Development and Characterization of Multiple Resin Based Hybrid Composite Material Reinforced With Natural Fiber

AUTHOR

M. Fahad Shahid

Registration Number

277865

PROJECT SUPERVISOR

Dr Aamir Mubashir

PROJECT CO-SUPERVISOR

Dr Atta Ur Rehman

DEPARTMENT OF MECHANICAL ENGINEERING SMME

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING
NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY
ISLAMABAD

MAY, 2021

Development & Characterization of Multiple Resin Based Hybrid Composite Material Reinforced With Natural Fiber

MS Thesis (2021)

Author

M. Fahad Shahid

Registration Number

277865

A thesis submitted in partial fulfillment of the requirements for the degree of

MS Mechanical Engineering

Thesis Supervisor:

Dr Aamir Mubashir

Thesis Supervisor's Signature: ____

DEPARTMENT SMME

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY,

ISLAMABAD

MAY, 2021

Declaration

I certify that this research work titled "*development & characterization of multiple resin based hybrid composite material reinforced with natural fiber"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Signature of Student

M. FAHAD SHAHID

2018-NUST-MS-Mech-00000277865

Plagiarism Certificate (Turnitin Report)

This thesis has been checked for Plagiarism. Turnitin report endorsed by Supervisor is attached.

Signature of Student

M. FAHAD SHAHID

Registration Number

277865

Signature of Supervisor

Copyright Statement

Acknowledgements

First of all, I would like to thank ALMIGHTY ALLAH, whose kindness rendered me to accomplish the lofty objectives of the examination. I am extremely appreciative to my instructors whose adoration, inspiration, supplications and direction have influenced me to achieve the consummation of this task.

I am copiously thankful to my parents who raised and continued to support me in every walk of life especially my father M. Shahid Anwar who helped me with the experimentation phase of the project.

I am also extremely appreciative to my supervisor and co-supervisor Dr Aamir Mubashir and Dr Atta Ur Rehman for the direction to deal with this undertaking in a consecutive way and helping me at whatever point his need was required. They were accessible whenever regardless of their bustling timetable.

I would also like to thank GEC members and express my special thanks to Mohsin Ejaz for his help.

“Dedicated to my exceptional parents and adored siblings whose tremendous support and cooperation led me to this wonderful accomplishment.”

Abstract

The main idea of the project is to create multiple resin-based hybrid composite material using two polymer resins i.e. polyester and vinyl ester reinforced with jute fiber. Jute possess some properties which are superior to those of synthetic fiber such as being ecofriendly, light weight, biodegradable and cheap. The hybrid composites were prepared using VARTM (Vacuum Assisted Resin Transfer Molding) method and the purpose was to enhance the tensile, impact and flexural properties of the material. These composites can be used to make sports goods, interior of vehicles, bumpers, side skirts etc. The hybrid composites were created by varying the composition both resins and then the concentration of fiber. After developing the composites, their tensile, impact and flexural strengths were measured and compared with both resins.

Nomenclature

PV-50-50	Polyester 50% Vinyl ester 50%
PV-70-30	Polyester 70% Vinyl ester 30%
PV-30-70	Polyester 30% Vinyl ester 70%
HF-22.8	Hybrid Composite reinforced with 22.8% Jute
HF-24.25	Hybrid Composite reinforced with 24.25% Jute
HF-27.75	Hybrid Composite reinforced with 27.75% Jute
HF 32.5	Hybrid Composite reinforced with 32.5% Jute
PVIPN	Polyester Vinyl ester Interpenetrating Polymer Network

Contents

Declaration......iii

Plagiarism Certificate (Turnitin Report)......iv

Copyright Statement v

Acknowledgements vi

CHAPTER 1: INTRODUCTION......14

1.1 BACKGROUND 14

1.2 OVERVIEW......14

Chapter 2: Literature Review......18

2.1 Executive Summary......18

2.2 INTRODUCTION TO COMPOSITE PROCESSING......18

2.3 Natural Fiber......21

2.4 Disadvantages......21

2.5 Mechanical properties of NFPC 22

2.6 Chemical Composition of Natural Fiber......22

2.7 Treatment of Natural Fiber 23

2.8 Flame Retardant Properties......24

2.9 Biodegradability......24

2.10 Behavior of Natural Fiber (Jute) with Resins: 25

2.11 Fiber Orientation 26

2.12 Treated and Untreated Fiber......26

2.13 Manufacturing......26

2.14 Applications of Bio-Composite 27

2.15 Conclusion 28

CHAPTER 3: MATERIALS AND PROCESS 30

3.1 Materials:......30

3.1.1 Polyester......30

3.1.1.1 Saturated Polyesters......30

3.1.1.2 Unsaturated Polyesters 30

3.1.2 Vinyl ester:......31

3.2 Process: 33

3.2.1 Components of VARTM: 33

3.2.1.1 Flat Surface: 33

3.2.1.2 Vacuum Bag:......33

3.2.1.3 Peel ply: 33

3.2.1.4 Flow Net: 34
3.2.1.5 Pipes: 34
3.2.1.6 Releasing Agent: 34
3.2.1.7 Vacuum Pump: 34
3.2.1.8 Sealant tape: 34
3.2.1.9 Breathing Cloth: 34
3.2.2 Procedure: 34
3.3 Composites: 37
3.3.1 Hybrid Matrix: 37
3.3.2 Hybrid Composite: 38
3.4 Testing Methods: 38
3.4.1 Tensile Test: 38
3.4.2 Impact Test: 40
3.4.3 Flexural Test: 41
Chapter 4: Results and Discussion 43
4.1 Fiber Results 43
4.2 Hybrid Matrix Results 44
4.3 Hybrid Composite Results: 49
4.3.1 Tensile test result of Hybrid Composite: 50
4.3.1.1 Stress Strain Curve of Hybrid Composite: 51
4.3.2 Bending Test Results of Hybrid Composites: 56
4.3.3 Impact Test Results of Hybrid Composites: 58
Applications 60
Chapter 5: Conclusion 61
References 63

List of Figures

Figure 1.1 Types of fiber reinforcements..........15
Figure 1.2 Fiber orientation in Fiber reinforced composites...........15
Figure 1.3 (a) Untwisted and (b) twisted fiber bundle..........16
Figure 1.4 Common weave patterns (a) plain weave, (b) basket or twill weave, (c) crowfoot or five-harness satin weave, (d) long-shaft (satin) or eight-harness satin weave, (e) leno weave..........16
Figure 1.5 Fiber Composite Matrix..........17
Figure 2.1 Classification of composite processing techniques...........18
Figure 2.2 Types of Composites..........19
Figure 3.1 Cellulosic fiber Classification..........32
Figure 3.2 Placed peel ply on plank after applying Releasing agent...........36
Figure 3.3 Spreading of Flow net..........36
Figure 3.4 Placing breathing cloth under Flow net..........36
Figure 3.5 Pipe from Vacuum Pump..........36
Figure 3.6 Resin inlet Pipe..........37
Figure 3.7 Applying of Vacuum Bag..........37
Figure 4.1 Stress vs. Strain curve for untreated fiber..........43
Figure 4.2 Stress vs. Strain curve for treated fiber..........44
Figure 4.3 Tensile properties of Matrix..........45
Figure 4.4 Tensile properties of matrix detailed..........46
Figure 4.5 IPN behavior for two different resins..........47
Figure 4.6 Tensile Strength comparison of Hybrid Composites..........50
Figure 4.7 Tensile Strength comparison of Hybrid Composites detailed..........51
Figure 4.8 Stress vs Strain Curve of HF-22.8..........52
Figure 4.9 Stress vs Strain Curve of HF-24.25..........52
Figure 4.10 Stress vs Strain Curve of HF-27.75..........53
Figure 4.11 Stress vs Strain Curve of HF-32.5..........54
Figure 4.12 Tensile Strength comparison of Hybrid Composites corrected..........55
Figure 4.13 Tensile Strength comparison of Hybrid Composites detailed corrected..........55
Figure 4.14 Bending Strengths Comparison for Hybrid..........56
Figure 4.15 Bending Strengths Comparison for Hybrid detailed..........57
Figure 4.16 Impact Energy absorbed..........58
Figure 4.17 Impact Strengths Comparison of Hybrid..........59
Figure 4.18 Impact Strengths Comparison of Hybrid detailed..........59

List of Tables

Table 2.1 The moisture content of different natural fiber at 21ºC and 65% humidity..*23*
Table 2.2 Impact strength of different specimen..*25*
Table 3.1 Unsaturated polyester properties *31*
Table 3.2 Properties of Vinyl Ester *32*
Table 4.1 Composition of Resins *45*
Table 4.2 Compositions for Hybrid Composite *49*

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Composite materials are now being used in the most demanding applications like satellites, aircrafts' structure and wind turbines. One of the challenges faced in this field is the technique to manufacture composite parts. A number of techniques are available and are selected according to the available resources. Generally, composites manufacturing has low tooling cost as compared to steel. But this could go up for the fabrication of advanced composites which requires auto clave. A number of techniques like VARTM is used in the place of autoclave molding and can deliver auto clave quality parts at a considerably lower cost. This research is focused on the fabrication of hybrid composite based on multiple resins such as polyester and vinyl ester reinforced with natural fiber jute.

1.2 OVERVIEW

Due to exceptional mechanical properties and ease of processing, advanced composite materials are now being sought for high performance applications. Generally speaking, composite materials are multiphase. This is a broader term and all naturally occurring materials falls into this category. Like steel is composed of two or more different phases. Composite materials can be defined as combination of two or more macroscopically distinct materials bonded together. The individual physical and chemical properties of the phases are preserved. The fibers are held by a matrix which transfers load to the fibers (reinforcement phase), protect them from atmosphere and retain the orientation. The reinforcement is the load bearing phase.

The reinforcing phase in polymer matrix composite can be in a number of different forms, they can be either discontinuous i.e. in the form of whiskers, particulates, flakes, short fibers or in the form of continuous long fibers, woven fabric and sheets. [1] The reinforcing phase can be classified as in the following Figures.

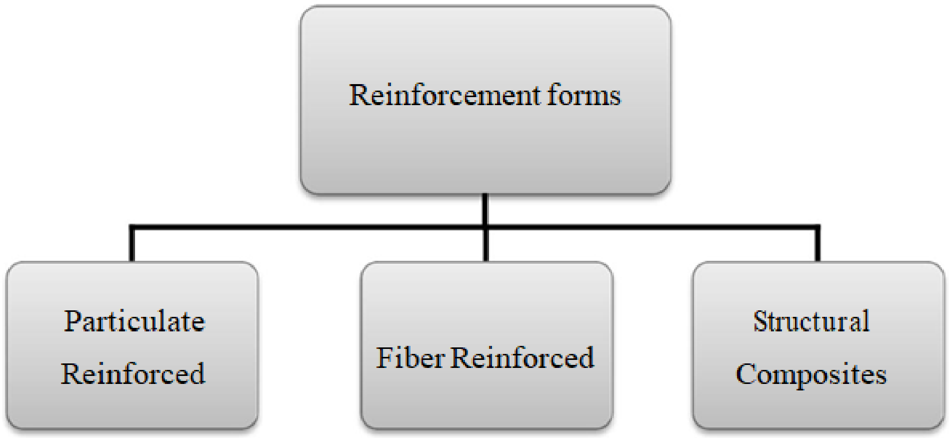


Figure 1.1 Types of fiber reinforcements

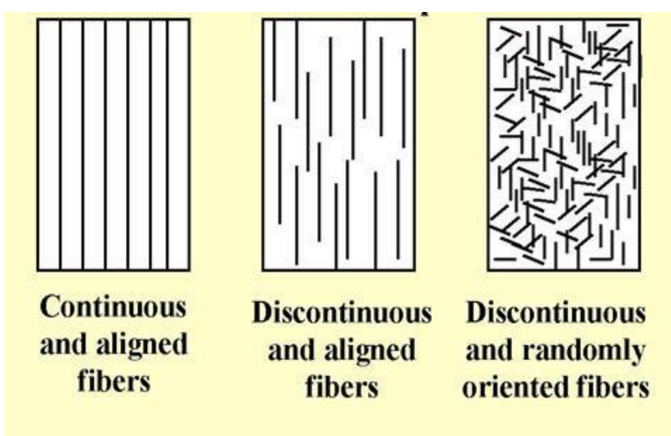


Figure 1.2 Fiber orientation in Fiber reinforced composites.

Fiber reinforcements are considered technologically important, the dispersed phase in this case is in the form of continuous fibers which could be randomly oriented chopped strand mat, woven, or in the form of yarn or roving. The difference between yarn and roving is that in the later one fiber are not twisted as in the case of yarn.

The fibers are generally made from carbon, boron or silica using different manufacturing approaches affecting the end properties desired. Hydrocarbons based on two fibers are also used some times. Textile technology is extensively used to get better special reinforcing fabrics. However natural fibers are extracted from plants and woven in the form of cloths and used as reinforcements. Fibers are available in the market in following forms.

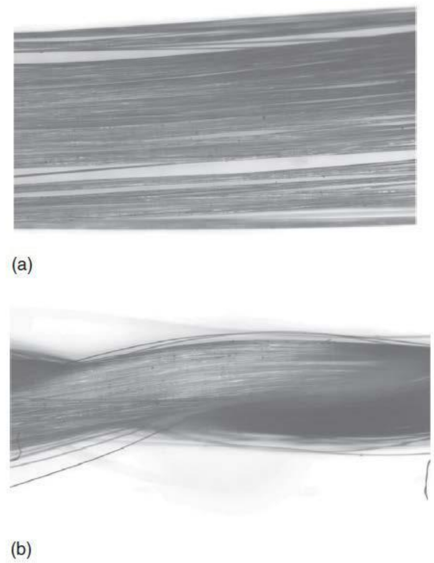


Figure 1.3 (a) Untwisted and (b) twisted fiber bundle

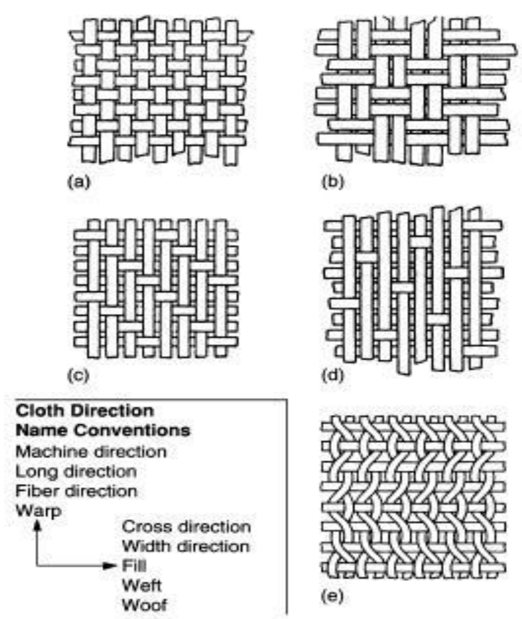


Figure 1.4 Common weave patterns (a) plain weave, (b) basket or twill weave, (c) crowfoot or five-harness satin weave, (d) long-shaft (satin) or eight-harness satin weave, (e) leno weave

FRP composites (fiber reinforced polymers), are made up of polymer matrix that is reinforced with natural or synthetic fiber (like glass, carbon, sisal, flax, jute). The matrix assists in protecting the fibers from external and environmental damage and transfers the load between the fibers. The fibers help in providing strength and rigidity to reinforce the matrix and helps it resist fracture and cracks.

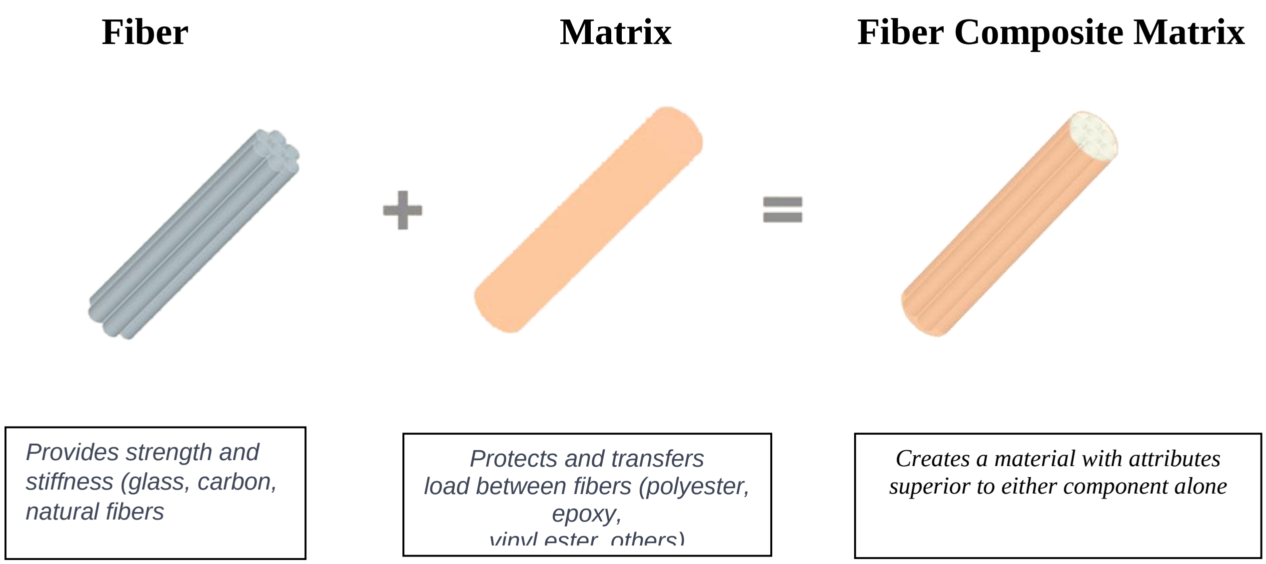


Figure 1.5 Fiber Composite Matrix

Fiber reinforced polymer composites may also contain additives, fillers, core materials which helps in improving the performance, appearance and manufacturing process of the final product.

Advantages of composite materials include:

1. Low costs compared to metals
2. Design flexibility
3. Resistance to a wide range of chemical agents
4. Low weight
5. Durability
6. Electric insulation
7. High Impact strength

Chapter 2: Literature Review

2.1 Executive Summary

The main idea of the project is to create resin-based hybrid composite material using two polymer resins i.e. polyester and vinyl ester reinforced with jute. The hybrid composites will be prepared using VARTM method and the purpose is to enhance the tensile, impact and flexural properties of the material. The hybrid composites will be created by varying the composition of both resins and then the concentration of fiber.

2.2 INTRODUCTION TO COMPOSITE PROCESSING

Composite parts can be fabricated by a number of different conventional and unconventional techniques. Selection of this technique is based upon the quality, quantity and design of the part itself. Generally composite manufacturing can be broadly classified into two types of techniques, Open mold and closed mold techniques.

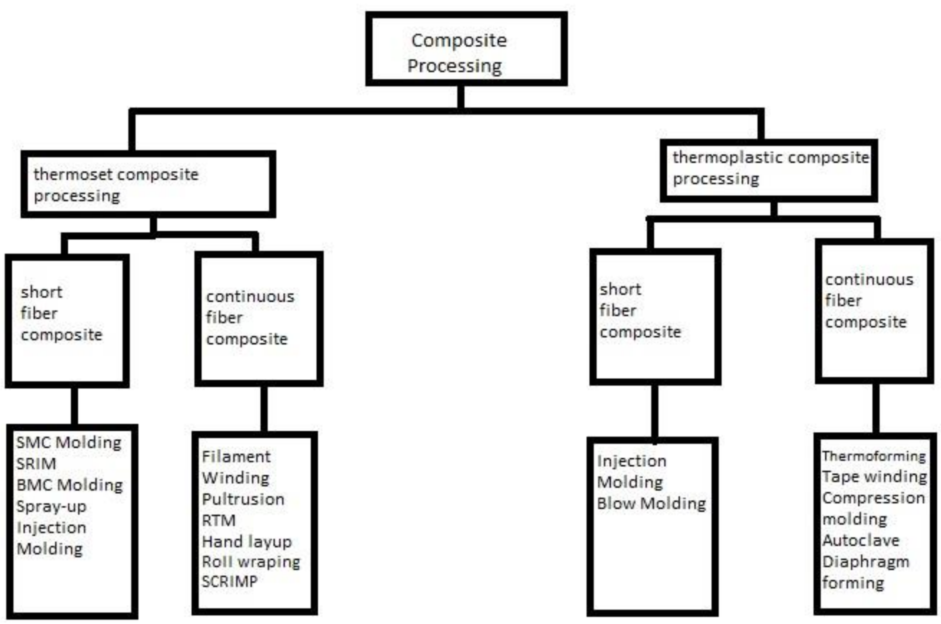


Figure 2.1 Classification of composite processing techniques.

Composite materials are now being used in the most demanding applications like satellites, aircrafts and wind turbines. One of the challenges faced in this field is the technique to manufacture composite parts. A number of techniques are available and are selected according to the available resources. Generally, composites manufacturing has low tooling cost as compared to steel. But this could go up for the fabrication of advanced composites which requires auto clave. A number of techniques like VARTM is used in the place of autoclave molding and can deliver auto clave quality parts at a considerably lower cost. Our research is focused on the fabrication of hybrid composite based on multiple resins such as polyester and vinyl ester reinforced with natural fiber jute.

Composite materials are categorized on basis of their content, i.e. filler and base material. The base material, which holds the filler material in structure form is also called matrix. The filler material is present in form of particles, fibers, fragments, sheets or whiskers of natural or synthetic material. As illustrated in the figure, there are three main categories of composites. [2]

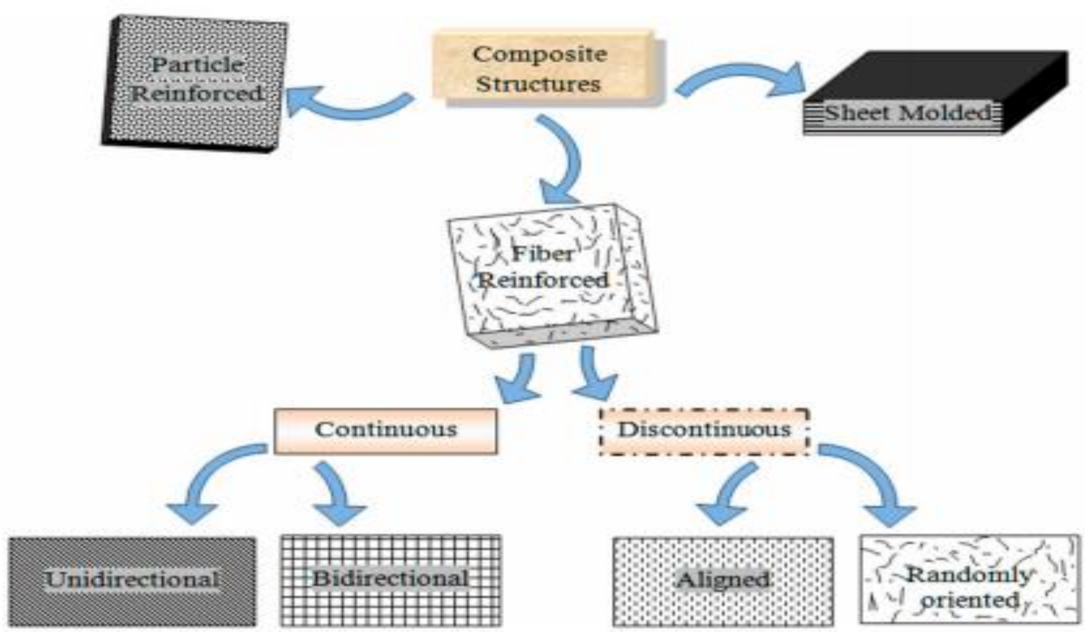


Figure 2.2 Types of Composites

There are two types of hybrid composites, one where multiple types of fibers are reinforced in a single matrix structure and the other one is where multiple resin are used to fabricate the matrix and then reinforced with a single type of fiber. [3]. In continuous fiber composites, fibers can be laid in unidirectional or bidirectional orientation in the matrix and the load is taken from the matrix to the fiber in a very efficient way. For particulate fibers, their length must be enough to transfer the load efficiently and restraining the growth of cracks to avoid failure of material in case of non-ductile matrices. The orientation and arrangement of fibers define the structural behavior and properties of the composite material [4] [5]. Chemical treatment of fibers can result in improvement in mechanical properties such as impact, tensile and fatigue strength.

Synthetic fibers, are produced by chemical synthesis and are categorized further as organic or inorganic on basis of their composition [6]. Fibers as compared to matrices, have higher strength and toughness which makes them a load-bearing element in the composite material [7] [8] [9] [10] [11]

Fiber Reinforcement	Matrix	Application	Manufacturing Technique	References
Carbon	PP, ceramics, , Polyether ether ketone (PEEK), epoxy resin, metals	Lightweight automotive products, fuel cells, satellite components, armor, sports	Injection molding, filament winding, resin transfer molding (RTM)	[12] [13]
Graphene	Polystyrene (PS), epoxy, Polyaniline (PANI)	Wind turbines, Gas tanks, aircraft/automotive parts.	hand/spray up ,CVD, pultrusion,	[14]
Sisal	PP, PS, Epoxy resin	Automobile body parts, roofing sheets	Hand lay-up, compression molding	[15]
Hemp	PE, PP, PU	Furniture, automotive	RTM, compression molding	[16]
Kenaf	PLA, PP, epoxy resin	Tooling, bearings, automotive parts.	Compression molding, pultrusion	[17]
Flax	PP, polyester, epoxy	Structural, textile.	RTM, spray/hand lay-up, vacuum infusion	[18] [19]

Ramie	PP, Polyolefin, PLA	Bulletproof vests, socket prosthesis, civil.	Extrusion with injection molding	[20] [21]
Rice Husk	PU, PE	Window/door frames, automotive structure	Compression/injection molding	[22]
Jute	Polyester, PP,	Ropes, roofing, door panels	Hand lay-up, compression/ injection molding	[23] [24]
Coir	PP, epoxy resin, PE	Automobile structural components, building boards, roofing sheets, insulation boards.	Extrusion, injection molding	[25] [26]

2.3 Natural Fiber

Natural fiber has good physical and mechanical properties such as low cost, recyclability, nontoxicity, easy accessibility and mechanical properties such as good low density, specific modulus and tensile strength properties of natural fibers are also advantages of natural fibers and due to these properties they are preferred in different industries such as building, furniture and automotive [27].

Natural fiber reinforcements are the future since they are cheap and have a number of applications.

2.4 Disadvantages

Natural fibers are extracted from renewable sources and the composite materials based on them are environmentally friendly but they also have some disadvantages. These disadvantages are high moisture, quality variation and low thermal stability of the fibers. High moisture absorption is the major disadvantage of the natural fibers. It weakens the interfacial bonding between the fiber and polymer substrate and weakens the mechanical properties. This drawback can be reduced substantially by the chemical treatment of fibers. Different types of chemicals such as, alkali sodium hydroxide, isocyanate, permanganate etc. have been used for the treatment and a considerable change in the physical and mechanical properties of the composites has been seen [28].

Alkali treatments can be used to counter the major disadvantage of natural fibers which is moisture absorption.

2.5 Mechanical properties of NFPC

These include:

- Physical properties of fiber
- Orientation of fiber
- Strength of fiber
- Interfacial properties of fiber

2.6 Chemical Composition of Natural Fiber

Most of the plant fibers are composed of lignin, hemicellulose, cellulose, some water-soluble compounds and waxes where hemicelluloses, lignin and cellulose are the major components. The properties of the components make contribution to the overall properties of the fiber. Hemicellulose is responsible for the thermal degradation, micro absorption and biodegradation of the fiber [29].

Natural fiber is made up of different constituents. The different percentages of these components in different types of fibers is what determines their overall properties.

2.7 Treatment of Natural Fiber

The different chemical treatment of natural fiber include silane, alkali, acylation, benzoylation, permanganate peroxide, stearic acid, triazine, sodium chloride

According to the research paper; the author examined the effect of alkali (NaOH) for treating sisal fiber-reinforced composite with various concentration level (0.5%, 1%, 2%, 4%, 10%,) was conducted and the result reported that 4% NaOH treated fiber gave the maximum tensile strength. NaOH treatment was done at the room temperature [30].

Another research paper suggested 5% NaOH treated NFRC had better tensile strength than 10% NaOH treated composites.

The reason is when the concentration of alkali has past beyond a specific threshold, excess delignification of fiber results in a weaker or damaged fiber. The overall toughness decreases drastically after specific value of NaOH concentration. [31].

$$\text{Fiber-OH} + \text{NaOH} \rightarrow \text{Fiber-ONa} + H_2O$$

Table 2.1 The moisture content of different natural fiber at 21ºC and 65% humidity

Fiber	**Equilibrium moisture content (%)**
Jute	12
Bagasse	8.8
Coir	10
Pineapple	13
Ramie	9
Abaca	15
Flax	7
Bamboo	8.9

Hemp	9
Sisal	11

2.8 Flame Retardant Properties

Two types of product are obtained upon burning of a composite;

1. Higher cellulose content: - Provides higher chances of flammability.
2. Higher lignin content: - Greater chances of char formation.

For flame retardant purposes, metal hydroxide in combination of char developing cellulose material is used

$$2Al(OH)_3 \rightarrow Al_2O_3 + 3H_2O$$

$$Mg(OH)_2 \rightarrow MgO + H_2O$$

The second reaction gives better thermal stability. Temperature range on decomposition is 320^o C and that of aluminum hydroxide is 200^o C. So, use of magnesium hydroxide is more appropriate for polyamide and polypropylene. [32]

2.9 Biodegradability

Natural fibers start deteriorating at the temperature of 240^{o}C whereas constituents of natural fiber such as cellulose, hemicelluloses, and lignin start deteriorating at different level of temperature for example, 200 C for lignin. Other constituents degrade at higher temperature than this.

Natural fibers have minimum environment damage upon degradation. On the other hand, synthetic fibers produce pollution. More than 50% weight of jute is lost after 1500 days of burial [32]

Natural fibers are biodegradable and environmentally friendly unlike synthetic fibers like carbon fiber and glass fiber.

2.10 Behavior of Natural Fiber (Jute) with Resins:

This paper included experimentation and study of mechanical properties of jute fiber strengthened epoxy and polyester composite. Experimentation for 11%, 22%, 33%, 44% and 55% by volume of jute with both epoxy and polyester were conducted and the results of impact strength, flexural strength were deduced.

The following table shows the impact strength of epoxy-jute and polyester-jute with percentage jute of 11%, 22%, 33%, 44% and 55% respectively [33].

Sample	**Value in j/m**
EJ-1	20.39
EJ-2	46.55
EJ-3	73.33
EJ-4	110.74
EJ-5	99.42
PJ-1	81.74
PJ-2	108.54
PJ-3	132.83
PJ-4	148.58
PJ-5	119.7

Table 2.2 Impact strength of different specimen

From the above-mentioned table, it can be deduced that the specimen with 44% jute by volume, both (epoxy and polyester) show the highest strengths while the polyester-jute strength is fairly higher than the epoxy-jute 44%.

2.11 Fiber Orientation

The best mechanical properties of composites are obtained when the orientation of fiber is parallel to that of the load applied. According to the paper, alfa fiber reinforced unsaturated polyester showed toughness compared to the orientation of fiber of (0°) of 69%, 29%, 22% and 12% at angles of 10°, 30°, 45° and 90° respectively and 93%, 66%, 52% and 41% of Young's Moduli respectively in the fiber direction [34].

The consideration of fiber orientation in composites is important because the maximum tensile strength is obtained when the fibers are parallel to the load and it reduces to minimum when the load is applied in direction perpendicular to that of fiber

.

2.12 Treated and Untreated Fiber

Surface of fibers is generally covered with a layer of different impurities such as lignin, pectin, and other substances. The surface of fibers is not smooth and it has nodes and irregularities on it. After the NaOH treatment a higher percentage of impurities such as lignin and pectin are removed which results in a rougher surface. This roughness increases the interfacial bonding between the fiber and the substrate during composite manufacturing [35].

Alkali treatment of natural fiber is important as it will smoothen out the surface fibers of all the impurities, provide better adhesion properties between fiber-matrix and in general increase the mechanical properties of the composite.

2.13 Manufacturing

Generally, the fabrication of NFRC is done by injection molding, compression molding, extrusion and resin transfer molding. Extrusion, IM and CM are mainly used for thermoplastic matrices but RTM is used for thermosetting resins. In resin transfer molding, resin is injected into a mold containing a fiber lay-up. The main variables in the process are temperature, resin viscosity, injection pressure and mold configuration. [36].

There are two basic methods for the manufacturing of thermosetting resins. Hand lay-up and RTM. Resin transfer molding has more advantages such as faster production, labor savings, good surface finish, low wastage of material and through this process, very large and complex shapes can be made efficiently.

Hand lay-up is the most popular manufacturing process for thermosetting resin. In this process, the fiber is placed in a mold where a layer of releasing agent is applied so that the polymer does not stick to the surface. The resin applied with the help of a brush on the fiber material. To force the resin into the fabric lay-up roller is used which ensures better interaction between the matrix and successive layers of reinforcement. [37] [38] [39].

Another manufacturing technique is spray-up technique and it is quite similar to hand lay-up method. A handgun is used in this process that sprays resin on a mould. Meanwhile, a roller is used to combine matrix material with the fiber. This is an open mold technique, which works better for particulate fibers as it gives better conformability and it is more efficient than hand lay-up method. [40] [41]

Vacuum bag is a flexible material which is used to provide a barrier from outside air. [42] [43]. The air between the chamber and the vacuum bag is sucked out with the help of a vacuum pump. Composites using carbon fiber as reinforcement were fabricated through vacuum bagging process, due to which the chances of improper impregnation and detectable porosity were eliminated and bending properties were increased by 15%. [44].

2.14 Applications of Bio-Composite

Bio composites are used in a number of building components with resins as binder. Its applications also include hard-boards, particleboard, medium density fiber boards, low-density insulation boards other building components such as roofs and walls [45].

The advancement in the automotive industry has concerned with the NFRPs. For this purpose, fibers which are mainly used are the bast fibers: jute, hemp, flax, etc. Automotive manufacturers like BMW and Mercedes Benz have fabricated their cars boot liners, parcel shelves, car door liners etc. using natural fiber reinforced composites. Peugeot, Citroen and Renault in France and Audi and Opel in Germany have also approved the use of natural fiber composites in door panel, side panel, seat back, head-liner panel and instrumental panel [45].

Bamboo fibers were added to polyurethane composite which lead to improved coefficient of sound absorption in automobile door panels. [46] [47].

Natural fibers are biodegradable and are increasingly being used as vibration and sound absorption material in interior automobile components. Composite material with flax, cotton and bamboo fibers with PLA fibers showed flexural strength of 2.5 GPa which is higher than all other composites [48] [49]

Carbon epoxy composite when used instead of steel engine sub frame material showed improvement in toughness with a decreased maximum stress and weight reduced from 16 kg to 5.5 kg [50]

Ramie fiber reinforced composites used in aircraft wing boxes resulted in 12-14% reduction in weight. [51] . For aircraft application, when hybrid kenaf/glass fiber reinforced composite was used, it showed increase in mechanical properties because of resistance to rain erosion. [233]. For aircraft brakes, carbon fiber reinforced silicon carbide is applied so they are able to withstand temperature of 1200^{o}C [52]

2.15 Conclusion

It has been concluded from the research that natural fibers have a number of advantages over synthetic fibers but they also have some disadvantages. To overcome these disadvantages; like moisture absorption and impurities on their surfaces, alkali treatments are used which also results in enhanced mechanical properties. There are also a number of methods of manufacturing composites but the most suitable ones for thermosetting resins are hand lay-up method and RTM process. VARTM (Vacuum assisted resin transfer molding) is a more sophisticated version of RTM where vacuum is used to impregnate the fabric lay-up with resin. VARTM will be used in the experiment which will be conducted with jute as fiber and polyester and vinyl ester as the resins. After the experimentation phase, these hybrid composites will be tested to acknowledge their tensile, flexural and bending properties.

CHAPTER 3: MATERIALS AND PROCESS

3.1 Materials:

The composite materials generally comprise of two major states, the reinforcement and the matrix. The materials selected for the study are as follows:

3.1.1 Polyester

One of the two resins that are being used in this project is polyester, which is a thermosetting resin. Thermosetting resins are those that require curing. The molecular cross-linking process which they undergo is irreversible therefore, offers them good rigidity high thermal stability and. There are two types of polyesters.

1. Saturated Polyester
2. Unsaturated Polyester

3.1.1.1 Saturated Polyesters

Saturated polyester contains hydroxyl groups and it is mostly used in paint and coating industry. It is combined with amino cross-linking resin to form a paint system.

3.1.1.2 Unsaturated Polyesters

Unsaturated polyesters are a thermoset. They can be cured from liquid to solid given the right conditions. Unsaturated polyesters are usually referred as polyester or polyester resins because there is a whole range of polyester which is made from different fatty acids having different properties.

This type has a high glossy finish, good resistance against chemicals, is rigid and it is cheap.

Its brittle film and shrinkage are some of its disadvantages.

Polyester's strength to weight ratio is extremely good due to its low density (approx. 1.8 grams/cc). It often replaces metal parts which are 5 times heavier.

Table 3.1 Unsaturated polyester properties

Properties	**Polyester**
Viscosity at 250^{o}C	250-350
Density (g/cm^3)	1.09
Modulus of Elasticity E (GPa)	33
Flexural Strength MPa	45
Tensile Strength	15-40
Maximum Elongation (%)	1

3.1.2 Vinyl ester:

The characteristics and properties of vinyl ester lies between those of epoxy and polyester. It has the maximum corrosion resistance to most fuel vapors and chemicals. It features decent impact and tensile strengths. It has low viscosity which makes it easy to pour for vacuum infusion processes.

The surface quality achieved curing vinyl ester is not as good as polyester. The double bonded nature of vinyl ester creates shrinkage which has a negative impact on surface quality. They are more tolerant to stretching than polyester. Due to this, vinyl ester is able to absorb more impact without damage. It is also less sensitive to ambient conditions i.e. humidity and temperature.

Both resins use same catalyst i.e. ethyl methyl ketone (butanone). It is an organic compound which has a sharp sweet odor.

Table 3.2 Properties of Vinyl Ester

Properties	Units	Vinyl Ester
Tensile Strength	MPa	5-75
Tensile strain	%	2-3
Tensile Modulus	GPa	3.2
Density	g/cc	1.14
Vol. Shrinkage	%	7-8

As reinforcement for the matrix, jute has been used. It is a natural (bast) fiber and one of the strongest natural cellulosic fibers.

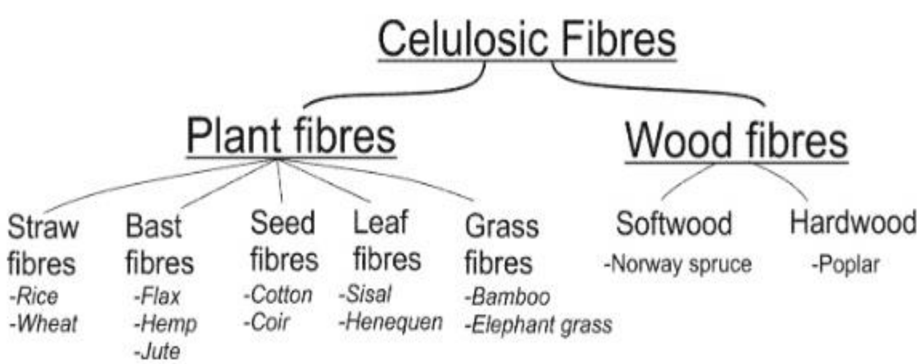


Figure 3.1 Cellulosic fiber Classification

The purpose of using jute as a reinforcement is because of its advantages over synthetic fiber. For example, its eco-friendly, biodegradable, light weight and cheap.

Jute has important applications in composite materials. It is a cellulosic fiber that can be used as load bearing constituents in composites due to their properties such as high strength to weight ratio which makes cellulosic fibers ideal for application in structures.

Table 3.3 Fabric Specification

Fabric Specifications	
Weave style	Box/ plain weave
Warp count	7 ends/cm
Weft count	7 picks/cm
Density	1.5 g/cm3
Tolerance on weight	+/-5%
Width	1250mm
Tolerance on width	+/-2%

3.2 Process:

3.2.1 Components of VARTM:

3.2.1.1 Flat Surface:

This surface is used to give the composite a flat appearance and is used as a mold to prepare the composite material.

3.2.1.2 Vacuum Bag:

Vacuum bag is a thin plastic sheet used to hold the vacuum which is created by the vacuum pump and the sheet we used is transparent and a bit flexible.

3.2.1.3 Peel ply:

This is a type of silky cloth which is used to keep the vacuum bag and flow net from sticking on with the composite so that they can be separated from the composite material/product.

3.2.1.4 Flow Net:

This is a porous mat which is responsible for the even flow of resin over the fabric.

3.2.1.5 Pipes:

Pipes are used in two different positions, one for the flow of resin and the second one for the creations of vacuum.

3.2.1.6 Releasing Agent:

Releasing agent is used to prevent the composite to stick to the mold/flat surface.

3.2.1.7 Vacuum Pump:

It is a device which is responsible for creating a vacuum in the mold, for the flow of resin and to get the resin distributed equally in the layers of fabric under pressure.

3.2.1.8 Sealant tape:

This is a special tape which is used to seal the vacuum bag with the flat surface. This tape can withstand high temperature up to 350 °F.

3.2.1.9 Breathing Cloth:

It is used to prevent the flow of resin out of the fabric and also stops it to get into the vacuum pump.

3.2.2 Procedure:

Step 1:

Make sure that the flat surface (wooden plank) is clean. Tape it for the required dimensions.

Step 2:

Apply the releasing agent on the wooden surface, after that place a layer of peel ply within the taped region.

Step 3:

Measure the weight of fabric (jute) and carefully place them layer by layer over the peel ply. Cover it with another layer of peel ply.

Step 4:

Spread the flow net over the top and place a strip of breathing cloth under one edge of the flow net.

Step 5:

Pipes are carefully placed so that there is no leakage. Place the breathing cloth over the vacuum pump pipe so that the resin doesn't flow inside the pump.

Step 6:

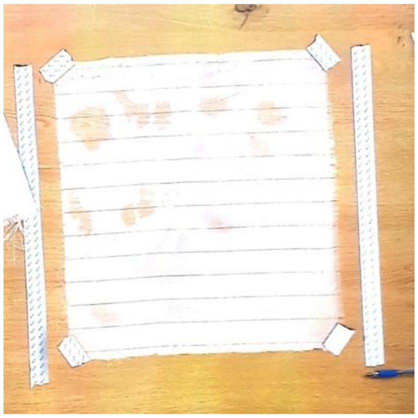
Seal the mold with the help of vacuum bag and the sealant tape applied earlier. Switch on the pump and make sure that there is no leakage.

Step 7:

Let the resin flow in the mold and wait until the resin completely spreads over the fiber. Seal the pipes with the help of zap ties and leave it to cure.

Step 8:

Once it is cured, remove the composite and cut the required sample from it.



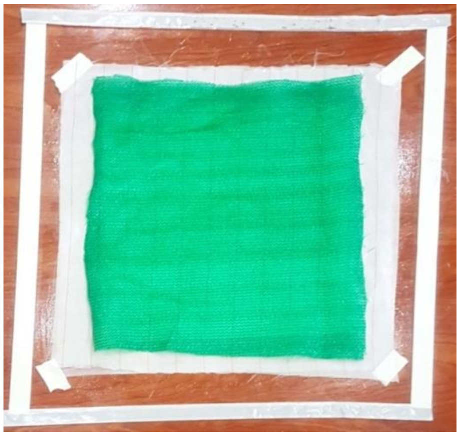


Figure 3.2 Placed peel ply on plank after applying Releasing agent.

Figure 3.3 Spreading of Flow net

Figure 3.4 Placing breathing cloth under Flow net

Figure 3.5 Pipe from Vacuum Pump

Figure 3.6 Resin inlet Pipe

Figure 3.7 Applying of Vacuum Bag

3.3 Composites:

Composite is a material which is the mixture of binder/matrix which is also known as resin and is then reinforced with a fabric. This fabric can be of any kind. The fabric which is used in the composite varies with the application where it has to be used. For example, if in making of aircraft panels' glass fiber is used with resin (epoxy) and the glass fiber used in this process is very refined and each fabric has its own grades according to their use. The resins that are used have their grades. Every fiber that exist has its significant properties and strengths. Such as carbon fiber which is the strongest fiber that can be used without the need of license and normal public can use it and in most of the automobiles carbon fiber is the cutting-edge material. This material is basically used where extremely light weight part is required as well as the strength must be up to the mark.

3.3.1 Hybrid Matrix:

Hybrid is a thing which is made up of two or more material and in case of composites, there are two types of hybrid composites. First one is where multiple resins are used with a single type of fiber and the second one is where a single resin is used as a matrix and multiple fibers are used as reinforcement. The former type of hybrid composite has been fabricated in this project. The hybrid matrix has enhanced mechanical properties as compared to the single matrix due to the formation of IPN structure. This hybrid matrix possesses the properties of both the resins and makes it more efficient to be used. In this study the hybrid matrix consists of polyester and vinyl ester with 70-30% composition respectively.

3.3.2 Hybrid Composite:

In hybrid composites, the hybrid matrix is used and it is reinforced with a desired fabric of desired type. For this study, the matrix used is 70% polyester resin and 30% vinyl ester and their hybrid matrix is then reinforced with jute bi-linear fiber. This hybrid consists of jute, polyester and vinyl ester and has more strength than all of these materials as an individual.

3.4 Testing Methods:

To investigate the properties of this hybrid composite, we perform different tests such as tensile, impact and flexural test.

3.4.1 Tensile Test:

In this test, the specimen is placed between the clamps of the UTM (Universal Testing Machine) and uni-axial load is applied in the longitudinal direction. The specimens are made according to the following standards:

ASTM D-3039

(250x25x3mm)

Figure 3.8 Tensile test on UTM

A universal testing machine (UTM) is used to test tensile and compressive loads. In some UTM there is also option of testing of bending strength. Following are the components listed of UTM

1. Load Frame: - It consists of two supports for the machine. Smaller UTMs have only a single support.
2. Load Cell: - A force transducer is used to measure the load. Calibration is required after a certain period of time to maintain the quality of system. In our case, the load cell used was of 100kN. It is used according to the specimen being tested. For specimen with relatively smaller tensile strength, a smaller load cell is used to reduce the percentage error.
3. Cross head: - A movable cross head is controlled to move the clamps up and down. This is done at a steady speed which can also be referred to as constant rate of extension. UTM cross head can be programmed for constant force, constant rate of deformation, cyclical testing etc.

4. Output Device: - This is where the results of the testing are illustrated. Older machines use digital display or chart recorders but newer models are attached to a computer for more comprehensive results and for the ease of the user.
5. Conditioning: - Some tests require standard conditions of temperature, pressure, humidity etc which is why UTMs are placed in a controlled environment.

To measure extension or deformation in the specimen, extensometers are used. It is a device used to measure change in length of an object. It is mainly used for stress-strain measurement and tensile strengths.

3.4.2 Impact Test:

This test is performed on the specimens which have a v-notch in the center and then the hammer is set lose to strike the back of that notch point and then the basic calculations are made by the following formula:

Impact Strength=(F/b.d).1,000,000

And the standard for impact is:

ASTM D-256

(64x12.7x3.2mm)

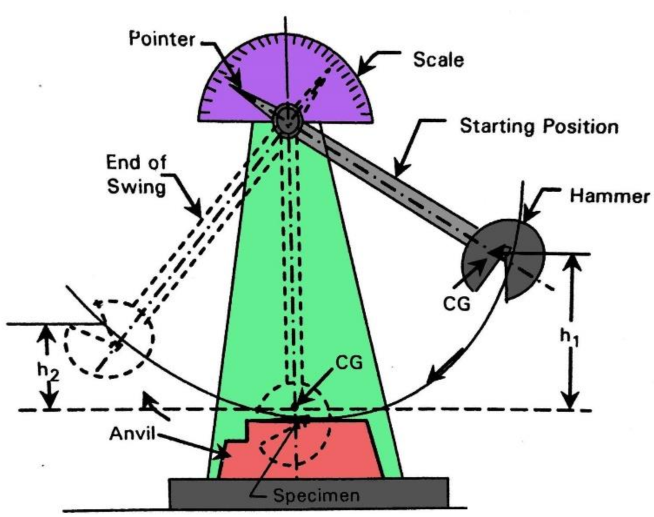


Figure 3.9 Impact Testing

Impact test signifies the amount of energy absorbed by a specimen during fracture. The energy absorbed relates to the given material's toughness. . In NFRC, the enhancement of impact property is very difficult and that is the reason glass fiber and carbon fiber are used. The basic purpose of this project is to improve the impact property of natural fiber reinforced composite. There are two types of impact tests i.e. izod impact test and charpy impact test.

In Charpy impact test, the specimen is placed horizontally and the v-notch is positioned opposite to the striking pendulum. Also both ends are locked in this test before striking.

In Izod impact test, the sample is placed in a vertical position where the notch is facing the striking pendulum and only the bottom of specimen gets locked.

In this case, Charpy impact test was used and difference between the two can also be clarified by the following two figures.

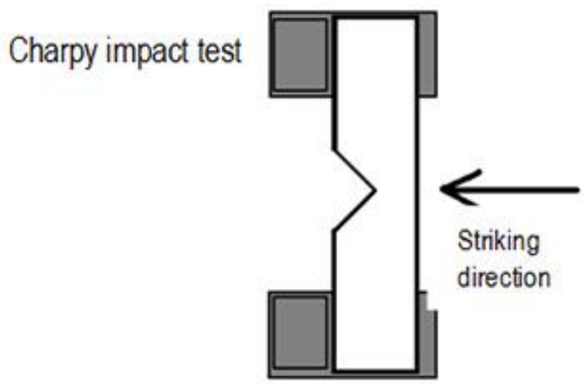


Figure 3.10 Charpy Impact Testing

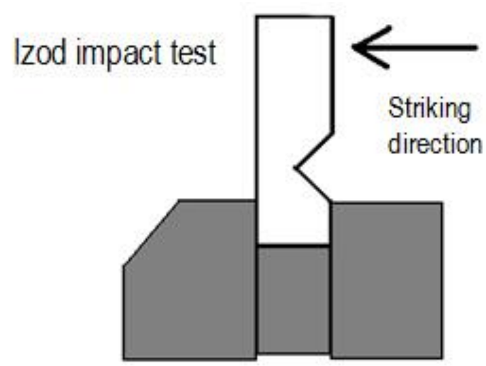


Figure 3.11 Izod Impact Testing

3.4.3 Flexural Test:

For flexural test the specimen is placed between two supports and then the load is applied in the center.

The standard is:

ASTM D-790

(125x12.7x3.2mm)

The formula used is:

$$\textbf{Flexural Stress} = 3.F.L/2.b.d^2$$

Flexural test is used to determine the maximum stress on the outermost fiber on either tension or compression side of specimen. There are two types of flexural tests i.e. three-point bending test and four-point bending test.

Three point flexural test gives the maximum bending strength under the loading. The stress is concentrated in the small area. It produces its peak stress at the center of the specimen. On the other hand, four point flexural test gives stress concentration value over a larger region. It produces peak stresses along a broadened region of material therefore larger length of material is exposed.

In this case, three-point flexural test has been used which can be seen in the figure below.

Figure 3.12 Flexural test on UTM

Figure 3.13 Flexural test (specimen breakage)on UTM

Chapter 4: Results and Discussion

4.1 Fiber Results

Following attached are two stress vs. strain graphs for treated and untreated jute fiber. The fiber has been treated with 5% NaOH solution. Surface of fibers is generally covered with a layer of different substances such as lignin, pectin, and other impurities. The surface of fibers has nodes and irregularities on it. After the NaOH treatment, most of the impurities are removed which results in a rougher surface. This roughness increase the bonding between the fiber and the substrate during composite manufacturing [35].

Treating with any higher percentage than 5 will result in delignification and damaged fiber. 4-5% NaOH treatment gives optimum results.

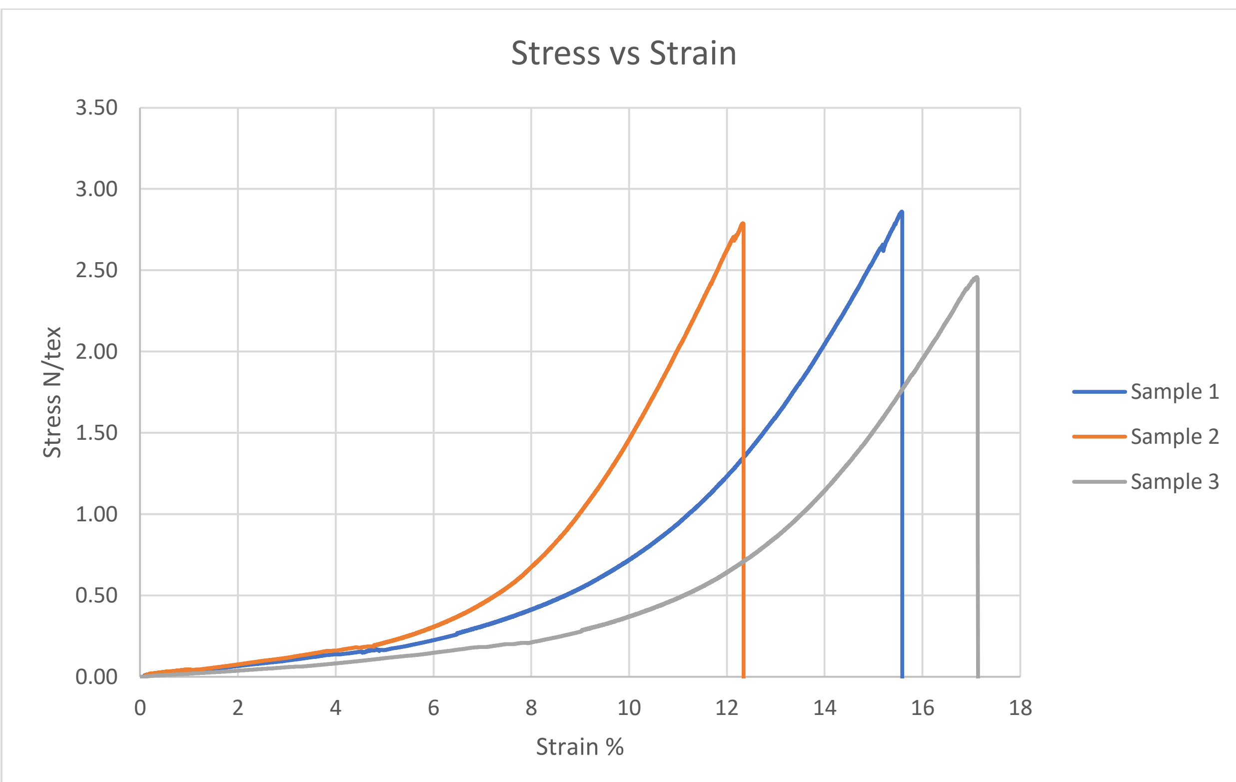


Figure 4.1 Stress vs. Strain curve for untreated fiber

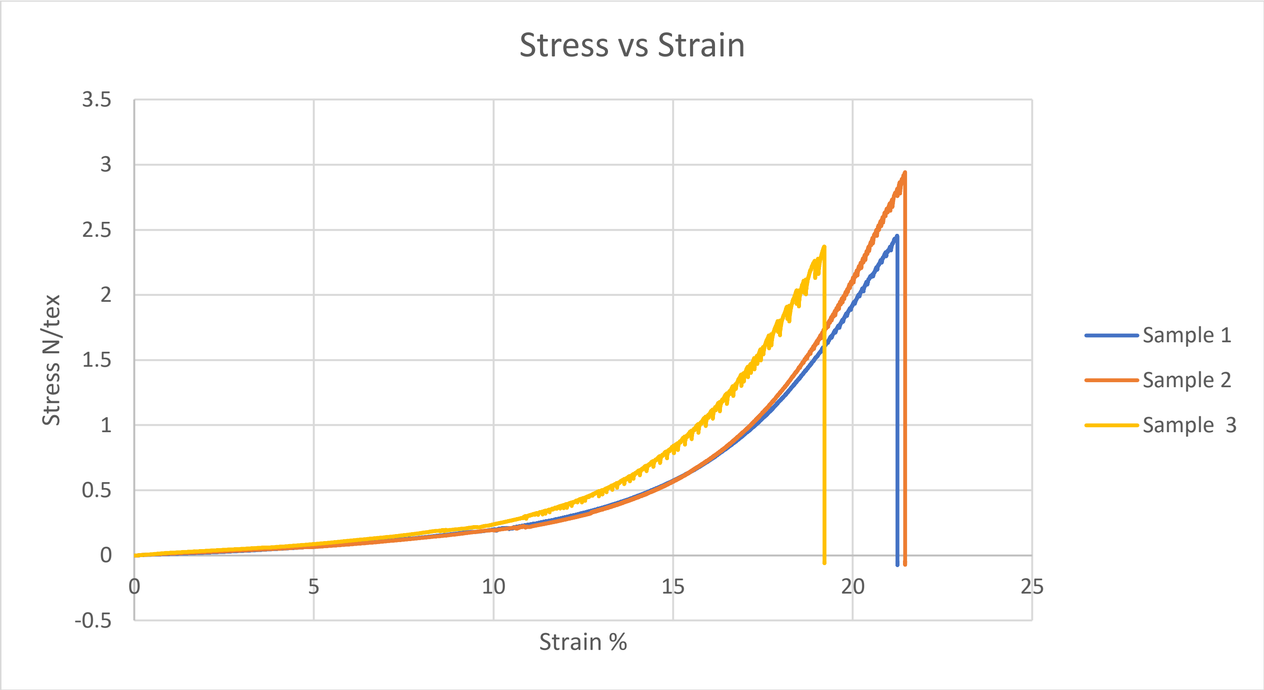


Figure 4.2 Stress vs. Strain curve for treated fiber

According to the graphs, the stress in both treated and untreated fiber is more or less the same without any enhanced capacity of treated fiber in load bearing scenario.

The difference can be noticed in the value of percentage strain in the treated fiber; as it is higher as compared to untreated fiber. The untreated fiber has shown at an average of 15% strain and the treated fiber demonstrates more than 20% average strain which means the percentage elongation has significantly increased after 5% NaOH solution treatment.

4.2 Hybrid Matrix Results

For the selection of matrix, tensile test on various compositions percentage of resins (Polyester and Vinyl Ester) and also the separate resins were performed and compared.

Table 4.1 Composition of Resins

Sr. No.	Vinyl Ester (Wt.-%)	Polyester (Wt.-%)
1	100	0
2	0	100
3	70	30
4	50	50
5	30	70

The results of the tensile test conducted on the above composition and the results are shown in the following graph:

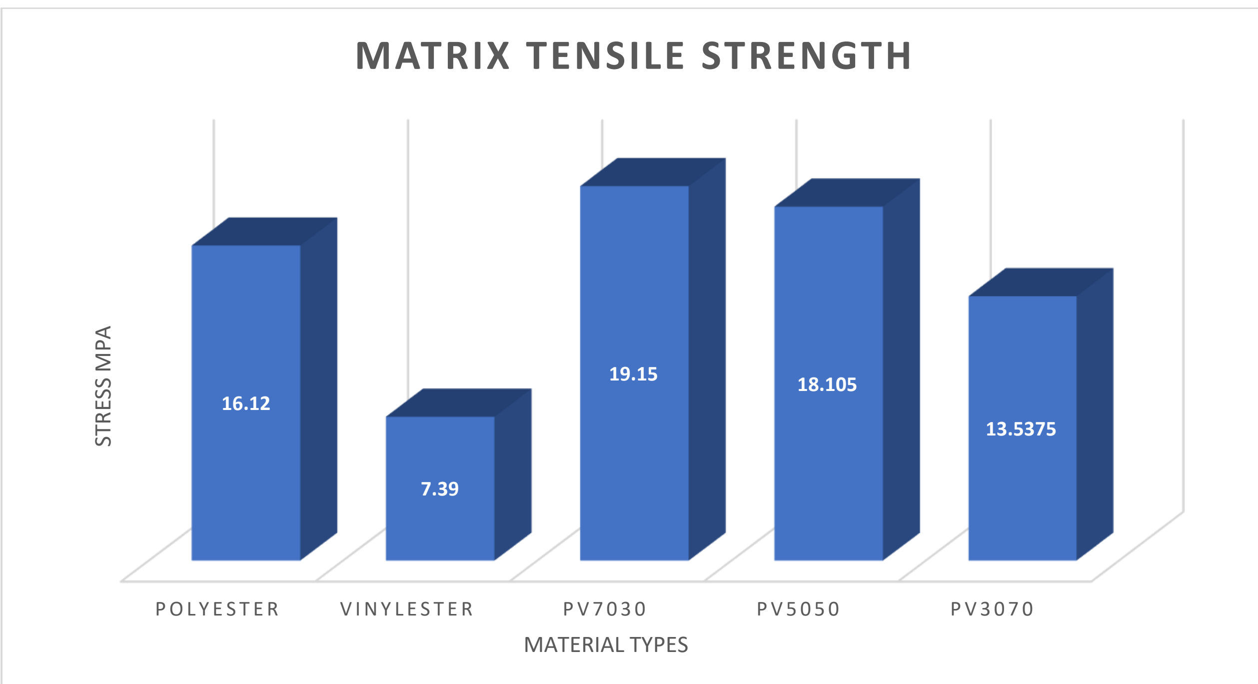


Figure 4.3 Tensile properties of Matrix

This graph shows that the Matrix PV-70-30 is more than 2.5 times stronger than vinyl ester and 16% stronger than polyester. Matrix PV-70-30 is selected and further used. The reinforcement is done with natural fiber jute.

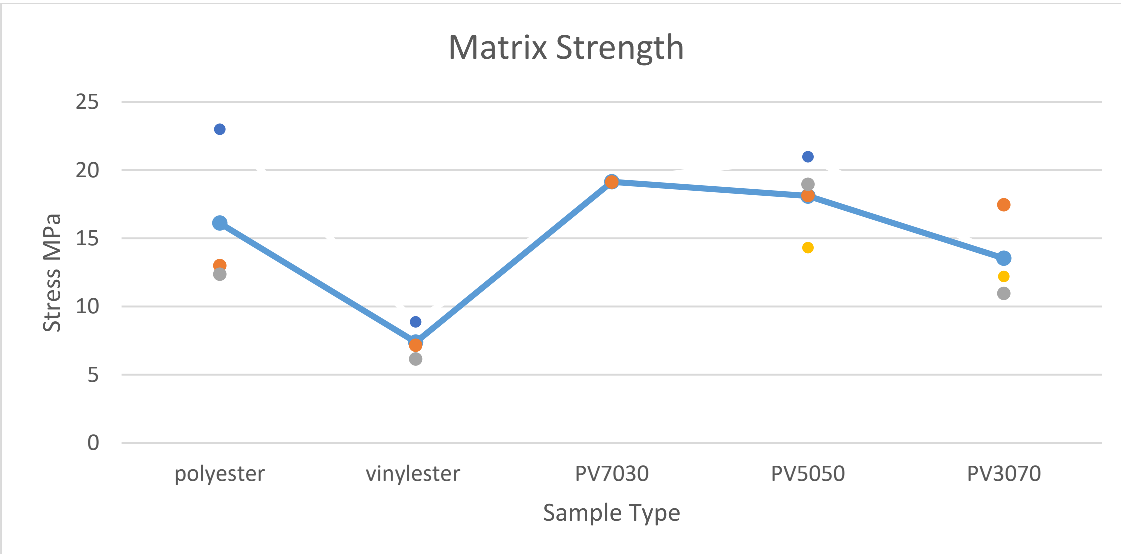


Figure 4.4 Tensile properties of matrix detailed

This is how different individual specimen performed during testing. The three specimen of vinyl ester shows precise values i.e. the fluctuation is between 6 MPa to 8.5 MPa which is very close to the average value which implies that all the vinyl ester specimen have performed more or less equally.

On the other hand, the three specimen of polyester shows the highest variation amongst the three specimen. This is because resins have a tensile strength limit bracket inside of which the cured resins perform. There is not a specific figure of its strength; there is an upper and lower limit. The three spread-out points of the specimen suggests that it’s because of the reason stated above. Also, if there is anomaly in the results, what we can do is inspect the specimen and see the mechanics of its breakage. If the specimen gives highly irregular value and the specimen has shattered near the either sides of clamp, there is a high chance that it’s a garbage value.

This variation in polyester resin is the reason for further variation in the rest of hybrid matrixes.

This matrix tensile strength test shows the improvement in strength is because of IPN (Interpenetrating Polymer Network) structure formation and according to this, the two networks can be seen to be entangled in such a way that they are linked together and cannot be pulled apart, but they are not bonded to each other by any chemical bond. To break this entangled linkage of polymers, a large amount of energy is required. This IPN structure helps the resin to elongate a bit more than the single resin and this is the major reason which helps the matrix to improve their properties as compared to single resin. This IPN theory can be explained by the following picture:

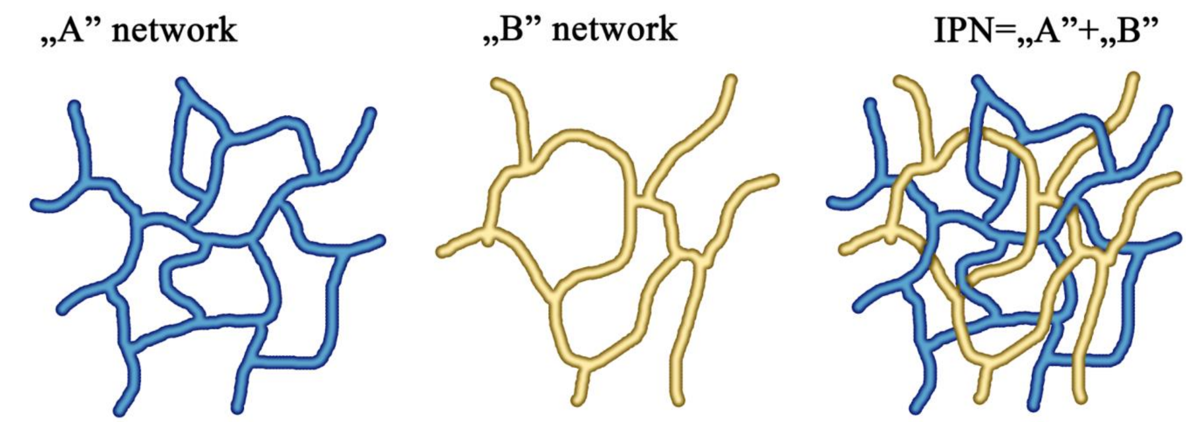


Figure 4.5 IPN behavior for two different resins

The above figure shows that Network 'A' is considered as polyester and consider Network'B' as vinyl ester and when they both are mixed together and they form the network called IPN='A'+'B' and due to this IPN structure, the hybrid matrix possess the properties of Network'A' and Network'B'.

Polyester and Vinyl ester acts as a primary constituents in the formation of interpenetrating polymer network. The curing process of the resins does not interfere with one another and it can be verified from the graphs that IPN results in enhanced mechanical properties.

There are two ways of further tweaking the mechanical properties. The PVIPN can be left in the room temperature for an extended period of time or a post curing process can be carried out which involves keeping the specimen in a controlled environment with elevated temperature which raises the crosslinking density resulting in enhanced thermo mechanical and mechanical properties. There are two fundamental parameters that determine the optimal post curing process. One is time and the other one is temperature. The specimen can be put in an oven at an 80^{o}C for a couple of hours or same outcome can be expected by keeping the samples in room temperature for two weeks. It has been reported that higher temperature post cured composites exhibit better properties than lower temperature post cured processes. After post curing the samples at high temperature, they should be left in the oven to slowly cool down to the room temperature to avoid the specimen from "thermal shock effect".

It is reported that 200^{o}C post curing temperature is optimal and it also results in higher flexural strength. Epoxy based composites can show further 1.2% increase in properties at 230^{o}C because of its slow cure rate behavior.

For our case, where polyester and vinyl ester are resins used, will exhibit deterioration in mechanical properties after 200^{o}C because of its high cure rate.

Simultaneous IPN is formed between polyester and vinyl ester. For such IPN to form, the monomers and cross linkers both are present at the start of polymerization.

When biphenyl-A diglycidyl ether grade of epoxy polymer is reacted with meth acrylic acid, vinyl ester is formed. The diluent used for both polyester and vinyl ester is styrene monomer. For vinyl ester, reactive sites are present only at the end of molecular chain therefore crosslinking can only take place at that position whereas styrene monomer has only one reactive site which can only provide extension in the linear chain so the branching points and crosslinking capacity can only be provided by vinyl ester.

Methyl ethyl ketone initiates curing for both resins and because of the independent reactions, there is a possibility of formation of simultaneous interpenetrating polymer network.

4.3 Hybrid Composite Results:

When a hybrid matrix is reinforced with fibers, it turns into hybrid composite.

After selection of matrix different percentages of reinforcement are introduced into the matrix. The compositions for the composite are given in the following table:

Table 4.2 Compositions for Hybrid Composite

Sr. No.	Resin (Wt.-%)	Fiber (Wt.-%)
1	85	15
2	80	20
3	75	25
4	70	30
5	65	35

All the compositions have been fabricated and then tested but composite with 15% reinforcement is not possible because the reinforcement present is in small ratio and most of the resin mixture is wasted in this process.

In the same way, hybrid with 35% reinforcement is practically impossible because the resin mixture quantity is very less and it would not even make a layer with jute and all the composite sheet will remain porous. There is no practical advantage in continuing the test with other compositions higher than this fiber percentage because it will only lead towards the wastage of material, both matrix and fabric.

There is a difference in the anticipated and actual percentage of fiber in matrix; as we have aimed to do a certain fiber percentage i.e. 20%, 25%, 30%, the actual percentage deviated from the expected value. This is because of the fact that not 100% resin will flow into the cavity. Some of the resin remains in the beaker, pipe and the non-reinforced area. All the extra uneven areas are cut out and the sample is weighed. The weight of the jute fabric is also noted and the percentage is hence calculated.

The actual fiber percentage for different samples obtained is 22.8%, 24.25%, 27.75%, and 32.5% against the expected percentage value of 15%, 20%, 25%, and 30%.

4.3.1 Tensile test result of Hybrid Composite:

Tensile tests on the hybrid composites show significant improvement in the mechanical properties and it can be seen in the following graph:

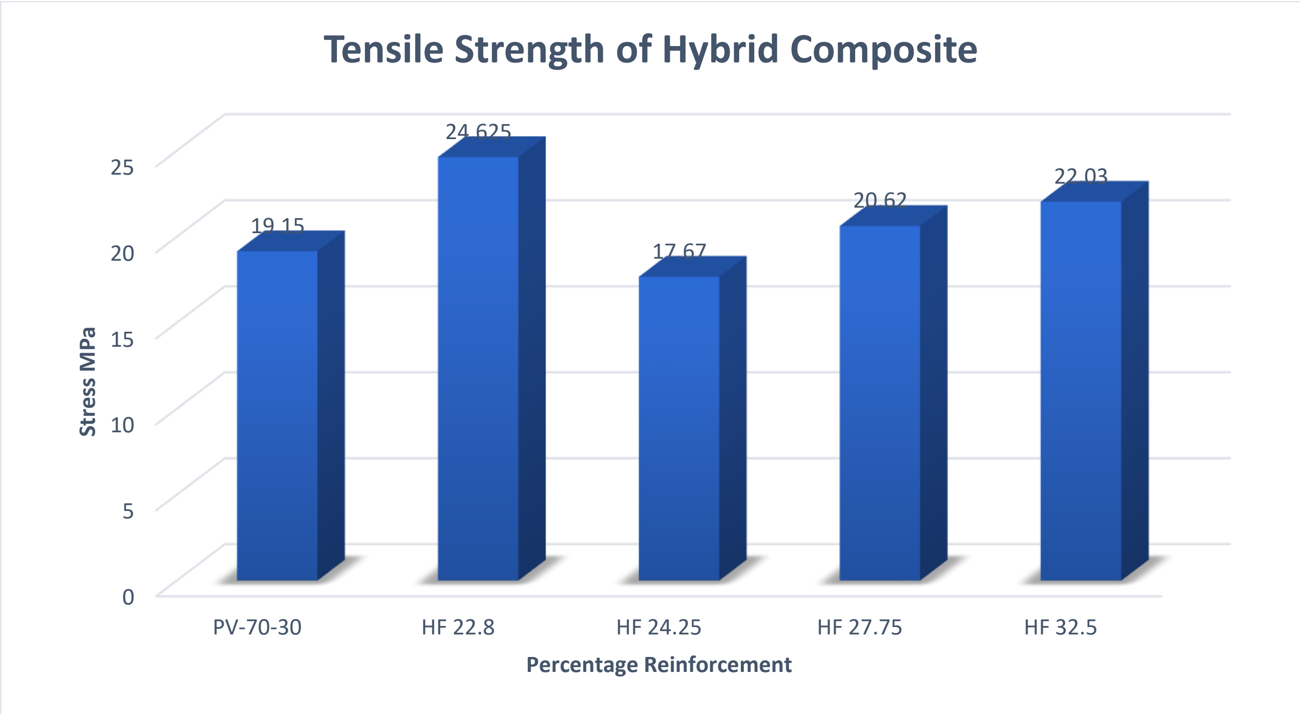


Figure 4.6 Tensile Strength comparison of Hybrid Composites

According the results in the above figure, HF-22.8 is the toughest material that can be achieved by using jute in the selected matrix and this material is almost 28.5% stronger than PV-70-30(selected matrix).

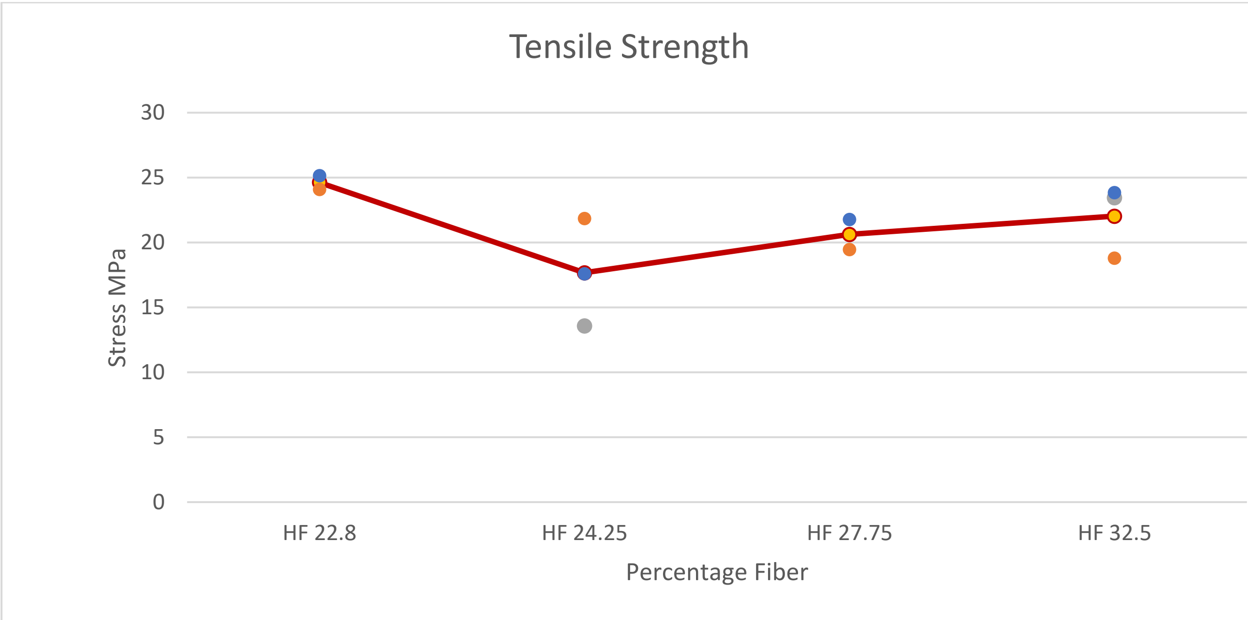


Figure 4.7 Tensile Strength comparison of Hybrid Composites detailed

According to the fig 4.7, the tensile specimen have shown a more precise values of stress. But the highest tensile value is given by the specimen with least amount of fiber (HF-22.8). This is the optimum percentage of matrix and fiber. As the ratio of fiber goes up, the percentage of matrix gets lower due to which it is not able to fully support the reinforcement as it does in HF 22.8.

4.3.1.1 Stress Strain Curve of Hybrid Composite:

Stress strain curves are formed between the stresses applied on the specimen in y-axis and strain (elongation produced in the result of the stress applied) in x-axis.

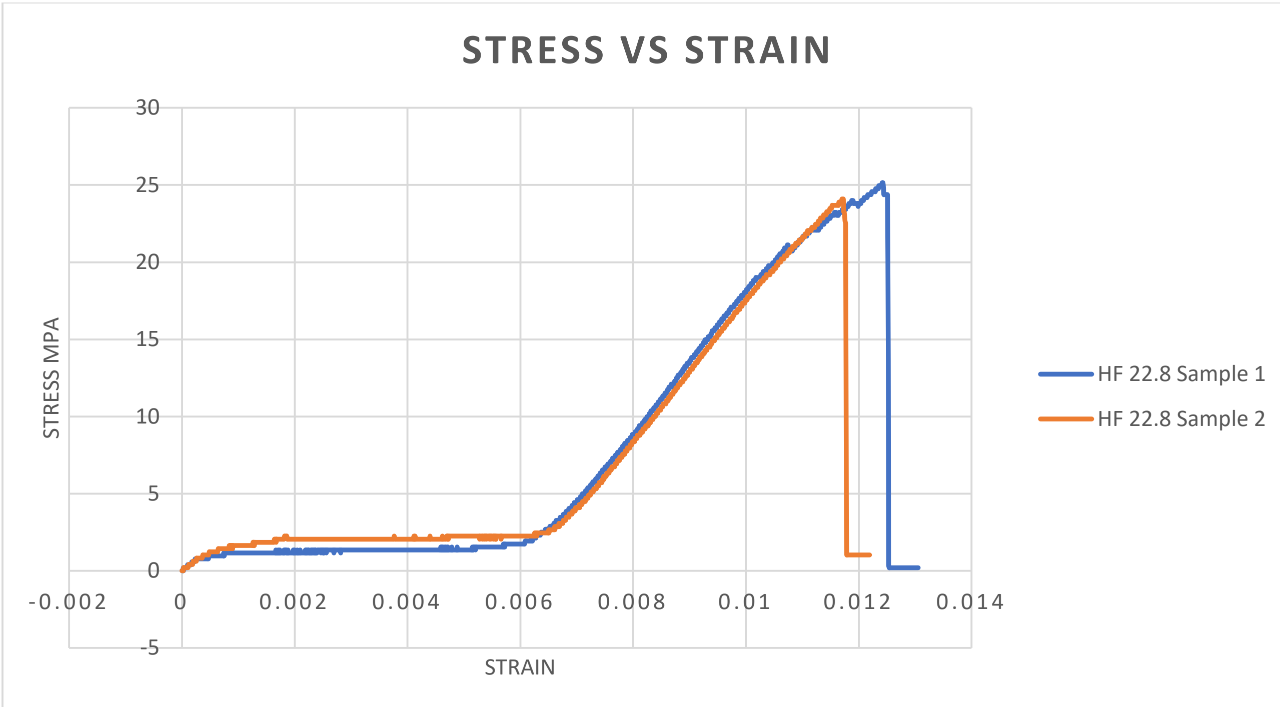


Figure 4.8 Stress vs Strain Curve of HF-22.8

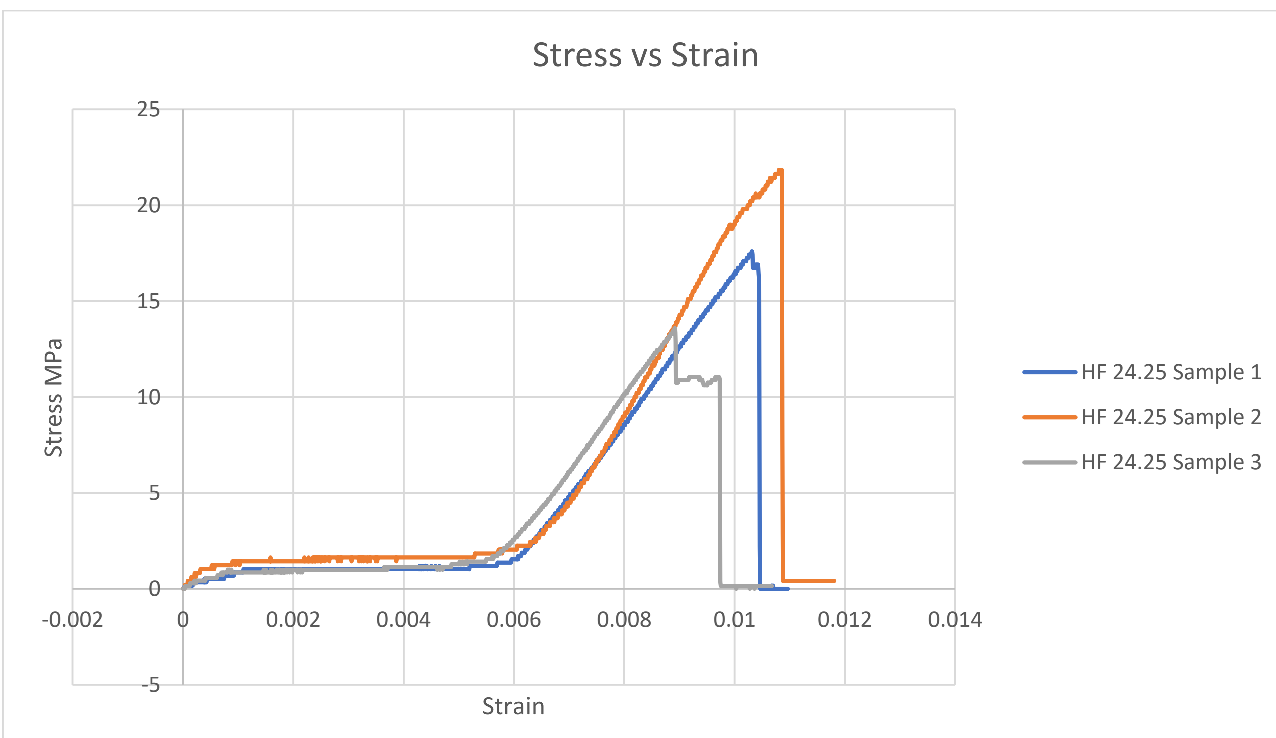


Figure 4.9 Stress vs Strain Curve of HF-24.25

According to fig 4.9 the sample 3 has shown an anomalous behavior. The curve starts to go up and then near 13 MPa it partially breaks, the specimen without taking any further load then breaks off completely. This 3rd sample shows garbage value and it cannot be considered since we already have two authentic values of sample 1 and sample 2 and this value is substantially smaller than the other two which suggests that this value isn't useful and the average of sample 1 and sample 2 will be taken for average stress.

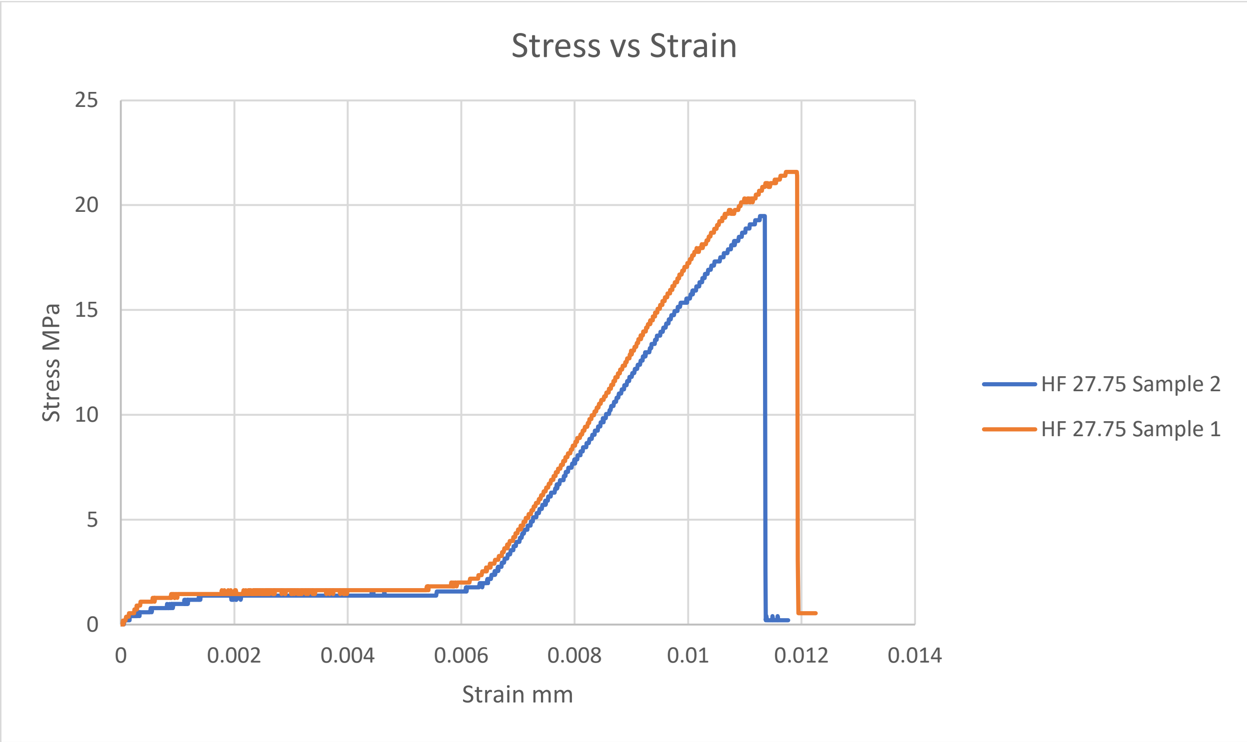


Figure 4.10 Stress vs Strain Curve of HF-27.75

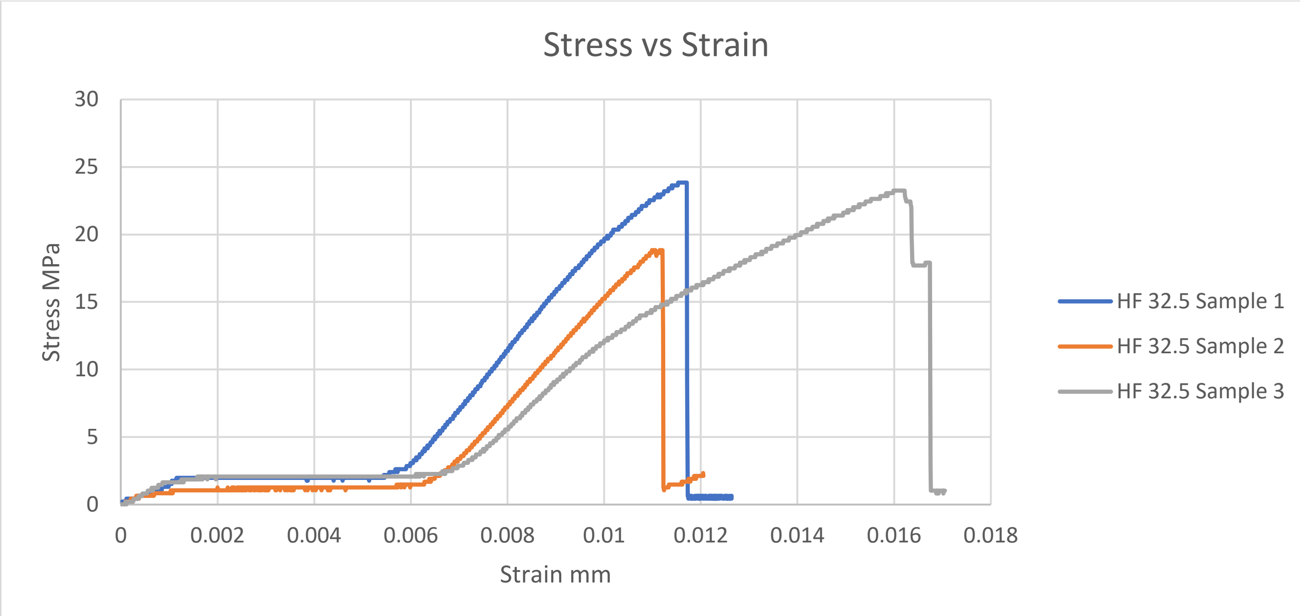


Figure 4.11 Stress vs Strain Curve of HF-32.5

So in the above figure, the sample 3 has shown anomalous results, it partially breaks and then without taking any further load it breaks off completely. But since the load taken by this sample is between the two authentic values of sample one and sample two, the value of 3rd can also be considered as reliable.

According to above four figs, HF-22.8 shows slightly more ductility as compared to HF-24.25 and HF-27.75. The strength of hybrid composite HF 22.8 is substantially higher as compared to HF-24.25 when 22.8% jute fiber is used. While in the 3rd graph, the strength has marginally increased while using 27.75% jute fiber as compared to HF-24.25. The 4th graph of HF 32.5 shows anomaly where the third specimen shows higher ductility. Looking at the graph, the third specimen partially breaks which shows that there is delamination between the two layers and then it finally breaks without taking any higher load. Another explanation could be that there is still a variation in the percentage of fiber-matrix. The fiber ratio is probably higher due to which its taking most of the load and instead of breaking the fiber has started to stretch due to which the graph is insinuating higher ductility.

After the study of these stress strain curves, the composite with most enhanced properties HF-22.8.

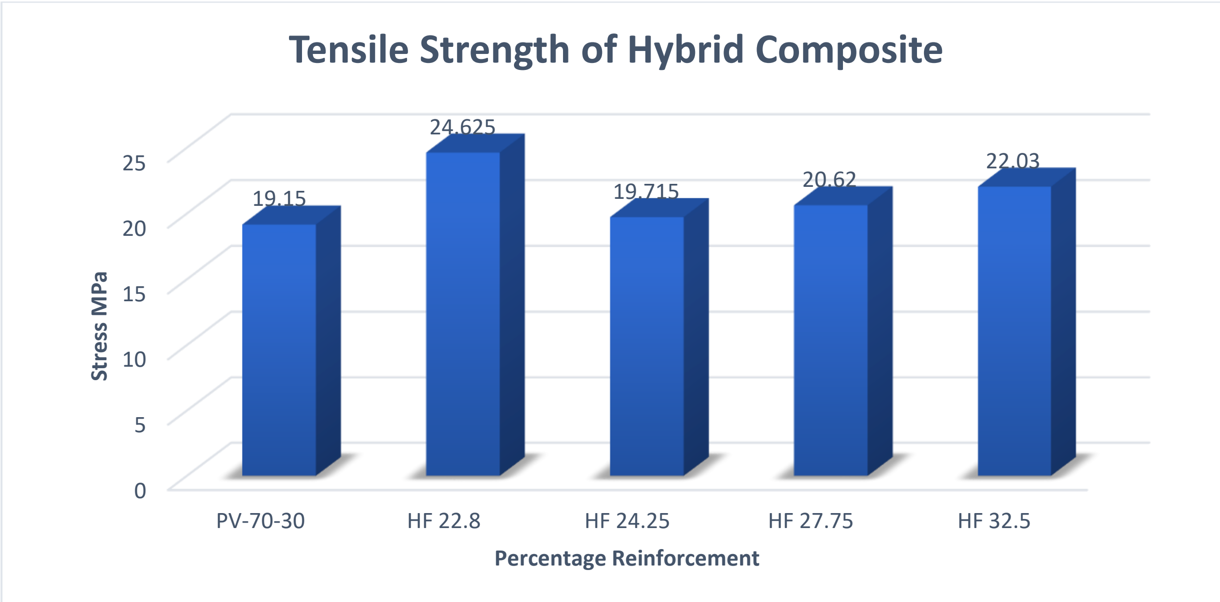


Figure 4.12 Tensile Strength comparison of Hybrid Composites corrected

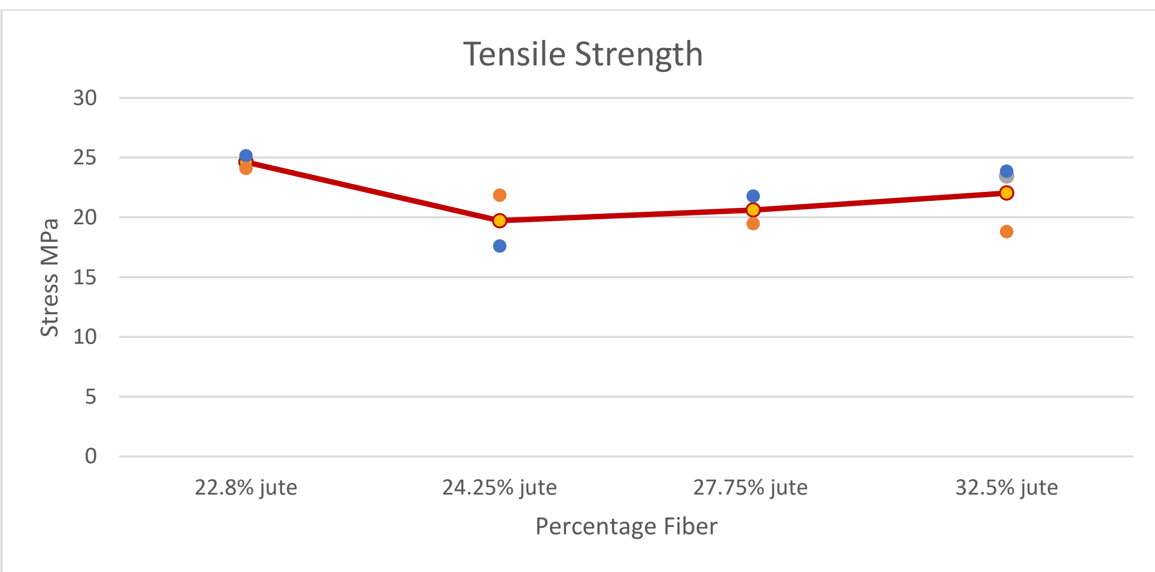


Figure 4.13 Tensile Strength comparison of Hybrid Composites detailed corrected

4.3.2 Bending Test Results of Hybrid Composites:

Bending tests are also conducted on the UTM (Universal Testing Machine) and 3-point load is applied on the specimen. Two points are of support and load is applied in the middle of the specimen. Result of the hybrid composite material in comparison with others are plotted in the following graph

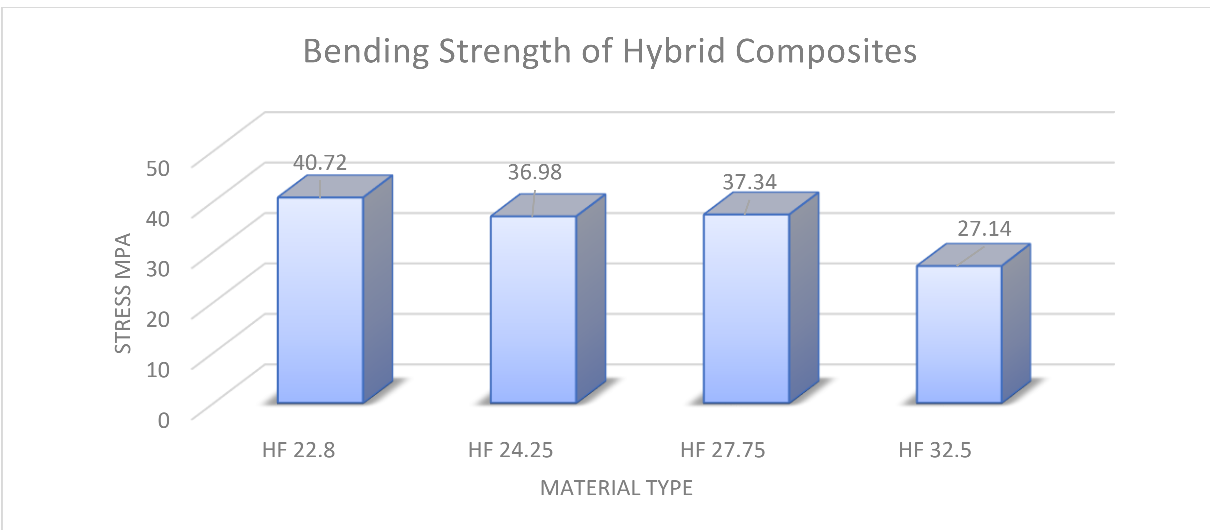


Figure 4.14 Bending Strengths Comparison for Hybrid

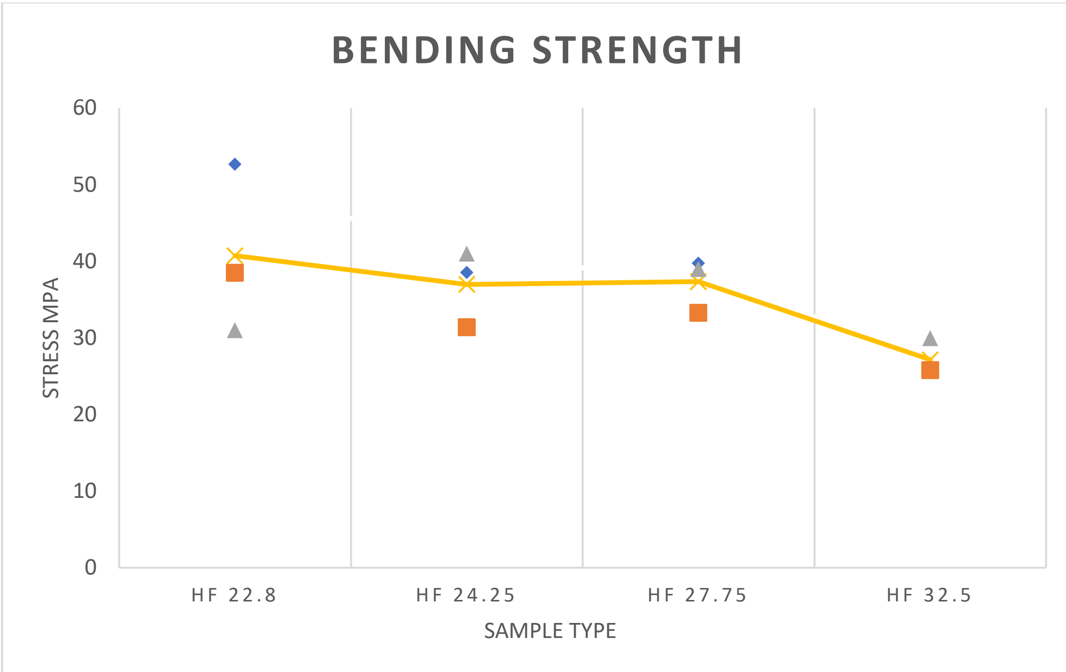


Figure 4.15 Bending Strengths Comparison for Hybrid detailed

According to the graph, HF 22.8, HF 24.25, HF 27.25 have a very small difference in average bending strength. But the 4th composite, HF 32.5 shows a substantial dip in bending strength. This could be because of very high fiber percentage. What happens here is, the matrix percentage gets so low that it is unable to adhere the multiple layers of composite. The matrix layer between the layers gets extremely thin so when the load is applied on the specimen, it is unable to bear higher load and there is also a chance of delamination which reduces its strength.

The graph shows a linearly decreasing trend of bending strength which suggests the higher percentage of matrix is necessary for higher bending strength. As we move forward and increase the fiber ratio, it is not able to absorb higher load because of the low ratio of matrix the specimen succumbs under gradually increasing load.

4.3.3 Impact Test Results of Hybrid Composites:

Impact property of any composite is considered as the most important property and almost all the manufacturers work and try to enhance the impact property of the composite. In natural fiber composites, the enhancement of impact property is very difficult and that is the reason glass fiber and carbon fiber are used. The basic purpose of this study is to improve the impact property of natural fiber and by this study there is a significant increase in the impact properties of the natural fiber reinforced composites. The results of this study can be understood by the following graph.

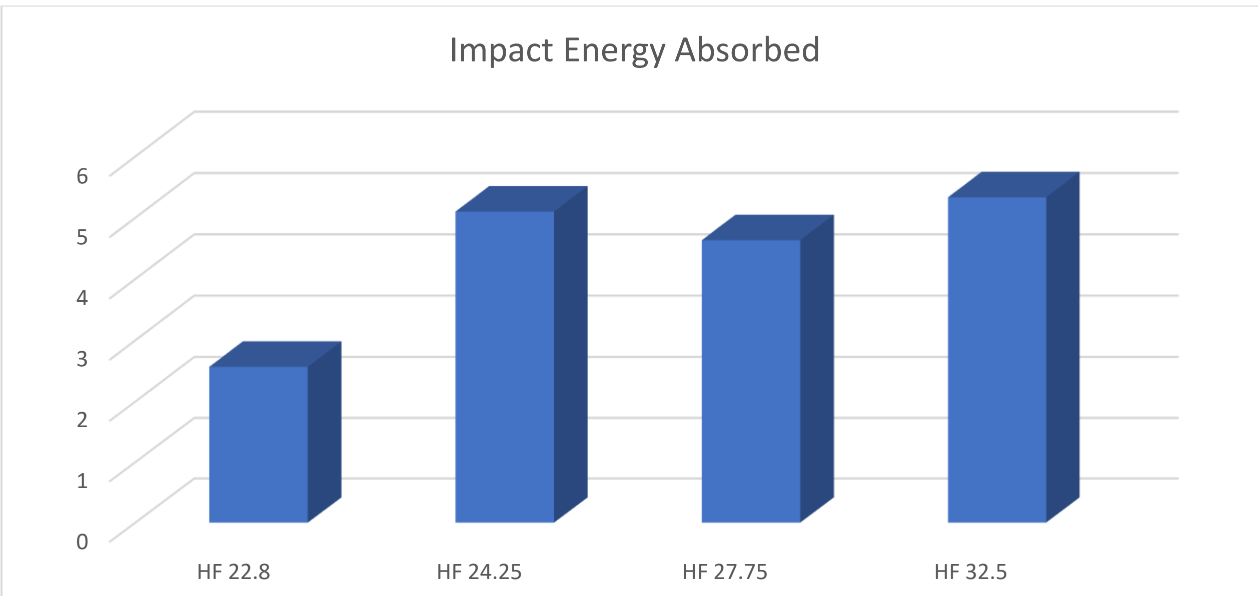


Figure 4.16 Impact Energy absorbed

This is the graph of impact energy absorbed by the specimen and the energy absorbed is measured in Joules. Charpy impact test was conducted. The v-notch is placed on the backside (opposite to the hammer). Further impact stress can also be calculated with the help of this data.

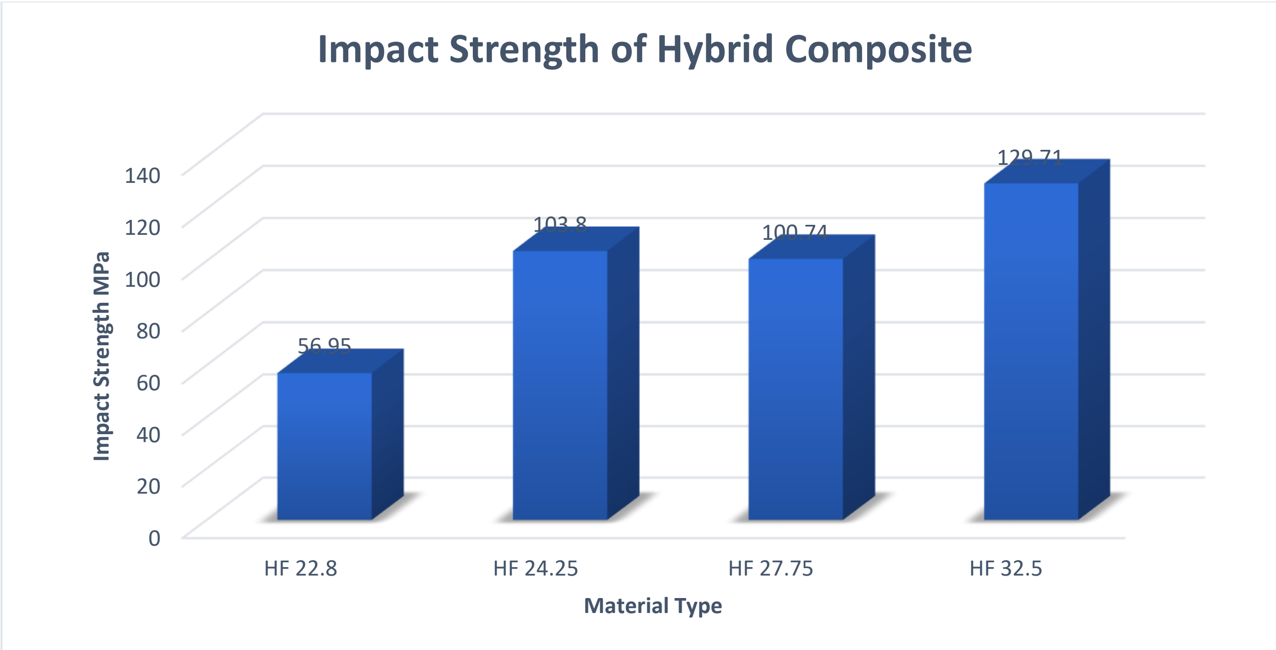


Figure 4.17 Impact Strengths Comparison of Hybrid

This is the impact strength graph which has been calculated with the help of impact energy absorbed data. The impact energy is divided by the cross section of the specimen and the units are same as stress MPa.

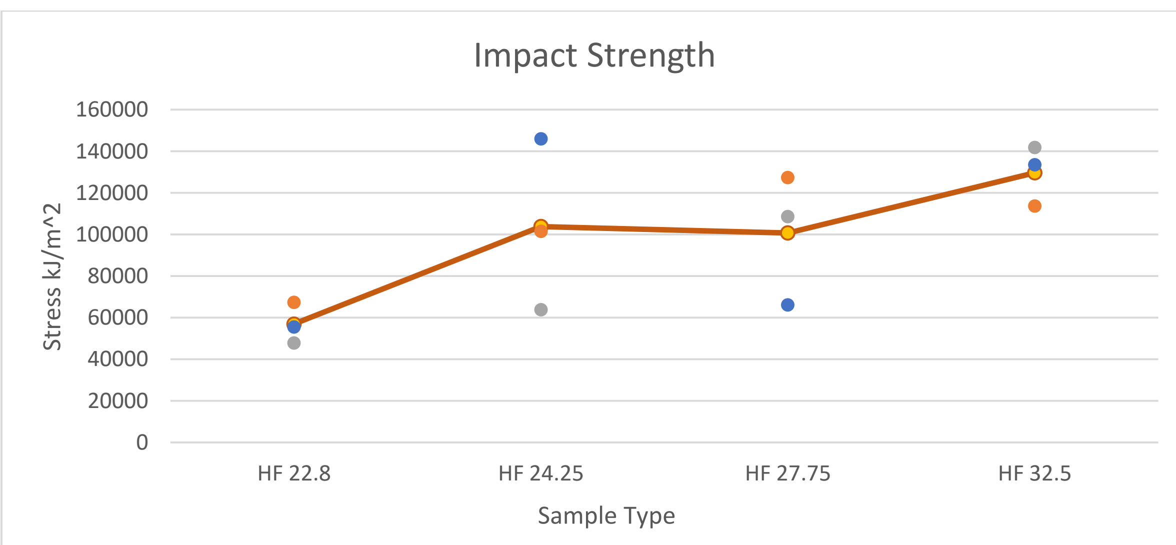


Figure 4.18 Impact Strengths Comparison of Hybrid detailed

As the fiber percentage has increased, the impact strength has gotten better according to the graph. This is because the impact is mainly absorbed by the reinforcement. The matrix is extremely brittle in nature hence it is not able to sustain large impact. As the fiber percentage is increased more energy is absorbed by the specimen.

The tensile and bending strength is higher with lower fiber percentage but the higher fiber ratio favors the impact strength. This is because of difference in the nature of two type of tests where the load is applied gradually for tensile and bending strength whereas for impact test the hammer strikes sharply against the specimen which is mainly absorbed by the reinforcement. On the other hand, for tensile and bending strength, lower fiber ratio is desired because the fiber and matrix complement each other in such type of tests where gradually increasing load is applied.

Applications

Hybrid composites are nowadays being used in automobiles and many places like fencing, railing system, bicycle frames, seat post and laptop cases. This fabricated hybrid composite is stronger than polyester and vinyl ester separately. It is environmental friendly as it contains natural fiber as the reinforcement and natural fibers are extracted from plants and that’s why they do not harm the environment. According to the mechanical properties of this composite, it can be used in the bicycle helmets. In automobiles, it can be used in roof and floor structures, boot liners. This composite is manufactured with the consideration of impact properties which is extremely important and developed for impact bearing purposes. That’s the reason there is a major increase in the mechanical properties mainly in impact properties.

Chapter 5: Conclusion

Conclusion

The objective of the project was to develop a hybrid composite material with enhanced mechanical properties.

The two resins used are polyester and vinyl ester. The tensile strength of these individual resins were found out (16.17 MPa for polyester and 7.35 MPa for vinyl ester). Later, hybrid matrix using different combination of these two in ratio 70-30, 50-50 30-70 were developed and the matrix having the highest tensile strength was selected; in our case PV70-30 came out with the highest average tensile strength of 19.15 MPa which is 18.5% higher than the individual polyester resin.

This PV70-30 combination was used with different percentage of jute fiber. Four different jute fiber percentage (by weight) used are 22.8%, 24.25%, 27.75% and 32.5%.

The reinforcement percentage 22.8% had the highest tensile strength of 24.62 MPa which is 28.5% higher than the original PV70-30 ratio matrix. This tensile strength is 52.2% greater than polyester (16.17MPa) and 235% greater as compared to vinyl ester resin (7.35 MPa) Furthermore, the cost of the composite specimen reduced considerably because of the usage of jute fiber which is relatively cheaper than the resin.

The bending and impact strength graph shows a trend. For bending strength, the highest value was given by 22.8% reinforcement. This could be because resins are stiffer and since 22.8% had the highest amount of percentage resin, its bending strength came out to be the highest. The bending strength reduced as the percentage fiber increased.

The impact energy absorbed had the opposite trend. The composite with highest reinforcement percentage 32.5% had the highest impact strength. The reason could be the same as the composite's impact strength increased as the percentage fiber increased. The resin is brittle in nature, therefore with the maximum amount of resin in 22.8% reinforcement the impact strength came out to be the least. And it increased almost in a linear fashion, with 24.25% and 27.75%

reinforcement having almost the same impact strength 103.8 MPa and 100.74 MPa respectively. The highest fiber percentage gave the highest impact strength of 129.7 MPa.

The fiber percentage lesser than 22.8% could not be used since the process used was VARTM and since the vacuum pump sucks out all the air from the chamber, the least fiber that could be used was 22.8%. The composite sample was intended with 15% reinforcement, the extra resin could not be absorbed by the fiber, and hence the fiber percentage increased and came out at 22.8%.

The fiber percentage higher than 32.5% could not be used because the resin was lesser in quantity than required to wet the whole fiber fabric. Going any higher would result in delamination between the fiber layers.

References

[1] R. A. Young and J. K. Rowell, Paper and Composites from Agro Based Resources, Lewis Publisher.

[2] H. Altenbach, J. Altenbach and W. Kissing, "Classification of Composite Materials," in *Mechanics of composite Structural Elements*, Singapore, Springer, 2004, pp. 1-14.

[3] S. Panthapulakkal, L. Raghunanan, M. Sain and K. Birat, Natural fiber and hybrid fiber thermoplastic composites, 2017.

[4] Broutman, L.J, B.D, Agarwal and K. Chandrashekhara, Analysis and Performance of Fiber Composites, NJ, USA: John Wiley and Sons: Hoboken, 2017.

[5] Nair, A.B and Joseph. R, "Eco-friendly bio-composites using natural rubber (NR) matrices and natural fiber reinforcements," in *Chemistry, Manufacture and Applications of Natural Rubber*, Cambridge UK, Woodhead Publishing: Sawston, 2014.

[6] T. Sathishkumar, S. Satheeshkumar and J. Naveen, "Hybrid fiber reinforced polymer composites—A review.," *J. Reinf. Plast. Comp,* vol. 33, pp. 454-471, 2014.

[7] R. Rahman, Zhafer Firdaus and S.P.S, "Tensile properties of natural and synthetic fiber-reinforced polymer," in *Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites and Hybrid*, Cambridge,UK, Woodhead Publishing: Sawston, 2019, pp. 81-102.

[8] M. Jawaid, M. Thariq and N. Saba, Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites, Cambridge, UK: Woodhead Publishing: Sawston, 2019.

[9] D. K. Rajak, D. D. Pagar, R. Kumar and C. Pruncu, "Recent progress of reinforcement materials: A comprehensive overview of composite materials," *J. Mater. Res. Technol.,* 2019.

[10] M. Ghalia and A. Abdelrasoul, "Compressive and fracture toughness of natural and synthetic fiber-reinforced," in *Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites and Hybrid Composites*, Cambridge, UK, Woodhead Publishing: Sawston, UK, 2019, p. 123–140.

[11] H. Abdellaoui, M. Raji, H. Essabir and R. Bouhfid, "Mechanical behavior of carbon/natural fiber-based," in *Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites and Hybrid*, Cambridge, UK, Woodhead Publishing: Sawston, UK, 2019, p. 103–122.

[12] A. Haim, "Stability of composite stringer-stiffened panels," in *Stability and Vibrations of Thin Walled Composite*, Cambridge, UK, Woodhead Publishing: Sawston,UK,, 2017, p. 461–507.

[13] D. Chung, "Introduction to carbon composites," in *Carbon Composites: Composites with Carbon Fibers,*, Elsevier Science: Amsterdam, The Netherlands, 2017, p. 88–160.

[14] B. Sreenivasulu, B. Ramji and M. Nagaral, "A review on graphene reinforced polymer matrix composites.," *Mater. Today. Proc,* p. 2419–2428., 2018.

[15] M. Saxena, A. Pappu, R. Haque and A. Sharma, "A. Sisal fiber based polymer composites and their applications.," in *Cellulose Fibers: Bio-and Nano-Polymer Composites*, Springer: Berlin/Heidelberg, Germany, 2011, p. 589–659.

[16] A. Shehzad, "Hemp fiber and its composites—A review," *J. Compos. Mater,* p. 973–986, 2011.

[17] C. W. Chin and B. F. Yousaf, "Potential of kenaf fibres as reinforcement for tribological applications," *Wear,* pp. 1550-1557, 2009.

[18] K. Huang, L. Q. N. Tran, U. Kureemun, W. S. Teo and H. P. Lee, "Vibroacoustic behavior and noise control of flax," *J. Nat. Fibers,* p. 729–743, 2019.

[19] S. Goutianos, T. Peijs, B. Nystrom and M. Skrifvars, "Development of flax fibre based textile reinforcements for Composite Application," *Appl. Compos. Mater.,* p. 199–215, 2006.

[20] D. Chen , C. Pi, Chen M, L. He, F. Xia and S. Peng, "Amplitude-dependent damping properties of ramie fiber-reinforced thermoplastic composites with varying fiber content," *Polym. Compos,* p. 2681–2689., 2019.

[21] Y. Du, N. Yan and M. T. Kortschot, "The use of ramie fibers as reinforcements in composites.," *Biofiber Reinf. Compos. Mater,* 2015.

[22] R. Arjmandi, A. Hassan, K. Majeed and Z. Zakaria, "Rice husk filled polymer composites," *Int. J. Polym. Sci.,* pp. 1-32, 2015.

[23] S. Das, A. K. Singha, A. Chaudhuri and P. Ganguly, "Lengthwise jute fibre properties variation and its effect on jute–polyester composite," *J. Text. Inst,* p. 1695–1702, 2019.

[24] J. A. Khan and M. A. Khan , "The use of jute fibers as reinforcements in composites," in *Biofiber Reinforcements in Composite Materia,*, Cambridge, UK, Woodhead Publishing: Sawston, UK, 2015, p. 3–34.

[25] Y. S. Munde, R. B. Ingle and I. Siva, "Investigation to appraise the vibration and damping characteristics of coir," *Adv. Mater. Process. Technol,* p. 639–650, 2018.

[26] D. Verma, A. K. Shandilya and A. Gupta, "Coir fibre reinforcement and application in polymer composites: A Review," *J. Mater. Env. Sci,* p. 263–276, 2013.

[27] A. Kılınç, C. Durmuşkahya and M. Ö. Seydibeyoğlu, Fiber Technology for Fiber-Reinforced Composites, izmir: Woodhead Publishing, 2017.

[28] B. K. and I. M.A, "Natural Fiber as a substitute to Synthetic Fiber in Polymer Composites:," *Research Journal of Engineering Sciences,* pp. 46-53, 2013.

[29] A. Bledzki and J. Gassan, "Composites reinforced with cellulose based fibres," *Progress in Polymer Science,* p. 221–274, 1999.

[30] M. Jacob, S. Thomas and K. Varughese, "Mechanical properties of sisal/oil palm hybrid fiber reinforced natural rubber composites," *Composites Science and Technology,* vol. 64, no. 7-8, pp. 955-965, 2004.

[31] S. Mishra, A. Mohanty, L. Drzal, M. Misra, S. Parija, S. Nayak and S. Tripathy, "Studies on mechanical performance of biofibre/glass reinforced polyester hybrid composites," *Composites Science and Technology,* pp. 1377-1385, 2003.

[32] L. Muhammad, M. N. M. Ansari, G. Pua, M. Jawaid and M. S. Islam, "A Review on Natural Fiber Reinforced Polymer Composite and Its Applications," *International Journal of Polymer Science,* p. 15, 2015.

[33] P. Kaushik, J. and K. Mittal, "Analysis of mechanical properties of jute fiber strengthened epoxy/polyester composites," *Journal of Engineering Solid Mechanics ,* pp. 103-112, 2017.

[34] S. B. Brahim and R. B. Cheikh, "Influence of fibre orientation and volume fraction on the tensile properties of unidirectional Alfa-polyester composite," *Composites Science and Technology,* pp. 140-147, 2007.

[35] A. K. V. S. Rao, N. S. V. Gupta and A. K. D S, "Mechanical Properties of Sisal/Coir Fiber Reinforced," in *IOP Conference Series: Materials Science and Engineering, Volume 149, conference 1*, Karnataka, 2016.

[36] G. Gastón Francucci, E. S. Rodríguez and A. Vázquez, "Experimental study of the compaction response of jute fabrics in liquid composite molding processes," *Journal of Composite Material,* pp. 155-167, 2011.

[37] A. Gunge, P. G. Koppad, M. Nagamadhu, S. Kivade and K. V. S. Murthy, "Study on mechanical properties of alkali treated plain woven banana fabric reinforced biodegradable composites.," *Compos. Commun,* p. 47–51, 2019.

[38] M. Elkington, D. Bloom, C. Ward, A. Chatzimichali and K. Potter, "Hand layup: Understanding the manual," *Adv. Manuf. Polym. Compos. Sci,* p. 138–151, 2015.

[39] M. R. M. Jamir, M. S. A. Majid and A. Khasri, "Natural lightweight hybrid composites for aircraft structural application," in *Sustainable Composites for Aerospace Applications*, Cambridge, UK, Woodhead Publishing: Sawston, UK, 2018, p. 155–170.

[40] A. S. Perna, A. Viscusi, A. Astarita, L. Boccarusso, L. Carrino, M. Durante and R. Sansone, "Manufacturing of ametal matrix composite coating on a polymer matrix composite through cold gas dynamic spray technique," *J. Mater. Eng. Perform,* p. 3211–3219, 2019.

[41] "Fibrous materials reinforced composites production techniques," in *Fibrous and Composite Materials for Civil Engineering Applications*, Cambridge, UK, Woodhead Publishing: Sawston, 2011, p. 191–215.

[42] J. Ervina, Z. A. Ghaleb, S. Hamdan and M. Mariatti, "Colloidal Stability of Water-based Carbon Nanotube Suspensions in Electrophoretic Deposition Process: Effect of Applied Voltage and Deposition Time.," *Compos. Part. A Appl. Sci,* pp. 1-10, 2018.

[43] J. Carruthers, "Vacuum Bagging Process Overview, Coventive Composites," 2018. [Online]. Available: https://coventivecomposites.com/explainers/what-is-vacuum-bagging/. [Accessed 8 April 2021].

[44] F. S. Awan, M. A. Fakhar, L. A. Khan , U. Zaheer, A. F. Khan and T. Subhani , "Interfacial mechanical properties of carbon nanotube-deposited carbon fiber epoxy matrix hierarchical composites," *Compos. Interface,* p. 681–699, 2018.

[45] P. Kandachar and R. Brouwer, "Applications of Bio-Composites in Industrial Products," in *ADVANCED FIBERS, PLASTICS LAMINATES AND COMPOSITES 2002 VOLUME 702*, Delft, 2001.

[46] S. Ashworth, J. Rongong, P. Wilson and J. Meredith, "Mechanical and damping properties of resin transfer moulded jute-carbon hybrid composites," *Compos. Part. B-Eng,* p. 60–66, 2016.

[47] J. Flynn, A. Amiri and C. Ulven, "Hybridized carbon and flax fiber composites for tailored performance.," *Mater. Des,* p. 21–29, 2016.

[48] J. Zhang, A. A. Khatibi, E. Castanet, T. Baum, Z. Komeily-Nia, P. Vroman and X. Wang, ". Effect of natural fibre reinforcement on the sound and vibration damping properties of bio-composites compression moulded by nonwoven mats.," *Compos. Commun,* p. 12–17, 2019.

[49] M. Farid, A. Purniawan, A. Rasyida, M. Ramadhani and S. Komariyah, "Improvement of acoustical Characteristics: Wideband bamboo based polymer composite," in *Iop Conf. Ser. Mater. Sci. Eng.*, 2017.

[50] G. Belingardi and E. G. Koricho, "Design of a composite engine support sub-frame to achieve lightweight vehicles.," *Int. J. Automot. Compos,* 2014.

[51] O. Boegler, U. Kling, D. Empl and A. Isikveren, "Potential of sustainable materials in wing structural design," in *In Proceedings of the Deutscher Luft- und Raumfahrtkongress*, München, Germany, 2014.

[52] S. Fan, C. Yang, L. He, Y. Du, W. Krenkel, P. Greil and N. Travitzky, "Progress of ceramic matrix composites brake materials for aircraft application," *Rev. Adv. Mater. Sci,* p. 313–325, 2016.