ISLAMIC UNIVERSITY OF TECHNOLOGY (IUT)

FABRICATION AND EXPERIMENTAL INVESTIGATION ON MECHANICAL PROPERTIES FOR DIFFERENT STACKING SEQUENCE OF JUTE AND CARBON FIBER REINFORCED EPOXY COMPOSITE

B.Sc. Engineering (Mechanical) THESIS

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Declaration

We hereby declare that the work presented in this thesis has not been submitted for any other degree or professional qualification, and that it is the result of our own independent work.

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Table of contents

CERTIFICATE OF RESEARCH .... **i**

Declaration .... **ii**

Table of contents .... **iii**

List of figures .... **vi**

Acknowledgements .... **viii**

Abstract .... **ix**

Chapter 1: Introduction **1**

1.1 Overview of Composite Material 1

1.1.1 Natural Fibers 1

1.1.2 Natural Fiber based composites 1

1.2 Application of composite material 3

1.2.1 Infrastructure 3

1.2.2 Aircraft 4

1.2.3 Bioengineering 5

1.2.4 Environmental Application 6

1.2.5 Industrial Application 7

1.3 Jute-Carbon Fiber Reinforced Epoxy Based Composite 8

1.3.1 Jute Fiber 8

1.3.2 Carbon Fiber 9

1.3.3 Resin 10

1.3.4 Stacking Sequence 11

1.3.5 Resin Infusion Process 12

1.3.6 The Testing of Mechanical Properties of Composites 13

Chapter 2: Literature Review **14**

Chapter 3: Methodology **21**

3.1 Initial specimen preparation 21
3.2 Vacuum Assisted Resin Infusion Process 22
3.3 Step by Step Infusion Procedure 23
3.3.1 Preparing the Mould 23
3.3.2 Adding Vacuum Bag Film On the Mould 24
3.3.3 Specimen Placement and covering on the mould 25
3.3.4 Installing the Infusion Spiral Tubes and Vacuum Hose Pipe 26
3.3.5 Vacuum Tight Seal Using Vacuum Bagging Gum 27
3.3.6 Vacuum Bagging Procedure 28
3.4 Preparing Specimen for Mechanical Property Test 30
3.4.1 Flexural Test Specimen Dimension 31
3.4.2 Tensile Test Specimen Dimension 32
3.4.3 Impact Test Specimen Dimension 33
3.5 Performing the Tests on UTM 33
Chapter 4: Results and Discussion 34
4.1 Introduction 34
4.2 Specimen Observation 35
4.2.1 Tensile Test Specimen 35
4.2.2 Flexural Test Specimen 36
4.2.3 Impact Test Specimen 37
4.3 Result Analysis 38
4.3.1 Tensile Test 38
4.3.2 Flexural Test 44
4.3.3 Impact Test 50
Chapter 5: Conclusion 52
5.1 Introduction 52

5.2 Corollaries 52

5.3 Future Scopes 55

References 56

List of figures

Figure 1: Stacking Sequence of Carbon and Jute Fibers... 21
Figure 2: Vacuum Assisted Resin Infusion Process 22
Figure 3: Acrylic Glass as Mould 23
Figure 4: Vacuum Bagging Filming on the mould 24
Figure 5: Attaching the Breather Layer Cloth and the Mesh 25
Figure 6: Installation of Spiral Medium Flow Coil and Vacuum Hose Pipe 26
Figure 7: Vacuum Sealing the specimen using Gum 27
Figure 8: Total Vacuum Bagging Procedure 28
Figure 9: Infused Hybrid Composites with Five Different Stacking Sequence......... 30
Figure 10: Specimen Dimension for Flexural Test 31
Figure 11: Specimaen Dimension for Tensile Test 32
Figure 12: Specimen Dimension for Impact Test 33
Figure 13: Fracture pattern of the specimen after the Tensile test 35
Figure 14: Fracture pattern of the specimen after the Flexural test 36
Figure 15: Fracture pattern of the specimen after the Impact test 37
Figure 16: Tensile Strain Vs Stresss Curve for $C_2J_6C_2$ 38
Figure 17: Tensile Strain Vs Stresss Curve for $J_2C_2J_2C_2J$ 39
Figure 18: Tensile Strain Vs Stresss Curve for $J_3C_4J_3$ 39
Figure 19: Tensile Strain Vs Stresss Curve for $C_2J_3C_2J_3$ 40
Figure 20: Tensile Strain Vs Stresss Curve for C_4J_6 41
Figure 21: Tensile graph based on stacking sequences.. 42
Figure 22: Tensile strength with different stacking sequences 43
Figure 23: Flexural Strain Vs Stresss Curve for $C_2J_3C_2J_3$ 45
Figure 24: Flexural Strain Vs Stresss Curve for $C_2J_6C_2$ 45
Figure 25: Flexural Strain Vs Stresss Curve for C_4J_6 46
Figure 26: Flexural Strain Vs Stresss Curve for $J_2C_2J_2C_2J_2$...................................... 46
Figure 27: Flexural Strain Vs Stresss Curve for $J_3C_4J_3$... 47
Figure 28: : Flexural graph based on stacking sequences 48
Figure 29: Flexural strength with different stacking sequences................................. 49
Figure 30: Impact strength with different stacking sequences 51

List of Tables

Table 1: Properties of jute fiber 8

Table 2: Properties of carbon fiber... 9

Table 3: Impact energy for composites with different stacking sequences 50

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Abstract

The use of natural fibre is increasing at a quick rate in case of not only households but also in the industries due to their economically viable characteristics and recycling abilities. Recently the growth in the use of composite material has been a phenomenon as it has shown better resilience and support when implemented in different sectors. This study aims at experimentally investigating the outcome of placing different layers of jute and carbon fibers in different position while structuring a hybrid composite. Six layers of woven unidirectional jute fiber and four-layer of carbon fiber has been used with five different stacking sequences in this study. The production of the hybrid composite was carried out by Vacuum Assisted Resin Infusion (VARI) technology. Tensile, flexural and impact tests were carried out to investigate the performance of the products. The analysis of the results of tensile, flexural and impact tests of the composites show that the stacking sequence has a significant effect on the structural and resilience properties of the composites. The result indicated that tensile strength of the composites was upgraded when all the layers of carbon fiber were placed in the middle of the sandwich-like composite structure whereas flexural strength of the composites was improved when carbon fibers were placed on the compression and tension side of the composite. In case of impact test the best performance was achieved when all the layers of jute were placed in the two sides of the composite structure.

Chapter 1: Introduction

1.1 Overview of Composite Material

1.1.1 Natural Fibers

Natural fibers are a renewable resource and provides advantages like imparting the composite with high stiffness and strength, have a good fibre aspect ratio, are biodegradable and readily available from the nature. Natural fibers are suitable for reinforcement because of having stiffness, high strength and low density. Natural fibers can be processed in different ways to yield reinforcing elements having different mechanical properties. [1] The properties that qualify natural fibres as reinforcements depend on the structure and technical treatments, and the natural fibers are particularly variable and not yet controllable in terms of such characteristics. The often rather large range for stiffness and strength values of natural fibers reflect both the natural variation of plant type, growth conditions, and harvest procedures, and the relatively early stage at present for the industrial use of natural fibers as reinforcements in composites. Natural fibers can be classified into their origin. The origins being animal, cellulose and mineral. The vegetable fibres can be divided into smaller groups based on their origin within the plant. The animal fibres consist exclusively of proteins and, with the exception of silk, constitute the fur or hair that serves as the protective epidermal covering of animals. In the case of mineral, it takes a liking for both water and vapour. Unlike synthetic fibers most natural fibers are non-thermoplastic which is that they do not soften when heat is applied. At temperatures below the point at which they will decompose, they show little sensitivity to dry heat, and there is no shrinkage or high extensibility upon heating, nor do they become brittle if cooled to below freezing. Natural fibres tend to yellow upon exposure to sunlight and moisture, and extended exposure results in loss of strength.

1.1.2 Natural Fiber based composites

Composites can be made from natural fibers since they hold the suitable characteristics that can be enhanced when they are combined with other natural fibers. This composite excels the unit natural fiber in all relative mechanical properties. Natural fiber composites are a combination of plant derived fiber with a polymeric matrix. The natural fiber can be wood, jute or flax, banana or cotton etc. and the matrix can be a polymeric material. The composites shape, surface appearance, environmental tolerance, and overall durability are dominated by the matrix while the fibrous reinforcement carries most of the structural loads, thus providing macroscopic stiffness and strength.[2] Natural fibers are a low-density material yielding relatively lightweight composites with high specific properties and therefore natural fibers offer a high potential for an outstanding reinforcement in lightweight structures. The mechanical properties of a composite depend on the nature of the resin, fiber, resin-fiber adhesion, cross-linking agents and not the least on the method of the processing. Therefore, any improvement in the property is evaluated as compared to that of the polymer matrix undergone the same processing.[3] The polymer matrix can be usually categorized into two categories, thermoplastics and thermoset. The structure of thermoplastic matrix materials consists of one or two dimensional molecular, so these polymers have a tendency to make softer at an raised heat range and roll back their properties throughout cooling. On the other hand, thermosets polymer can be defined as highly cross-linked polymers which cured using only heat, or using heat and pressure, and/or light irradiation. This structure gives to thermoset polymer good properties such as high flexibility for tailoring desired ultimate properties, great strength, and modulus. [4] Epoxy resin-based composites are gaining more popularity nowadays. Epoxy resins are a broad class of thermosetting matrix resins characterized by a reactive epoxide ring functionality. With the different types of curatives and heat, they cure (react) chemically to an inter-cross-linked network and become insoluble and infusible solid. Epoxy resins have more desirable properties such as high mechanical strength, modulus and outstanding adhesion to various substrates, and easy processing ability. In the epoxy resin based natural fiber composites the mechanical strength was found to be increased as the resin improved adhesion and in turn increased the tensile, flexural and impact properties.[5] Different natural fibers show different range of properties in case of composites. The mechanical strength of bamboo fiber based epoxy composite is less than that of glass based composite.[6] The effect of fiber content on the mechanical characteristics of the piassava fiber/epoxy composites showed that they started increasing with a 41% increase in tensile properties and a 30% increase in the flexural properties. [7] The mechanical strength of the jute fiber/epoxy composites showed that void content are reduced in composite by the addition of fiber up to a certain limit. The composite exhibits superior flexural and inter-laminar shear strength at 48 wet% fiber content because at this point it has less void content.[8] The epoxy resin based composites have water absorbing quality as well based on what fiber is being used. The effect of sodium hydroxide treatment on the water absorption characteristics of the agave reinforced epoxy composites. It is observed that sodium hydroxide treated fiber composite exhibits the low value of water absorption as compared with untreated fiber composites. [9] Natural fibers filled composites have great potential for engineering applications due to their environmental suitability, technical feasibility and economic viability. A lot of effort has been put in this direction to generate these relatively new composites. Natural fiber reinforced epoxy composites with effective mechanical properties and high durability were developed in the last decade. The main challenges for the near future are to further improve the durability and the mechanical performance of these composites by decreasing the costs of fabrication while developing an eco-friendly strategy.[10] This study aims at improving the properties of epoxy based composites by changing different aspects of the natural fibers and resin and testing the required properties and comparing it with the previously achieved results of the natural fiber composites.

1.2 Application of composite material

1.2.1 Infrastructure

The infrastructure of constructed facilities for the transportation and housing of people, goods, and services, which was developed and rapidly expanded in the middle of this century is now reaching a critical age with widespread signs of deterioration and inadequate functionality. Problems in the existing bridge inventory range from those related to wear, environmental deterioration and aging of structural components, to increased traffic demands and changing traffic patterns, and from insufficient detailing at the time of original design to the use of substandard materials in initial construction, to inadequate maintenance and rehabilitation measures taken through the life of the structure. Fiber reinforced composites are used in infrastructure because of their high specific strength and stiffness, enhanced fatigue life, corrosion resistant, controllable thermal properties, integrated parts and lower life cycle costs. Composites are used for renewal strategies of the infrastructures. In `repairing' a structure, the composite material is used to fix a structural or functional deficiency such as a crack or a severely degraded structural component. In case of retrofitting the columns in the pillars of bridges composite jackets are used that are wrapped around the pillars to provide strength, durability and ease of installation. The seismic retrofit of columns is a fiber dominated application, hence with the predominant role of the composite being to enable the application of constraint to the concrete core. Hence the ability to fabricate a predominantly hoop oriented unidirectional jacket using composites is an advantage. In case of beam or deck plate that are made of composites are used. It is done by the use of an appropriate adhesive and through the achievement of a good bond between the concrete substrate and the composite adhere. In case of building new decks the resin infusion process of the composite material is a widely used method. Besides the potentially lower overall life-cycle costs, decks fabricated from fiber reinforced composites would be significantly lighter, thereby affecting savings in substructure costs, enabling the use of higher live load levels in the case of replacement decks, and bringing forth the potential of longer unsupported spans and enhanced seismic resistance. In case of designing a new structure the composite shell method is used. The main advantage is that it can be incorporated with the conventional structure building systems.[11] Roofing sector has the second largest percentage of glass fiber usage in building and construction in Europe while usage for industrial infrastructure including corrosion resistance, pipes and tanks has the third rank in percentage. These sectors where moderate strength is required and high demand is shown, offer significant opportunity where natural fiber composites can be easily introduced. Roof materials made of natural fiber composites that have been developed are for example woven mat sisal fiber/cashew nut shell liquid (CNSL) and recycled paper reinforced AESO with a foam core. The recycled paper reinforced AESO composites is in the form of sandwich panel and was used to construct a monolithic roof for a single story A-frame house. [12] The use of composites in building structures are on the increase and it will keep on building.

1.2.2 Aircraft

The designing of aircraft changed drastically with the introduction of laminated composite material in the production of the body structure of the aircraft. It is accepted that designs in composites should not merely replace the metallic alloy but should take advantage of exceptional composite properties if the most efficient designs are to evolve. In a laminated structure, since the layers (laminae) are elastically connected through their faces, shear stresses are developed on the faces of each lamina. The transverse stresses thus produced can be quite large near a free boundary (free edge, cut-out, an open hole) and may influence the failure of the laminate. The laminate stacking sequence can significantly influence the magnitude of the inter-laminar normal and shear stresses, and thus the stacking sequence of plies can be important to a designer. [13] In case of the hybrid laminar composites that are used Tensile properties of FML are influenced by their individual components. So, stress/strain behavior of composites exhibits well defined elastic response from the composite laminae and aluminium up to 2.0% strain, and load bearing capability, associated with the aluminum stress/strain plastic region, responsible for the toughness and notch sensitivity. The compressive and shear stress behaviour are also significantly better than the traditional metals that are generally used in the designing of the aircraft. [14]

1.2.3 Bioengineering

Bioengineering refers to the application of concepts and methods of the physical science and mathematics in an engineering approach towards solving problems in repair and reconstructions of lost, damaged or deceased (or ‘‘non-functional”) tissues. In case of bone repair stainless steel and titanium have been used as bone plates or a long time. But it has it’s own problems of taking it out through surgery once the bones are back to their place which may cause unnecessary pain and inconvenience to the patients. Therefore stiff plates can be used as bone plates.[15] This can be achieved by using natural fiber reinforced composites. Silk fiber based bio-composites has been used in biomedical applications particularly as sutures by which the silk fibroin fibre is usually coated with waxes or silicone to enhance material properties and reduce fraying. Since silk has excellent moisture absorbing and desorbing abilities also with high oxygen permeability in wet state. [16] In case of bone tissue repair the plastic bandage or casting material is made of composite material. [17] Casting material is made of woven cotton matrix and plaster of Paris matrix. Other reinforcements are glass fiber and polyester fibers. In case of spine instrumentations discs made of bio-glass/PU composites are used [18] Other biomedical instruments and operations that the composite can help with are total knee replacement, other joint replacement, bone cement, bone replacement, dental application and other biomaterials as prosthetic limb and medical instrumentation. [19]

1.2.4 Environmental Application

Polymer composites have been widely used for several years and their market share is continuously growing. It is widely known that the use of a polymer and one (or more) solid fillers allows obtaining several advantages and, in particular, a combination of the main properties of the two. But these are difficult to recycle and thus contributes to the increasing wastes around the world. This situation can be eliminated to a large extent by the use of natural fibre reinforced composites. Research have been going on to produce 100% eco green fibres that can reduce the use of biodegradable materials. [20] The comparative analysis between natural reinforced fibre and glass reinforced fibre showed that the natural reinforced fibre is superior in higher impact, higher fibre content for equivalent performance reducing the polymer based components in environment, improve fuel efficiency and reduce emissions in the use phase of the component, especially in auto applications, end of life incineration of natural fibres results in recovered energy and carbon credits.[21] Plant fibers are more preferable than other natural fibers. In comparison to other fibrous materials, plant fibers are in general suitable to reinforce plastics due to relative high strength and stiffness, low cost, low density, low CO2 emission, biodegradability and annually renewable. This has a growing popularity in the automotive industry since automakers are aiming to make every part either recyclable or biodegradable, there still seems to be some scope for green-composites based on biodegradable polymers and plant fibers. From a technical point of view, these bio-based composites will enhance mechanical strength and acoustic performance, reduce material weight and fuel consumption, lower production cost, improve passenger safety and shatterproof performance under extreme temperature changes, and improve biodegradability for the auto interior parts. [22] Thus with the increasing use of natural fibers their needs to be more research on making the green composite more reachable and popular among the consumers.

1.2.5 Industrial Application

Proper utilization of the available natural resources and wastes became crucial for developing sustainability in industry. The use of date palm fibers are growing in the automotive industry. DPF was the best regarding specific Young's modulus to cost ratio criterion. Technical properties and performance, environmental, economical, and societal aspects strongly contribute toward adopting DPF into the automotive sector to improve its sustainability and productivity. [23] Natural-fiber composites with thermoplastic and thermoset matrices have been embraced by car manufacturers and suppliers for door panels, seat backs, headliners, package trays, dashboards, and interior parts. Natural fibers such as kenaf, hemp, flax, jute, and sisal offer such benefits as reductions in weight, cost, and CO2, less reliance on foreign oil sources, and recyclability. [24] In the recent years car manufacturers have embraced the use of reinforced fiber composites for producing door panel, seat backs, headliners, package trays, dashboards and trunk liners. Kenaf and hemp fiber bundles as well as their mixtures significantly increase tensile strength and Young’s modulus of composites; they markedly lower the impact strength of pure Poly lactic acid. Thus, these composites should be used for parts that need high tensile strength and stiffness but are subjected to low impact stress. Examples are furniture, boardings or holders for grinding discs. A mixture of bast and cotton could combine the positive tensile characteristics of bast with the good impact properties of cotton, making the composites suitable for various car parts as well as for suitcases. [25] Bamboo has several advantages over other plant fibers such as its low density, low cost, high mechanical strength, stiffness, high growth rate and its ability to fix atmospheric carbon dioxide. Bamboo has traditionally been used in construction and as a material for the manufacture of tools for daily living due to its high strength to weight rati cotton fibers cause high impact strength but lower tensile strength and stiffness. These composites could be used for impact stressed components like interior parts in cars or safety helmet. [26]

1.3 Jute-Carbon Fiber Reinforced Epoxy Based Composite

1.3.1 Jute Fiber

Jute is most commonly used natural fiber as reinforcement in green composites. Jute is a type of bast fibers from Tiliaceae family.It is one of the low-cost natural fiber and is presently the bast fiber with the maximum production volume. Jute is intuitive to the Mediterranean but now a days Bangladesh, India, China, Nepal, Thailand, Indonesia, and Brazil provide the finest type for the growth of jute. The overall world production of jute fiber is around $2300x10^3$ to $2850x10^3$ tones. Jute can grow 2–3.5 m in height and are very brittle, with a low extension to break because of the high lignin content (up to 12–16%) [27]

Jute fibre has some unique physical properties like high tenacity, bulkiness, sound & heat insulation property, low thermal conductivity, antistatic property etc. Due to these qualities, jute fibre is more suited for the manufacture of technical textiles in certain specific areas. Moreover, the image of jute as a hard and unattractive fibre does not affect its usage in technical textiles. Jute is 100% bio-degradable and thus environment- friendly. Jute fibers are always known as strong, coarse, environment friendly, and organic. The use of jute was primarily confined to marginal and small manufacturers and growers, but now it is used as important raw materials for several industries.[28] The properties of jute fibers are given below

Table 1: Properties of jute fiber

Material	Areal Density	Weaving Pattern	Tensile Strength	Modulus of elasticity	Thickness
Jute Fiber	504(g/m^2)	Unidirectional	500 MPa	15 GPa	6.1 mm

Jute fiber reinforced hybrid composites are the category of the composites in which more than one reinforcement material would be there along with the matrix material. In development the hybrid composites in used jute fiber along with another natural fiber as reinforcement and polymer as the matrix material. Since jute has properties like higher tenacity, insulation property and features such as strong, coarse, and organic they can be made into composites that provide higher tensile module than bamboo or kenaf based reinforced hybrid material.[29] The flexural and impact strength of jute/glass woven composites are lower than those of jute woven composites.[30] Thus it is observed that jute fiber based composites due to their physical and structural properties provide better mechanical properties for the hybrid composite.

1.3.2 Carbon Fiber

Carbon fiber is a material consisting of fibers about 510 μm in diameter and composed mostly of carbon atoms. The carbon atoms are bonded together in crystals that are more or less aligned parallel to the long axis of the fiber. The crystal alignment gives the fiber high strength-to-volume ratio (making it strong for its size). Several thousand carbon fibers are bundled together to form a tow, which may be used by itself or woven into a fabric. These are high tensile fibers and they are 7-8 microns in diameter and 90% carbonized.[31] These fibers are the stiffest and strongest reinforcing fibers for polymer composites, the most used after glass fibers. Made of pure carbon in form of graphite, they have low density and a negative coefficient of longitudinal thermal expansion. Depending on the orientation of the fiber, the carbon fiber composite can be stronger in a certain direction or equally strong in all directions. A small piece can withstand an impact of many tons and still deform minimally. The complex interwoven nature of the fiber makes it very difficult to break. They are also lightweight, has good vibration damping, strength and toughness and electromagnetic characteristics. The most relevant properties are given in the following table below

Table 2: Properties of carbon fiber

Material	Areal Density	Weaving pattern	Tensile strength	Modulus of elasticity	Thickness
Carbon fiber	300(g/m^2)	Unidirectional	3500 MPa	240 GPa	4.2 mm

The carbon fiber is a stronger material than any other fiber it is being reinforced with. It is also 20 times stronger than titanium or any other metal alloy having a high elastic modulus, is an excellent material selection to sustain the static and long-term cyclic loadings imposed on such structural components. [32] The carbon fiber when reinforced with other natural fiber material shows better tensile and flexural abilities compared to only a carbon fiber composite. Carbon fibers combine low weight and exceptional mechanical properties, making them ideal reinforcements for polymer composite materials.[33] As a excellent intensifier, carbon fibre can smartly enhance intensity of materials. Results show that 20% CF join in PA66/CF system can make its draw and extend intensity increase three times. The fluidity of system depress because of carbon fibre, and its accession quantity commonly under 30%(volume point).And the production mostly applied in commonly industrial non structure production.[34] That is the reason carbon fiber is a good material for producing hybrid reinforced composite materials.

1.3.3 Resin

The hybrid composites are made by adding resin to create a fiber matrix to join the fibers together. There are mainly two types as thermosets and thermoplastic. These resins are made of polymers (large molecules made up of long chains of smaller molecules or monomers). Thermoset resins are used to make most composites. They're converted from a liquid to a solid through a process called polymerization, or cross-linking. When used to produce finished goods, thermosetting resins are "cured" by the use of a catalyst, heat or a combination of the two. Once cured, solid thermoset resins cannot be converted back to their original liquid form. Common thermosets are polyester, vinyl ester, epoxy, and polyurethane. We will be using epoxy to form our hybrid composite made of jute and carbon fiber since Epoxy resins have a well-established record in a wide range of composites parts, structures and concrete repair. The structure of the resin can be engineered to yield a number of different products with varying levels of performance. A major benefit of epoxy resins over unsaturated polyester resins is their lower shrinkage. Epoxy resins can also be formulated with different materials or blended with other epoxy resins to achieve specific performance features. Epoxies are used primarily for fabricating high performance composites with superior mechanical properties, resistance to corrosive liquids and environments, superior electrical properties, good performance at elevated temperatures, good adhesion to a substrate, or a combination of these benefits. Epoxy resins do not however, have particularly good UV resistance. One of the other main reason of using epoxy as resin is using carbon fiber in composite hybrid for the study. As Carbon fibers with high strength and modulus can be incorporated into a range of matrix materials.

When a load is applied to a carbon fiber composite, the stress is transferred from one carbon filament to another through the matrix material. If a fiber-resin bond is weak, this load transfer will weaken or break bonds between the resin matrix and fiber filaments. [35] . Carbon fibers are usually coated with sizing, a polymeric solution applied to improve their adhesion with the resin matrix. [36] Epoxy/carbon fiber composites are used more extensively for structural applications than other high performance composites due to their overall high specific stiffness and strength properties. [37] We have used **Epoxy LY556** as epoxy based resin and **Araldite HY951** as hardener in our processing of the hybrid composite since both are used in high performance composites. Epoxy LY556 is used as Anhydride-cured, low-viscosity standard matrix system with extremely long pot life. The reactivity of the system is adjustable by variation of the accelerator content. The system is easy to process, has good fibre impregnation properties and exhibits excellent mechanical, dynamic and thermal properties. It has an excellent chemical resistance especially to acids at temperatures up to 80 °C. Araldite HY951 has viscosity at 25°C of 10-20 MPa*s and Specific Gravity at 25°C of 0.98 g/cm^3 It also has appearance of a Clear liquid [38]

1.3.4 Stacking Sequence

Our study is based on the change of mechanical properties of the reinforced hybrid composites based on the change in sequence of the jute and carbon fibers in it. Change in sacking sequence has a significant impact on the properties of the composites. Our goal is to do a thorough mechanical investigation on different stacking sequence of the jute and carbon fibers to improve the mechanical properties of the reinforced hybrid composite. The mechanical investigation that will be carried out includes the tensile, flexural and impact tests. It is reported that the hybrid stacking sequence design strongly affects the different properties such as flexural strength, modulus fatigue behaviour and impact performance of the composite. It helps improve the balance of mechanical properties of the hybrid composite. [39][40] Impact damage in the composites start with fiber cracking and fiber de-bonding. Though the influence of stacking sequence is not yet fully understood in case of the impact test but some studies suggest that minimizing difference in orientation between the stack of fibers creates increased resistance to delamination. [41] The present results showed that the flexural strength and modulus of hybrid composite laminates were strongly dependent on the sequence of fiber reinforcement. All the stacking sequences showed a positive hybridization effect. The test of hybrid composite with carbon fiber at the compressive side exhibited higher flexural strength and modulus than when basalt fabric was placed at the compressive side. [42] In case of tensile properties the different sacking sequences are found to be quite fruitful as each stacking sequence shows variation in the tensile properties. [43] Our study focuses at giving a verdict based on the stacking sequence to find out not only which has the highest mechanical properties but also to differentiate the composites based on the highest tensile, flexural and impact properties.

1.3.5 Resin Infusion Process

In the field of composites, resin infusion is a process where the voids in an evacuated stack of porous material are filled with a liquid resin. When the resin solidifies, the solid resin matrix binds the assembly of materials into a unified rigid composite. The reinforcement can be any porous material compatible with the resin. The infusion process is used because of the following benefits [44]:

- The process is carried out within a “closed” system; that is within the void between a sealed bag and a mould, or between 2 sealed moulds. Hence there is minimal exposure of the uncured resin to the atmosphere. The potential for harm to worker health and to the environment from volatile resin components is consequently reduced. Because of the low emission of volatiles, factory ventilation costs can be reduced.
- When performed under a flexible film, infusion uses the minimum amount of resin needed to fill the voids in the dry laminate. Especially for smaller/repetition parts where multiple-use flexible films are practical, infusion offers an opportunity to reduce manufacturing cost compared with hand lay-up, while enhancing laminate quality.
- Infusion is a particularly practical and cost-effective solution for the construction of large, high strength/light weight one-piece parts, such as boat hulls, wind turbine blades, bridge beams and building cladding panels. The number of components required to make a part can often be significantly reduced using infusion.

We will be using the **Vacuum Assisted Resin Infusion (VARI)** process to infuse the resin to produce the reinforced hybrid composite of carbon and jute fiber since this best suit the benefits we want to obtain from the process.

1.3.6 The Testing of Mechanical Properties of Composites

Our main goal is to test the mechanical properties of the hybrid composites that are prepared based on different stacking sequences. The three mechanical properties test we will be carrying out are **Tensile Test**, **Flexural Test** an **Impact Test**. A tensile test applies tensile (pulling) force to a material and measures the specimen's response to the stress. By doing this, tensile tests determine how strong a material is and how much it can elongate. Flexure tests are generally used to determine the flexural modulus or flexural strength of a material. A flexure test is more affordable than a tensile test and test results are slightly different. The impact test is a method for evaluating the toughness and notch sensitivity of engineering materials. It is usually used to test the toughness of metals, but similar tests are used for polymers, ceramics and composites. We will be following the ASTM standards to perform the aforementioned tests. We will be doing a result analysis based on the obtained results and give out decisions on which has the highest mechanical properties.

Chapter 2: Literature Review

Over the past few decades there is a rapid increase in the demand of the fiber reinforced polymer (FRP) composites because of the unique combination of high performance, great versatility and processing advantages at favourable costs by permutation and combination of different fibers and polymers. [45] Reinforced composites possesses interesting properties like high specific strength and stiffness, good fatigue performance and damage tolerances, low thermal expansion, non-magnetic, properties, corrosion resistance and low energy consumption during fabrication. Fiber reinforced composites made up of carbon, boron, glass and kevlar fibers have been accepted widely as the materials for structural and non-structural applications [46]

In the work of Akash.S and Avinash.S it is found that tensile strength of 6% silicon carbide filled with dupion silk fiber reinforced epoxy bio-composite material obtained about 41.4 MPa and flexural strength about 53 Mpa. [47]

In the work of H. P. S. Abdul Khallil and S. Hanida, the incorporation of both EFB and glass fibers into the polyester matrix has resulted in the improvement of the mechanical properties of the composites. The enhancement of tensile, flexural and impact properties of the composites were observed with increasing loading of both EFB and glass fibers. Composites showed the highest mechanical performance at 35 wt% of total fiber loading. This is due to the excellent dispersion of the fibers and good load transference occurring at this composition. Furthermore, increasing the amount of EFB fiber in composites reduced the resistance of water absorption and thickness swelling. [48]

M.M. Davoodi and S.M. Sapuantensile said in their work that strength and Young's modulus of the specimens were higher than common bumper beam materials. The maximum typical Young's modulus and yield strength of the epoxy were 3.08 GPa and 71.68 MPa, respectively, which are significantly higher than polypropylene.[49]

In the paper of A. Alavudeen and N. Rajini it is shown that the hybrid composite shows a significant increase in tensile strength over the pure woven banana and kenaf fiber-reinforced polyester composites. The plain-woven hybrid banana/kenaf composite exhibits the highest tensile strength of 139 MPa, as shown in Fig.2. An increase of

54% in tensile strength was observed for HP composites over pure BP composites, whereas this increase was only 15% over KP composites. The SLS-treated kenaf/banana woven hybrid composite exhibits the 11 maximum flexural strength of 150 MPa, while the same for alkali-treated composite and untreated composite are 150 MPa and 133 MPa, respectively. Thus, the flexural strength of the SLS-treated woven hybrid composite is 25% higher than that of the untreated composite. Similarly, the flexural strength of the SLS-treated woven banana composite is 33% higher than that of the untreated composite. Further, the flexural strength of the SLS-treated woven kenaf composite is 26% higher than that of the untreated composite.[50]

Yongli Zhang and Yan Li showed that the stacking sequence of the FFRP plies and the GFRP plies showed bigger influence on the tensile strength and tensile failure strains of the hybrid composites. The tensile strength and failure strain of GF type composite were the highest among the three types of hybrid composites. More fiber layers interaction between flax fiber plies and glass fiber plies which led to higher tensile strength and bigger failure strain.[51]

M. Jawaida and H.P.S. Abdul Khalil showed that, tensile strength of the composite is influenced by the strength and modulus of fibres. It is observed that pure woven jute composite (53.31 MPa) showed a higher tensile strength and modulus than pure EFB composite (22.61 MPa). This is because woven jute fibres are stronger and stiffer than oil palm EFB fibres. t laminate sequence Jw/EFB/Jw with 20% woven jute fibre has higher flexural strength and modulus compared to EFB/Jw/EFB. This indicate that arranging woven jute fibre as skin and oil palm EFB fibre at core leads to considerable improvement in flexural strength and modulus. Hence, altering the sequence of arrangement of fibre mat show improvement in the flexural properties. It can be justified from the fact that flexural strength and modulus is controlled by the strength of extreme layers of reinforcement. The pure woven jute composite showed a higher flexural strength and modulus than the oil palm EFB composites and unreinforced epoxy sample.[52]

T D Jagannatha and G Harish showed that the ultimate tensile strength of the carbon reinforced composite was higher as compared to other type of composites. The 60% carbon fiber reinforced composites shows 65.24% increase in the UTS as compared to

60% glass fiber reinforced composites and 38.01% increase in the UTS with that of 30% glass fiber and 30% carbon reinforced hybrid composite.[53]

I.D.G. Ary Subagia and Yonjig Kim showed that placing carbon fiber layers at the compressive side was found to increase the flexural strength and modulus of the hybrid composites when compared to placing basalt fiber layer on the compressive side. When the load was applied, the outermost layer bears most of the applied load, so that a high flexural strength was achieved when carbon fibers were located at the skin region. The flexural strength of H1, i.e., 3 carbon fiber layers at the compressive side, was 740.197 MPa, which was about 86% of that of the plain CFRP which is 860.929 MPa. [54]

N. Venkateshwaran and A. ElayaPeruma showed that increasing the fiber length and weight percentage, the mechanical properties also increases up to certain limit. Further, addition causes them to decrease due to poor interfacial bonding between fiber and matrix. The maximum mechanical properties, tensile strength, flexural strength and impact strength are found out as 16.39 MPa, 57.53 MPa and 13.25 kJ/m2 respectively. On comparing the tensile strength of the banana fiber/epoxy composite has 43.54 % more tensile strength than Palmyra /polyester composite, 12.3% greater than the woven banana/epoxy composite and 15% more than banana empty fruit bunch polyester composite. In a Similar fasion flexural strength is 17% higher than banana empty fruit bunch polyester composite, around 20% higher than sisal–silk composite, 22% more than hemp–polyester composite. The addition of sisal fiber in the composite, results in 16% increase in tensile strength, 4% increase in flexural strength and 35% increase in impact strength. [55]

Chensong Dong and Heshan A. Ranaweera-Jayawardena showed in the experiments that the flexural strength of the G1C4 (G= Glass and C= Carbon) configuration is 8.0% higher than that of full carbon configuration and 3.2% higher than the full glass configuration. The FEA prediction suggests that the flexural strength of the G1C4 configuration is 27.5% higher than that of full carbon configuration and 31.1% higher than the full glass configuration. The average flexural strength of the G2C3 configuration from the experiments shows an increase of 1.2% and a decrease of 3.3%

when compared with those of the full carbon and glass configurations, respectively. However, the FEA prediction shows an increase of 8.9% and 11.9%, respectively.[56]

Wang Mingchao and Zhang Zuoguang showed that small-diameter carbon fibers net among large-diameter boron fibers, and triangle and quadrilateral hybrid formations form, which increases the hybrid interfacial area. Therfore much more energy is dissipated, and the crack growth is retarded due to the large amount of interface debonding. Thus the compressive strength of the hybrid exceeds that of the two kinds of single fiber reinforced composites. For SiCF-CFRP, the break elongation for carbon fiber (1.3%) is six times higher than that for SiC fiber (0.2%). This means the two fibers are difficult to coordinate in bearing load, and high shear stress acts on interfaces which reduces the compressive strength of the hybrid. On the other hand, although small-diameter carbon fibers nest among large-diameter SiC fibers, which increases hybrid interfacial areas, this effect is offset by the mismatching of the two kinds of fiber with large differences in properties.[57]

The panels being Panel 1 - $[(+45,02)_2]_s$, Panel 2 - $[(+45)_{2,04}]_s$, Panel 3 - $[(+45,0,-45,0)_z]$, Panel 4 - $[(02,+45)_2]$, Panel 5 $[04,(+45)_2]$, Panel 6 - $[(0,+45,0,-45)_2]_s$ S. A. Hitchen and R. M. J. Kemp showed in their study that the plain compression failure stresses were influenced by the stacking sequence, with values ranging from 881 MPa for panel 2 to 659 MPa for panel 5. Comparison of the different lay-ups revealed similarities between the plain compression failure stresses in panels 1 and 2, panels 3 and 6, and between panels 4 and 5. The residual strength after impact was lower than the plain compression failure strength, with values ranging from 344 MPa for panel 1 to 273 MPa for panel 5. In case of the impact test an approximately circular damage zone was observed in panel 2 whereas the other five panels contained elongated maximum delamination parallel to the fibre direction in the surface plies. All six panels contained a crush zone at the impact site which sustained considerable fibre damage. In addition to delamination, splitting was observed which tended to be most extensive in the plies furthest from the impact site.[41]

Alaattin Aktas and Mehmet Aktasor showed that for $[2D_2R_2]_S$, $[2D_2M_2]_S$, $[R_{22}D_2]_S$, $[M_22D_2]_S$, $[M_2R_2]S$ and $[R_2M_2]_S$ stacking sequence of hybrid composites The penetration threshold energy levels are 42.5 J, 40 J, 32.5 J, 30 J, 20 J, and 20 J for

$[2D_2R_2]_S$, $[2D_2M_2]_S$, $[R_{22}D_2]_S$, $[M_{22}D2]_S$, $[M_2R_2]_S$, and $[R_2M_2]S$ hybrid composites, respectively. The perforation threshold energy levels are 45 J, 42.5 J, 35 J, 32.5 J, 22.5 J, and 22.5 J for $[2D_2R_2]_S$, $[2D_2M_2]_S$, $[R_{22}D_2]_S$, $[M_{22}D_2]_S$, $[M_2R_2]_S$, and $[R_2M_2]_S$ hybrid composites, respectively. It can be clearly seen that hybrid composites having orientation of outer layer of woven fabric with an inner layer of knit fabric have the highest impact strength as in $[2D_2R_2]S$ and $[2D_2M_2]_S$. Examined the perforation threshold energy of hybrid composites, perforation threshold energy of $[2D_2R_2]_S$ hybrid composites is 5.88%, 28.57%, 38.46%, 125% greater than that of the perforation threshold energy of $[2D_2M_2]_S$, $[R_{22}D_2]_S$, $[M_{22}D_2]_S$, and $[M_2R_2]S$, and $[R_2M_2]_S$, respectively.[58]

Y. Karaduman and L. Onal clearly suggested that the load was carried out by outer fabric layers in a tensile test. Furthermore, [NWNW] layering sequence has also yielded comparable tensile properties as that of [WNNW]. The composite with alternating and asymmetric fabric reinforcement, i.e., [NWNW] also showed improved tensile properties in comparison to a composite sample having only nonwoven fabrics [NNNN]. This was attributed to the integration of woven and nonwoven fabrics with heat and pressure during the composite fabrication that yielded a highly integrated and balanced structure. The sample [NNWW] has obtained the lowest tensile strength amongst all the hybrid composites. This may be associated with highly unbalanced structure as a result of the reinforcement with nonwoven fabrics on one side and woven fabrics on the other side that caused a non-uniform load distribution and a premature specimen failure. Flexural modulus followed a different pattern from the strength with the highest value recorded in the samples [NWNW] and [NWWN]. It can be seen that hybridization improved the flexural modulus of the composites when compared to all-woven and all-nonwoven composites. In particular, the samples with the nonwoven fabrics on the loading side showed better flexural modulus values. The [WNNW] sample having woven fabric placed on the surface yielded the lowest magnitude of flexural modulus. This was attributed to the fact that the woven fabrics experienced compression loading with no fibers aligned in the through-thickness direction unlike needle punched nonwoven fabrics and hence, resulted in so-called “kink band formation” under flexural loading which yielded a non-homogenous distribution of load leading to local stress concentration point. The fiber reinforcement increased the impact force and delayed the specimen failure under impact. It should be noted that all-woven composite sample [WWWW] showed the third highest impact force value indicating that hybridization of the woven composite with nonwoven fabrics improved the impact properties of the composites. [NWNW] This is attributed to higher energy absorption characteristics of needle punched nonwoven fabrics placed as a surface layer during the impact test. Nonwoven fabrics on the surface of composite distributed the initial impact load effectively and simultaneously assisting the woven fabric underneath to carry the load free of local stress concentrations. Therefore, the nonwoven and woven fabrics support each other in a hybrid composite that improved impact loading characteristics. (N= Jute/PP non-woven fiber W=Flax/PP woven fiber) [59]

Anshida Haneefa and Panampilly Bindu showed that the effect of fiber loading on the flexural strength of the hybrid composites. From the figure it is clear that the flexural strength increases with fiber loading. At 20% fiber loading, there is a slight increase in flexural strength, i.e., 8.74 MPa. But at 30% fiber loading, there is an increase of 53%. The effect of fiber loading on flexural modulus was shown in Figure 19. Flexural modulus also shows a similar trend and the maximum improvement is observed with 30% fiber loading.[60]

R. Yahaya and S.M. Sapuan experimented sample with 3-layer hybrid laminates exhibited average tensile strength values of 99.4MPa. The average tensile strength of 4-layer hybrid laminates was found to be 123MPa. The increase of tensile strength of4-layer hybrid composite is due to the addition of one more layer of Kevlar layers. The average flexural properties of treated woven kenaf were slightly better than non-treated woven kenaf/epoxy. It was shown in that the flexural strength and modulus for sample k/ET is 51.28MPa and 2741.8MPa respectively, compared to sample k/E with 21.76MPa and 722.04MPa. These may indicate a positive effect of 6% NaOH mercerization on woven kenaf. Sample A/k/A/k* has recorded highest impact properties; that is 3.97J impact energy and 50.1kJ/m2 impact toughness. In term of layering numbers, it was found that; 4-layer hybrid laminates display a higher charpy impact properties compared to 3-layer hybrid laminates except for sample A/k/A/k*. Lower impact energy and impact toughness for sample A/k/A/k* where the kenaf surface was subjected to load, may be due to failure process including crack initiation and growth, fibre breakage and delamination in kenaf impacted surface. In 3-layer hybrid laminates, the sample with Kevlar at the middle opposed the impact load better than the sample with kenaf layer at the middle. This is because kenaf fibres fail quickly than the Kevlar fibres (A= Kenaf fiber, K= Kevlar Fiber) [61]

Haydar U. Zaman and Avik Khan showed that the effect of jute content on the mechanical properties of jute oligomer composites was measured. Tensile strength (TS) and bending strength (BS) of the composites were found to increase up to 55 wt%, and then decreased. The results are presented in Figure 1. The highest TS and BS (55 wt% jute) of the composites were found to be 47.88 and 49.56 MPa, respectively. The variation of tensile modulus (TM) and bending modulus (BM) with jute content in the composite is shown in Figure 2. It was found that TM values of the composites were increased with increasing jute content up to 55 wt% and after that TM values were composites against jute content. Decreased with increasing jute content. The highest TM value of the composite was found to be 1.24 GPa. But the BM was increased with increasing jute content up to 60 % and above 60 %, it decreases with the increase in fiber loading. The maximum BM was observed to be 1 .38 GPa. The effect of jute content on the elongation at break (Eb %) of the composites is shown in Figure 3. It was found that Eb % of the composites were increased with increasing jute content up to 55 % and after that Eb % were found to decrease. The highest Eb % value (15.5 %) was observed at 55 % jute content and the lowest (8.45 %) was observed at 45 % jute content.[45]

Chapter 3: Methodology

3.1 Initial specimen preparation

We will be producing a 10 layers hybrid composite of carbon and jute fibers. We will be using 6 jute fibers and 4 carbon fibers which are incised with a measurement of 20 cm by 20 cm square shape. The carbon and jute fibers are then placed in five different sequences with a 0° orientation.

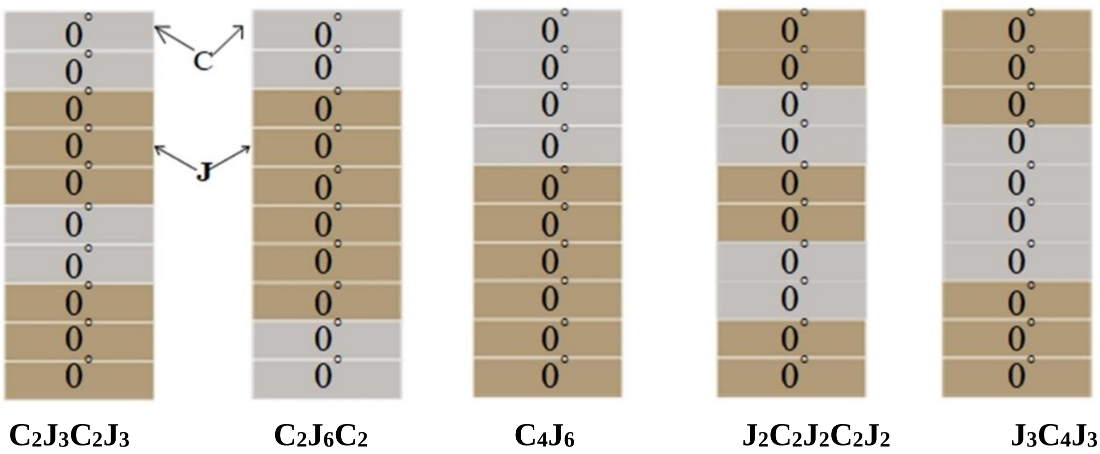

Figure 1: Stacking Sequence of Carbon and Jute Fibers

The first sequence is C2J3C2J3 where two carbon fibers are placed first followed by 3 jute fibers and again the process is repeated. The second sequence is C2J6C2 where 2 carbon fibers are followed by 6 jute fibers which is again followed by 2 carbon fibers. The third sequence is C4J6 which has 4 carbon layers followed by 6 jute layers. The fourth one is J2C2J2C2J2 which has two jute layers followed by 2 carbon layers twice with the last layer being 2 jute fibers. The fifth and the last sequence is J3C4J3 which has 3 jute fibers followed by 4 carbon fibers with again 3 jute fibers. The five specimens will now be infused with the Vacuum assisted resin infusion process to prepare the final hybrid composite.

3.2 Vacuum Assisted Resin Infusion Process

The hybrid samples of carbon and jute fiber were fabricated by a process called the 'Vacuum Infusion Process'. Vacuum infusion process is a technique that uses vacuum pressure to drive resin through the hybrid samples. The samples are each placed on the mold at a time and vacuum is applied on it. Once complete vacuum is achieved, the resin is quickly sucked into the sample via carefully paced PVC vacuum hoses. The process is helped by reserved supply of materials. The main reason behind the use of this process is because it provides better fiber-to-resin ratio, less watered resin, consistent resin usage, flexible set-up and a cleaner approach.

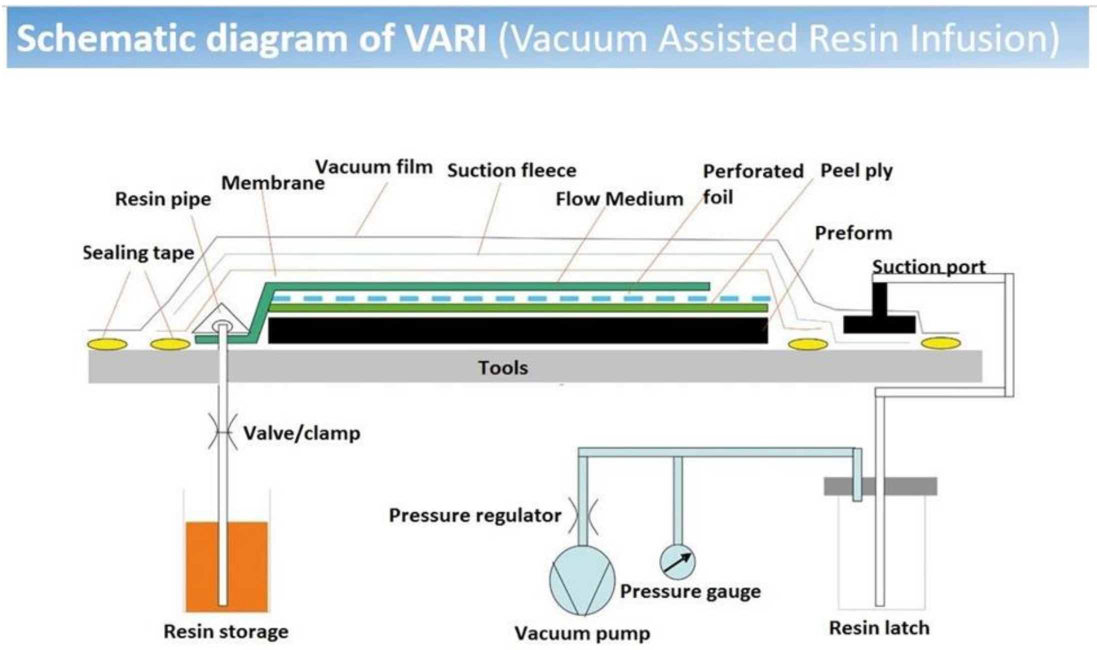

Figure 2: Vacuum Assisted Resin Infusion Process

The vacuum infusion process is established by the setting up the following equipment: a vacuum pump, a professional resin infusion catch-pot and a resin infusion starter kit which includes vacuum bagging gum, PVC vacuum hose, resin infusion line clamp, resin infusion spiral medium, flow coil, resin infusion silicon connector and vacuum bagging film. All this are set up to complete the initial preparation for the vacuum infusion process. This will be followed by the step by step infusion procedure to achieve the final composite material.

3.3 Step by Step Infusion Procedure

The following steps were followed to infuse the five specimens with epoxy-based resin:

3.3.1 Preparing the Mould

Our first priority is to prepare the mould where the samples will be placed for infusion. For acquiring highest grade of samples, the mould must be rigid and have a high-gloss finishing. The mould should have a flange enough for placing the vacuum sealing sealant tape and spiral mesh around the sample without any interference.

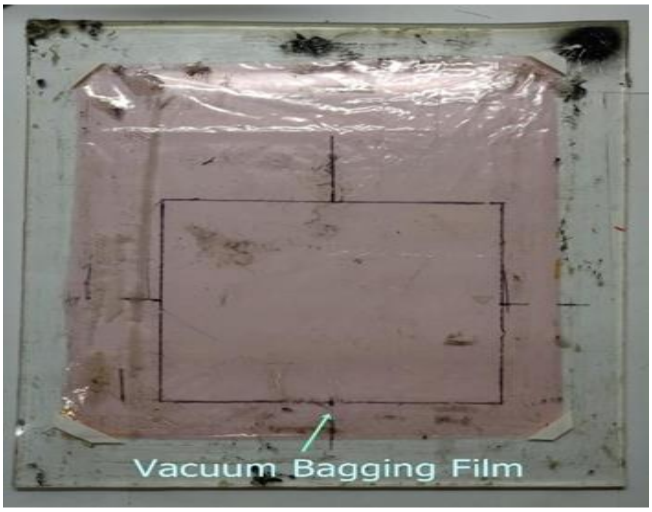

Figure 3: Acrylic Glass as Mould

We will be using an acrylic glass plate as the mould for fabricating our samples. After the selection of mould to be used we cleaned it properly so that no external material enters the infusion process. The mould is very important as it provides the basic structure for the shape of the composite material. The acrylic glass is cut in 20 cm by 20 cm square area and the fibers that are cut in the same size measurement are placed so that the exact size of the specimen is intact when the resin will be infused.

3.3.2 Adding Vacuum Bag Film On the Mould

The vacuum bagging film is cut according to the size of the plate keeping the flange area out and placed on the glass plate. This vacuum bagging film act as the separator between the resin flow and acrylic. This also ensures proper removal of the composite from the acrylic layer. Otherwise the composite would stick to the acrylic permanently. Generally plastic bag is used for this purpose.

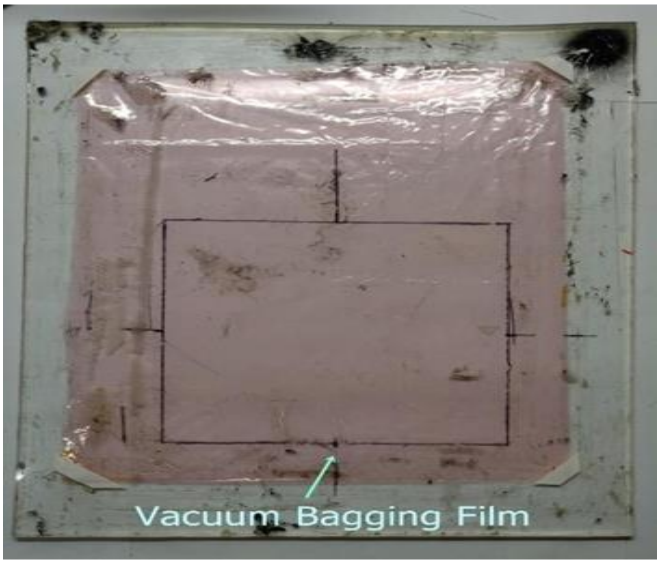

Figure 4: Vacuum Bagging Filming on the mould

One of the major points to be noted while using the vacuum bag is to inspect whether the bag is leaked or not. If there is any leak which is present in the vacuum bagging process it will be hampered as the full vacuum of the mould would not complete. If the leak is detected than the bag needs to be removed or vacuum gum needs to be used to seal the position from where the leak is taking place but removing the film and using a new one is always recommended since it reduces the chance of the process being fully completed.

3.3.3 Specimen Placement and covering on the mould

The sample is then carefully placed on top of the vacuum bagging film which will help in infusing the sample. During this we need to ensure the proper alignment and uniformity of the layers. This composite is placed at the middle of the acrylic and enough room is kept for the resin hose that will be used. First of all the breather layer cloth is placed on top of the sample which is cut according to the size of the vacuum bagging film.

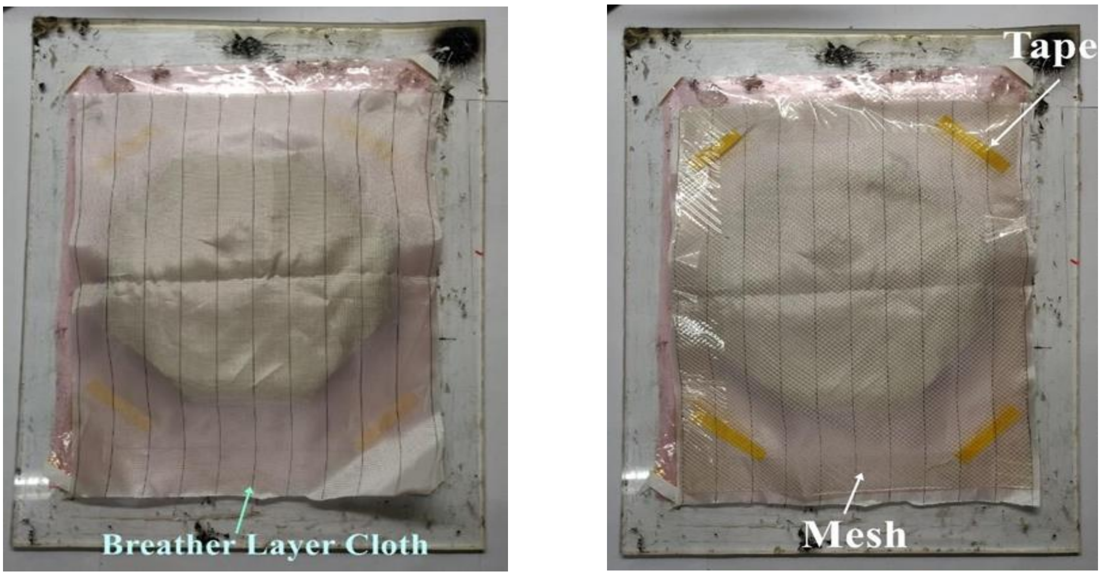

Figure 5: Attaching the Breather Layer Cloth and the Mesh

We used tape to attach the vacuum film to the plate and the breather layer to the vacuum film. Then the mesh is cut in same size as the breather layer cloth and placed it on top of it. All the sides of the mesh were wrapped by duct tape to cover the sharp edges that might create a leak in the vacuum bag. The mesh is also tapped to the breather layer same as the previous ones. The mesh and the breather layer were provided so that he resin might easily flow through the whole composite witout being disrupted at any point of the flow.

3.3.4 Installing the Infusion Spiral Tubes and Vacuum Hose Pipe

selecting and installing the vacuum lines through which the resin will pass. We will use spiral resin infusion flow tubes which is a coil that is coiled into a tube shape. Due to its construction criteria resin can enter and leave through the wall of entire length of the tube. This property is ideal for the in-bag vacuuming feed lines. When we use a feed lie resin can quickly pass through the tube but also simultaneously seep out along the way. This helps acquire a quick infusion of the entire area inside the vacuum bag.

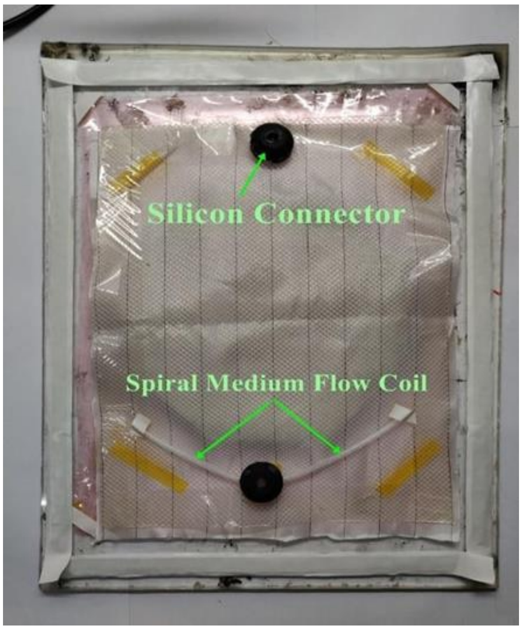

Figure 6: Installation of Spiral Medium Flow Coil and Vacuum Hose Pipe

. We attach the spiral flow coils to the resin infusion silicon connector and place it at one end of the prepared bed. The spiral tubes have a tendency of straightening up when the stretch is released so we used duct tape to attach both ends to the breather layer. In the silicon connector there is a 4-way channel that forms a good flow of resin into the spiral tubes. This connector can accept a PVC vacuum ID hose of 6 mm for transferring the resin to the tubes underneath. The other silicon connector is placed on the other side of the bed so that it can suck in the additional resin that is present inside the vacuum bag. It can also use a vacuum hose of the previously mentioned diameter

3.3.5 Vacuum Tight Seal Using Vacuum Bagging Gum

Now that all the dry materials are in place we will advance to creating the vacuum bag. The bag should be tight but still have enough room for all the materials and also the vacuum lines since shortage of space can result in improper infusion.

Figure 7: Vacuum Sealing the specimen using Gum

The vacuum film is used to create the vacuum bag. First the sealant tape is attached around the flange area so that it has all the dry material in the middle. The vacuum film which is cut a tad large in measurement than the glass plate is then carefully attached with the sealant tape serially completing all the sides. The bagging should be done very carefully so that there is no leak in the film.

3.3.6 Vacuum Bagging Procedure

First a PVC vacuum hose is attached to the resin infusion catch-pot. The catch-pot ensures that any additional resin does not draw down the vacuum line into the vacuum pump. It has a barb-type fitting for easy connection of the vacuum line as well as an easy to tighten resin infusion line. The vacuum hose is entered through the tight infusion line also called the gland nut so that the additional resin can fall into the buckets placed inside the catch-pot. The other side of the vacuum hose is entered into the resin infusion silicon connector placed for collecting the additional resin. Both ends are sealed with sealant tapes to avoid any kind of leakage from inside the vacuum bag. Another vacuum hose is entered into the silicon connector that holds the spiral tubes for flowing resin and it is also sealed in the previous way with sealant tape.

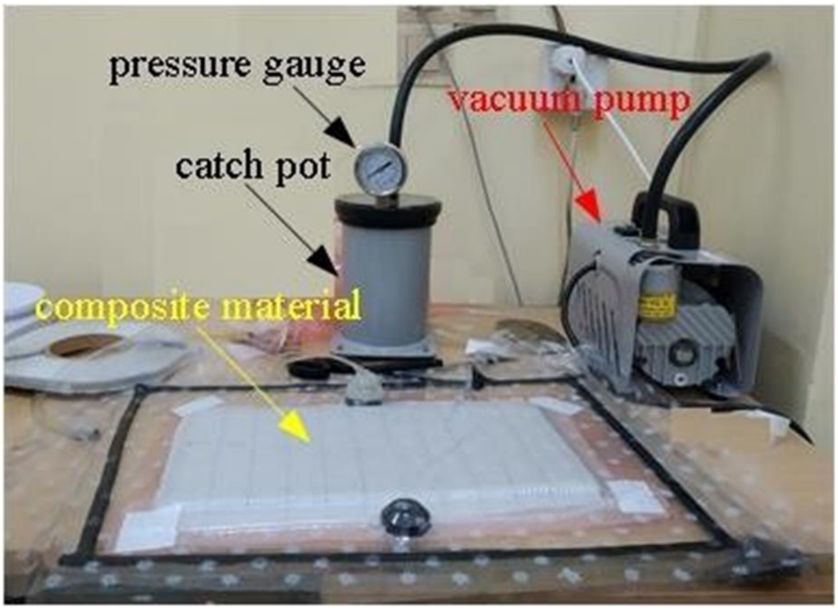

Figure 8: Total Vacuum Bagging Procedure

Lastly, we are ready for the pumping process that will create the vacuum pressure inside the bag. Before the pump is switched on the resin line is clamped using the resin infusion line clamp because the hose will act as a temporary leak that must be closed. Now the pump is turned on. Right after turning it the air is sucked out of the vacuum bag. We then turn off the pump and wait for 30 minutes to check whether any leak is present in the vacuum bag because in any vacuum bagging, leak poses the biggest threat. Even a small leak can greatly hinder the infusion process or maybe ruin the whole process. After we have confirmed that the vacuum bag is officially leak proof we move on to the next step. The next step involves the selection of resin and hardener. The most important aspect while selecting a resin is viscosity. Since lower viscosity aids the infusion, we have chosen Epoxy LY556 as the resin to be used in the fabrication of our sample material. Choosing the hardener is also equally important. While selecting hardener we have to keep in mind the time it takes to harden the resin-hardener mixture. At one stage the mixture will get immensely dense and the flow through the hose into the vacuum bag will eventually stop which will hinder the infusion process. So, in accordance with the resin we have chosen Araldite HY951 as the hardener. The ratio of resin to hardener we have used for our infusion process is 10:1. This ratio gives us enough time to infuse the whole hybrid sample before the mixture tends to harden. We attach the hose to the resin bucket and double check so that the hose does not leave the bucket. Once everything is satisfactory, we open the clamp. The machine is again turned on and now the resin starts to flow through the hose into the silicon connector and the spiral tube placed underneath to the bed prepared with dry materials. Since the bag is covered with vacuum pressure it quickly sucks in the resin and transfers it through-out the whole reinforcement infusing the sample in the process. Once it has infused the whole reinforcement the additional resin starts to climb through the hose that is connected to the catch pot. We remove the clamp attached to the hose and the resin starts to fall into the bucket place inside the catch-pot. Once the whole reinforcement is infused with resin there is no need for resin to enter further. We also were careful that the bucket was not sucked dry so the destructive air bubbles could enter and to prevent this we clamped of the hose line carrying the resin in the same way it was previously accomplished. After the completion of the infusion process, we have got five specimens of five different stacking sequences.

Figure 9: Infused Hybrid Composites with Five Different Stacking Sequence

3.4 Preparing Specimen for Mechanical Property Test

We have used American Society for Testing and Materials (ASTM) standard for the production and testing of our specimens**. ASTM D039** is used for Tensile test. We have followed **ASTM D790** for Flexural test and for impact test we have used **ASTM D6110** standards. The composite material forms are limited to continuous fiber or discontinuous fiber-reinforced composites in which the laminate is balanced and symmetric with respect to the test direction.

3.4.1 Flexural Test Specimen Dimension

For flexural test we have used **ASTM D790** standard. This is the standard test standard for composites used in flexural test. The dimensions of this **180mm x 10 mm** rectangular slab of thickness 6 – 7 mm.[62] For flexural test we have done **Three Point Bending Test** IN the UTM. The test is done by applying force from the top of the plate at a single point and supporting it from the bottom at two different points. Then due to the applied force bending occurs slowly. This is automatically logged by the UTM machine and gives us the output. The span between the bottom support pins is 100 mm.

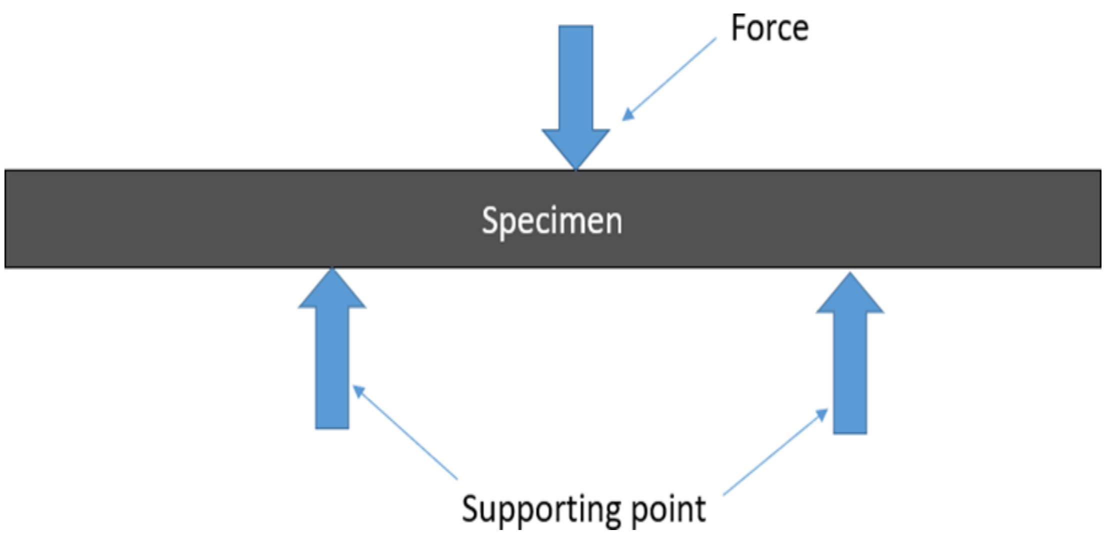

Figure 10: Specimen Dimension for Flexural Test

3.4.2 Tensile Test Specimen Dimension

We have used ASTM D3039 standard for this study. This standard is the test method for tensile properties of polymer matrix composite materials. The size of the specimen used is 250mm*25mm. [63] A thin flat strip of material having a constant rectangular cross section is mounted in the grips of a mechanical testing machine and monotonically loaded in tension while recording load. The ultimate strength of the material can be determined from the maximum load carried before failure. If the coupon strain is monitored with strain or displacement transducers then the stress-strain response of the material can be determined, from which the ultimate tensile strain, tensile modulus of elasticity, Poisson's ratio, and transition strain can be derived.

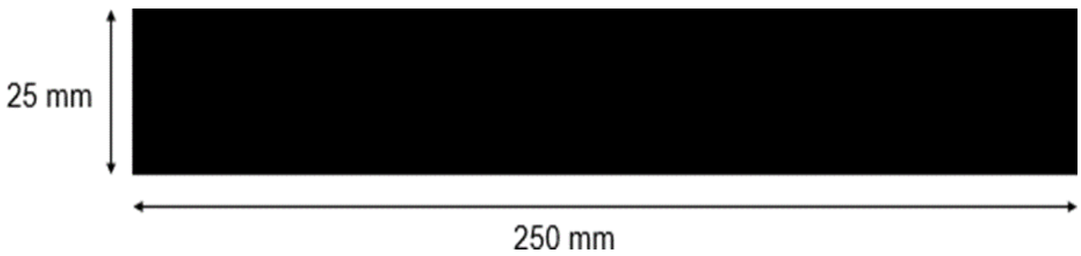

Figure 11: Specimaen Dimension for Tensile Test

The shape of the specimen is a thin rectangular slab. Using this we can easily use a universal testing machine for determining the tensile strength of the specimen. Tensile strength of a material is the maximum amount of tensile stress that it can take before failure, breaking. We will find out the tensile strength in the axial direction in our case along the length of the specimen. This rectangular shape ensures uniform distribution of load and a better gripping surface in the UTM.

3.4.3 Impact Test Specimen Dimension

For the impact test of our specimen we have followed ASTM D6110 standard. The length and width of the specimen is 60mm and 15mm respectively.[64] We have used Charpy Impact test for testing this property. We measured the amount of energy absorbed by the specimen.

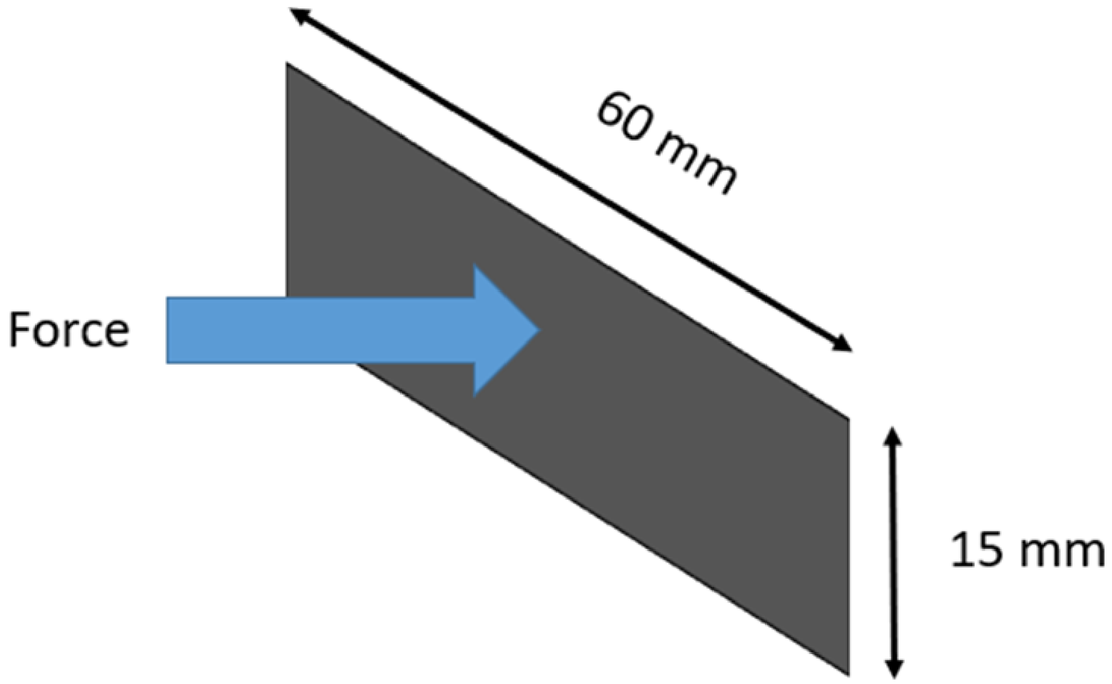

Figure 12: Specimen Dimension for Impact Test

3.5 Performing the Tests on UTM

After all the specimen were cut according to the ASTM standards for the flexural, tensile and impact test, the tensile and flexural tests were performed on the UTM machine.[65] The UTM machine produced stress vs strain graph with an excel file containing all the data concerning applied force and displacement due to the force with respect to time. The graphs and the concerning data will be analysed in the following result and discussion section to conclude which composite specimen has the highest mechanical properties.

Chapter 4: Results and Discussion

4.1 Introduction

The UTM machine provided the stress vs strain graph along with excels files with the data that includes the force applied by the load being put on the specimen and the displacement due to this with respect to time. The specimens have been observed and a conclusion has been reached from the observation. The tensile stress vs strain graphs have also been analysed which has enabled us to provide some corollaries based on the behaviour and damage pattern of the composite specimens.

The tensile, flexural and impact test were carried out by ASTM standard sizes for each test specimen respectively. The tests are performed to check the mechanical properties to observe if any change occurs based on the change in stacking sequence. The observation will focus on the fracture and cracks on the composite post testing and the strain vs stress curves will discuss about the characteristics and properties of a composite based on the values attained from the tests.

The following sections will discuss in detail about the aforementioned parameters and observations.

4.2 Specimen Observation

4.2.1 Tensile Test Specimen

The tensile test was performed on all five specimens and observation is performed on the post testing condition of each of the composites.

$C_2J_6C_2$ $C_2J_3C_2J_3$ C4J6 $J_2C_2J_2C_2J_2$ $J_3C_4J_3$

Figure 13: Fracture pattern of the specimen after the Tensile test

If we analyse the fractures and breaking points in the five specimens, we can see that in case of the jute layers the breaking is uniform. Which is an indication that the jute layers break uniformly when load is applied on it. The resin could not hold the jute fibers in the matrix strong enough to provide resistance to the strain applied. If we see the fracture pattern closely, we can see that the jute fibers starts to crack from one position one after the other. As the first layer is cracked a cracking sequence is initiated which moves from one layer to the other until all the jute fiber is fractured. In case of the carbon fibers being placed on the side where load is applied there is no uniform breaking point or fracture on the composite surface. The carbon fibers are held more rigidly in the matrix and does not fracture until it totally disengages from one another to the last fiber laminae. The carbon fiber laminae are seen in the figure to be edged out from the fracture point which tends to point that it takes more stress to cause damage to a composite specimen having a sequence where carbon fiber is placed on the top and bottom side of the composite thus more tensile strength.

4.2.2 Flexural Test Specimen

The flexural test was performed on all five specimens and an observation is performed on the post testing condition of each of the composites

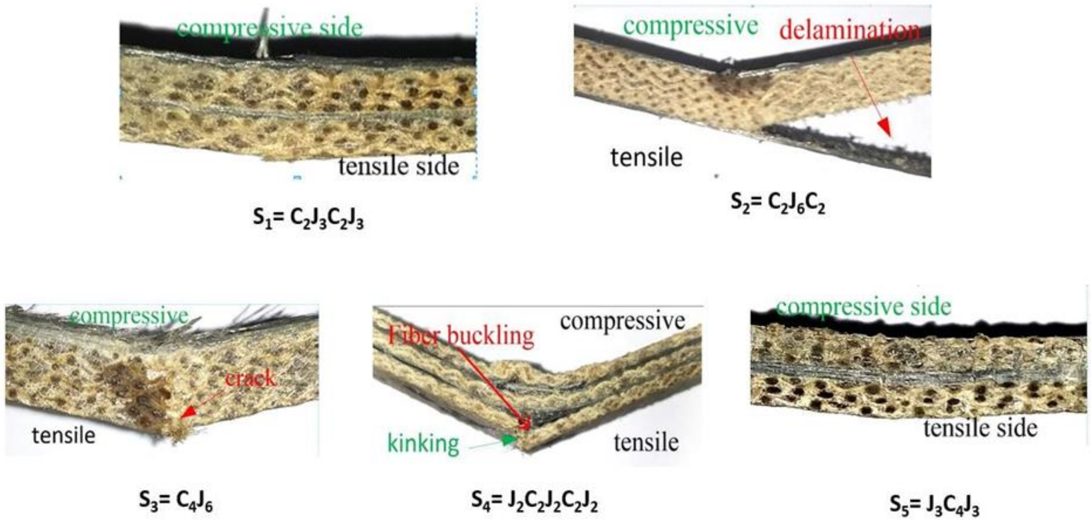

Figure 14: Fracture pattern of the specimen after the Flexural test

It can be observed that there is fiber buckling, fracture and delamination on the specimens after the three-point bending test. Due to bending we can see that there is compressive force developed on the top layer and tensile force is created at the bottom of the sample. If the jute layer is placed on the top or bottom side of the composite specimen the fracture occurs quickly due to the load being applied on the tensile and compressive sides which quickly initiates the cracking and buckling on the jute fiber layers and there. The de-laminations are a major phenomenon in the flexural test as the strength of the matrix is lower in the junction of the jute and carbon composite. The jute fibers or the carbon fibers that are infused together after one another in a sequence are generally not delaminated. In case of the carbon fibers being placed on the tensile and compressive side of the composite specimen the matrix strength is more than that of the jute fiber and the fracture is not uniform rather laminates are detached from one another slowly which result in more flexural strength.

4.2.3 Impact Test Specimen

The impact test was performed on all five specimens and an observation is performed on the post testing condition of each of the composites.

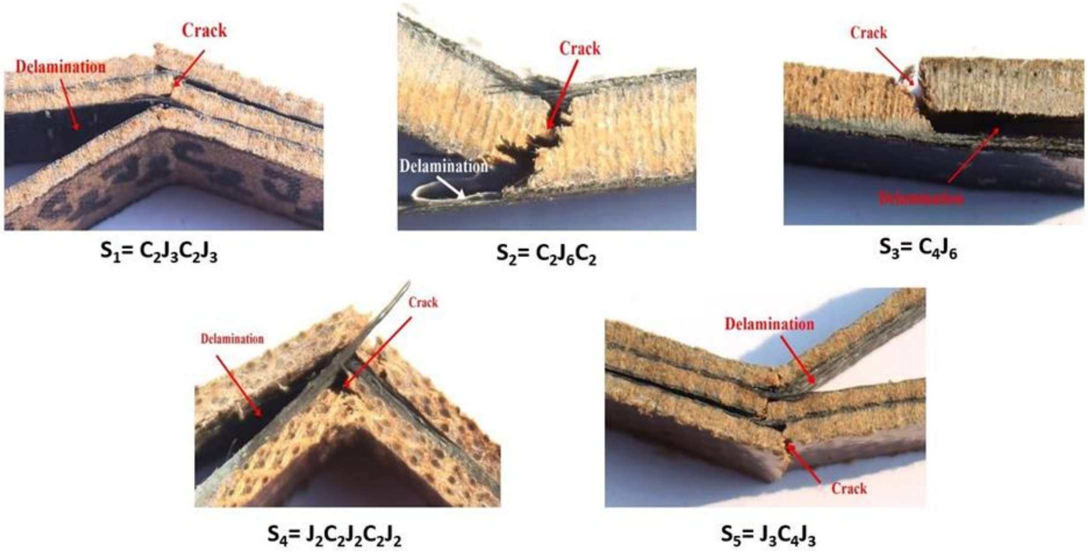

Figure 15: Fracture pattern of the specimen after the Impact test

In the post impact test specimen observation, it can be seen that the fracture occurs where the impact force is the highest that was applied. When the jute fibers were placed on the side of the impact the fracture occurs quickly and it is very much uniform. This is initiated by the same reason as previously mentioned in case of the tensile and flexural test specimen. If the carbon fibers are placed on the impact side the fracture is not as uniform as in the case of the jute fibers since the laminates are strongly held in the matrix by the epoxy-based resin. The laminates slowly detach from one another and final breakdown occurs when the last laminate loses contact. Thus, providing more impact strength than in case of the jute fibers being placed on the impact side. The delamination also occurs in couple of specimens. The delamination occurs at the carbon and jute fiber junction rather than between two jute layers or carbon layers. Since the strength of the matrix is stronger between two layers of the same fiber rather than two different fibers.

4.3 Result Analysis

4.3.1 Tensile Test

The tensile strain vs stress curve is generated by obtaining the stress and strain value from the applied force and displacement that occurs due to this with respect to time that is given as output by the UTM. The five specimens are discussed in detail in this section with reasoning behind the curve behaviour in each of the stacking sequence based composite.

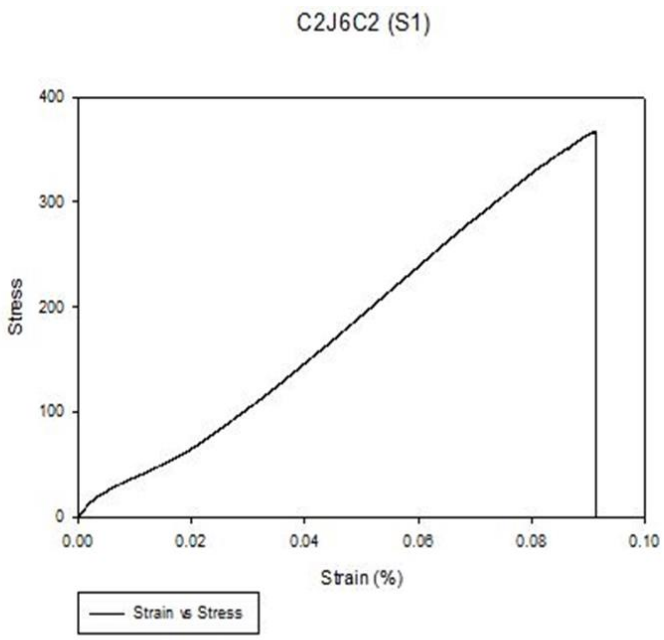

Figure 16: Tensile Strain Vs Stresss Curve for $C_2J_6C_2$

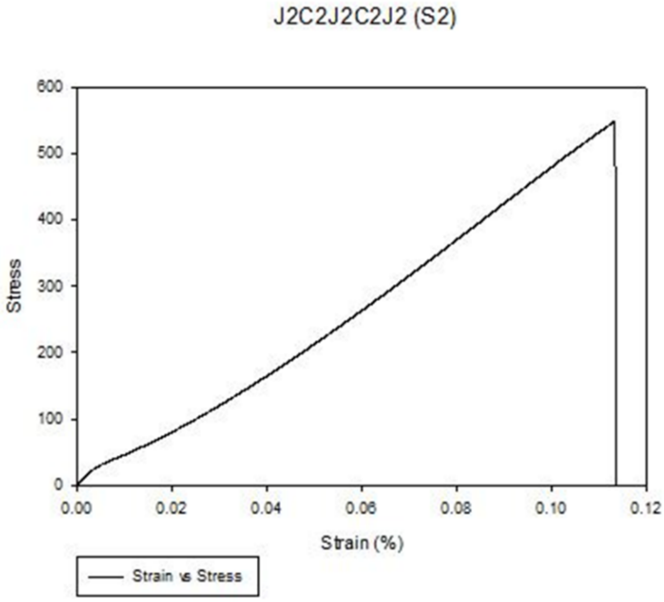

Figure 17: Tensile Strain Vs Stresss Curve for $J_2C_2J_2C_2J$

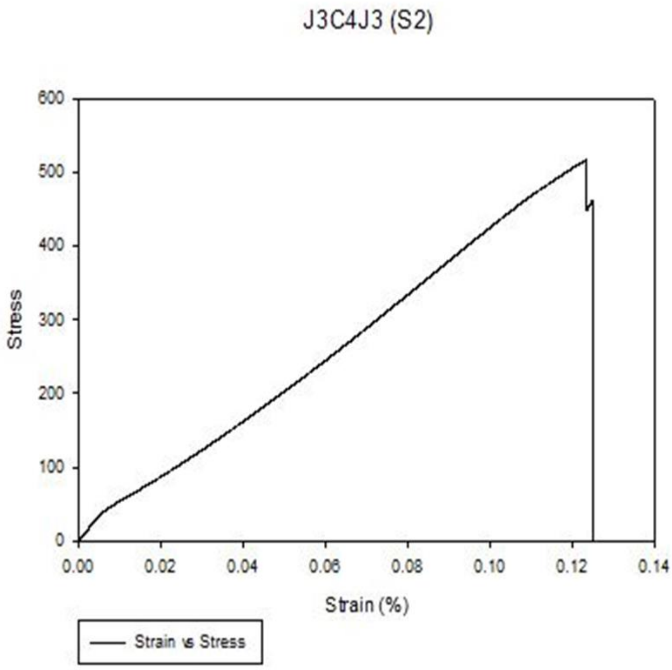

Figure 18: Tensile Strain Vs Stresss Curve for $J_3C_4J_3$

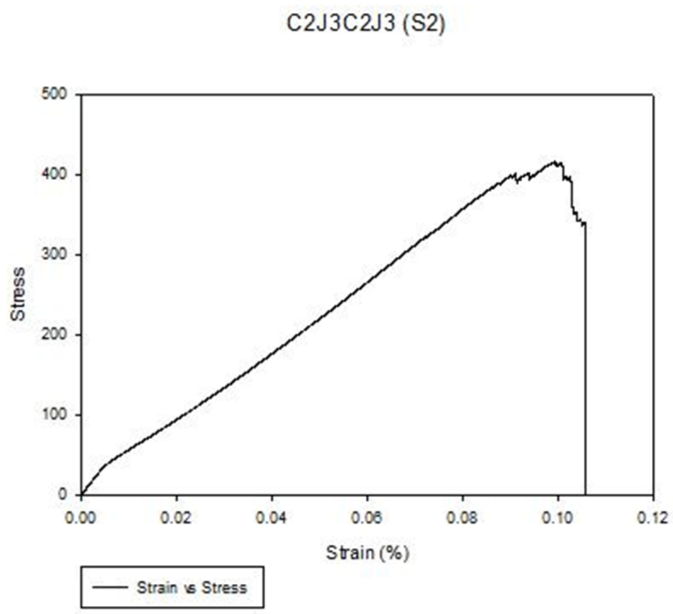

Figure 19: Tensile Strain Vs Stresss Curve for $C_2J_3C_2J_3$

Figure 17, 18, 19 reflects a failure process involving crack initiation, growth in resin matrix, delamination and final catastrophical breakdown.It can be analysed that with increasing stress by the load being applied the tensile stress also increases almost linearly. At one point the tensile stress reaches maximum and the breakdown of the composite occurs which triggers a sudden load down which causes the tensile stress to decrease back to zero. In this composite the cracking does not initiate nor slowly grows rather it suddenly cracks and quickly breaks down. This kind of characteristics of the curve suggests the availability of maximum tensile strength from the hybrid composite specimens.

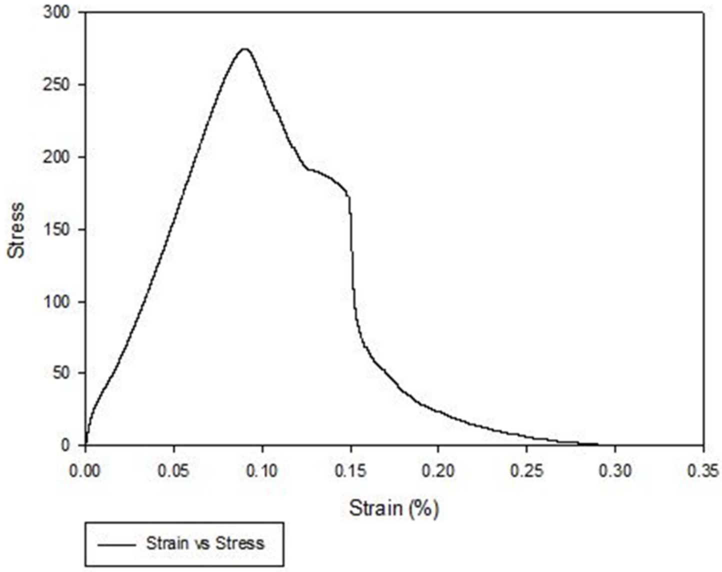

Figure 20: Tensile Strain Vs Stresss Curve for C_4J_6

From **Figure 20** it is observed that all the jute and carbon fibers are stacked together in one layer after the other. When tensile strength is being applied the jute fibers break easily by initiating a sudden load but since four carbon fibers provide more rigidity is the matrix the process first initiates a crack formation which later grows and causes delamination and final catastrophe. Since a crack is initiated in place of a sudden load down due to breakage the tensile strength is significantly lower for this composite compared to the other composites.

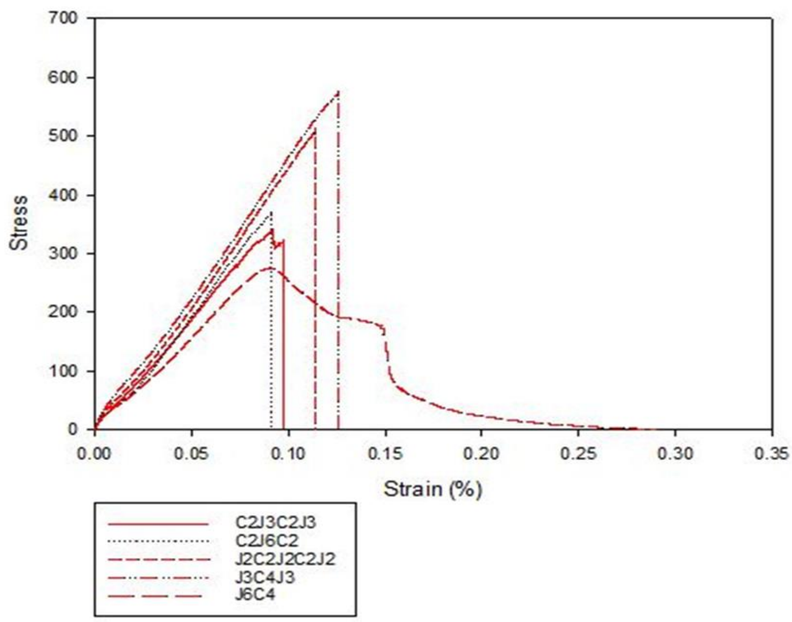

Figure 21: Tensile graph based on stacking sequences

Figure 21 expresses the tensile strain vs stress curves based on the stacking sequences. Analyzing this graph the tensile strength for composites based on different stacking sequences can be found out and compared to each other to recommend the composit with best tensile strength. This can be further illustrated in a bar chart that shoews the tenile strength with respect to stacking sequences.

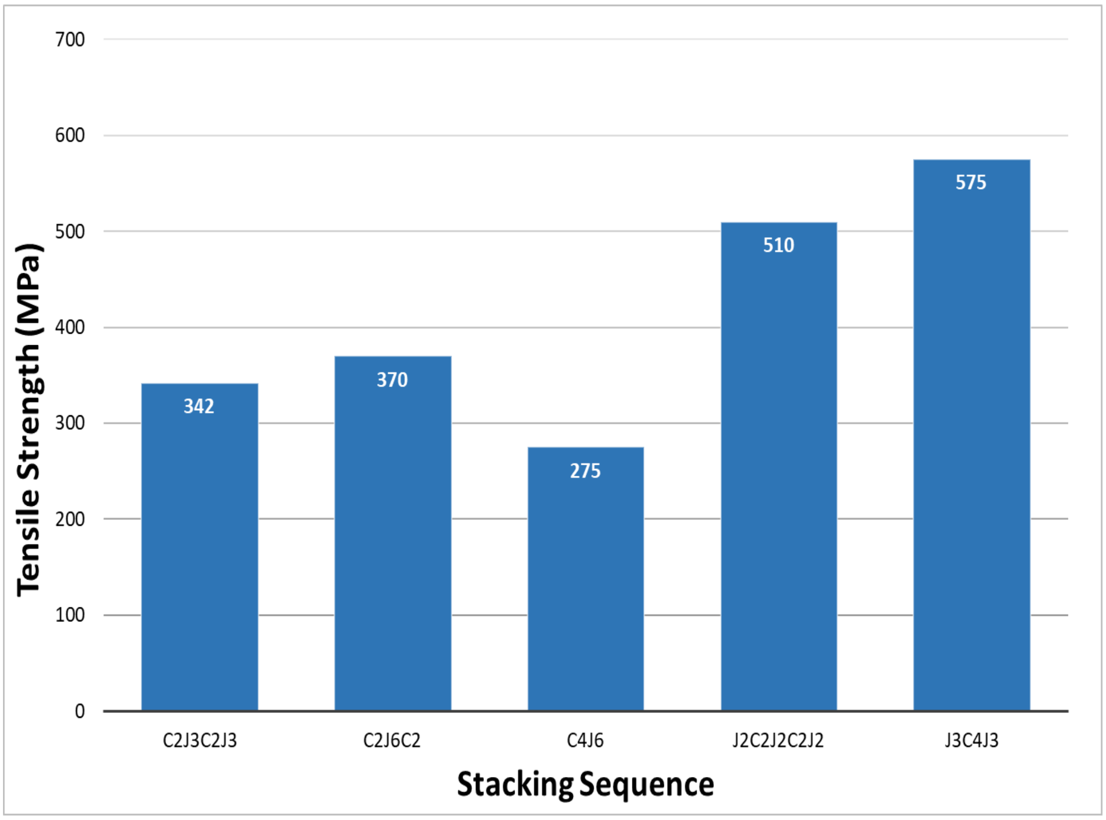

Figure 22: Tensile strength with different stacking sequences

The analysis of the **Figure 22** shows that the highest tensile strength is acquired for the composite **$J_3C_4J_3$** which is **575 MPa**. The tensile strength than decreases by **12.75%** to **510 MPa** for composite **$J_2C_2J_2C_2J_2$**. It further decreases by **37.8%** to **370 MPa** for **$C_2J_6C_2$** composite. The next composite has a tensile strength of **342 MPa** which is **40.52%** less than the highest tensile strength. The lowest tensile strength is achieved for the composite **C_4J_6** which decreases a significant **52.2%** to a tensile strength of **275 MPa**. So we can see the highest tensile strength is found for one of the composite sequence and others are significantly lower in order compared to this composite.

4.3.2 Flexural Test

The flexural strain vs stress curve is generated by obtaining the stress and strain value from the applied force and displacement that occurs due to the force with respect to time that is given as output by the UTM. The following formula was used to determine the flexural strength from the output given by UTM machine:

$$\sigma_f = \frac{3PL}{2bd^2}$$

Here,

P= Applied Pressure

L= Length of the specimen

b= Width of the specimen

d= Depth of the specimen

σ_f= Flexural strength of the specimen

The five specimens are discussed in detail in this section with reasoning behind the curve behaviour in each of the stacking sequence based composite.

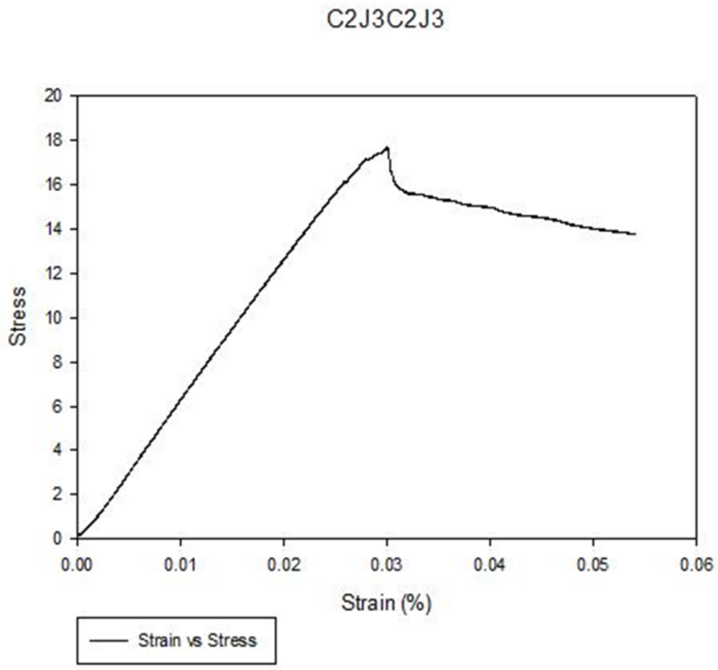

Figure 23: Flexural Strain Vs Stresss Curve for $C_2J_3C_2J_3$

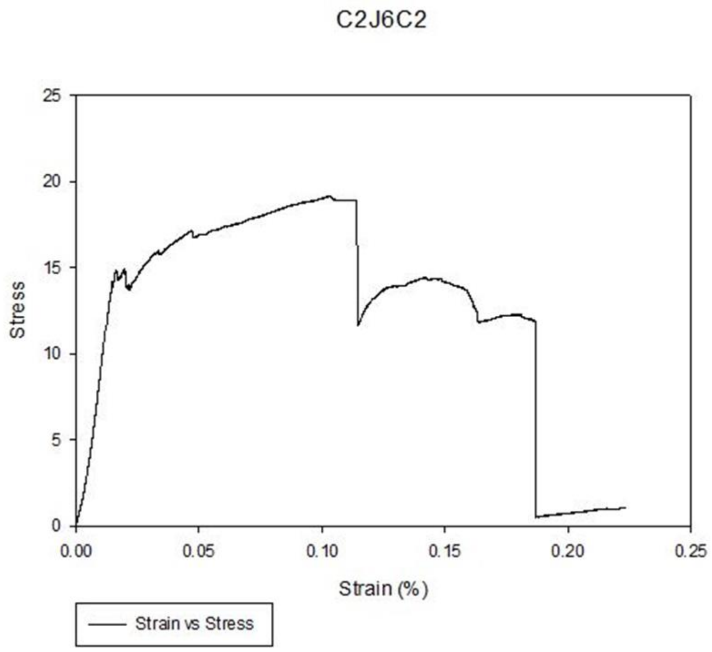

Figure 24: Flexural Strain Vs Stresss Curve for $C_2J_6C_2$

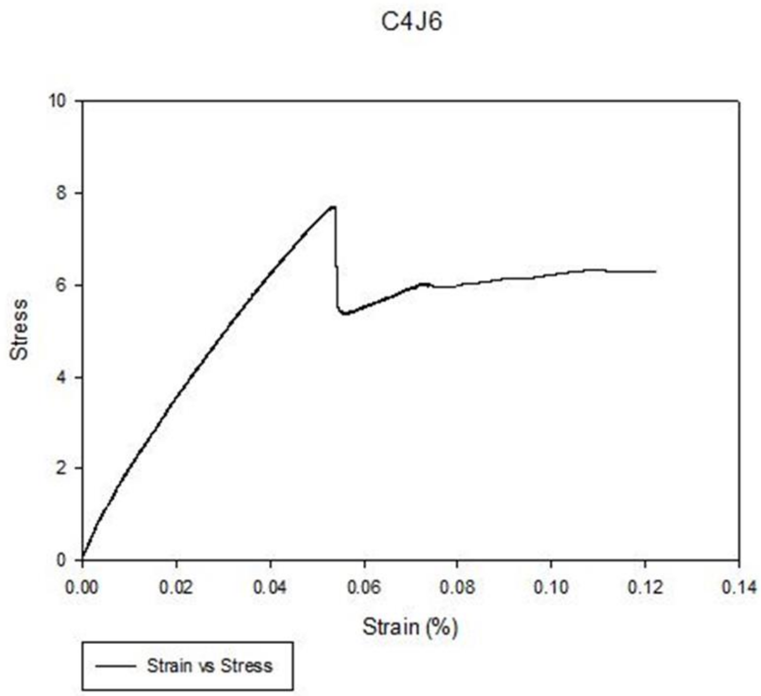

Figure 25: Flexural Strain Vs Stresss Curve for C_4J_6

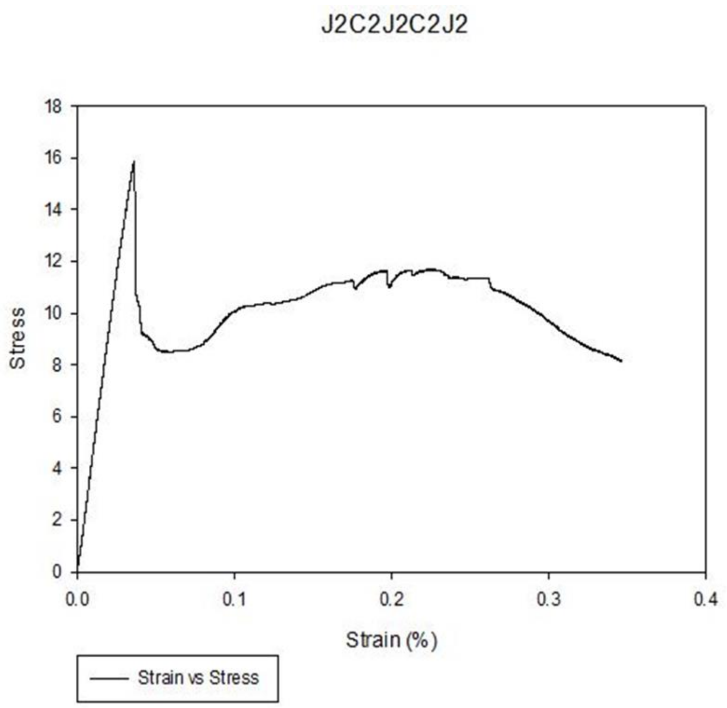

Figure 26: Flexural Strain Vs Stresss Curve for $J_2C_2J_2C_2J_2$

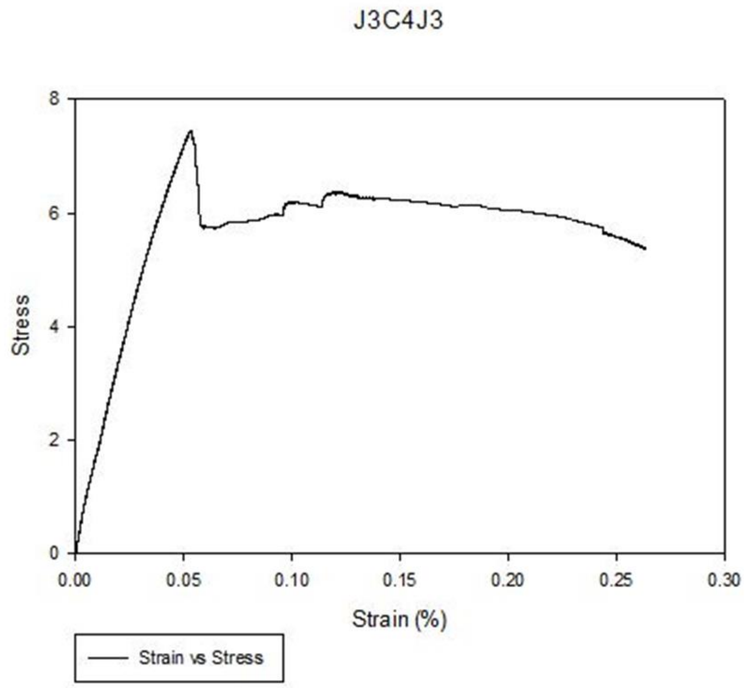

Figure 27: Flexural Strain Vs Stresss Curve for $J_3C_4J_3$

From **Figure 23,24,25,26 and 27** it is observed that in the three-point bending test the composite is applied load with one side being the tensile side and the other being compressive side. As load is applied the strain increases and at a certain load if the fiber on the compressive side of it is jute initiates crack which grows and at a time causes delamination, detachment and final catastrophe. Since cracking starts at a lower load the flexural strength is low for the composites compared to the tensile strength shown in the previous section. If carbon is placed on the compressive side, the crack is resisted by the resin infused carbon fiber matrix to a certain stress before the sudden load down occurs. This provides better flexural strength than placing jute on the compressive side of the composite while testing.

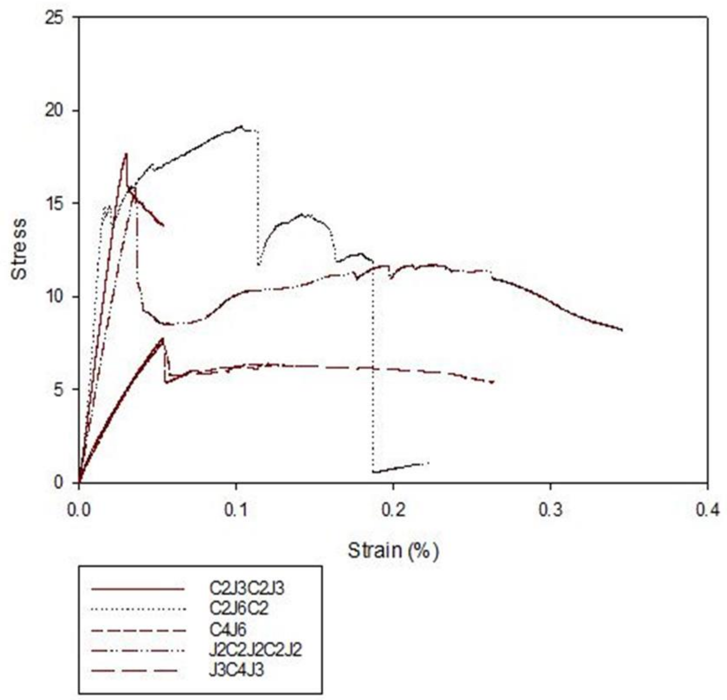

Figure 28: : Flexural graph based on stacking sequences

Figure 28 expresses the flexural strain vs stress curves based on the stacking sequences. Analyzing this graph the flexural strength for composites based on different stacking sequences can be found out and compared to each other to recommend the composit with best flexural strength. This can be further illustrated in a bar chart that shows the flexural strength with respect to stacking sequences. Using this the determination of which composite has the higest flexural strength is easier to comprehend.

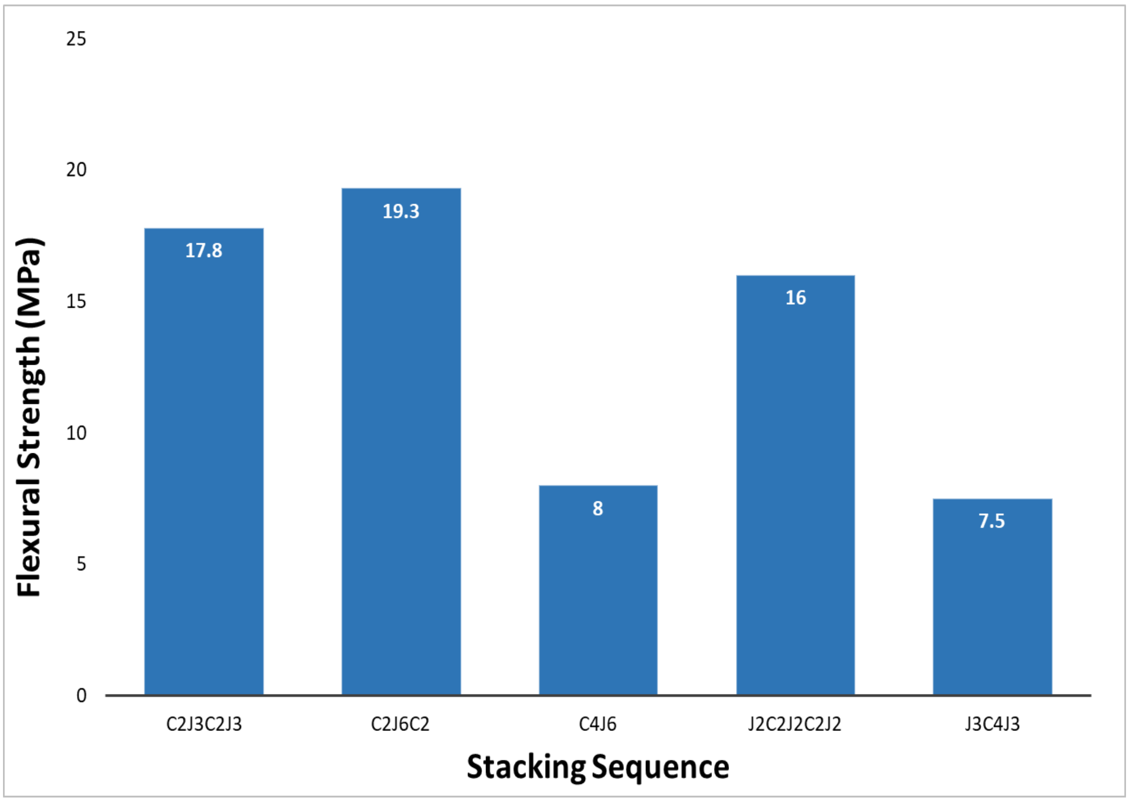

Figure 29: Flexural strength with different stacking sequences

From the **Figure 29** it is analysed that **$C_2J_6C_2$** has the highest flexural strength of **19.3 MPa**. This decreases by **8.4%** to reach a flexural strength of **17.3 MPa** for **$C_2J_3C_2J_3$** composite. The flexural strength further decreases by **11.3%** to **16 MPa** for **$J_2C_2J_2C_2J_2$**. There is a drastic drop of **50%** flexural strength in case of **C_4J_6** to **8 MPa** which has the second lowest flexural strength. Lastly strength reduces by **6.7%** to reach the lowest flexural strength that is available for composite **$J_3C_4J_3$**.

4.3.3 Impact Test

The Charpy Impact Machine calculates the impact energy required to cause catastrophic damage to the composite. The more the compact energy the more the rigid structure. The impact energy for the five specimens are given in the following table

Table 3: Impact energy for composites with different stacking sequences

Stacking Sequence	Impact Energy (Joule)
$C_2J_6C_2$	30
C_4J_6	12
$J_3C_4J_3$	19
$J_2C_2J_2C_2J_2$	22
$C_2J_3C_2J_3$	25

If the carbon fibers are placed on the impact side of the composite, since carbon fibers infused has more rigidity in their matrix which results in higher impact energy required to cause catastrophic damage or breakage in the composite. If the jute fiber is placed on the impact side of the composite it cracks at a lower impact energy since the jute fibers are not as structurally rigid as carbon fibers in a matrix. So, the jute fiber will be damaged more rapidly and catastrophically. If carbon fiber layer is added on both sides of the composite with jute in the middle layers most of the impact energy will be initially absorbed by the carbon fibers which will allow the jute fibers to provide more impact resistance thus increasing the impact energy required to cause breakage or delamination to the composite. In case of jute fiber on both side and since it is prone to breakage at lower impact force will cause more damage quickly to the carbon fiber thus reducing the amount of impact energy required to cause catastrophic damage. The required impact energy can be showed in a bar chart to better understand the comparative change in composites based on their stacking sequences.

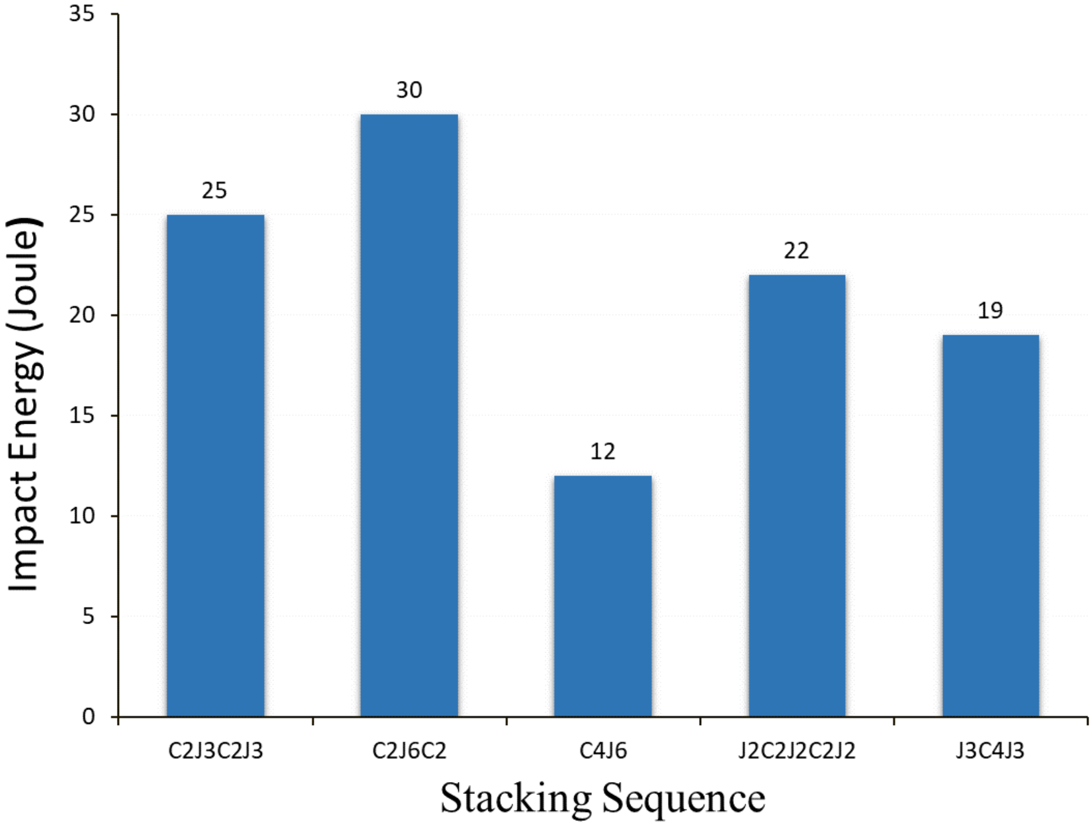

Figure 30: Impact strength with different stacking sequences

From **Figure 30** it is observed that the impact energy required is highest for the composite **$C_2J_6C_2$** and it is **30 Joule**. This decreases by **20%** to reach **25 Joule** in case of the composite **$C_2J_3C_2J_3$**. The impact energy required further decreases by **13.6%** to reach **22 Joule** for **$J_2C_2J_2C_2J_2$**. It again reduces by **15.8%** to **19 Joule** for **$J_3C_4J_3$** composite. Energy required drastically reduces by **58.3%** to **12 Joule** for **C_4J_6** which is the lowest among all the composite specimens.

Chapter 5: Conclusion

5.1 Introduction

In our study of finding out the mechanical properties of carbon jute fiber hybrid epoxy based reinforced composite we have used 5 different staking sequences and compared their mechanical properties with each other in order to find out the maximum mechanical properties among the stacking sequences. The five stacking sequences are $\mathbf{J_3C_4J_3}$, $\mathbf{J_2C_2J_2C_2J_2}$, $\mathbf{C_2J_3C_2J_2}$, $\mathbf{C_2J_6C_2}$ and $\mathbf{C_4J_6}$ respectively and the mechanical properties that are tested on them are tensile test, flexural test and impact test. Each of the tests was carried out in the Universal Testing Machine as per the **ASTM** standards. The obtained results and graphs have been analysed in the result analysis section to determine which has the maximum value in case of each mechanical property and also overall in all of them combined. There have been complications while producing the composites such as the hardening of resin, vacuum leak in the vacuum infusion process, the infusion process remaining unfinished in the parts of composite material area, the measurement error while cutting the specimen according to the standard size for the tests. As a result more lots composite were produced than it was required, to seek out the best specimen that was available for the accurate values during the tests and compare them with each other to select the best sequence.

5.2 Corollaries

From the study we can reach a number of corollaries by analysing the results we have obtained from the tests on the **UTM** machine. They are discussed below:

- The tensile strength is influenced significantly by the change in the sequence of layers of the carbon and jute fibers in the composite. When load is applied to the composite specimen the tensile strength continues to increase and at the maximum tensile stress it suddenly breaks down and values slowly decreases back to zero. If all the layers of carbon or jute fibers are placed together one after another then the sudden load down doesn't occur instead it initiates a crack and it grows to cause delamination and detachment before the final catastrophe occurs. As the crack is initiated first the stress does not get as high as in case of the sudden load breakdown. Thus, this results in lower tensile strength for the composite. So, placing the carbon fibers in the middle of the structure will reduce the crack initiation and increase the chance of sudden load down thus increasing the tensile strength. **$J_3C_4J_3$** composite provides the maximum tensile strength as it follows the case described above. For real life application this is the best recommended option if the primary requirement is maximum tensile strength.

- In case of the flexural strength load is applied from both sides with one being the tensile side and the other compressive side. The flexural values are a bit different than the tensile ones. In this case there is no sudden breakdown as the load is slowly provided from both the tensile and compressive side. As a result a crack is initiated first which later grows to cause delamination and detachment of fiber layers from one another until final breakdown of the composite occurs. So the flexural strengths are not as high as the tensile strength. If the carbon fibers are stacked together in layers than they provide more strength than jute fibers because of their compactness, fiber structure. So when they are placed at the tensile and compressive side and load is applied it takes more flexural stress than in the case of the jute fibers to initiate a crack as the fibers are strongly held in the matrix by the resin. So the flexural strength is more than what it would be if carbon fibers are placed on the compressive side. The flexural strength is maximum for **$C_2J_6C_2$** as the carbon fiber is placed on both the tensile and compressive side of the composite. For real life application if flexural strength is the highest priority than this composite is recommended.

- For the impact strength as it is determined by how much impact force the composite can withstand also depends significantly on the change of fiber layers in the sequence. If carbon fiber layers are placed on the front and back side of the composite and jute fibers are all stacked in the middle the force of impact is higher as it provides a large amount of resistance before breaking down. As the carbon fiber layers are more compactly held in the matrix they provide the first line of defence. The jute layers when stacked together which creates a strong structured layer that is difficult to break through than each on individually. Then again, the carbon fiber layers provide the last line of defence. That is why a large amount of impact energy is generated as the impact force works its way through the carbon and jute fiber layers. The maximum impact energy is achieved in the $\mathbf{C_2J_6C_2}$ composite. So, for real life application when the impact strength is the highest priority than this composite sequence is recommended.

- In case none of the aforementioned mechanical properties are a first priority we can recommend the composite with all the moderate properties. In our study we can see that $\mathbf{J_2C_2J_2C_2J_2}$ is only composite that has properties close to the maximum in case of each of tensile, flexural and impact properties. This also closely fits the requirements required for having the maximum strength in all three sectors. So in case of moderate mechanical properties this composite is the best viable option.

- The lowest strength in case of tensile and flexural is obtained for the composite $\mathbf{C_4J_6}$. As all the jute fibers are stacked together and same in the case of the carbon fiber the sudden breakdown doesn't occur instead it initiates a crack faster than any other composite in this study. As a result, this has the lowest tensile strength. In case of flexural strength though either the tensile or compressive side has the carbon fibers but the other side having jute fibers quickly cracks causing the flexural stress to be very small thus providing the lowest flexural strength.

So of the five stacking sequences for the composites 3 of them has maximum values of tensile, flexural and impact strength and one is used in case of moderate mechanical properties.

5.3 Future Scopes

We have done our study based on carbon and jute fiber hybrid composite. If we expand the criteria of natural fibers we can hope to see a significant change in the mechanical properties based on the new natural fiber that will be used to produce the composite with synthetic fiber carbon. The five stacking sequences of composite were based on the **0º** or unidirectional orientation of the carbon and jute fibers. In future we are planning to implement the **90º** and **45º** orientations of the fibers to produce composites in the same procedure and test the mechanical properties to compare between the three orientations to determine which has the best tensile, flexural or impact strength. The **90º** orientation can be obtained by placing the carbon and jute fibers in perpendicular direction to each other. In case of **45º** orientation the fibers are placed at 45º to each other. Our current study suggests that with unidirectional fibers there has been a significant change in the mechanical properties of the composites. So we hope to open new scopes by changing the orientation of the fibers. We also would like to implement the SEM (Scanning Electrical Microscope) technology on the tested composites to analyse the damaged areas by producing images of the sample by scanning it with a focused beam of electron. This will further help us to analyse the breaking points and the reason behind the occurrences of simultaneous breaking in a composite material. We are also planning to observe the applications based on infrastructure, automobiles or industry to find scopes for introducing more variety of stacking sequences and increase the number of layers to provide better applicability with higher strengths.

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