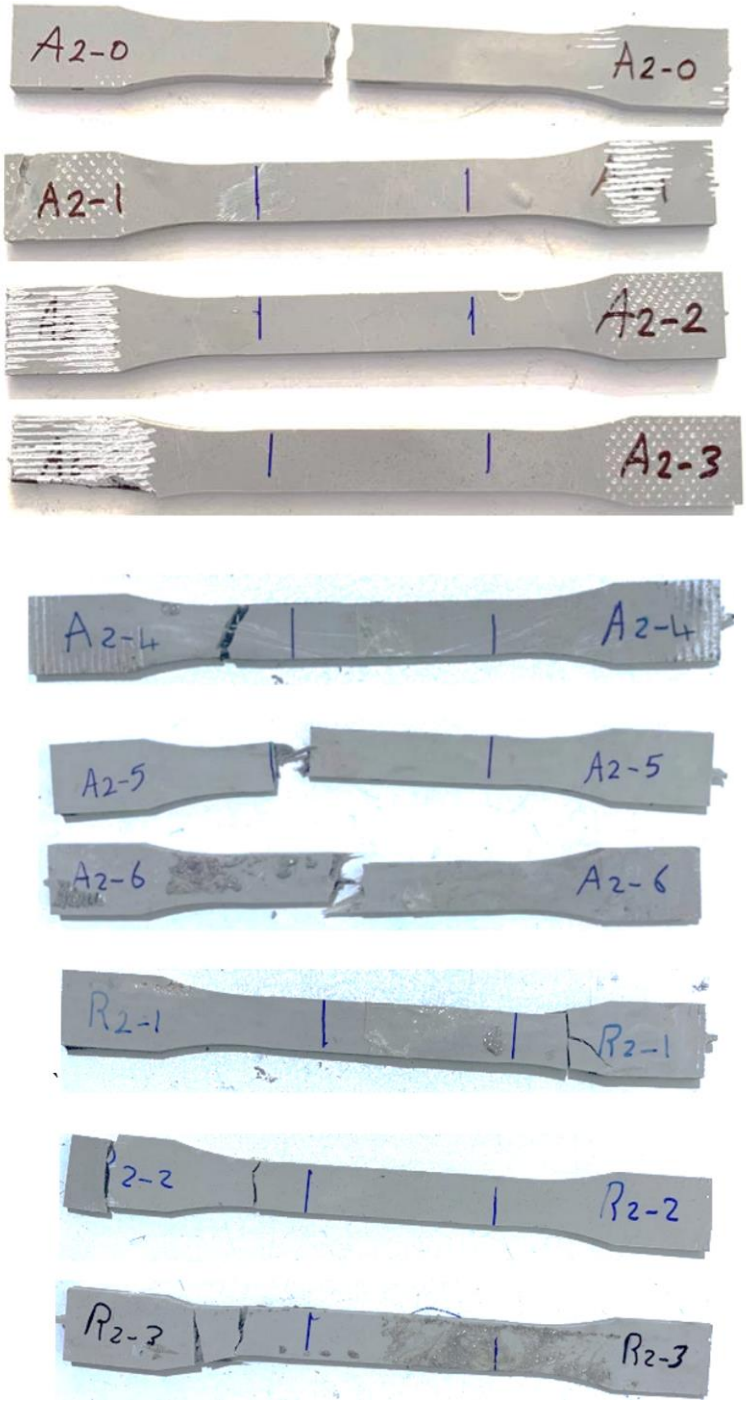


Figure 5. 4 Tensile sample after testing (second group Master Brace ADH 1406)

5.3. Impact Test Result and Discussion

5.3.1. Impact Test for the First Composite Master protect 180

Table 5.3 shows the mechanical test results of unidirectional carbon fiber reinforced epoxy composites and fiber glass. As its visible from the table as the percentage of wight of UDC increased the kinematic energy inside the composite samples will increase too because of the rigid bond between the epoxy and UDC fibers, the results are shown in the figure 5.5 column chart and samples after testing are in Figure 5.6. As which indicated in demonstrated from the column, the left side; region of the column chart is more than the right side; that's the reason of fiber glass layers as an addition. Meanwhile, The most extreme impact strength is 6.387 J because of the most layers on it on A1-3 sample and has the highest toughness compared to others, and surely, its reason is UDC that gives more ductility to the sample, and the fracture area is less. Moreover, both samples B1-2 which contains 10% of two layers of UDC and B1-4 which contains 3% of UDC in one layer and 3% of fiber glass in one layer , they have extremely number near each other and this is a point that shows a number of layers of fiber glass layer in B1-4 sample it have a good effect for increasing the toughness of the sample by this little range as adding to it, which is 3%. The minimum value of toughness energy is in the M1-1 sample which contains 5% of fiber glass with epoxy resin, and this result number indicates that adding a low rate of fiber glass doesn't make any sense, and it made it more brittle to be fractured at a very low energy level, as (Bhagwat et al., 2017) have the same result.

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Table 5. 3 Impact result (first group Master Protect 180)

Composite code	Energy (J)
B1-0	0.103
B1-1	1.488
B1-2	2.757
B1-3	6.387
B1-4	2.059
B1-5	1.578
B1-6	0.867
M1-1	0.083
M1-2	0.701
M1-3	1.388

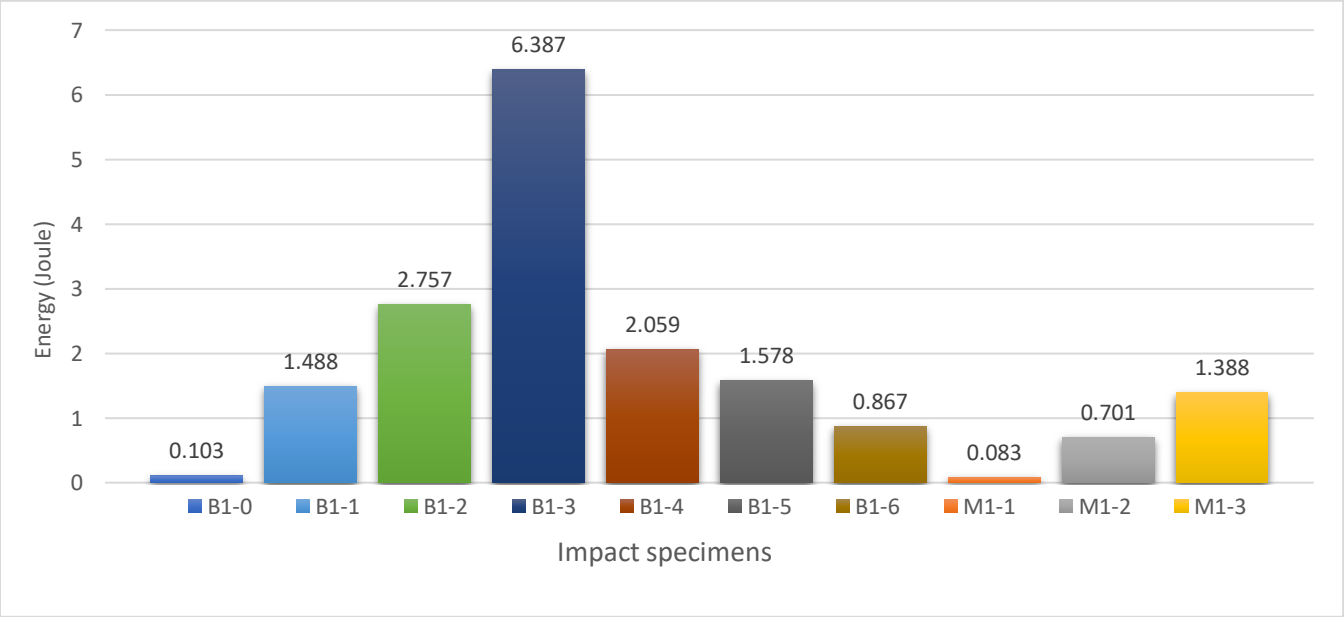


Figure 5. 5 Impact test result chart (first group Master Protect 180)

Figure 5. 6 Impact samples after testing (first group Master Protect 180)

5.3.2. Impact Test for the Second Composite Master Brace ADH 1406

Table 5.4 shows the results of the impact test of epoxy composites reinforced with Unidirectional Carbon fibers, and the glass fibers. As can be seen from the table, as the carbon layers increase, the kinetic energy in the composite samples also increase due to the strong bond between the epoxy fibers and the UDC fibers. On the other hand, by adding 3% glass fiber to the sample, and mixing it with the other compound, the energy will be very close to that which contains only UDC fibers. The maximum impact energy was 5.43 J due to the presence of the largest layer on B2-2. See Figure 5.7 an impact result chart and Figure 5.8 impact samples after testing. This test also indicated the rate of toughness and the amount of energy absorbed by the composite sample during fracture, and the ductility would increase with increasing energy.

It can be seen that the most flexible sample is B2-2, compared to the others. Also, the B2-4 sample is 4.57 J, which is close to 5,430 J, but most layers of UDC are still the highest. As well, the fiber glass with epoxy resin on this epoxy resin gives a semi high value, and M2-1 which contains 5% of fiber glass is near o B2-4 that contains a mixture of triple UDC, fiber glass, and epoxy resin this related to the density and viscosity of the epoxy resin are higher than other thus the glass fibers made a rigid bond to have this value of energy toughness, as (Viña et al., 2020) have the same result.

Table 5.4 Impact test result (second group Master Brace ADH 1406)

Composite code	Energy (J)
B2-0	0.059
B2-1	1.059
B2-2	5.430
B2-3	1.388
B2-4	4.573
B2-5	3.083
B2-6	0.701
M2-1	2.41
M2-2	0.806
M2-3	1.966

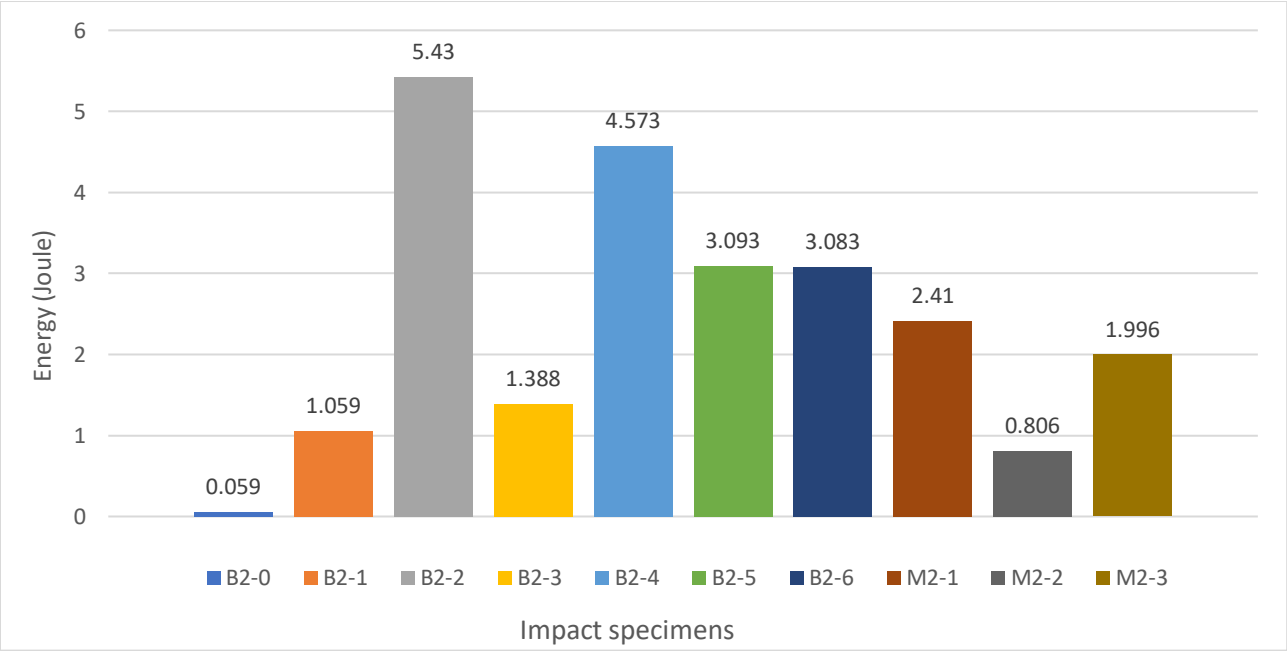


Figure 5. 7 Impact test result chart (second group Master Brace ADH 1406)

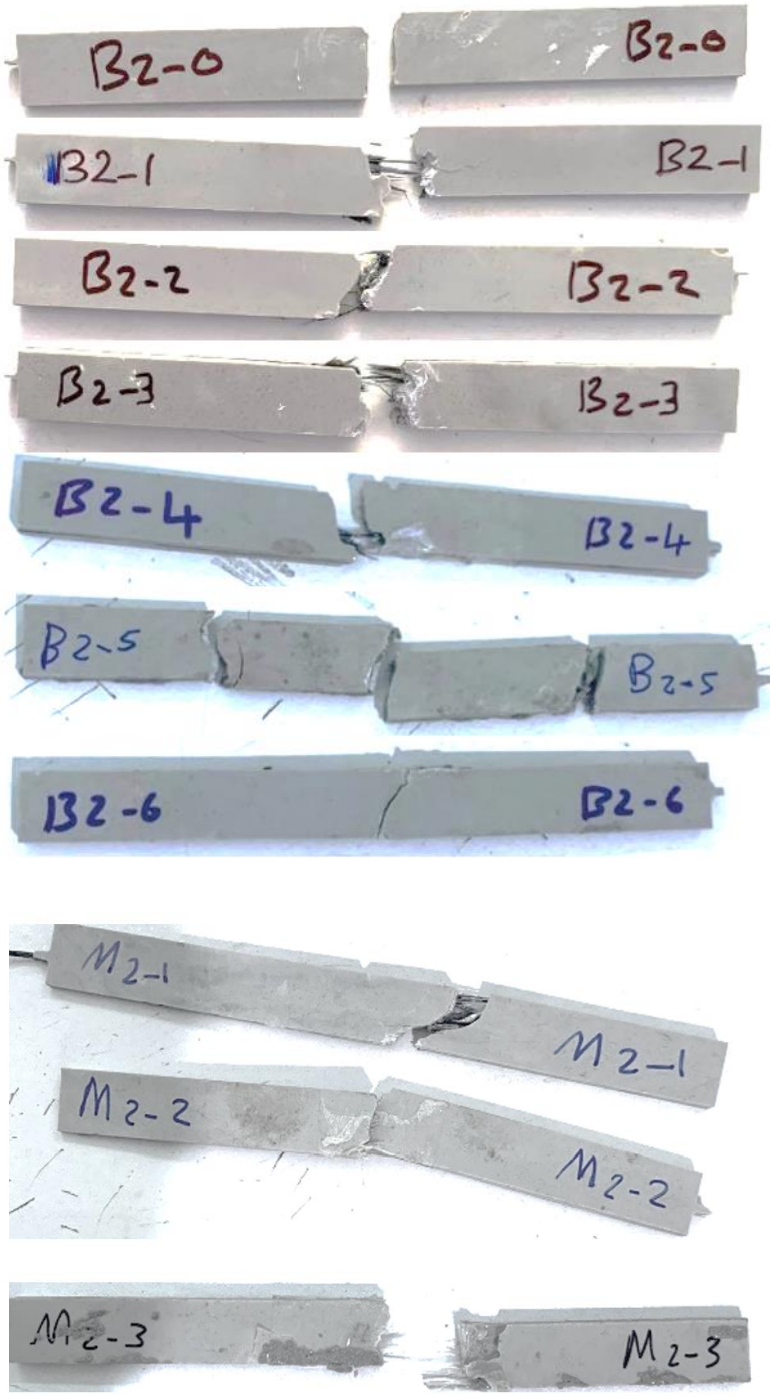


Figure 5. 8 Impact samples after testing (second group Master Brace ADH 1406)

5.4 Flexural test result and discussion

5.4.1 Flexural Test for the First Composite Master protect 180

The variance of the flexural strength with the UDC and fiberglass is shown in Table 5.5. The flexure stress was increased by this additional percentage of both reinforcements, as well as the maximum stress is (110 MPa) with the load (120 N) containing two layers of fiber glass in sample N1-3. The flexural behavior of the composite increased by the interfacial bond between the fiber glass and the matrix. Moreover, sample C1-3 also has a high stress and load (100MPa) and (207N) respectively, which is near to value of sample N1-3, but the difference in the percentage of reinforcement material. the sample N1-3 contains (10%) of weight of fiber glass as well, C1-3 contains (15%) of weight of UDC. Form this point the fiber glass has a higher effect on increasing flexural strength property than UDC, because of the strength bond between the matrix and the fiber glass while the upper cylinder is kicks the spicemen. Additionally, the combination of fiberglass and UDC has an intermediate value of results which is (135N) with (65MPa). Figure 5.9 shows the relation between stress and strain as well; Figure 5.10 shows samples the after testing.

Table 5. 5 Flexure test result (first group Master Protect 180)

Composite code	Load (N)	Stress (MPa)	Strain	Flexural Extension (mm)
C1-0	43	20.9	0.064	15
C1-1	118	57	0.054	10
C1-2	141	68	0.033	8.3
C1-3	207	100	0.0292	7
C1-4	135	65	0.062	15
C1-5	29.8	27.37	0.07	20.77
C1-6	25.02	22.99	0.06	15.89
N1-1	37.86	37.77	0.06	15.62
N1-2	26.92	24.72	0.05	14.29
N1-3	120	110	0.047	12.89

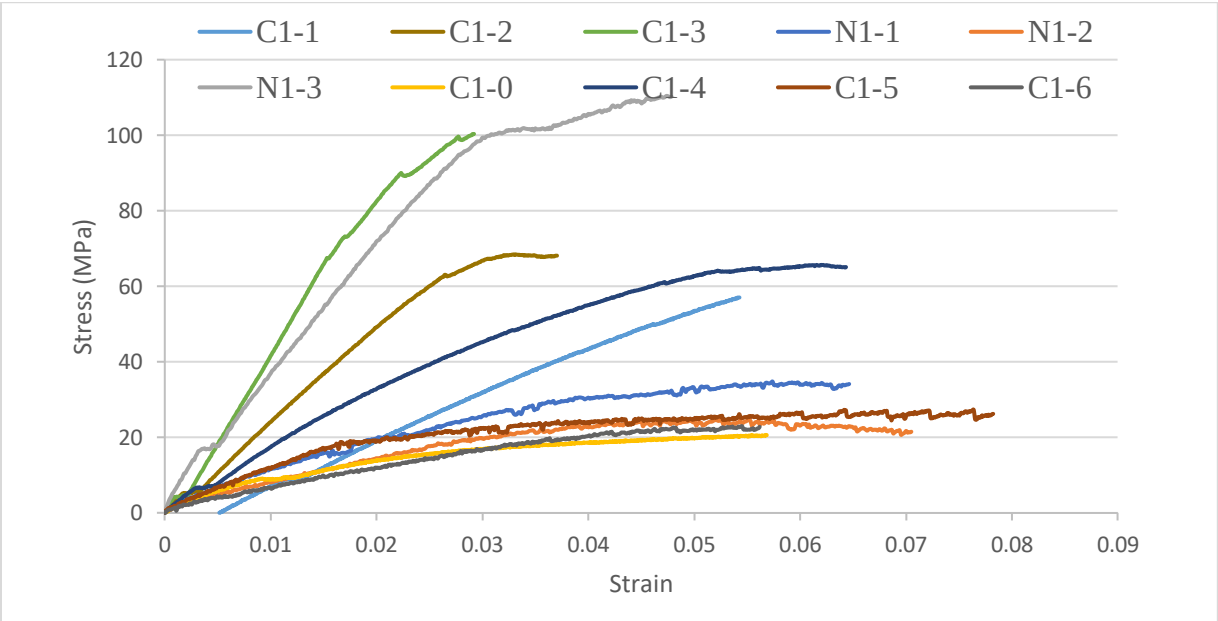


Figure 5. 9 Flexure test result chart (first group Master Protect 180)

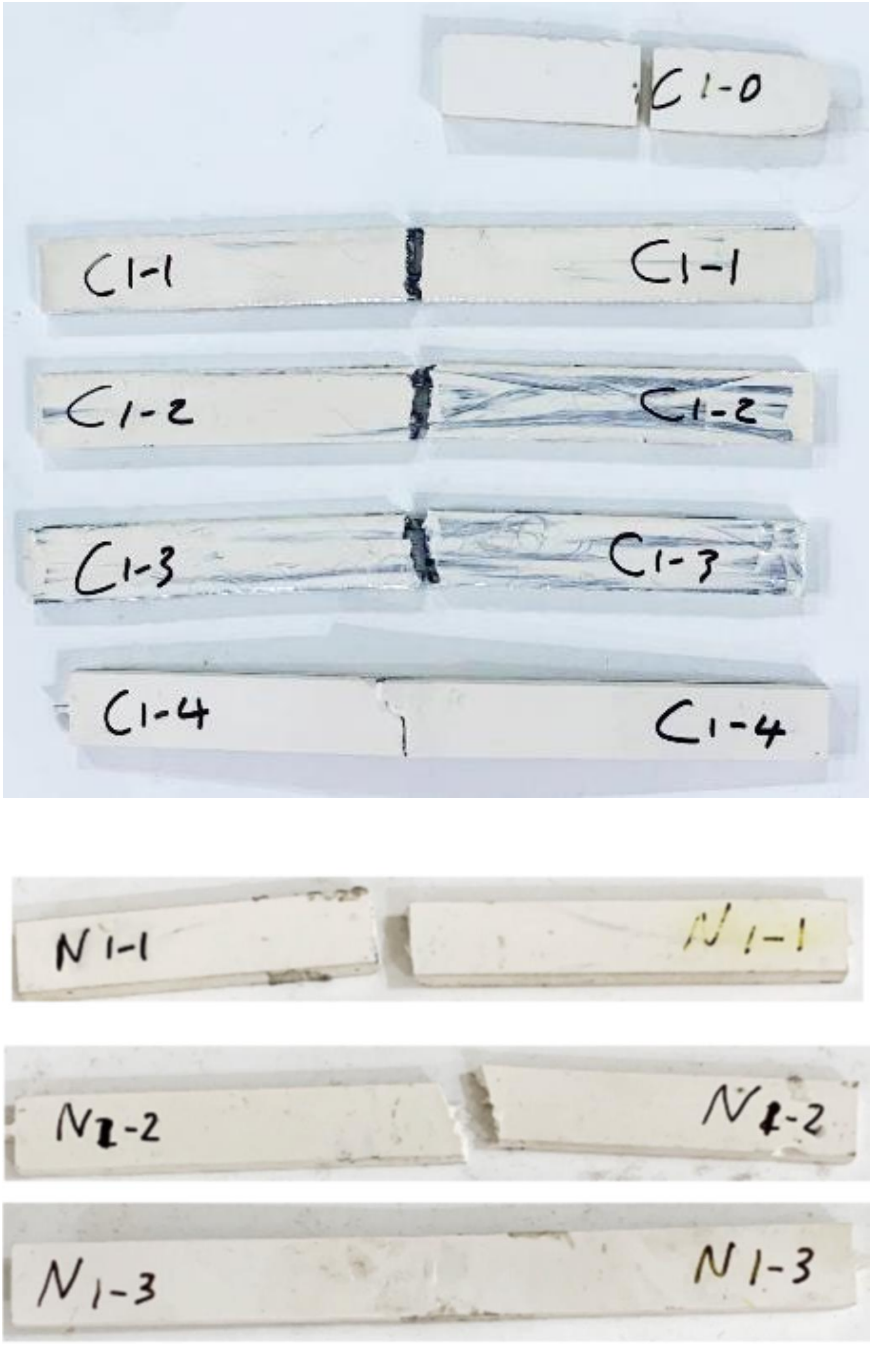


Figure 5. 10 Flexure specimens after testing (first group Master Protect 180)

5.4.2 Flexural Test for the Second Composite Master Brace ADH 1406

The variance of flexural strength with of UDC and fiber glass is shown in Table 5.6. The stress increased with this additional percentage, as did the maximum (109 MPa) in the load (226N) and strain percentage (0.025) containing two coats of UDC. The flexural behavior of the composite increased by the interfacial bond between the UDC and the matrix. The bending extension of each sample depends on the samples resistance to bending because the resistance also increases. Due to the rigid bond between the C2-3 composite sample. It has a maximum value of flexural extension which is 13.44 MPa , due to there is only one layer of UDC. The flexural samples results are illustrated in Figure 5.11. As well as, the sample C2-6 compared to C2-5 and C2-4 has the highest value of flexural stress (41 MPa) and that's mean as much as adding layers of wight percentage of fiber glass to the composite that contain epoxy resin and UDC the flexural stress will be increased. In Figure 5.12 samples are shown after testing. However, the fiber glass only with this epoxy has an intermediate results between either using UDC and the combination of both of them, and the highest one is with N2-2 sample which contains 3.3 % of wight of fiber glass. And fiber glass with this epoxy doesn't have the highest strength of bending because the density and viscosity of this epoxy resin is stronger which is (1.7 g/ cm^3) and more ductile than other ones.

Table 5. 6 Flexure test result (second group Master Brace ADH 1406)

Composite code	Load (N)	Stress (MPa)	Strain	Flexural Extension (mm)
C2-0	36	17	0.0059	1.49
C2-1	51	24	0.0081	2.2
C2-2	226	109	0.025	6.1
C2-3	75.18	69	0.06	13.44
C2-4	75	36	0.0071	1.6
C2-5	29.12	26.75	0.055	7.63
C2-6	40	41	0.042	8.14
N2-1	31.09	28.56	0.042	11.21
N2-2	31.84	29.25	0.025	6.49
N2-3	26.61	21.69	0.05	12

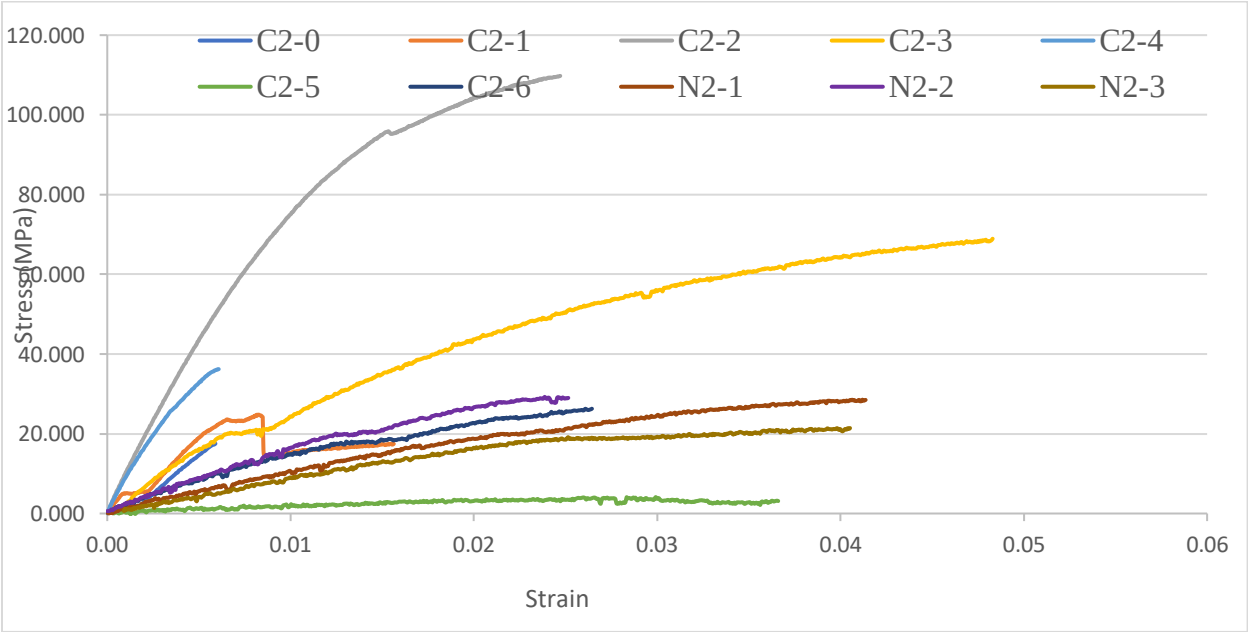


Figure 5. 11 Flexural result chart (second group Master Brace ADH 1406)

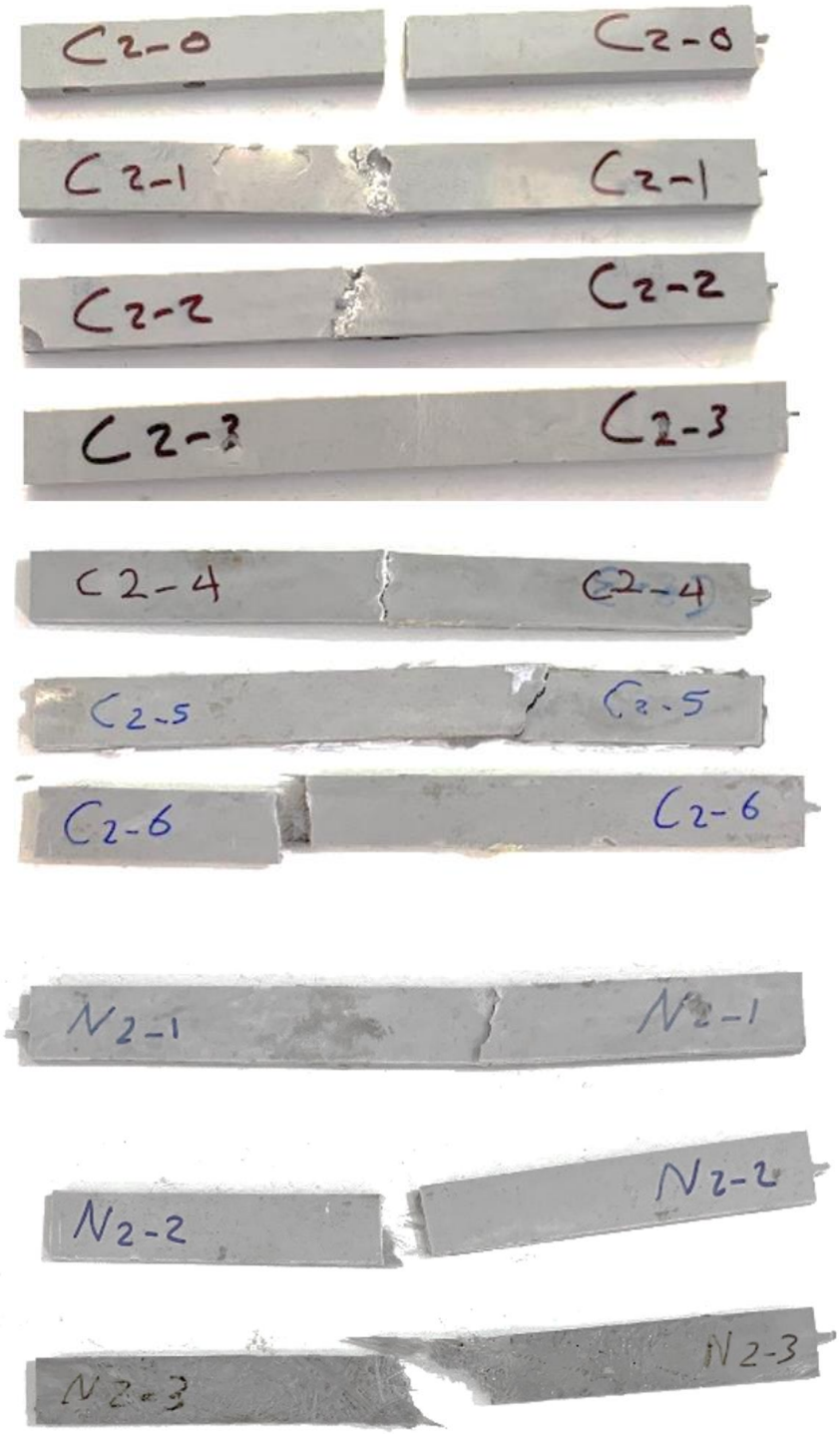


Figure 5. 12 Flexural specimens after testing (second group Master Brace ADH 1406)

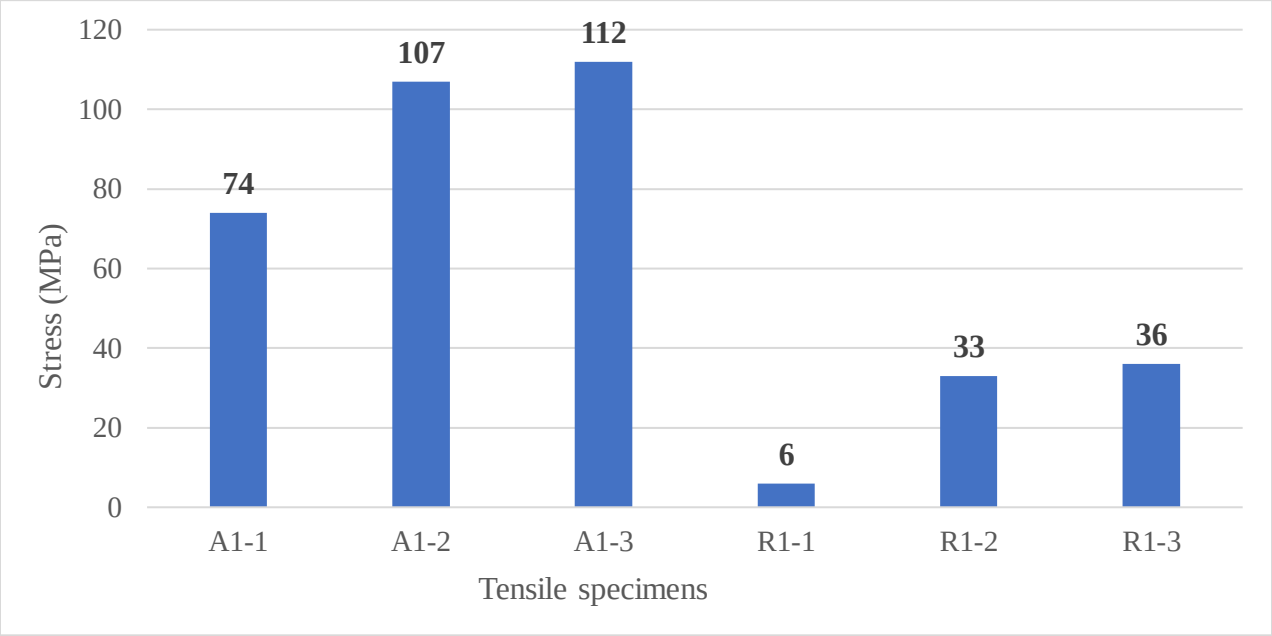
5.5 Comparison Between Unidirectional Carbon and Fiber Glass Composites

Comparing two types of reinforcement that used on this study was a very important point, because each of them has its own property and resistance to external load. It`s clear that by adding wight percentage of layers of reinforcements will increase mechanical properties of any sample. Here, from tensile test it can be seen that as much a UDC layers by a weight percentage added to the epoxy resin the tensile stress will be increased, in the first group of composite Master Protect 180 the UDC weight percentage was (5%, 10% and 15%) the tensile stress was increased respectively, and as much as adding fiber glass by wight percentages (5%, 705% and 10%) the tensile stress was increased in a small value respectively as shown in figure 5.13 b. As well in the second group of composite Master Brace ADH 1406 the UDC weight percentage was (3%, 5.5% and 1.5%) and the tensile stress were increased respectively, and as much as adding fiber glass by wight percentages (1.5%, 3.3% and 5.5 %) the tensile stress wasn't increased and can ignored as compared to those samples with UDC composite as shown in figure 5.13 b.

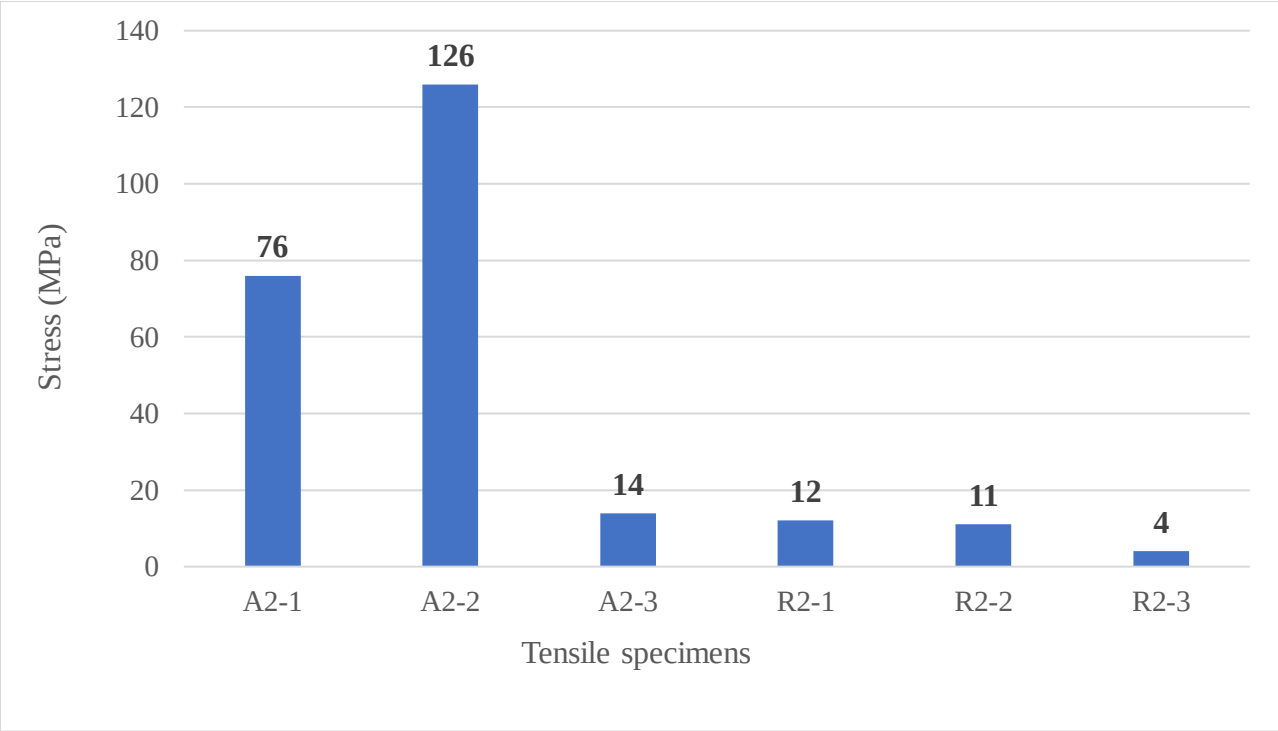
In another hand from impact test, the same scenario of tensile test for UDC, but in fiber glass case the increased of percentage of layers was make an intermediate change of strength for the specimens compared to UDC changes in both groups of composite as shown in figure 5.14.

However, from flexural test this scenario will changed totally in a first group Master Protect 180 , and the fiber glass has a very good effect of raising flexural stress, the maximum value is with sample N1-3, moreover the UDC is still got the high value with sample C1-3, and the second group Master Brace ADH 1406 of composite the

UDC has the highest value of flexural stress and have a bigger of effect on rising the flexural properties than fiber glass, as shown in figure 5.15.

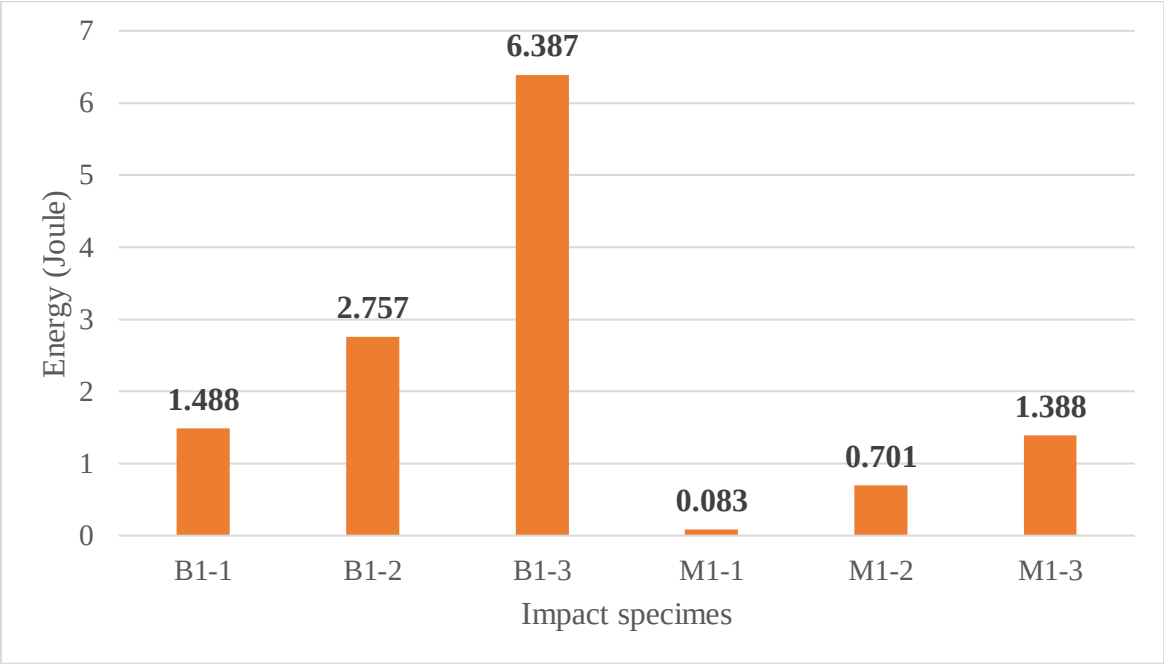


(a)

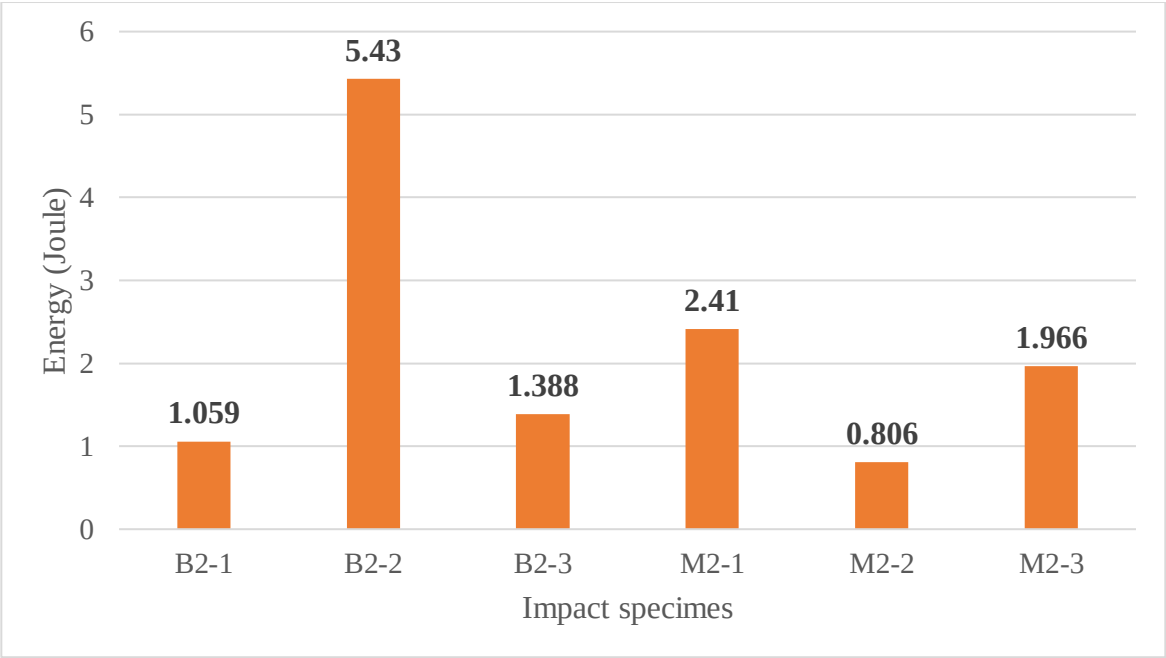


(b)

Figure 5. 13 Tensile comparisons (a) first group Master Protect 180 (b) second group Master Brace ADH 1406 of composites

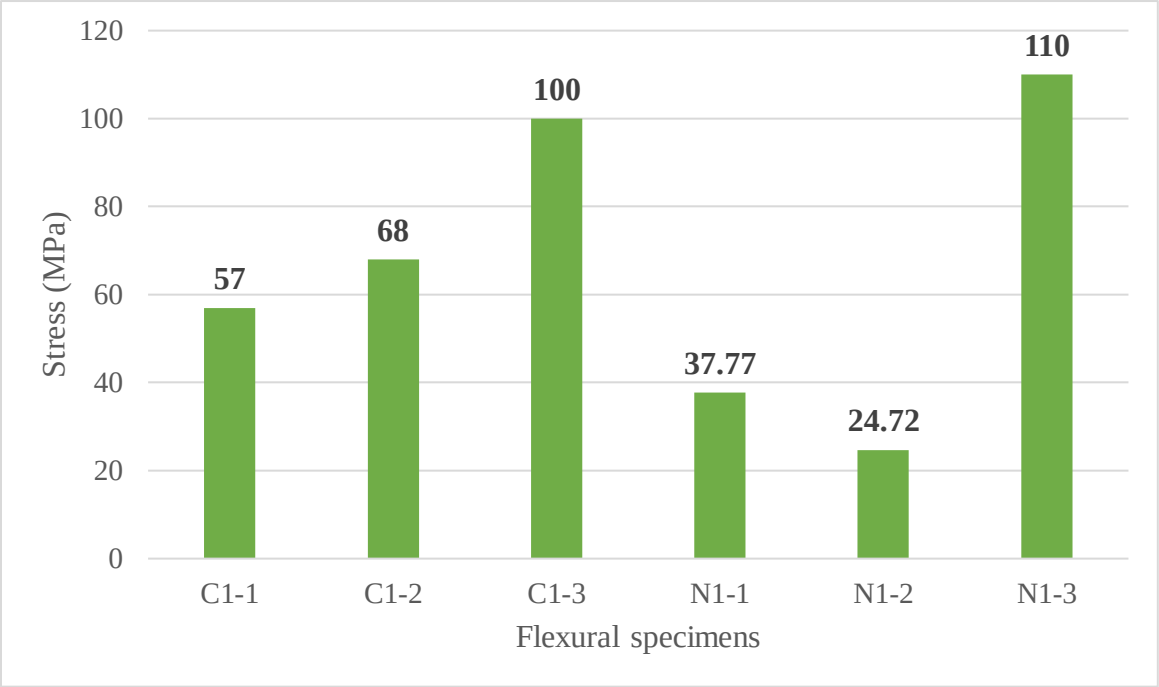


(a)

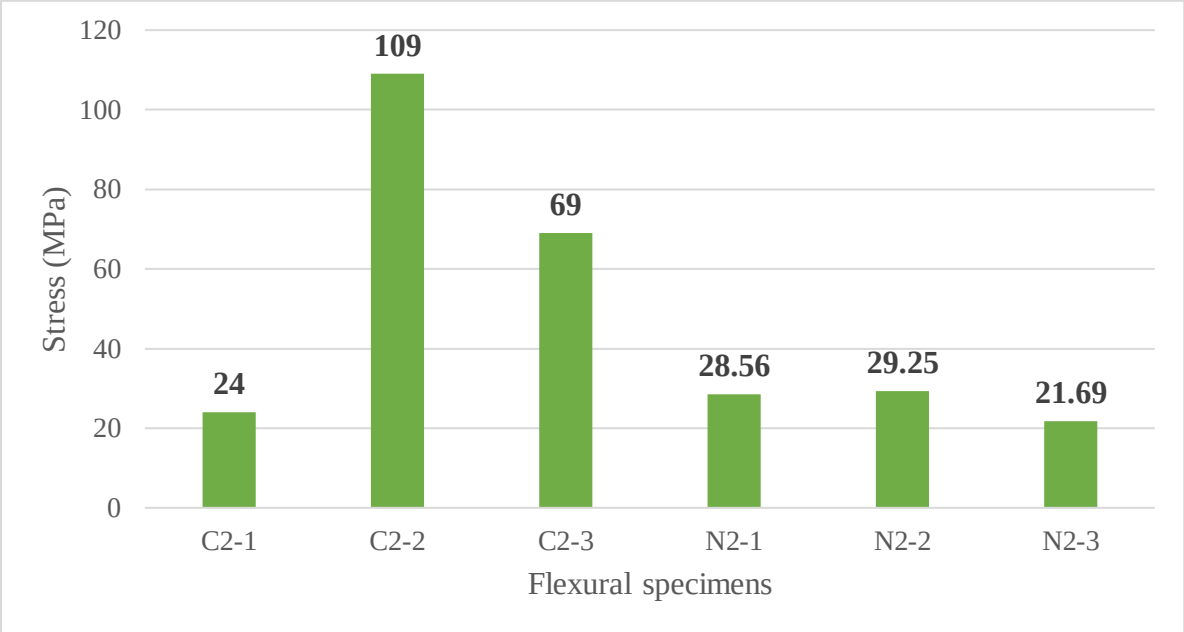


(b)

Figure 5. 14 Impact comparison (a) first group Master Protect 180 (b) second group Master Brace ADH 1406 of composites



(a)



(b)

Figure 5. 15 Flexural comparison (a) first group Master Protect 180 (b) second group Master Brace ADH 1406 of composites

5.6 Comparison Between Experimental Data and Computational Simulation

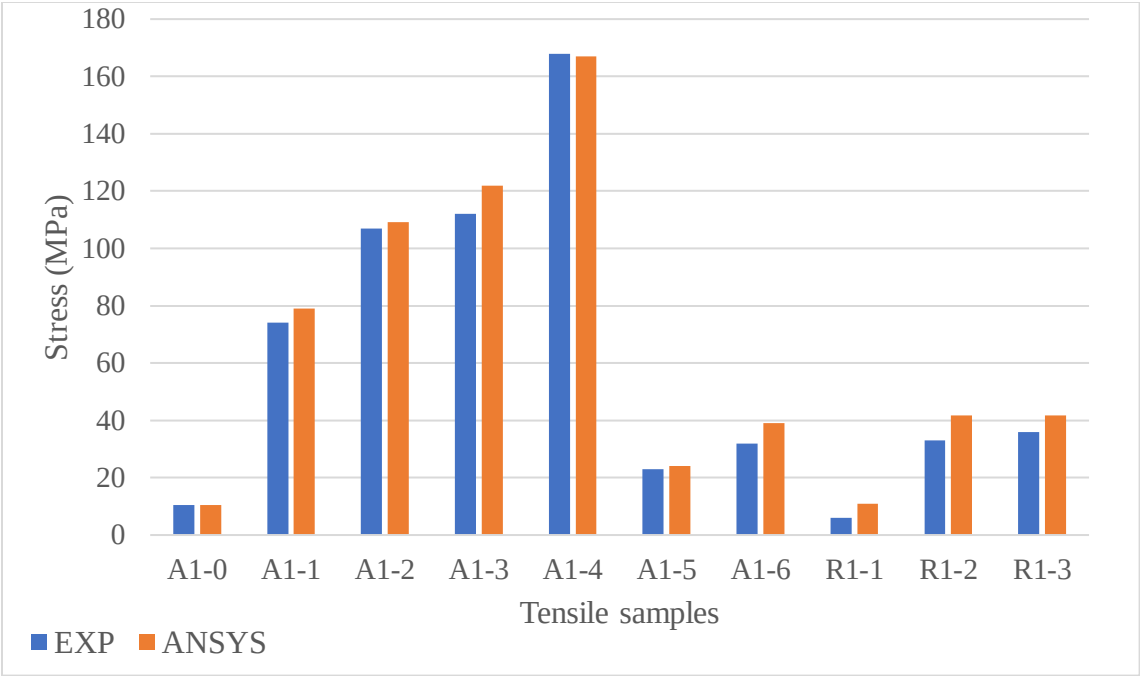
As can be seen from charts in figures 5.16, 5.17 and 5.18 that were achieved from the comparative of experimental and computational which ANSYS 2022 R1 Workbench used. The results varied from triple of tests (Tensile, Impact and Flexural) as compared to each other.

In all points of tensile in the first group Master Protect 180 of composites they're approximately got the same , but overall results shows that the ANSYS results are higher than experimental results, and about the second group of composite the same of the pervious group in overall situation of tensile comparing the ANSYS result's values are more than experimental values because of an experimental working on the real contact and interface occur and a rigid bond between fibers and epoxy resin takes place while in finite element analysis way this contact has not taken place as shown n Figure 5.16 both groups of composite for tensile test results.

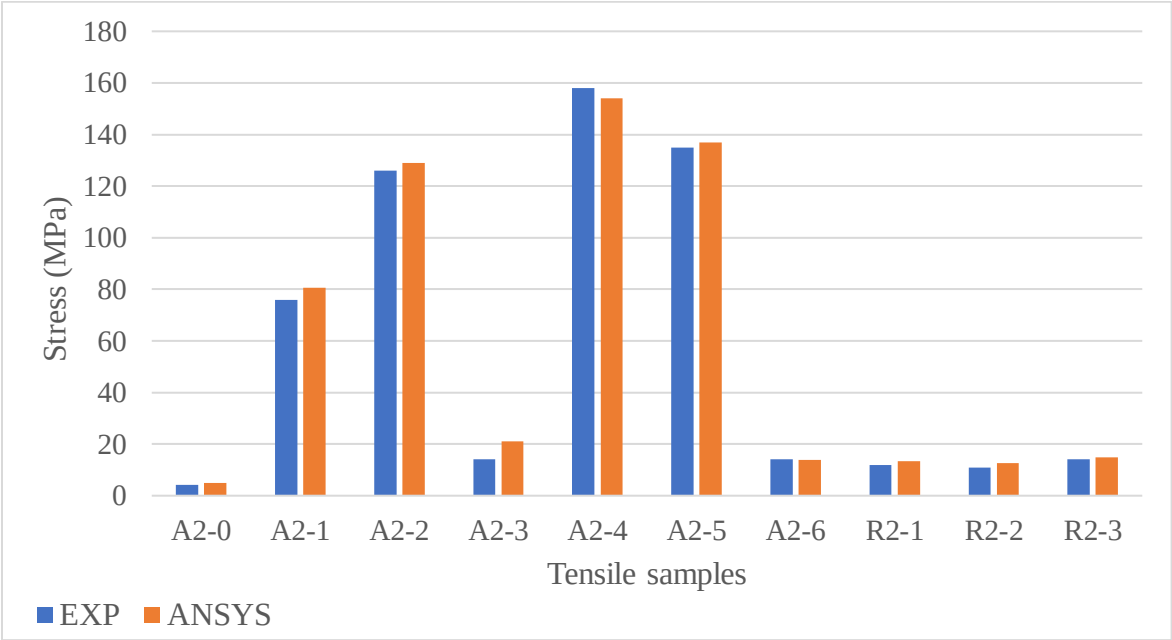
As well as, from impact test result comparison in the first group Master Protect 180 and second group Master Brace ADH 1406 of composite have an approximate quantity. Meanwhile, in overall results of comparison for both groups shows that the ANSYS results are higher than the result that taken from experimental results, this is related to that using a specific meshing size that were done for samples in ANSYS to be much more near than in real as mentioned in section 4.6.2.

About flexural test results the comparative shown in Figure 5.18 chart has shown that in the first group Master Protect 180 , ANSYS and experimental value is near to each other but, the experimental results have higher values in most sample, because of the sufficient contact taken place, instead of C1-3, C1-5, C1-6 and N1-3

and the changes are very small they can be neglected. While in a second group Master Protect ADH again they have an approximate results but this time the ANSYS results are more than experimental results because of the physical reaction between the matrix and fibers didn’t take place in experimental testing , thus the interface bond neglected and this increased the ANSYS results.

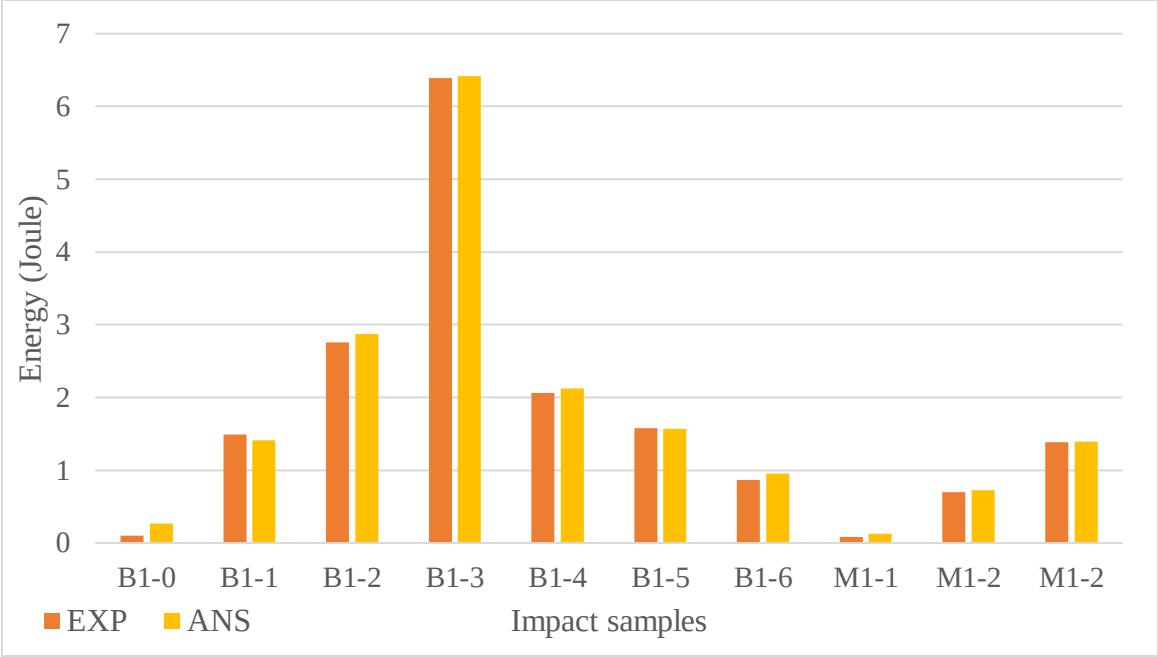


(a)

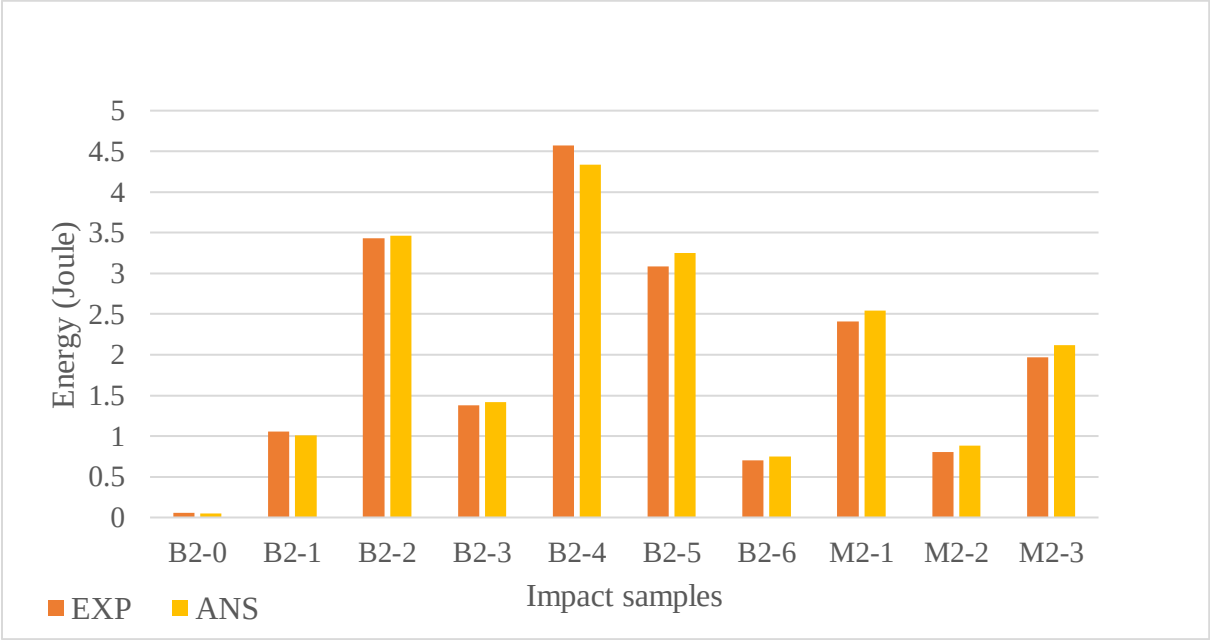


(b)

Figure 5. 16 Tensile stress sample comparison between Experimental and ANSYS (a) first group Master Protect (b) second group Master Brace ADH 1406

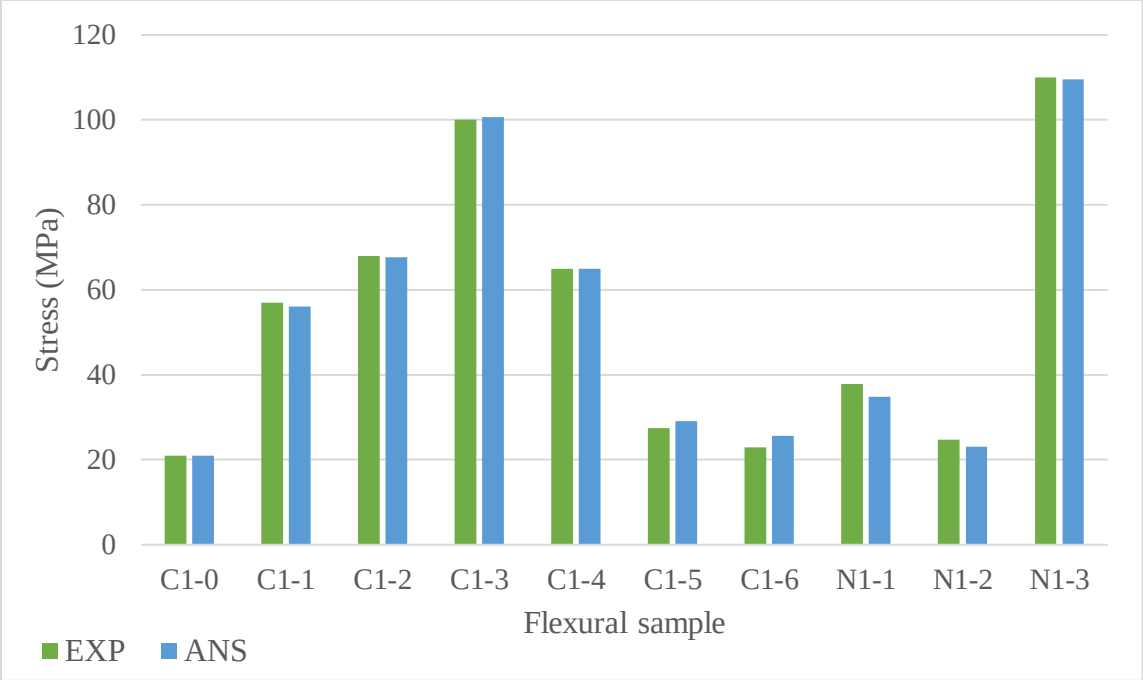


(a)

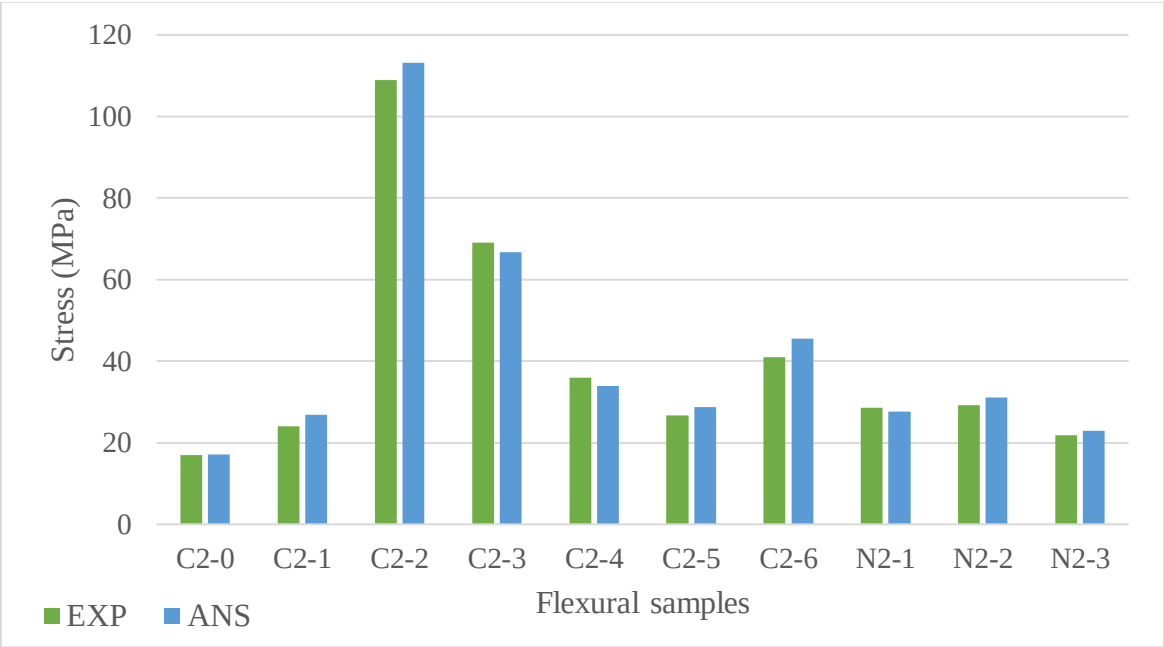


(b)

Figure 5. 17 Impact energy sample comparison between Experimental and ANSYS (a) first group Master Protect 180 (b) second group Master Brace ADH 1406



(a)



(b)

Figure 5. 18 Flexural stress sample comparison Experimental and ANSYS (a) first group Master Protect 180 (b) second group Master Brace ADH 1406

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusions

An experimental and numerical investigation of mechanical properties of Unidirectional Carbon epoxy resin and S-glass fiber for composites at different rates of layering and comparison between theoretical and experimental data were clearly discussed. The main findings are summarized as the following:

- ✓ Tensile strength and the maximum value of modulus of elasticity of all specimens varied when fiber glass will added to the composite specimens, this variation takes place and shows the maximum value when adding by a wight percentage 3% UDC and 3% fiber glass were mixed and achieving maximum value in the first group Master Protect 180 of composites.
- ✓ From the impact test the toughness of the samples was known. And the most toughened one was B1-3 for the first grup Master Protect 180 of composite.
- ✓ In flexural test the lowest number for flexural extension was found in the C1-3 sample which is (7 mm/mm) in which have the highest value of load that needs for bending.

- ✓ the maximum tensile strengths of A2-4 and A2-2 are respectively 158 MPa and 126 MPa of the compounds for the second group Master Brace ADH 1406 of composites because of highly bonded between fibers and epoxy.
- ✓ The highest value for flexural stress in second group Master Brace ADH 1406 is (109 MPa) is with C2-2 sample that contains double layer of wight of UDC.
- ✓ As it is clear from the tests composite samples with triple content have better mechanical properties than samples which consists of double content.
- ✓ The tensile and flexural tests were shown by stress-strain curve. Which indicated that incorporation of UDC would have a bigger effect on increasing flexural and tensile stress than fiber glass
- ✓ In a comparison of first epoxy Master Protect 180 and the second epoxy Master Brace ADH 1406 the affection for increasing energy for impact test using fiber glass the most strengthen sample with fiber glass is M2-1 (2.41 J), which with second epoxy.
- ✓ Using finite element analysis way for making a simulation is more accurate than experimental way because of using mathematical way and formulations.
- ✓ The ANSYS simulation results are higher than experimental results because of the connection between fiber reinforcement with epoxy resins actually were conducted.

6.2 Recommendations for Future Work

For improving this work and making it more flexible for performing and using in applications below are some recommended works:

- ✓ Use different fiber reinforcement to predict more strength at a lower price.
- ✓ Show more details by using SEM (Scanning Electronic Microscope) to verify at samples interface and bonding between the matrix and reinforcement fibers in samples.
- ✓ Constructing more samples to predict a factor that makes a computational and experimental result values to be closer to each other.

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APPENDIX

Calculation of Mixing Ratio

For knowing how to control the mixing ratio of the epoxy for fulfilling the mold and doing the correct percentage of UDC with fiber glass these calculations were done. And all calculations are represented by a wight fraction.

- ✓ First group Master Protect 180 of composites

- ➢ For Tensile Sample

$\text{Volume} = \text{Area} \times \text{Thickness}$ …….....A.1

V=2509 mm × 3mm = 7527 mm^2 = 7.527 cm^3

$\text{Weight of sample} = \text{Density of epoxy} \times \text{Volume}$……A.2

=1.5 gm/ cm^3 × 7.527 cm3 =11.2905 gm

5% of UDC = 0.5645 gm

10% of UDC = 1.12 gm

15% of UDC = 1.6935 gm

3% of UDC +3% of fiber glass = 0.3388 + 0.3388 = 0.6774 gm

1.5% of UDC = 0.1693 gm

- ➢ Impact Sample

Volume =16.10 × 0.3=4.83 cm^3

Wight of sample = 1.5 x 4.83 = 7.245 gm

5% of UDC = 0.36225 gm

10% of UDC = 0.724 gm

15% of UDC = 1.086 gm

3% of UDC +3% of fiber glass = 0.2173 + 0.2175 = 0.4347 gm

1.5 % of UDC = 0.1086 gm

- Flexural Sample

Volume=16.51 × 0.3=4.953 cm^3

Wight of sample = 1.5 x 4.953 = 7.2495 gm

5% of UDC = 0.3624 gm

10% of UDC = 0.7249 gm

15% of UDC = 1.0874 gm

3% of UDC +3% of fiber glass = 0.2174+ 0.2174 = 0.4349 gm

1.5 % of UDC = 0.1087 gm

- ✓ Second group Master brace ADH 1406 of composites
- Tensile sample

V = 2509 × 3 = 7.527 cm^3

Wight of sample = 1.7 x 527 =12.7957gm

3% of UDC = 0.3838 gm

5.5% of UDC = 0.7 037 gm

3% of UDC & 3% fiber glass = 0.3838+ 0.3838 = 0.7676 gm

1.5% of UDC = 0.1919 gm

- Impact sample

V = 16.1 × 3 = 4.83 cm^3

Wight of sample = 1.7 x 4.83 =8.211 gm

3% of UDC = 0.2463 gm

5.5% of UDC = 0.4516 gm

3% of UDC & 3% of fiber glass = 0.2463 + 0.2463 = 0.4926 gm

1.5% of UDC = 0.1231 gm

UDC = 0.1919 gm

- Flexural sample

V = 16.51 ×x 3 = 4.953 cm^3

Wight of sample = 1.7 × 4.953 =8.4201 gm

3% of UDC = 0.421 gm

5.5% of UDC = 0.4631 gm

3% of UDC & 3% of fiber glass = 0.1485+ 0.1485= 0.842 gm

1.5% of UDC = 0.1263 gm