FINITE ELEMENT ANALYSIS OF JUTE AND BANANA FIBERS REINFORCED COMPOSITES FOR MECHANICAL PROPERTIES

Dissertation-II

Submitted in partial fulfillment of the requirement for the award of degree

Of

Master of Technology

IN

MECHANICAL ENGINEERING

By

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Under the guidance

Of

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DEPARTMENT OF MECHANICAL ENGINEERING
LOVELY PROFESSIONAL UNIVERSITY

TOPIC APPROVAL PERFORMA

School of Mechanical Engineering

Program : P178::M.Tech. (Mechanical Engineering) [Full Time]

COURSE CODE : MEC601 **REGULAR/BACKLOG :** Regular **GROUP NUMBER :** MERGD0018

Supervisor Name : Sumit Shoor **UID :** 14602 **Designation :** Assistant Professor

Qualification : ____________________ **Research Experience :** ____________________

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SPECIALIZATION AREA : Design **Supervisor Signature:** ________________

PROPOSED TOPIC : Analysis of green composites using Finite element analysis and compare result experimentally

	Qualitative Assessment of Proposed Topic by PAC	
Sr.No.	**Parameter**	**Rating (out of 10)**
1	Project Novelty: Potential of the project to create new knowledge	6.75
2	Project Feasibility: Project can be timely carried out in-house with low-cost and available resources in the University by the students.	6.75
3	Project Academic Inputs: Project topic is relevant and makes extensive use of academic inputs in UG program and serves as a culminating effort for core study area of the degree program.	7.00
4	Project Supervision: Project supervisor's is technically competent to guide students, resolve any issues, and impart necessary skills.	6.75
5	Social Applicability: Project work intends to solve a practical problem.	6.75
6	Future Scope: Project has potential to become basis of future research work, publication or patent.	7.00

PAC Committee Members		
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Final Topic Approved by PAC: **Finite element analysis of green composites for mechanical properties.**

Overall Remarks: Approved (with minor changes)

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Approval Date: 03 Oct 2016

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ABSTRACT

Natural fiber biocomposites are gaining popularity as an environmentally friendly alternative and solution to the problems of non-degrading and energy consuming synthetic fiber composites. Research on single natural fiber composites mainly focuses on advancing the physical and chemical properties like improper wettability, insufficient adhesion and high water absorption. However, hybridization in composites design is adapted to attain improved mechanical properties.

The present study focuses on (i) fabricating hybrid biocomposites of jute and banana fibers using hand layup technique, (ii) evaluating the mechanical and physical properties of the fabricated hybrid biocomposites, (iii) evaluating the mechanical properties using Finite Element Analysis software like ANSYS and, (iv) comparing the experimental results and ANSYS results for the mechanical properties.

The hybrid biocomposites have fabricated with four layers of fibers aligned at $90^0/45^0/-45^0/90^0$ directions and varying ratios of resin and hardener (100:10 and 100:20). The fiber volume fraction for all the composites have maintained equal to 25.92%. It has observed that, for the same fiber volume fraction and similar fiber orientations, the hybrid biocomposites fabricated with resin and hardener ratio of 100:10 shows maximum properties.

Theoretical rules of mixture and hybrid rules of mixture have used to estimate the orthotropic elastic properties of the hybrid biocomposites. Furthermore, these properties have used to evaluate the mechanical properties of the hybrid biocomposites in ANSYS. Comparison between the experimental results and ANSYS results for the mechanical properties shows good agreement with each other.

ACKNOWLEDGEMENT

This research work consists of vast steps and dedication. In completion of this work, many individual have supported. I am very grateful that they gave their precious time and support. Hence, I would like to extend my sincere gratitude to all of them.

I am highly indebted to **Mr. Sumit Shoor (Assistant Professor)**for his guidance and constant supervision as well as for providing necessary information regarding my thesis work and for their support in discussing about the selected topic.

I am also thankful to **Mr. Gurpreet Singh Phull**, (HOS) School of Mechanical Engineering, Lovely Professional University, Punjab.

I would like to thank all the staff members of School of Mechanical engineering who have been very patient and co-operative.

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CERTIFICATE

I hereby certify that the work being presented in the dissertation entitled "FINITE ELEMENT ANALYSIS OF JUTE AND BANANA FIBERS REINFORCED COMPOSITES FOR MECHANICAL PROPERTIES" in partial fulfillment of the requirement of the award of the Degree of master of technology and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of Mr. Sumit Shoor (Assistant Professor) Department of Mechanical Engineering, Lovely Professional University. The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

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The external viva-voce examination of the student was held on successfully ______________

Signature of Examiner

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ABBREVIATIONS

APDL	ANSYS parametric design language
BD	Bidirectional
CLT	Classical Lamination Theory
CMCs	Ceramic Matrix Composites
CMT	Compression-molding technique
CNSL	Cashew Nut Shell Liquid
CS	Compressive Strength
DOF	Degree of Freedom
E	Young's Modulus
E_{11}	Young's Modulus in longitudinal direction
E_{22}	Young's Modulus in transverse direction
E_{Bf}	Young's Modulus of Banana fiber
E_{Jf}	Young's Modulus of Jute fiber
E_m	Young's Modulus of matrix
FEA	Finite Element Analysis
FEM	Finite Element Method
FM	Flexural Modulus
FS	Flexural strength
G	Specific gravity of fibers
G_{12}	In-plane shear modulus
G_{23}	Transverse shear modulus
G_m	Shear modulus of matrix
GUI	Graphical User Interface
HBCs	Hybrid Biocomposites
HGCs	Hybrid Green Composites
HLT	Hand Lay technique
HPT	Hot press technique
HROM	Hybrid Rules of Mixture
IMT	Injection molding technique
IS	Impact strength
M_1	Mass of empty Pycnometer
M_2	Mass of Pycnometer +fibers
M_3	Mass of Pycnometer + fibers + water
M_4	Mass of pycnometer + water
MMCs	Metal Matrix Composites
M_s	Weight of dry samples
M_w	Weight of wet samples
NFs	Natural fibers

P.E	Potential Energy
PLA	Poly lactic acid
PMCs	Polymer Matrix Composites
PVA	Poly vinyl alcohol
ROM	Rules of Mixture
RTMT	Resin transfer molding technique
SFs	Synthetic fibers
SS	Shear Strength
TM	Tensile Modulus
TS	Tensile strength
TSET	Twin-screw extrusion technique
UD	Uni-directional
V	Volume of the composite sample
VARTMT	Vacuum-assisted resin transfer-molding technique
V_{Bf}	Volume fraction of Banana fiber
V_f	Volume fraction of fiber
V_{Jf}	Volume fraction of Jute fiber
V_m	Volume fraction of matrix
W	Weight of the composite sample
W_f	Weight of the fiber

LIST OF SYMBOLS

ρ_f *Density of fiber*

ρ_w *Density of water*

ρ_J *Density of Jute fiber*

ρ_B *Density of Banana fibe*

ρ_m *Density of* ¿

σ_t *Tensile Strength*

σ_{fl} *Flexural Strength*

ϑ_{12} *Major Poisson's ratio of composites*

ϑ_{23} *Minor Poisson's ratio of composites*

ϑ_m *Poisson's ratio of* ¿

ϑ_{Jf} *Poisson's ratio of Jute fiber*

ϑ_{Bf} *Poisson's ratio of Banana fiber*

TERMINOLOGY

Composite Materials	A composite material or Composition of Materials is a material made from two or more constituents materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from individual components.
Fiber-reinforced Composite	It is a composite material made of matrix (biopolymer of synthetic polymer) reinforced with synthetic fibers like glass fiber, carbon fiber, etc.
Bio-composites	Bio-composite is a composite material formed by a matrix (resin) and a reinforcement of natural fibers.
Green Composites	It is a composite material made of biopolymer reinforced with natural fibers.
Hybrid Biocomposites	These are biocomposites comprise of matrix and reinforcement of two or more than two natural fibers.

Fiber Volume Fraction Fiber volume ratio or fiber volume fraction, is the percentage of fiber volume in the entire volume of a fiber-reinforced composite material.

Tensile Strength Tensile strength is the ability of the material to withstand a pulling (tensile) force.

Flexural Strength flexural strength, also known as modulus of rupture, bend strength, or transverse rupture strength is a material property, defined as the stress in a material just before it yields in a flexural test.

Impact Strength Impact strength is the capability of the material to withstand a suddenly applied load and is express in terms of energy.

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CHAPTER- 1

INTRODUCTION

1.1 Overview:

Materials are the substance or substances from which the things are prepared or composed synthetically or naturally e.g. ceramics, glass, metals, metamaterials, plastics, etc.

Composite materials are the advanced types of materials. Composite materials are the combination of several materials with varieties of properties combined together to produce a new material with advanced properties. The individual materials remain distinct within the new material. Fiber reinforced composites are the combination of fibers and resin matrix.

Composite materials are preferred as these are stronger, lighter or less expensive when compared with individual materials. Due to these reasons, composite materials are replacing individual materials in the engineering and construction applications.

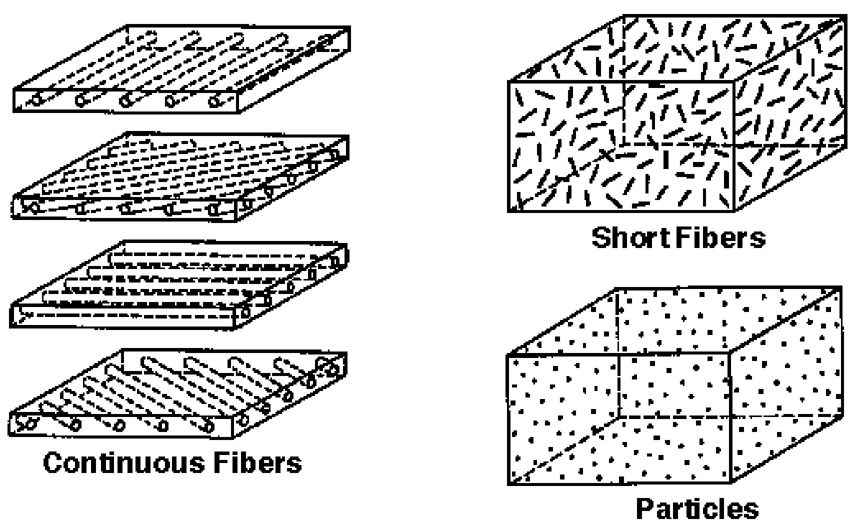


Figure 1.1: Fiber-Reinforced Composites [4].

Classification of composite materials mainly depends upon the class of the reinforcement and the kind of the matrix used. The reinforcement used can be either synthetic fibers or natural fibers and the matrix used can be either synthetic resin or bio resin based on plant oil. Depending on the combinations of the fiber-resin used, it is easy to conclude whether the composite material is non-degradable, partially degradable or completely degradable. Sometimes classification also depends upon the geometry of the reinforcement. It explains the size of the fibers, orientation and fibers direction arrangement. The chapter of review of literature gives the detail explanation on the classification of composite materials.

1.2 History of composite materials:

Humans have made the use of composite materials from past centuries. The earliest uses of composite materials have made in 3400 B.C. when ancient Mesopotamians produced plywood by combining wood sticks at different orientations. Egyptians used mummy made from tightly fitting layers of linen or papyrus fastened together in many thicknesses and generally soaked in plaster, around 2100-2000 B.C. Around in 1200 A.D., Mongols invented the first composite powerful bow made from cattle tendons, wood, horns, bamboo, bone and silk joined with natural resin.

In the early 1900s, plastics like vinyl polystyrene, phenolic and polyester were formulated which proved to be better in performance compared with resins obtained naturally. Nevertheless, these plastics alone were not able to provide sufficient strength and rigidity. Hence, there was the need of the reinforcements for their better strength and rigidity. Owens corning in the year 1935, announced the first glass fibre, fiberglass which when combined with polymers produces inconceivable lightweight strong structure. In 1940s, during World War II, greatest investments in the composites have nurtured. World War II guided FRP industry from scientific experiments into genuine production. Engineers discovered that fiberglass composites are light in weight and strong. This made their use in the military aircraft applications. Fiberglass has also used for radar domes since these were transparent to the radio frequencies.

By the end of World War II, the entire automobile body has fabricated from composite and analyzed. This led to the evolution of the first generation Chevrolet Corvette in 1953, which has fabricated using fiberglass impregnated with resin and shaped in counterpart metal dies.

In early 1950s, Brandt Goldsworthy, the father of modern composites, invented fiber-reinforced laminates and pultrusion process. Other processes like vacuum bag molding and large-scale filament winding processes have also developed. Industries today use pultrusion process for manufacturing continuous lengths polymer structure having constant cross sections. In 1961, carbon fibers have invented. Carbon fibers when combined with synthetic resins produced improved mechanical properties resulting in wide applications in different fields. Stephanie Louise Kwolek, an American chemist invented synthetic fiber of high strength and stiffness aramid fiber called as Kevlar. During 1970s, the composites industry began to grow.

In mid 1990s and 2000s, manufacturing and construction industries began to use composites owing to their exceptional properties and cost effectiveness.

1.3 Manufacturing processes of fiber reinforced composite materials:

The manufacturing of the composites follows advanced manufacturing techniques, which allows the fabrication of the composites of intricate shapes. These techniques are as follows.

1.3.1. Hand lay-up technique (HLT):

Fibers layered in the shape of unidirectional woven mat, bi-directional woven mat or randomly chopped in the mold followed by resin impregnation with the assist of rollers and brushes or a roller type impregnator. The impregnation pushes the resin inside the fabric. Curing of the fabricated laminates takes place under standard atmosphere. Mixture of resins like polyester, vinylester, epoxy, phenolic and any kind of fiber material can be use without any restrictions.

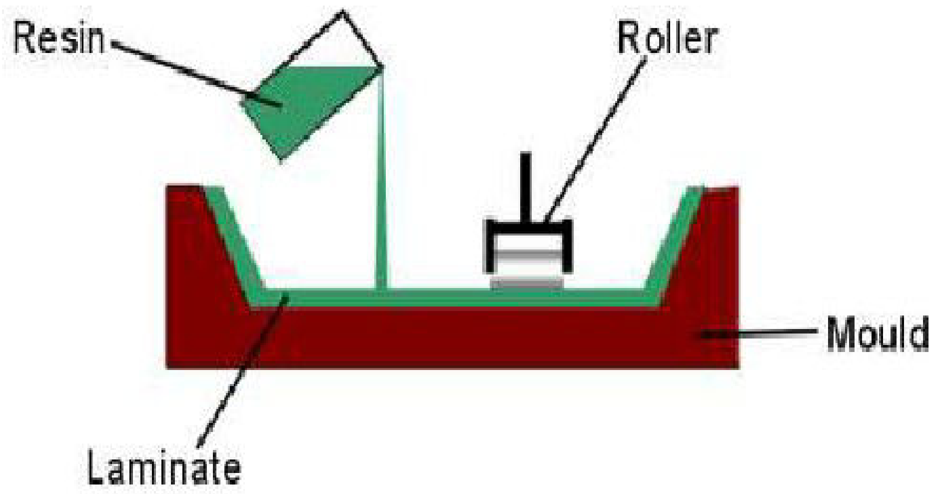


Figure 1.2: Hand Lay-up Technique [4].

1.3.2. Vacuum-assisted resin transfer-molding technique (VARTMT):

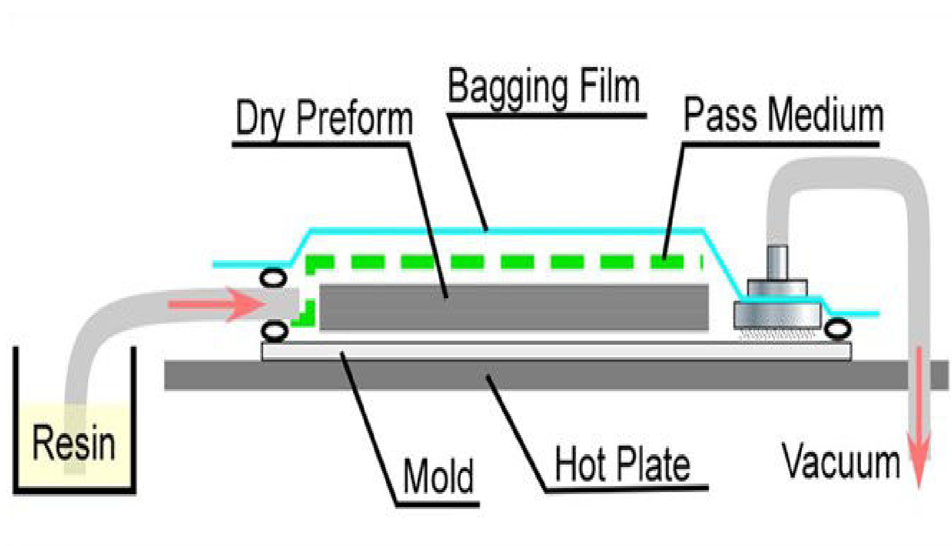


Figure 1.3: Vacuum-Assisted Resin Transfer-Molding Technique [4].

VARTMT is a shut mold composite producing technique. It is a variety of Resin Transfer Molding technique (RTMT) with its top section modified with a vacuum pack, which uses vacuum for the movement of resin to flow into the fibers that have placed inside the mold. After the impregnation of the resin into the fibers, curing of the composites takes place at room temperature followed by post curing.

1.3.3. Compression molding technique (CMT):

CMT is a shut mold composite producing process that utilizes coordinated metal molds with the use of external force. In this technique, mixture of fibers and the resin is arrange in the open form hole, the form is shut, and merging force is applied. The force stays on the mold all through the cure cycle, which for the most part happens in oven. The effect of pressure and heat creates a composite part with minimum void content and high fiber volume fraction about net shape complete component.

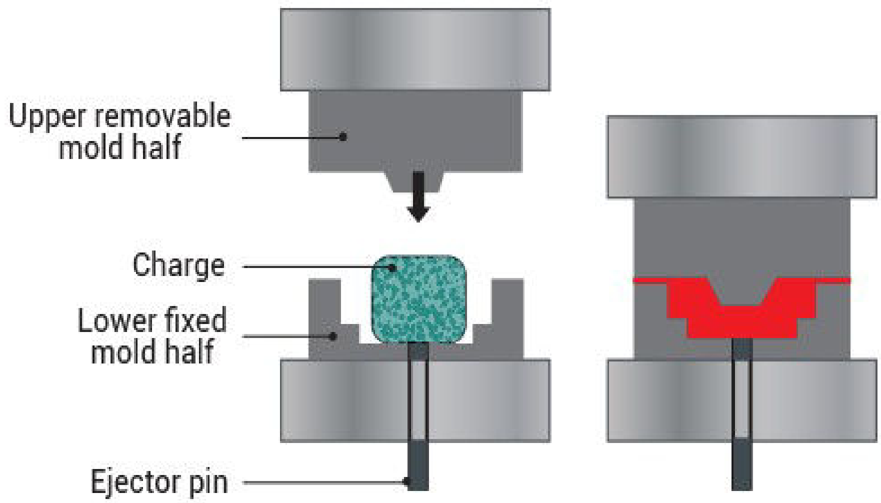


Figure 1.4: Compression-Molding Technique [4].

CMT frequently yields composite parts that have the ideal mechanical properties conceivable from the specific blend of constituent materials.

1.3.4. Hot press technique (HPT):

HPT is use for molding fiber-reinforced thermoplastics. The material, for the most part a woven mat, is a blend of plastic fibers and reinforced fibers. When it is heated, plastic fibers liquefy and spread through the reinforcement. The fibers mat according to the dimensions are arrange one after another until the required laminate thickness is obtain. Further, the mold is heated (380-400 C), and squeezed into shape. For setting the shape, it is subjected to force (0.3-1 MPa) is for around 5 minute. The composite part is properly cool before removing from the mold.

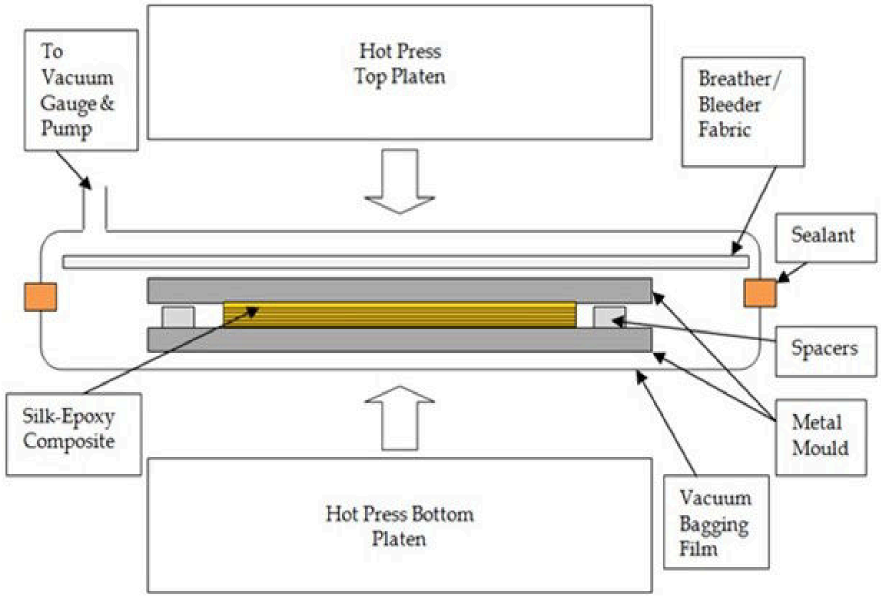


Figure 1.5: Hot Press Technique [4].

1.3.5. Twin-screw extrusion technique (TSET):

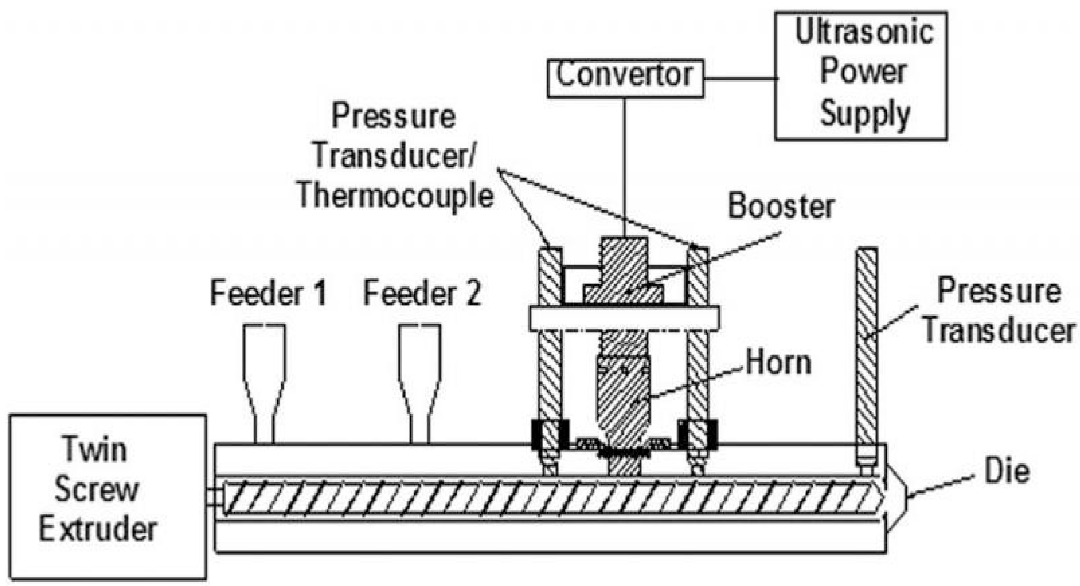


Figure 1.6: Twin-Screw Extrusion Technique [4].

TSET comprise of two firmly coordinated screws rotating in an eight-formed barrel, have used as a part of plastic industry for applications going from liquefying and pumping of a polymer to aggravating, blending, and devolatilization and for artificially responding the constituent materials. The intermeshing area between two screws, which gives a twin-screw extruder its one of a kind capacities, for example, fabulous blending abilities, likewise makes it hard to foresee the execution of a twin-screw extruder, and to outline an extruder given the execution necessities. Because of the many-sided quality of the stream and absence of consistency, the screws for twin-screw extruders are commonly accessible as tradable components. By investigating different achievable blends, this secluded outline permits suitable determination of the screw components as per the required stream attributes.

1.3.6. Injection molding technique (IMT):

IMT is the closed molding technique. The procedure is reasonable for both thermoplastic and thermosetting polymer based short fiber reinforced composites. Fibers and polymer are properly mix physically and sustained into the hooper. The blend goes into the heated barrel where softening of the material happens because of heating from the barrel. As the screw pivots, blending of fiber and resin takes place, which push the combination near the merging area of tank where it infuses from nozzle into the mold cavity with high pressure.

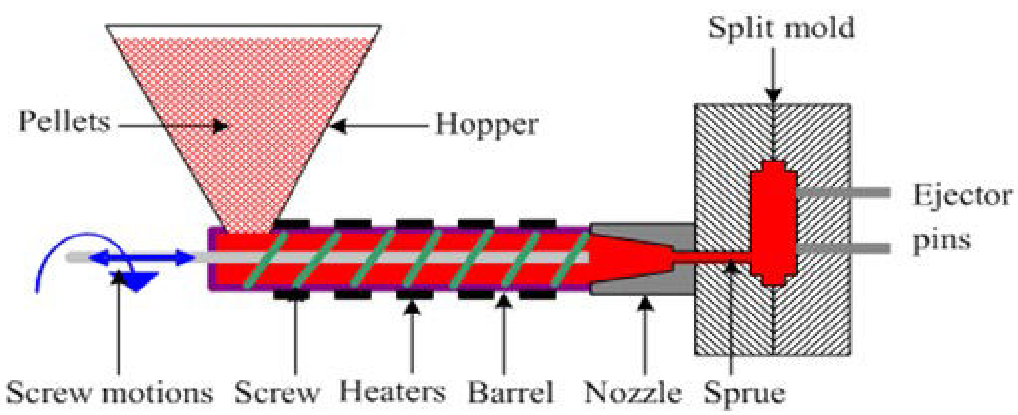


Figure 1.7: Injection Molding Technique [4].

1.4. Types of Composite Matrix Materials:

1.4.1. Ceramic Matrix Composites (CMCs):

CMCs are the subtype of composite materials. They comprise of ceramic fibers ingrained in a ceramic matrix, hence producing a ceramic fiber reinforced ceramic material (CFRC). Both the fiber and the matrix element can comprise of any ceramic materials. CMCs have designed to overcome the real inconveniences, for example brittleness, lower fracture toughness and finite resistance to thermal shock.

1.4.2. Metal Matrix Composites (MMCs):

MMCs comprise of either a metal and different material or metal. The purpose of doing so is to improve the wear resistant and strength of the material. MMCs are preferred in structural or high-temperature application. For structural application, the matrix material is comprised of lighter metals like aluminum. For high-temperature applications, cobalt and nickel alloys are commonly preferred. MMCs are fire proof, work in an extensive variety of temperatures, resistant to water absorption and have better thermal and electrical conductivity.

1.4.3. Polymer Matrix Composites (PMCs):

PMCs are classified into three sub categories that are thermoset, thermoplastic and rubber. A polymer has large molecular weight comprise of repeated structural units joints together by chemical covalent bonds. PMCs comprise of reinforcing phase such as fibers, sheets or particles ingrained in matrix phase. They are less expensive and less dense compared to CMCs and MMCs. They have good resistance to corrosion and electric current.

Table 1.1: Types of Composite Matrix Materials

Sr.No	Types	Reinforcing Phase	Matrix Phase
1	CMCs	Ceramic fiber	Ceramic matrix
2	MMCs	Metal	Metal or different material
3	PMCs	Fibers, sheets or particles	Thermosets, thermoplastics and rubber

1.5 Advantages of fiber-reinforced composites:

1. Light Weight: Composite materials are up to 30% to 40% light in weight contrasted with different metals with comparable or more enhanced mechanical properties.
2. High Strength: Composite materials indicate higher quality in contrast with the metals. Composites accomplish their quality when settled inside epoxy matrix.
3. Easy to Shape: Composites can be mold into confounded shapes at relatively low cost. This property permits designers to utilize composites into extensive variety of utilizations.

4. Integration of Functions: With the use of composite materials, numbers of stages of fabrication for the part is reduce into one single stage.
5. Corrosion Resistance: Composites remains unaffected due to chemical, temperature and ecological conditions. This facilitates composite to use for open-air exposures, substance handlings and for other ecological administrations.
6. Durability: Composite structures demonstrate great long life expectancy.
7. Cost Saving: Composites have low weight and high mechanical properties which facilitates to use in extensive variety of applications, in this way diminishes assembling, delivery and maintenance cost when contrasted with different metals.

1.6. Applications of fiber-reinforced composites:

1. Building and construction : partition panels, false ceiling, walls, floors, frames for windows and doors, tiles
2. Containers : post boxes, grain containers, etc
3. Furniture : chair, table, bed, cupboard
4. Transportation : interior of automobile, railway coach, boat, airplane
5. Toys
6. Electrical appliances : Electric boards
7. Casing of different materials
8. Sports equipments
9. Packaging

CHAPTER- 2

SCOPE OF THE STUDY

Composite research is captivating contribution from governments, manufacturers and research institutes. These investments will be utilize in finding new fibers and resins to generate even more better applications of composite materials. Composites hold high structural properties and are presently catching broad application area. The foremost disadvantage in using these composites is that these are not biological degradable in nature and causes environmental and global catastrophe. Furthermost, environmentally friendly composites are on the way being develop. These composites are composed of matrix and a reinforcement of natural fibers and are partially or completely biodegradable.

Research on single natural fiber reinforced biocomposites mainly focuses on improving the physical and chemical properties of the composites. In order to improve the mechanical properties of the natural fiber reinforced biocomposites, the method of hybridization is adapted.

The present research aimed in developing hybrid biocomposites composed natural fibers reinforced with liquid epoxy resin. Furthermore, the mechanical properties of the fabricated hybrid biocomposites will be determined.

Finite Element Method (FEM) software such as ANSYS APDL 16.2 will be use for the simulation of the evaluated mechanical properties of the hybrid biocomposites. FEM has added advantages such as time saving since it help in analyzing the properties of the material using FEM software without going for actual experimentations.

In future, synthesize of the composites will be as per the integrated design processes which will result in the engineering optimization and construction applications.

CHAPTER- 3

OBJECTIVES OF THE STUDY

The present investigation aimed to evolve hybrid biocomposites comprise of alkali treated unidirectional jute and banana fibers reinforced liquid epoxy resin and study its mechanical properties. The principle objectives are as follows:

1. To fabricate hybrid biocomposites from alkali treated unidirectional jute and banana fibers oriented in the directions $90^0/45^0/-45^0/90^0$ using the hand lay-up procedure with varying resin and hardener ratios.
2. To evaluate experimentally the mechanical properties of the fabricated hybrid biocomposites such as:
   i. Tensile strength
   ii. Flexural strength
   iii. Impact strength
3. To evaluate physical properties such as :
   i. Hardness
   ii. Water absorption test
4. To evaluate the orthotropic elastic constants of the fabricated hybrid biocomposites using theoretical rules of mixture and hybrid rules of mixture.
5. To analyze the mechanical properties of the hybrid biocomposites through simulation using FEM software like ANSYS APDL 16.2
6. To compare the experimental results and ANSYS APDL results.

CHAPTER- 4

REVIEW OF THE LITERATURE

This chapter reviews the outcome of research work by various researchers in the area of refining the mechanical properties of the natural fibers composites and the methods of surface modification of natural fibers. The chapter also discusses the classification of the composites in detail.

A composite material that is "Composition of Materials" consists of reinforcing phase like fibers, particles or sheets ingrained in the matrix phase. The reinforcing material is the main load-carrying member. The matrix phase holds the reinforcing material in the defined position and transfer the load between them. It also protects the reinforcing materials from damage throughout the composite processing. Compared to the reinforcing phase, the matrix phase is ductile and hence is the source of composite toughness. Combination of these phases evolves a new material with advanced properties than the individual ones.

Composite materials are reliable, have improved mechanical properties per unit weight and their modern manufacturing techniques allows manufacturer to fabricate large and complex shapes components [1].

4.1. Classification of composite materials:

Composite materials are of the type synthetic fiber-reinforced polymer composites and natural fiber-reinforced or biocomposites. Fiber-reinforced composites have practiced in engineering and other industrial applications owing to their either comparable to or better properties in contrast with conventional materials [2].

Furthermost, fiber-reinforced resin-matrix composite materials with high strength and high stiffness are gaining popularity in weight delicate applications like aircrafts and other space vehicles, automotive, marine and construction industries [3, 4].

Biocomposites have extensively used in making body parts of the automobile [5]. Synthetic fibers used for reinforcing includes carbon, glass, aramid, Kevlar, boron, etc.

4.1.1. Synthetic fibers (SFs) reinforced polymer composites:

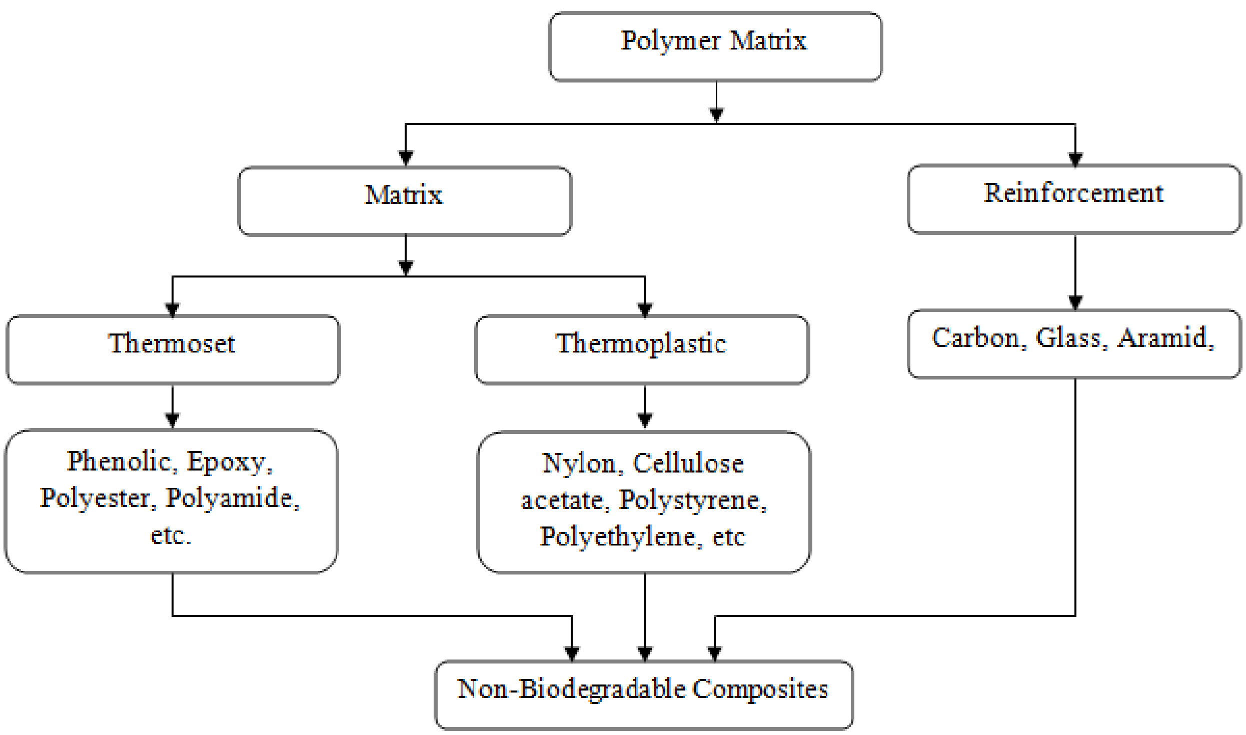


Figure 4.1: Constituents used in synthetic fibers composites

SFs reinforced polymer composites are the blend of SFs and synthetic resin polymer matrix. These composites hold high structural properties and presently catching broad application area. The foremost disadvantage in using these composites is that these are not biological degradable in nature and causes environmental and global catastrophe. This has given an idea for the development of eco-friendly bio-composites.

Furthermore, research is focus on replacing synthetic fibers with natural fibers owing to their biological degradation.

4.1.2. Biocomposites (BCs) or natural fibers (NFs) composites:

The BCs incorporate (NFs) reinforced polymer matrices from both non-renewable [5] and renewable resources. BCs are either partially biodegradable or completely biodegradable.

NFs when blended with non-biodegradable synthetic resin produce partially degradable composites called as BCs. For the composites to be completely biodegradable in natural, NFs are blend with biodegradable resin like poly lactic acid (PLA), poly vinyl alcohol (PVA), plant based oil resins, etc. NFs reinforced with biopolymers are termed as 'Green Composites' (GCs). NFs for reinforcing include wood fibers and non-wood fibers like jute, hemp, flax, sisal, banana, pineapple, sugarcane, etc.

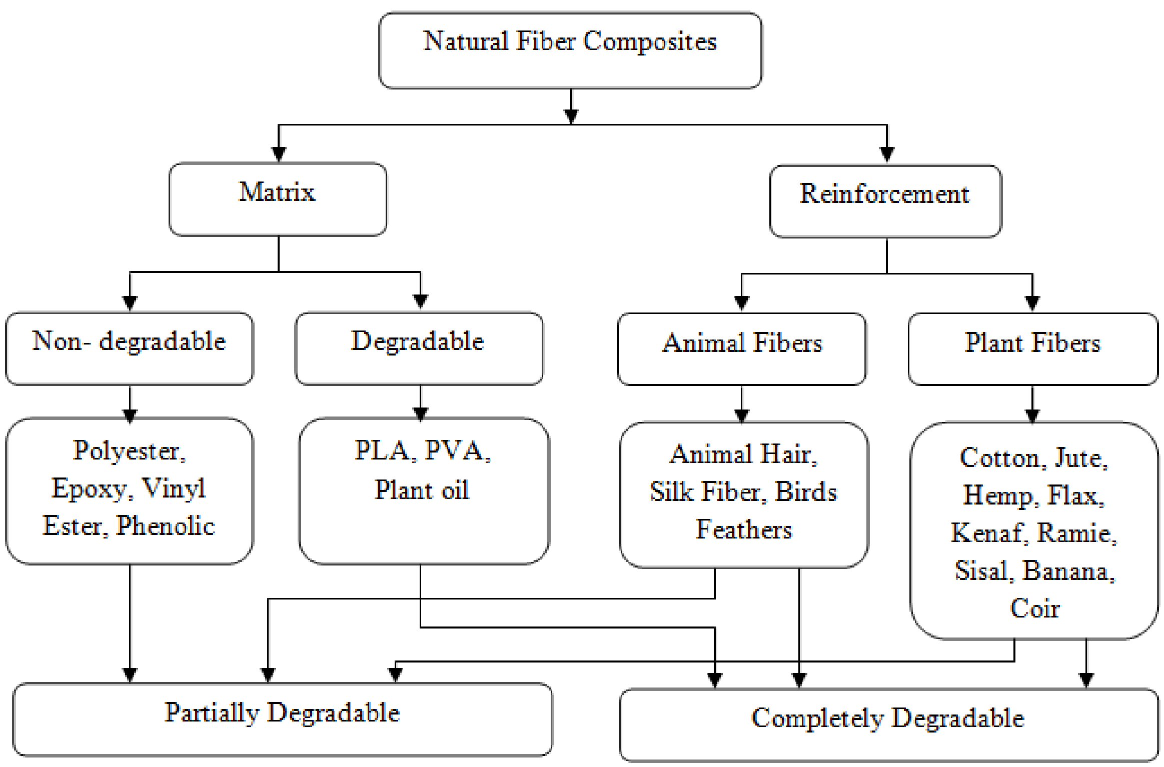


Figure 4.2: Constituents used in natural fibers composites.

Nowadays, NFs are gaining popularity over SFs as reinforcement in polymers since they have exceptional properties such as comparable high specific strength [6], renewability [7], eco-efficiency [8], non-abrasive nature [9], low energy consumption [10], low density [11], reduced tool wear [12] , reduced cost [13], good thermal properties [14], light weight [15] and environmentally friendly [5]. The only major disadvantage in the use of NFs is their relatively poor interface with the matrix and vey less moisture resistance, which greatly affects the final composite properties [16].

There are many studies and works based on the various types of NFs and their combinations reinforced biodegradable GCs present in the literature [6, 17, 18, 19]. These days, automobile industries have shown their interests in the utilization of BCs. These include bast fibers like jute [19, 20, 21, 22], ramie [23], hemp [24], flax [25] and kenaf [20, 26, 27], leaf fibers like sisal [28, 29, 30], pineapple [31] and banana fibers [32, 33, 34]. NFs also find their applications in construction, packaging, etc.

The widely used NFs for reinforcements in GCs or BCs are the bast fibers like flax, jute, hemp, sisal, kenaf and banana fibers.

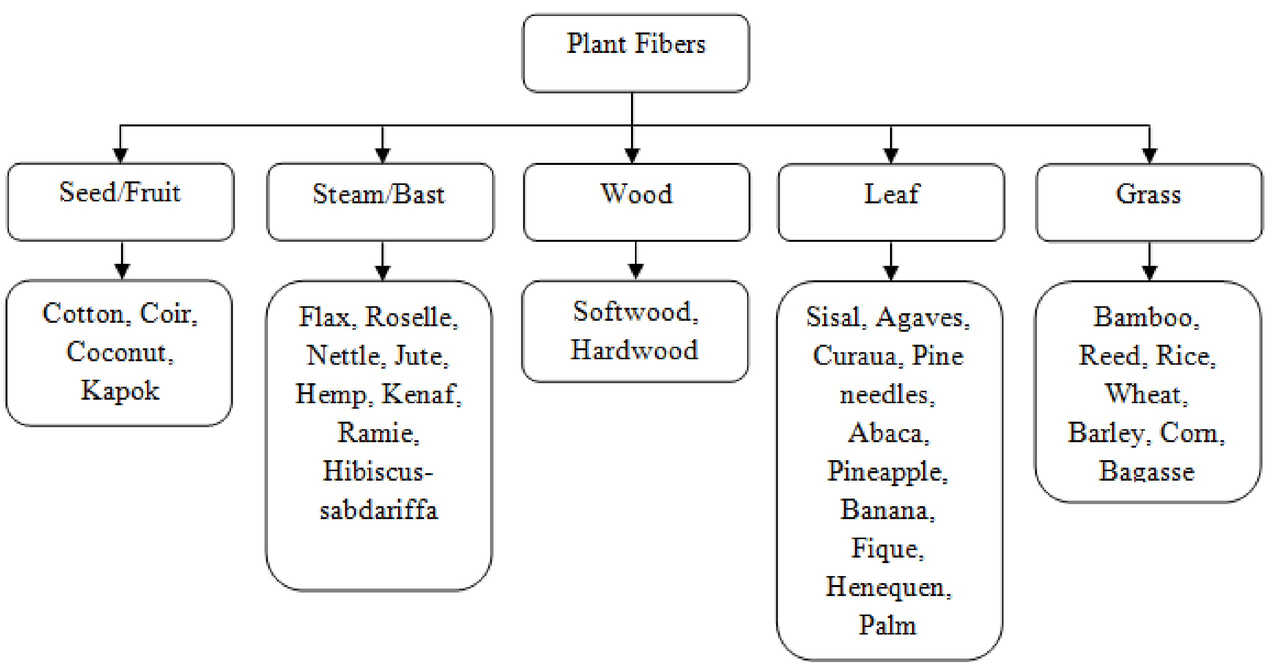


Figure 4.3: Plant fibers classification.

Compared to all these NFs, jute fibers turn out as promising fibers owing to its better toughness and aspect ratio [35] and are the second mostly produced cellulose fiber in the world [36].Jute is a substantial bast fiber with numerous advantages. Jute fibers have low density, great specific properties and eco-friendly [37, 38, 39, 40, 41, 42]. Jute fibers are available in plenty [13] and comparatively easy to transport. Jute products are cheap and being biodegradable, they are absorbed completely in soil and supplies good nourishment. Cellulose is the principle ingredient of jute and it does not release any harmful gases in the environment on its combustion. Jute composites are cheaper to fabricate with much higher surface finish comparatively with different manufacturing processes [43].

Banana fiber is another important bast fiber with number of advantages. Similar to the jute fibers, banana fibers has low density, great specific properties and eco-friendly [38, 39, 40, 41, 42, 44] and are available in plenty [13]. Banana fibers modified with alkali solution shows good adhesion with epoxy resins and enhanced the mechanical properties of the final composites [15]. The overall mechanical properties of the jute fiber BCs improve when hybridized with banana fibers [44].

Table 4.1: Properties of natural fibers in contrast with synthetic fibers [5, 45, 12, 16].

Sr. No.	Natural Fibers	Density (g/cm^3)	Elongation (%)	Tensile Strength (MPa)	Young's Modulus (GPa)
1	Cotton	1.5-1.6	7.0-8.0	400	5.5-12.6
2	Jute	1.3	1.3-1.8	393-773	26.5
3	Hemp	1.47	1.8-4.0	690	70
4	Flax	1.5	1.9-3.2	500-1500	27.6
5	Kenaf	1.45	1.5-1.6	930	53
6	Ramie	1.5	3.6-3.8	400-938	61.4-128
7	Sisal	1.5	1.5-2.5	511-635	9.4-22
8	Banana	0.75-0.9	4.1	180-430	23
9	Coir	1.2	3	593	4.0-6.0
10	E-glass	2.5	0.5	2000-3500	70
11	S-glass	2.5	2.8	4600	86

NFs can be blend with synthetic polymers as well as biopolymers. Biopolymers like PVA, PLA, plant oil, etc. are use in the form of matrices for the fully biodegradable composites. Plant oil resins such as soybean oil and cashew nut shell liquid resin have varieties of applications. Other than plant oil, lignin and proteins also serves as a raw renewable materials source in making biopolymers due to their high performance and abundantly available [46,47,48,49,50,51,52].

4.2. Chemical treatment of Natural Fibers:

Since, NFs possesses hydrophilic nature**,** it leads to poor water absorption resistance and low interfacial properties among the fibers and matrix. Chemical treatment of the NFs improves these interfacial properties. Chemical treatment examines better adhesion of NFs among the polymer matrix.

Alkali treatment or mercerization is widely used treatments of the NFs [55]. Alkali used has two objectives. It reacts with the hydroxyl groups in cellulose and with the functional groups in the matrix [56]. It causes the hydrogen bonding to break in the cellulose structure and increases the roughness of the surface [55]. The composites fabricated with alkali modified jute fibers and banana fibers with 5% NaOH have improved mechanical properties in contrast with untreated fibers [37, 39, 44, 57, 58, 59].

Alkali treatment eliminates the lignin and hemicelluloses present in the fibers and also lower the twist in the fibers thereby increasing molecular orientation and hence, increase the elastic modulus of the fibre [19, 60, 61, 62]. Improvement of interfacial bonding is essential in strengthening the mechanical properties of the final composite [37, 39, 44, 57, 58, 59, 63, 64]. Alkaline treatment reduces defects in the fibers, decrease moisture absorption and produce finer fibers [37, 39, 44, 57, 58, 59].

4.3. Finite Element Analysis (FEA):

Fiber-reinforced composites comprise of fiber and matrix phases. The mechanical properties of the composites greatly relay upon the properties of the fibers and the matrix. The properties of the composites also depend upon microstructure like fiber array, fiber volume fraction and fiber array. Micromechanical models have utilized to anticipate the properties beginning from the characteristic properties and their constituents. These models validates that the fiber strength is not effectively utilize due to poor fiber matrix interfacial bonding and fiber length.

S. Rao et al., 2012 [97] implemented FEA to determine flexural strength of the sisal fiber composite panels. They observed that the experimental results and the FEA results were in good agreement with each other.

I. Balac et al., 2012 [99] studied FEA of particulate composites. They constructed a 3D FCC model of particulate composite with porous matrix and compared with theoretical models. The FEA results found to be matching with the theoretical ones.

L. José et al., 2012 [100] employed FEA to determine the properties of uni-directional sisal and banana fibers BCs. They determined the tensile strength of the BCs using two-dimensional (2D) model and three-dimensional (3D) model. They stated that FEA could help to evaluate the mechanical properties of uni-directional NFs reinforced BCs.

The curing behavior of randomly oriented hemp fiber green composites was determined by T. Behzad and M. Sain, 2007 [103] considering the transient heat transfer analysis and cure kinetics. They employed FEA using MATLAB coding to validate the experimental results.

The assumptions used for the analysis have reported in the literature [96-103]

1. Fibers are not permeable.
2. The material property for individual material is treated same in all the direction and that the material is isotropic.
3. Fibers have uniform properties and diameter throughout the length.
4. Fibers and matrix have good interfacial properties.
5. There is no slippage between fibers and the matrix.
6. Composite material is completely dense and there are no voids.

4.4. Biocomposites (BCs):

This section reviews the work done by various researchers in the area of BCs. BCs comprise of either biodegradable fiber or biodegradable matrix [17]. The use of NFs to produce BCs that have comparable properties to that of SFs composites is gaining interest from few decades [53].

V. Paul et al., 2015 [80] evaluated mechanical properties of randomly oriented banana fiber-reinforced epoxy resin BCs. They prepared BCs of 30% fiber volume fraction (V_f) with and without addition of banana sap into the resin. They observed improvement in the mechanical properties with the addition of banana sap.

A thorough investigation of tensile strength (TS) and flexural strength (FS) of BCs comprise of unidirectional (UD) jute and bamboo fibers reinforced with epoxy resin was carried out by S. Biswas et al., 2015 [7]. They compared the properties of jute fibers composites and bamboo fibers composites. They observed higher TS in case of bamboo fiber composites on the other hand jute fiber composites have higher Young's Modulus (E). They also concluded that composites with fiber reinforced in longitudinal direction posses better FS compared with fibers reinforced in transverse direction.

A. Gopinath et al., 2014 [43] looked into the mechanical properties like FS, impact strength (IS), TS, tensile modulus (TM), elongation at break, flexural modulus (FM) and hardness of the composite samples developed with randomly oriented jute fibers and polyester and epoxy resins. They treated jute fibers with 5% and 10% NaOH solutions. They found that the jute-epoxy composites have better properties in contrast with jute-polyester composites.

P.V. Senthil and A. Sirsshti 2014 [67] evaluated FS, hardness, wear and IS of NFs composites. They prepared composite samples from coir fiber, hay fiber and jute fiber reinforced epoxy resin. They found optimal mechanical properties in case of hay fiber reinforced composites.

R. Badrinath and T. Senthilvelvan 2014 [14] determined comparative investigation on TS, IS, FS and hardness of NFs composites compose of UD as well as bi-directional (BD) banana and sisal fibers reinforced polymeric composites. They observed that UD sisal fiber composites have better TS compared to BD sisal fiber composites whereas BD banana fiber composites have better TS than UD banana fiber composites. Their experimental results revealed that banana fiber composites have better IS and hardness compare to sisal fiber composites. The results also revealed that UD sisal fiber composites have better FS compare to UD banana fiber composites.

The TS, FS and IS of banana fiber reinforced epoxy resin have determined by M. Ramesh et al., 2014 [15]. They fabricated composite samples with V_f of 40%, 50% and 60%. They observed composites with 50% V_f shows optimal properties.

V. Mishra and S. Biswas 2013 [69] investigated mechanical properties like TS, TM, FS, IS and hardness of BD jute-epoxy composites compose of 0%, 12%, 24%, 36% and 48% V_f. They observed improved physical and mechanical properties of the composite with the increase in the V_f.

C.C. Ugoamadi 2013 [70] evaluated TS and compressive strength (CS) of composite samples processed from Glass fiber reinforced cashew nut shell liquid (CNSL) resin, polyester-glass fiber composites and samples from both the resins without fibers. He observed that polyester resin have better CS whereas CNSL have better TS. He also noticed that with the inclusion of fibers, the properties of polyester resin remains unchanged on the other hand CNSL resin shows remarkable change in the properties.

G. George et al., 2012 [84] implemented commingling of polypropylene and jute yarn and examined TS, FS and IS of the BCs consist of 55.89% V_f. They stated that commingling process results better homogeneous distribution of fibers into matrix and improve the mechanical properties.

A thorough investigation of the mechanical properties such as TS, FS and IS have carried out by B. Mathew et al., 2013 [85] of the BCs consist of banana fibers and phenol formaldehyde resin subjected to various aging conditions. They fabricated composites with varying V_f of banana fibers. They used banana fibers in the forms of macro fibers, micro fibrils and nano fibers. They observed composites of nano fibers have withstood all the aging conditions and shows better mechanical properties.

H. Liu et al., 2009 [86] determined TS, FS and IS of BCs compose of banana fibers and high-density polyethylene incorporated with binding agent. They observed incorporation of binding agent have improved mechanical properties.

The FS of randomly oriented coir fiber-reinforced polyester BCs have evaluated by S.N. Monteiro et al., 2008 [71]. They manufactured composite samples with less than and more than 50% V_f. They concluded that composite samples with more than 50% V_f have better FS.

S. Harish et al. 2008 [72] determined TS, FS and IS of randomly oriented coir fiber epoxy BCs. They compared the properties of coir fiber epoxy BCs and glass fiber reinforced composites. The results revealed that coir-epoxy BCs possess average values in contrast with glass fiber reinforced composites.

The TS and FS of the BCs comprise of banana fibers and epoxy resin have determined by S.M. Sapuan et al., 2006 [73]. They observed better mechanical properties in longitudinal direction compared to transverse direction.

P. Wambua et al., 2003 [18] investigated the mechanical properties like TS, FS and IS of varieties of NFs reinforced polypropylene BCs. They fabricated BCs of sisal fiber, kenaf fiber, hemp fiber, jute fiber and coir fiber. The results revealed that NFs reinforced composites have comparable properties in contrast with glass fiber composites.

D. Ray et al., 2002 [74] looked into the FS, IS and fatigue properties of alkali treated jute fibers and vinylester resin matrix biocomposites. They concluded that, alkali treatment of jute fibers have improved the mechanical properties.

4.5. Green Composites (GCs):

Since, BCs constituents of either degradable fibers or degradable matrix, the non-degradable component again creates environmental issues. This has given the idea in developing biological degradable composites termed as 'Green Composites' (GCs). GCs are the blend of biodegradable fiber reinforced with biodegradable resin [82, 83]. This section reviews the research attempted by several researchers in advancing the mechanical properties of the GCs and their results.

W. Liu et al., 2016 [75] looked into the mechanical properties such as TS, FS, IS, storage modulus and glass transition temperature of randomly oriented hemp fiber reinforced with bio-based thermosetting resin. They formulated thermosetting resin from copolymerization of acrylated epoxidized soybean oil and N-vinyl-2-pyrrolidone (IPDI). They observed incorporation of IPDI have improved the mechanical properties of the GCs but have reduced the thermal stability slightly.

A. Jabbar et al., 2015 [9] analyzed the creep behavior of chemically treated BD micro jute fibers and green epoxy composites. They concluded that with the incorporation of chemically treated micro jute fibers, creep deformation of the composites reduces.

K. Kalita et al., 2015 [76] evaluated the mechanical properties such as TS, IS, hardness and ultimate strength of jute fiber-reinforced PLA GCs and stated that the jute-PLA GCs have comparable properties to that of Graphite-Epoxy composites.

Y. Arao et al., 2015 [88] prepared randomly oriented jute-PLA GCs. They fabricated composites of 50% V_f with long fiber pellets and short fiber pellets. They obtain optimal results with the composite fabricated from short fiber pellets.

G. Rajesh et al., 2014 [25] looked into the TS of alkali treated jute fiber-reinforced PLA GCs. They treated jute fibers with 5%, 10% and 15% NaOH solution and fabricated composite samples with 5%, 10%, 15%, 20% and 25% V_f. They observed that composites of jute fibers treated with 10% NaOH solution and fiber 20% V_f have better mechanical properties.

H. N. Dhakal et al., 2014 [77] examined IS of randomly oriented and BD woven jute fibers reinforced with methacrylated soybean oil (MSO). They concluded that composites with woven fibers show better IS.

A detailed study on the mechanical properties such as TS, TM, FS, FM and elongation at break of the GCs compose of randomly oriented as well as BD jute fiber-reinforced soybean resin have carried out by A. Kumar et al., 2012 [89]. They fabricated composite sample with 40%, 50%, 60%, 70% and 80% V_f. They observed optimal mechanical properties in case of composite samples with 60% V_f.

The TS, FS, thermal and acoustic properties of GCs comprise of jute fiber and soy protein have determined by N. Reddy and Y. Yang, 2011 [90]. They maintained V_f of 40% and compared the properties with similar composites of polypropylene. They concluded that composites of soy protein have better mechanical properties

C. Merlini et al., 2011 [78] determined the TS and dynamic properties of alkali treated randomly oriented banana fibers reinforced with epoxy resin and castor oil polyurethane. They fabricated composites with 5%, 10% and 15% V_f. Their investigations shows that composites from alkali treated banana fibers in both the matrices have improved mechanical properties than untreated banana fibers.

E. Mistri et al., 2011 [91] analyzed FS and IS of the GCs prepared from randomly oriented jute fibers and maleated castor oil. They stated that the properties of jute fibers and maleated castor oil are similar to unsaturated polyester resin composites.

M. K. Hossain et al., 2011 [92] evaluated TS and FS of randomly oriented jute fiber reinforced biopolymer GCs with the incorporation of nanoclay. They fabricated composite samples with 28%, 29% and 30% V_f of alkali treated jute fibers. They stated that the mechanical properties of the composites have improved with the incorporation of nanoclay.

R. Hu et al., 2010 [93] determined the aging effect on the TS of coated and uncoated GCs consist of randomly oriented jute fiber-reinforced with PLA. They concluded that coating reduces the aging process and moisture absorption. They also concluded that aging process reduces the TS.

A comprehensive inspection of dynamic mechanical analysis, FS, effect of fiber content and permeability of NFs reinforced with acrylated epoxidized soybean oil GCs have conducted by A.O' Donnel et al., 2016 [79]. They developed GCs of flax fiber, cellulose pulp and hemp fiber with varying fiber volume fraction. They concluded that these composites have good mechanical properties.

O. A. Khondker et al., 2006 [94] studied TS and FS of UD jute-PLA GCs consist of 22.5%, 27.5% and 38% V_f processed at 170 degree. They stated that composites with 38% V_f shows better TS while those with 22.5% V_f show better FS.

H. Takagi and A. Asano, 2008 [95] evaluate FS of GCs comprise of cellulosic micro fibrils and nano fibers with HPT. They maintained 70% V_f . They observed with increase in the molding pressure, the FS increases.

4.6. Hybrid biocomposites (HBCs):

Research on single NFs reinforced composites is primarily focus on improving the physical and chemical properties of NFs composites such as wettability, resistance to water absorption and poor interfacial properties between NFs and epoxy resin. In order to improve the mechanical properties of the composites [8], hybridization is adapted in the composites design. HBCs are the combination of two or more NFs embedded in the single matrix phase [44, 54].

G. Sheshanandan et al., 2016 [65] investigated TS, FS and shear strength (SS) of the HBCs compose of randomly oriented E-Glass fiber, BD jute fiber and polyester resin. They incorporated nano titanium oxide particles as filler material. They fabricated different samples of HBCs with varying nano titanium oxide particles weight ratios. They observed enhanced mechanical properties of the HBCs with the increase in nano titanium oxide particles weight ratio.

M. R. Sanjay and B. Yogesha 2016 [66] studied TS, IS, FS and inter laminar SS of HBCs consist of BD jute and glass fiber reinforced epoxy resin. They concluded that HBCs of jute and glass fibers have better mechanical properties in contrast with the composites of individual jute and E-Glass fibers.

H. Essabir et al., 2015 [8] determined the TS of HBCs consist of coir fibers reinforced with polypropylene matrix incorporated with coir shell particles. They concluded that the homogeneous dispersion of coir shell particles strengthened the mechanical properties.

The TS, IS and CS were examined by K Deepak et al., 2014 [10] of the HBCs made from jute and coir fibers reinforced with polyester resin. They incorporated nanoclay into the composites. They observed improved mechanical properties with the incorporation of nanoclay.

R. Bhoopathi et al., 2014 [81] investigated TS, FS and IS of the HBCs comprise of banana fiber, hemp fiber and glass fiber reinforced epoxy resin. They fabricated composite samples of banana-glass fiber, hemp-glass fiber and banana-hemp-glass fiber. They observed banana-hemp-glass fiber HBCs have better mechanical properties.

A thorough investigation of mechanical properties like TS, FS, IS and hardness of jute-coir fiber reinforced polypropylene HBCs with varying V_f have analyzed by S. Siddika et al., 2013 [68]. They reported that with increase in V_f, the TS decreased whereas, E, FS, FM, IS and hardness increases.

M. Boopalan et al., 2013 [44] looked into TS, FS, IS water absorption and thermal properties of HBCs consist of BD jute and banana fibers reinforced epoxy resin with varying V_f. They concluded that HBCs of 50% V_f have better properties in all respects.

The TS, tear strength and hardness have investigated by M. J. John et al., 2008 [87] of the HBCs comprise of alkali treated randomly oriented sisal fiber, oil palm fiber and natural rubber. They prepared composite samples with 10%, 20%, 30%, 40% and 50% V_f. They observed alkali treated NFs produce composites with high mechanical performance.

4.7. Hybrid green composites (HGCs):

HGCs are the combination of two or more NFs ingrained in biopolymer, producing completely biodegradable composites with improved mechanical properties.

A comparative investigation of the TS and FS of HGCs comprise of NFs like UD kenaf, bamboo and coir fibers reinforced with PLA have analyzed by R.B. Yusoff et al., 2016[6]. They observed that the mechanical properties of HGCs compose of kenaf, bamboo and coir fibers is better than the HGCs of kenaf and coir fibers whereas, the HGCs of kenaf and coir have better mechanical properties compare to HGCs of bamboo and coir fibers.

A detailed investigation of the finite element analysis for the mechanical properties of jute and banana fibers reinforced cashew nut shell liquid resin HGCs have analyzed by V. Prasad et al., 2014 [13]. They observed that the experimental results and finite element results were in good agreement with each other.

4.8. Summary of review of literature:

From the review of the literature, it can be concluded that the research in the area of BCs and GCs have increased remarkably in the past years because of the advantages like cost effective, nature friendly and low density in contrast with traditional fibers.

Alkali treatment eliminates the hydrophilic nature and improves the bonding between NFs and the matrix and these results in the overall strengthening of the properties of the composites. In order to advance further mechanical properties, hybridization in the composite design is adapted. Hybridization produces composites with high-end properties.

Review of literature also concludes little work has done in the application of FEA in the areas of NFs reinforced composites. Applications of FEA in the areas of NFs reinforced composites have added advantages. It helps in determining the properties of these composites with the available software and thus can be time saving and cost effective.

CHAPTER- 5

MATERIALS AND EQUIPMENTS

The chapter details about the equipments, materials and experimental set-up used in this research.

5.1. Materials:

Jute fiber and banana fiber are the NFs, belongs from the family of bast fiber, with many advantages. Jute fibers are obtain from the phloem of plants comes from family “Tiliaceae” [104] while, banana fibers obtain from stem of banana tree, belongs from the family “Musaceae” [14].

Figure 5.1: Unidirectional Jute Fibers

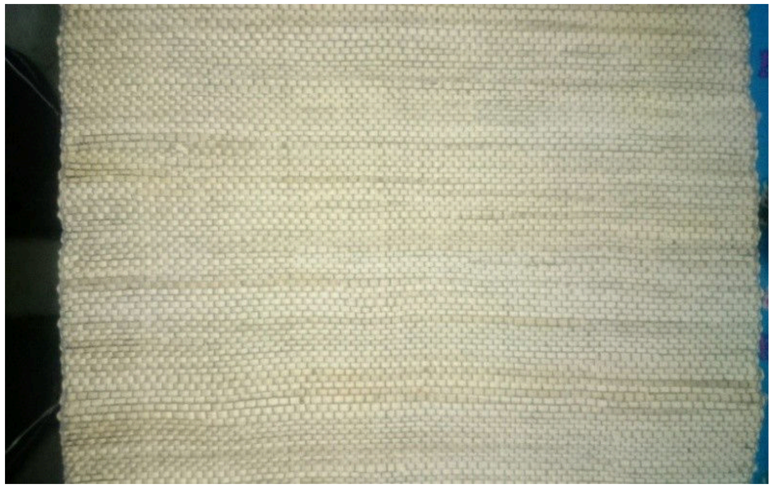


Figure 5.2: Unidirectional Banana Fibers

Table 5.1: Chemical composition of natural fibers used

Natural Fibers	Cellulose (Wt %)	Hemi cellulose (Wt %)	Lignin (wt %)	Moisture Content	Ref
Jute	59-71.5	30	5-31	8.9	105
Banana	62-64	19	5	10-11.5	14

Epoxy Resin EPOFINE-230 and Polyamide Hardener FINEHARD-951 have used as matrix. Below are the detailed specifications of the EPOFINE-230 and FINEHARD-951.

Table 5.2: Characteristics of epoxy resin EPOFINE-230

CHARACTERSITICS	**TEST METHOD**	**UNIT**	**VALUE**
Viscosity at 25ºC	ASTM-D 445	mPas	1,200 - 1,900
Epoxy Content	ISO - 3001	Eq/Kg	4.00 – 4.50
Density at 25ºC	ASTM-D 4052	g/cc	1.12 - 1.16
Flash Point	ASTM-D 93	°X	190 - 200
Storage life		Years	3

Table 5.3: Characteristics of polyamide hardener FINEHARD-951

CHARACTERSITICS	TEST METHOD	UNIT	VALUE
Viscosity at 25ºC	ASTM-D 445	mPas	< 20
Flash Point	ASTM-D 93	°X	110 - 120
Density at 25ºC	ASTM-D 4052	g/cc	0.97 – 0.99
Storage life		Years	1

Table 5.4: Mechanical properties of the matrix

PROPERTY	TEST METHOD	UNIT	VALUE
Tensile strength	ISO 527	N/mm^2	55 – 80
Elongation at break	ISO 527	%	2.0 – 2.2
Flexural strength	ISO 178	N/mm^2	90 – 100
Glass transition temperature (DSC)	IEC 1006	oC	50 – 60
Thermal Conductivity	ISO 8894-1	W/mK	0.8 – 0.9
Impact strength	ISO 179	KJ/m^2	15 - 22
Density	DIN 55990	g/cc	1.5 – 1.7
Coefficient of liner thermal expansion	DIN 53752	K^{-1}	90 - $95x10^{-6}$

Sodium Hydroxide (NaOH) has used for alkali treatment of the natural fibers and polyvinyl alcohol have used as releasing agent.

5.2. Equipments:

1. Pycnometer has used to determine the density of natural fibers using the formula:

$$G = \frac{M_2 - M_1}{(M_2 - M_1) - (M_3 - M_4)}$$

(5.1)

$$G = \frac{\rho_f}{\rho_w}$$

(5.2)

Where

M_1 = Mass of empty Pycnometer

M_2 = Mass of Pycnometer +fibers

M_3 = Mass of Pycnometer +fibers+water

M_4 = Mass of pycnometer + water

G = Specific gravity of fibers

ρ_f= Density of fibers

ρ_w = Density of water

Density of Jute Fiber ρ_J=1.0 g. /cc

Density of Banana Fiber ρ_B=0.926 g. /cc

2. Universal tensile testing machine for determining tensile properties
3. Flexural testing machine for evaluating flexural strength
4. Charpy impact test set-up
5. Rockwell hardness tester
6. Electronic weighing machine

CHAPTER- 6

RESEARCH METHODOLOGY

This chapter explains the processing of raw materials and manufacturing process of HBCs.

6.1. Alkali Treatment of Jute and Banana Fibers:

Alkali treatment cleans lignin, wax and oily matter present [106] and results in higher surface roughness of NFs [84]. The preferred reaction is [85]:

$$Fiber-OH+NaOH \rightarrow Fiber-O^{¿} -¿\ Na^{¿} +¿+H_2O \quad (6.1)$$

Jute and banana fibers have first washed with water to remove dirt and other unwanted substances and then immersed in 5% aqueous NaOH solution (5 grams of NaOH in 100 ml of water) for 1 hour.

Figure 6.1: Alkali Treatment of Jute Fibers

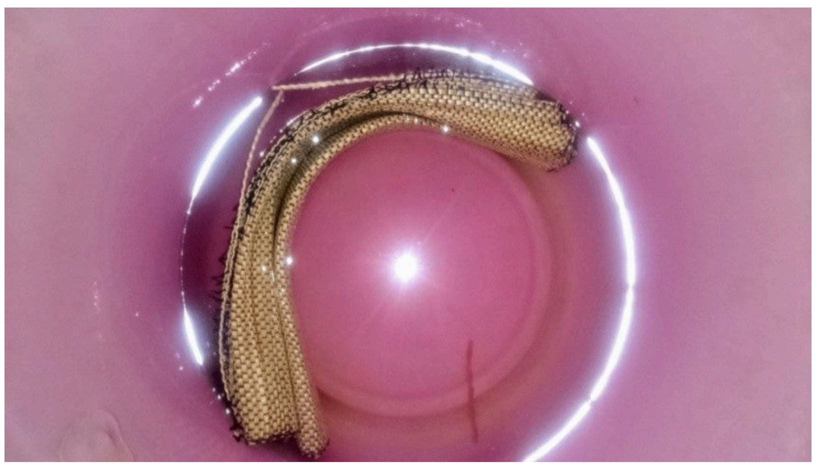


Figure 6.2: Alkali Treatment of Banana Fibers

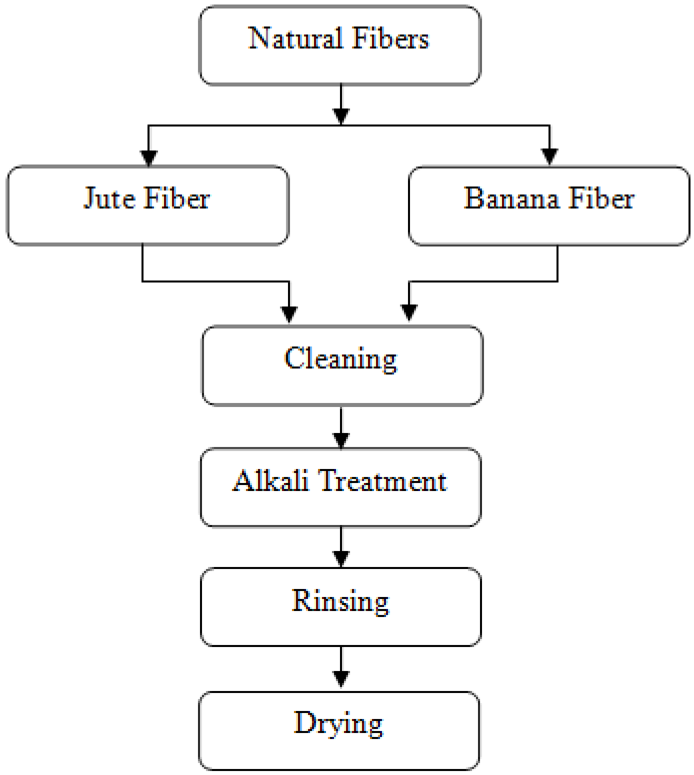


Figure 6.3: Flow Chart showing Steps in Alkali Treatment of Jute and Banana fibers

. After the fibers have rinsed with water several times to remove excess of NaOH and dried at room temperature.

6.2. Preparation of resin and hardener:

Epoxy Resin of grade EPOFINE-230 and density 1.12-1.16 g. /cc homogeneously blend with Hardener of grade FINEHARD-95 and density 0.97-0.99 g. /cc has used as matrix. The epoxy resin and hardener were blend in the ratio 100:10 and 100:20 for composites manufacturing.

6.3. Manufacturing of Hybrid Biocomposites:

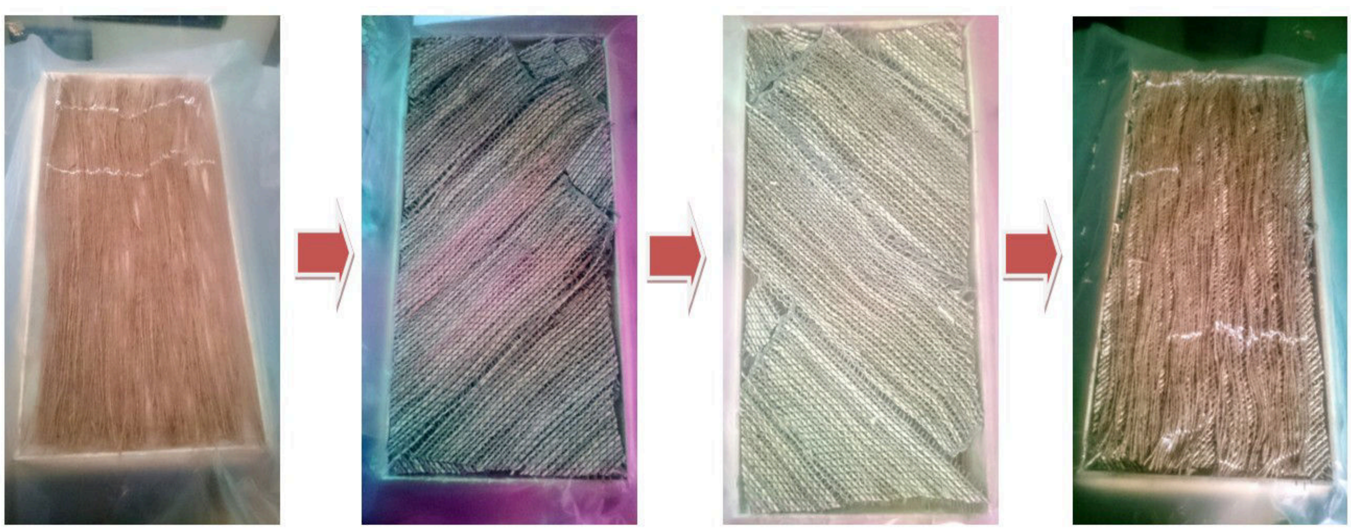
The composite samples have manufactured using hand lay-up technique of composites manufacturing. Firstly, wooden mold of dimension 300 x 150 mm have cleaned and dried to remove dirt. Then a thin layer of releasing agent has applied for the easy removal of the composite samples. Then, the first layer of natural fibers have placed oriented in the direction of 90^0. Above the layer of NFs, a layer of epoxy resin has applied. The process has continued by placing the NFs oriented in the directions 45^0, -45^0 and 90^0. The final composite sample has four layers of NFs placed in between five layers of epoxy resin.

The composite sample has then allowed for curing at room temperature for 12 hours. The final composite sample has the dimension of 300 x150 mm. After curing, the composite sample has cut as per the ASTM standards.

Four composite samples have fabricated with the resin and hardener ratio of 100:10 and 100:20.In the first composite sample, the extreme two layers were of jute fibers oriented at 90^0 and the middle two layers were of banana fibers oriented at 45^0 and -45^0 with the resin and hardener ratio of 100:10. The composite sample has designated as JBBJ-1

In the second composite sample, the extreme two layers were of banana fibers oriented at 90^0 and the middle two layers were of jute fibers oriented at 45^0 and -45^0 with the resin and hardener ratio of 100:10. The composite sample has designated as BJJB-1.

The third and fourth composite samples have similar orientation of jute fibers and banana fibers as that of first and second composite samples with resin and hardener ratio of 100:20. The third composite sample has designated as JBBJ-2 and the fourth composite sample as BJJB-2.



Jute Fibers Oriented @ 90^0 **Banana Fibers Oriented @ $+45^0$** **Banana Fibers Oriented @ -45^0** **Jute Fibers Oriented @ 90^0**

Figure 6.4: Stacking Sequence for the HBCs Samples JBBJ-1 and JBBJ-2

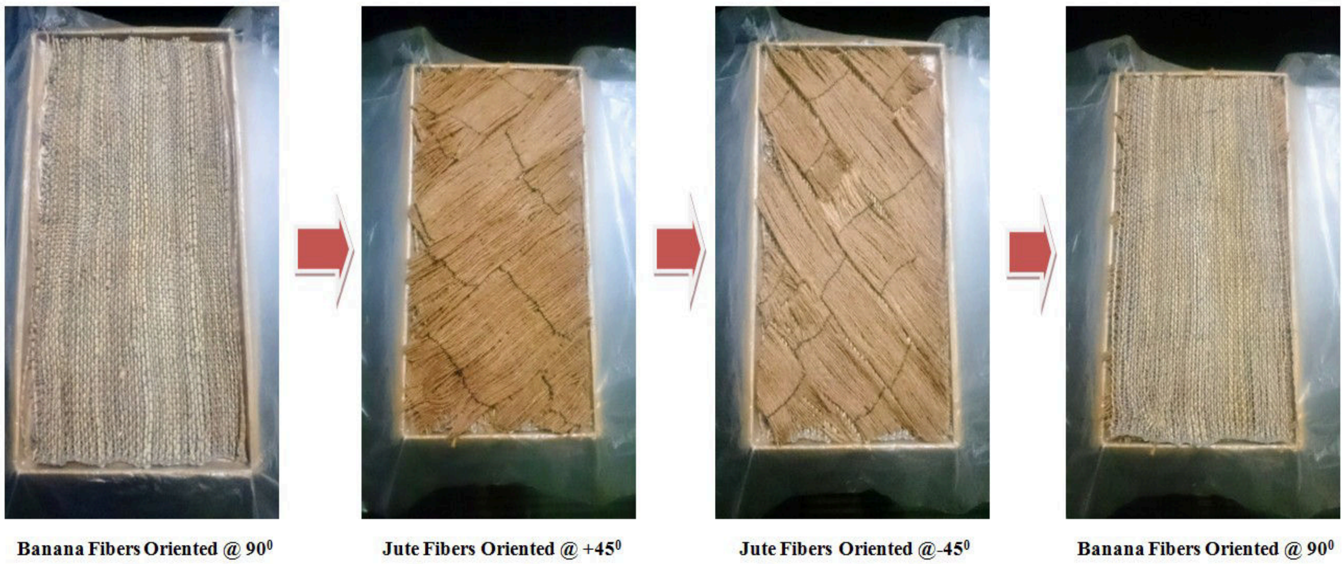


Figure 6.5: Stacking Sequence for the HBCs Samples BJJB-1 and BJJB-2

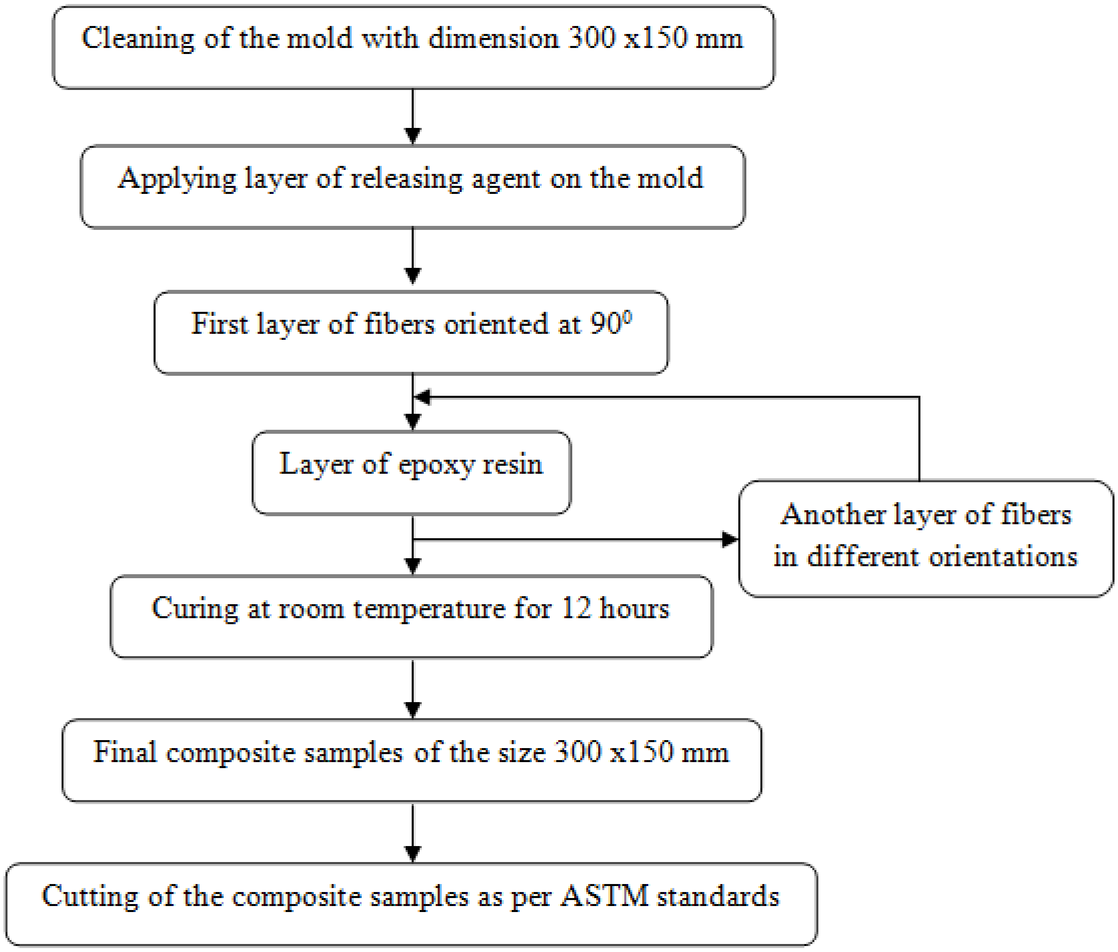


Figure 6.6: Manufacturing Process of Hybrid Biocomposites

All the composite samples fabricated, have the fiber volume fraction (V_f¿ of 25.92% calculated using the formula:

$$V_f = 1 - \frac{W - W_f}{\rho_m V}$$

(6.2)

Where

W = Weight of the final composite sample

W_f = Weight of the fibers

ρ_m = Density of the matrix

V = Volume of the composite sample

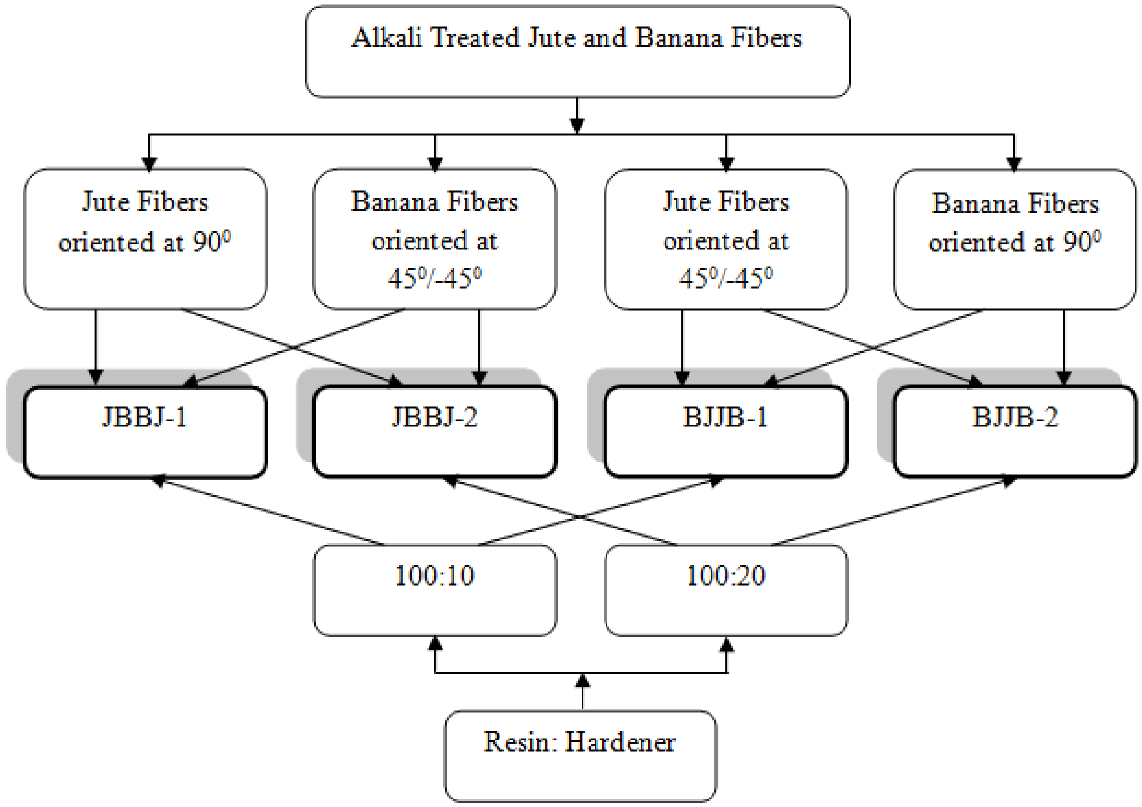


Figure 6.7: Constituents of Hybrid Biocomposites

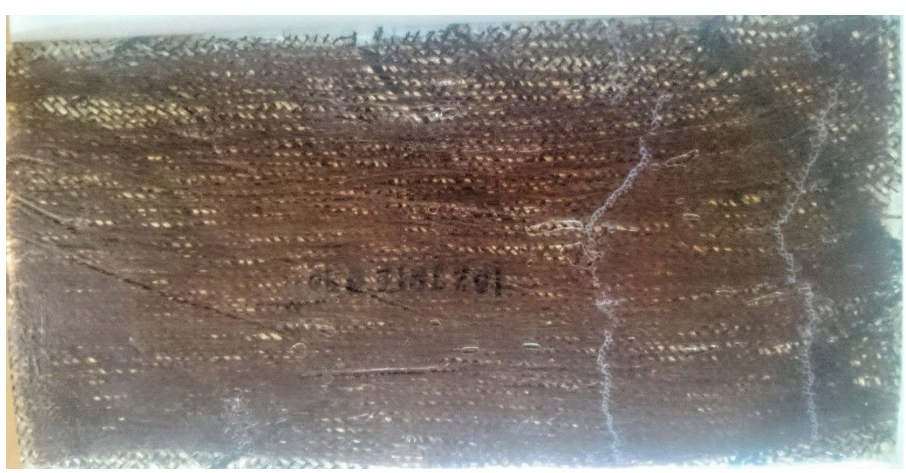


Figure 6.8: HBCs sample JBBJ-1

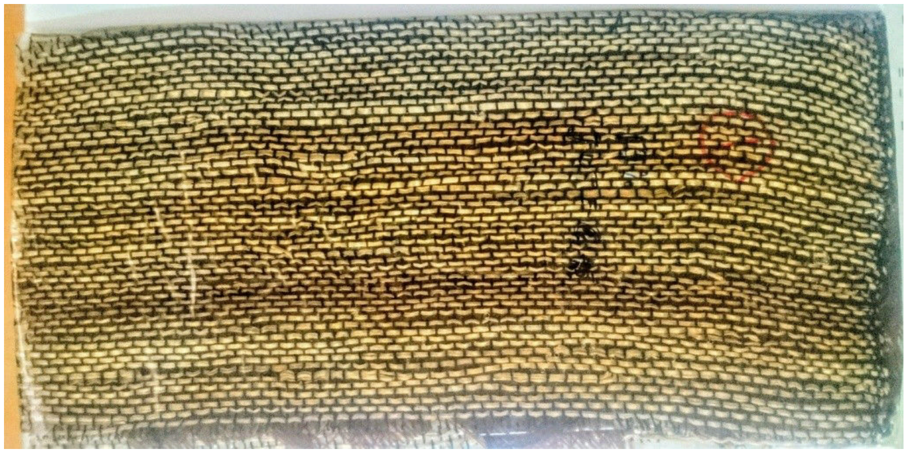


Figure 6.9: HBCs sample BJJB-1

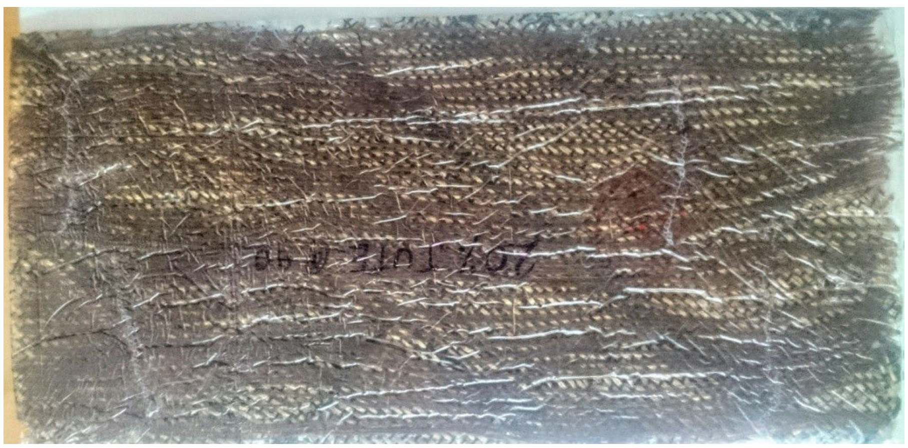


Figure 6.10: HBCs sample JBBJ-2

Figure 6.11: HBCs sample BJJB-2

The fabricated HBCs samples have then cut as per the ASTM standards and the properties have evaluated experimentally. The test method and process of determining different properties have explained in Chapter-7. Further, in Chapter-8, the orthotropic elastic constants and the Finite Element Analysis of the HBCs have evaluated.

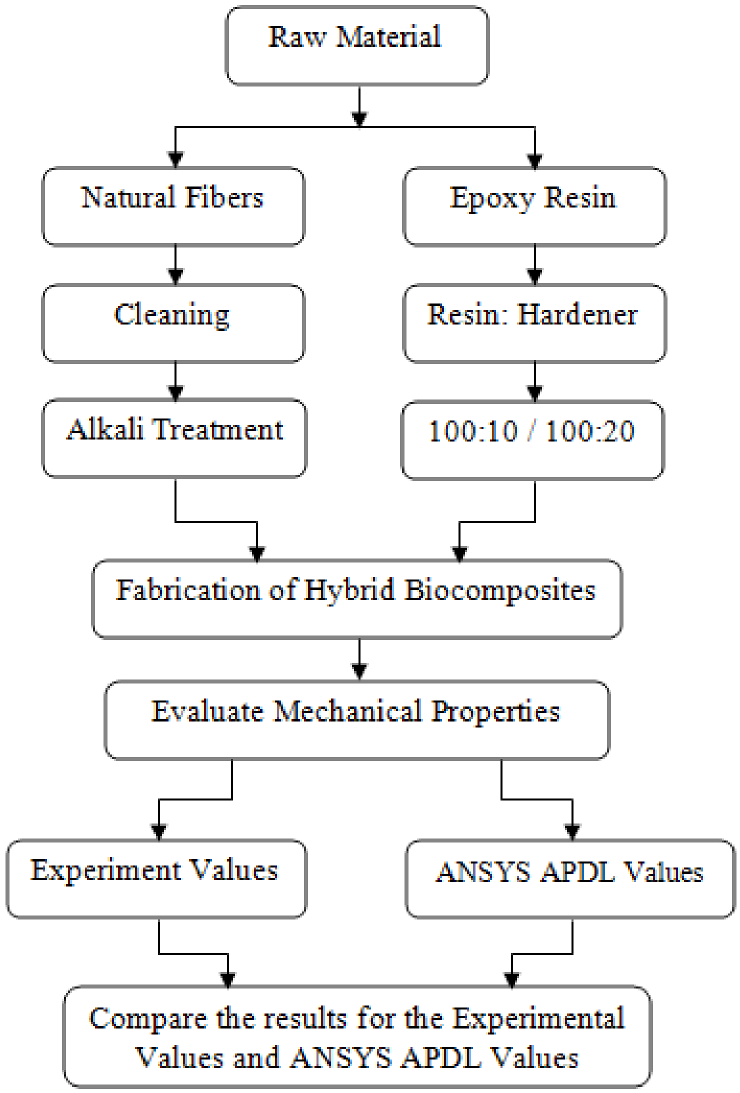


Figure 6.12: The overview of Research Methodology

CHAPTER-7

EXPERIMENTATION

In this chapter, the actual process of evaluating the mechanical and physical properties of HBCs has detailed.

7.1. Determination of Mechanical Properties:

In this section, the mechanical properties of HBCs such as tensile strength, flexural strength and impact strength have evaluated experimentally.

7.1.1. Tensile testing:

The tensile properties of the HBCs were determined in the Computerized Twin Screw Universal Testing Machine with the maximum capacity of 1000 Kg., Model: CAL 400-4. The testing has conducted with the fixed gauge length of 150 mm as specified in the standard ASTM D-3039 at a feed rate of 10 mm/min. The tensile strength (σ_t) and Young's Modulus (E) has evaluated as per the equation:

$$\sigma_t(MPa) = \frac{Load\,at\,failure\,of\,the\,specimen\,(KN)}{Cross\,sectional\,area\,of\,the\,specimen\,(mm)} \quad (7.1)$$

$$E = \frac{Stress\,(MPa)}{Strain}$$

(7.2)

(Within proportionality limit)

Elongation (%) at failure that is increase in length of the material at failure to original length is given by the equation:

$$Elongation\left(\right) = \frac{Increase \in the\ lenth\ at\ failure\left(mm\right)}{Original\ length\left(mm\right)} \qquad (7.3)$$

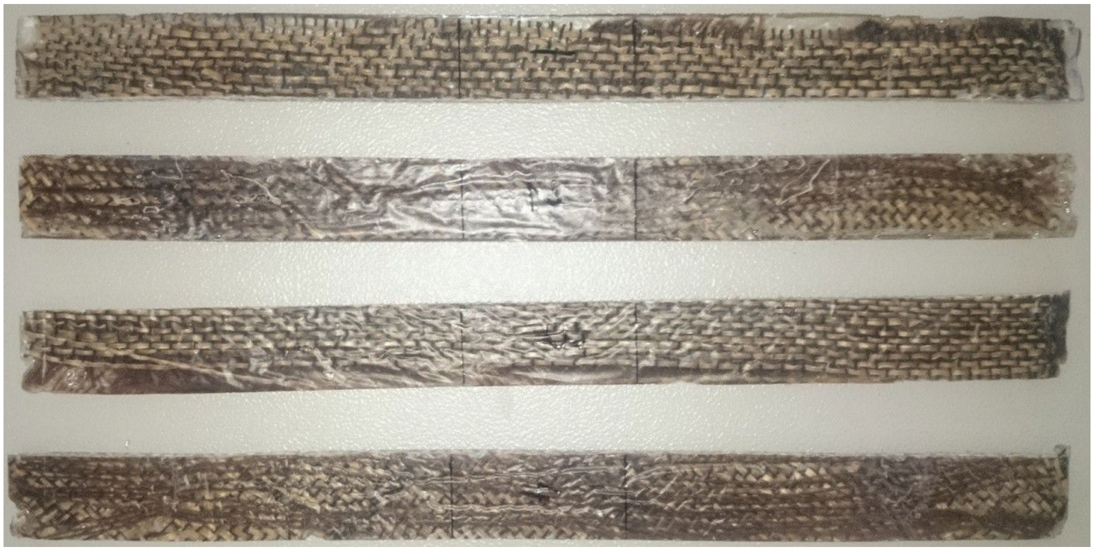


Figure 7.1: Specimens for Tensile Testing

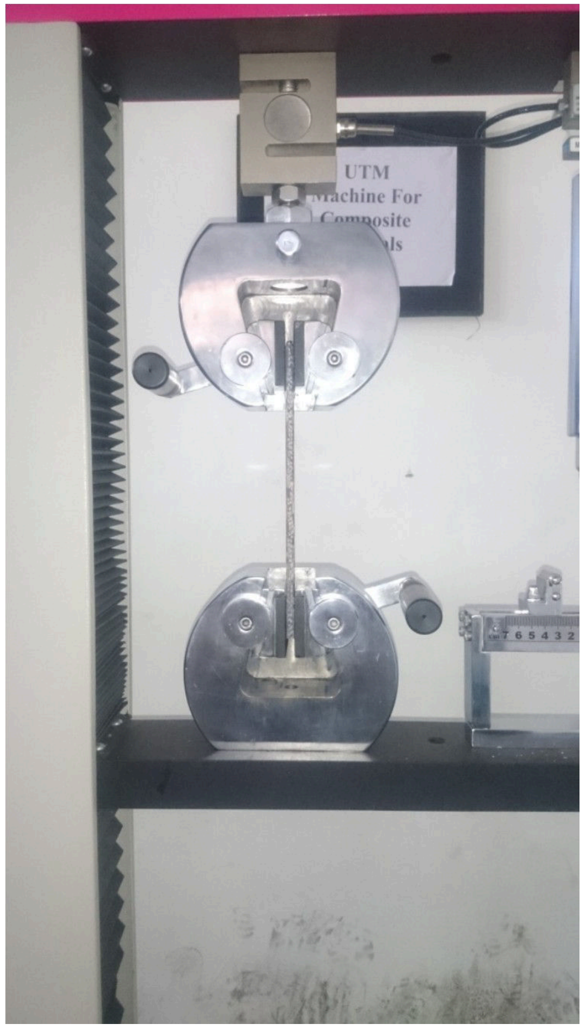


Figure 7.2: Tensile testing of HBCs sample

7.1.2. Flexural testing:

The flexural properties of the HBCs have evaluated on the same machine with the maximum capacity of 225 Kg., on the load cell of three-point flexural testing as per the standard ASTM D-790. The specimen has supported horizontally in between two edges 60 mm apart and the load has applied in the middle of the specimen. Increase in the loads gives the values of maximum stress and maximum strain. The point of failure of the specimen gives the value of flexural strength of the HBCs. The flexural strength (σ_{fl}¿ is determined using the equation:

$$\sigma_{fl}(MPa)=\frac{3Fl}{2bh^2} \quad (7.4)$$

Where

F = Load at the break (N)

l = Length of span (mm)

b = Breadth of the specimen (mm)

h = Height of the specimen (mm)

The flexural modulus (E_{fl}) is determined using the equation:

$$E_{fl}=\frac{Fl^3}{4bh^3D}$$

(7.5)

$$D=\frac{Fl^3}{48IE}$$

(7.6)

$$I=\frac{bh^3}{12}$$

(7.7)

Where

D = Deflection (mm)

$E = Elastic\ Modulus$

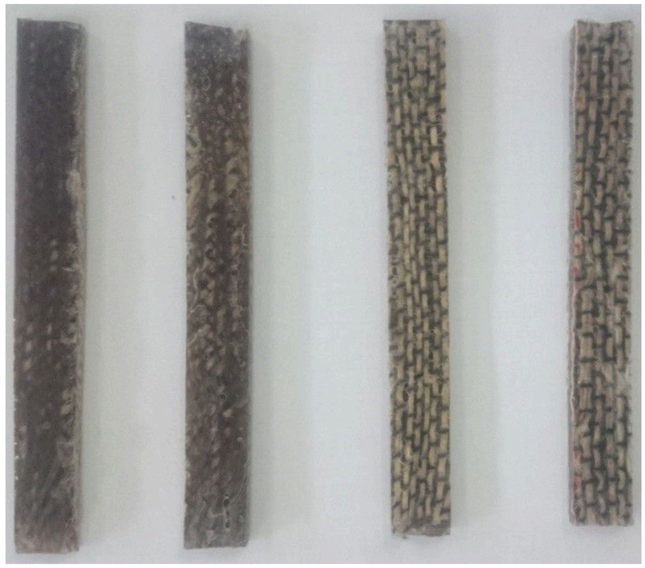


Figure 7.3: Specimens for Flexural Testing

Figure 7.4: Flexural Testing of HBCs sample

7.1.3. Impact testing:

The impact strength was determined in Charpy impact test set-up. It is the amount of energy absorbed by the test specimen before fracture. The dimensions of the specimens were 67.5 x 12.5 x4 mm^3 as per the standard ASTM D-256.

Figure 7.5: Specimens for Impact Testing

The specimens with 2.5 mm deep notch in the middle have loaded in the test set-up and the pendulum has allowed to strike the specimens till the specimens break.

7.2. Determination of Physical Properties:

In this section, the physical properties of the HBCs such as harness and water absorption test have determined experimentally.

7.2.1. Water absorption test:

It is one of the important properties for NFs composites as they have wide range of applications. For water absorption test, square samples of dimension 25 mm x 25 mm as per the standard ASTM D-570 have cut from the composite slabs, weighed using an electronic weighing machine and completely immersed in water for 72 hours. After, the samples have removed from the water and weighted. The percentage water absorption is determined using the equation:

$$Water\ absorption = \frac{M_w - M_s}{M_s} \times 100 \tag{7.8}$$

Where

M_w = Weight of wet samples (grams)

M_s = Weight of dry samples (grams)

7.2.2 Rockwell Hardness Test:

The hardness tests of HBCs have determined using ball indentor of 1/16” with 100 kg load applied as per the standard ASTM D-785. The readings obtained were on B-scale.

CHAPTER-8

NUMERICAL MODELING AND FINITE ELEMENT ANALYSIS

In this chapter, the orthotropic elastic constants of the HBCs have evaluated theoretically. To determine these values, rules of mixture (ROM) and hybrid rules of mixtures (HROM) have used. The chapter also explains Finite Element Analysis (FEA) of HBCs. The modeling has done using the orthotropic elastic constants as obtained from ROM and HROM.

8.1. Rules of mixture (ROM) and Hybrid Rules of Mixture (HROM):

ROM in the composite design is the mathematical expression, which helps us to derive mechanical properties of the composites with respect to arrangement, quantity and properties of the individual materials in the composites [107]. ROM has used to obtain theoretical properties of composites [6] determined using the equations (8.1 to 8.10):

$$E_{11} = E_f V_f + E_m V_m$$

(8.1)

$$\frac{1}{E_{22}} = \frac{V_f}{E_f} + \frac{V_m}{E_m}$$

(8.2)

$$V_f = \frac{\frac{M_f}{\rho_f}}{\frac{M_f}{\rho_f} + \frac{M_m}{\rho_m}}$$

(8.3)

$$V_m = 1 - V_f$$

(8.4)

$$E_{11} = E_f V_f + E_m (1 - V_f) \quad (8.5)$$

$$\frac{1}{E_{22}} = \frac{V_f}{E_f} + \frac{(1 - V_f)}{E_m}$$

(8.6)

$$\vartheta_{12} = \vartheta_f V_f + \vartheta_{\vartheta m} V_m$$

(8.7)

$$\vartheta_{23} = \frac{E_{22}}{E_{11}} \times \vartheta_{12}$$

(8.8)

$$\frac{1}{G_{12}} = \frac{V_f}{G_f} + \frac{(1 - V_f)}{G_m}$$

(8.9)

$$G_{23} = \frac{E_{22}}{2(1 + \vartheta_{23})}$$

(8.10)

The modified ROM for HBCs that is HROM used to obtain properties of the HBCs determined using the equation (8.11 to 8.14):

$$E_{11}=E_{Jf}V_{Jf}+E_{Bf}V_{Bf}+(1-V_{Jf}-V_{Bf}) \quad (8.11)$$

$$\frac{1}{E_{22}}=\frac{V_{Jf}}{E_{Jf}}+\frac{V_{Bf}}{E_{Bf}}+\frac{(1-V_{Jf}-V_{Bf})}{E_m}$$

(8.12)

$$\vartheta_{12}=\vartheta_{Jf}V_{Jf}+\vartheta_{Bf}V_{Bf}+\vartheta_m V_m \quad (8.13)$$

$$\frac{1}{G_{12}}=\frac{V_{Jf}}{E_{Jf}}+\frac{V_{Bf}}{E_{Bf}}+\frac{(1-V_{Jf}-V_{Bf})}{E_m}$$

(8.14)

Where

E_{11} = Young's Modulus in Longitudinal direction

E_{22} = Young's Modulus in Transverse direction

E_m = Young's Modulus of the Matrix

G_{12} = In-plane Shear Modulus

G_{23} = Transverse Shear Modulus

G_m = Shear Modulus of Matrix

V_f = Volume Fraction of Fiber

V_m = Volume Fraction of Matrix

V_{Jf} = Volume Fraction of Jute Fiber

V_{Bf} = Volume Fraction of Banana Fiber

υ_{12} = Major Poisson's Ratio of Composites

υ_{23} = Minor Poisson's Ratio of Composites

υ_m = Poisson's Ratio of Matrix

υ_{Jf} = Poisson's Ratio of Jute Fiber

υ_{Bf} = Poisson's Ratio of Banana Fiber

8.2. Finite Element Analysis (FEA) of HBCs:

The FEA is the most powerful discretization approach used in structural mechanics. The primitive theory of FEA is that, it subdivides the mathematical model into smaller elements with no elements in common through shape function known as finite elements in physical interpretation. The steps involved in FEA are:

i. Selection of appropriate elements and field variables
ii. Discretization
iii. Selection of Interpolation or Shape functions
iv. Determination of element properties
v. Arranging the element properties to obtain global properties
vi. Applying boundary conditions
vii. Solving the system equations to obtain nodal values
viii. Post calculations to obtain the expected values.

The multilayered composite materials with high-end properties comprised of reinforcing phase like fibers, sheets or particles ingrained in matrix phase like polymeric materials. These composite materials are cited as "laminates" and each layer is referred to as a "lamina" or "ply". These days numerous FEA software is economically available incorporated with the features that are useful in analyzing a composite material. For the present research work, ANSYS parametric design language code (APDL) version 16.2 has used. ANSYS APDL is one of the most popular software used in industry.

ANSYS is available with different types of options such as facility to alter ply layup, distinct material models and various elements used in composites analysis. The selection of preferred element type depends on the expected results or the applications. Distinct finite strain shell elements is selected based on number of composite layers, each layer thickness and desired values of displacements and rotations. Table presents the different types of elements for composites analysis.

Table 8.1: Element types available for composites analysis in ANSYS

Element	Type	Nodes
SHELL1	Structural Shell	4

63		
SHELL181	Finite Strain Shell	4
SHELL281	Finite Strain Shell	8
SOLSH190	3D Layered Structural Solid Shell	8
SOLID185	3D Layered Structural Solid	8
SOLID186	3D Layered Structural Solid	20

For modeling of HBCs in the present research, element type SHELL181 is selected from the available element types. The characteristics of SHELL181 are:

i. 4-Node structural shell,
ii. 4-Node 3D space and
iii. DOF: UX, UY, UZ, ROTX, ROTY, ROTZ

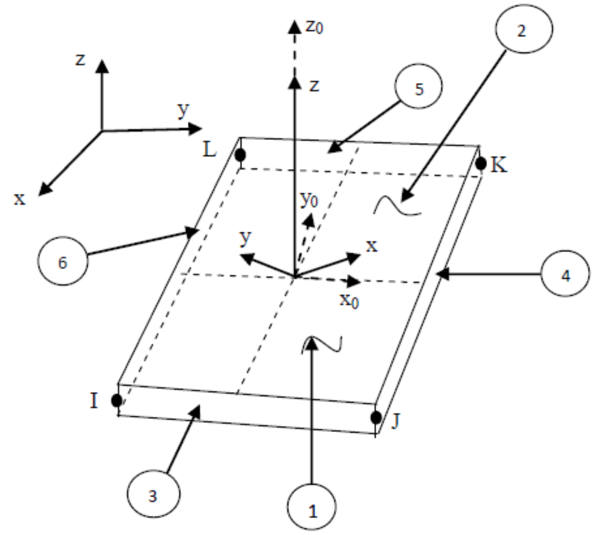


Figure 8.1: Geometry of SHELL181 element

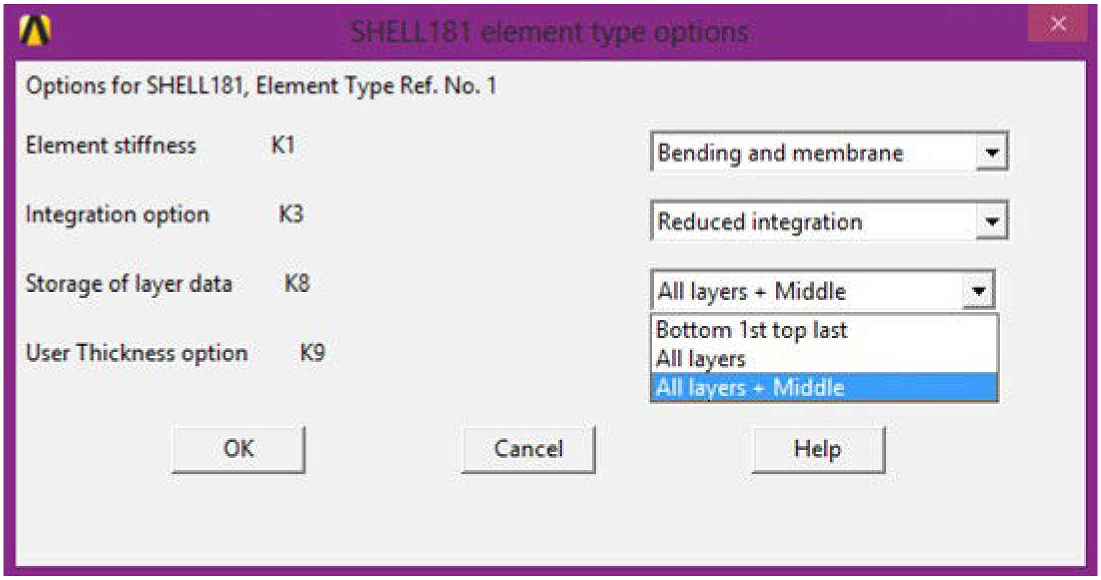


Figure 8.2: Interface of SHELL181 Element

The figure shows the element SHELL181 defined by four nodes I, J, K and L with six degrees of freedom each node. This element is suitable to analyze composite materials.

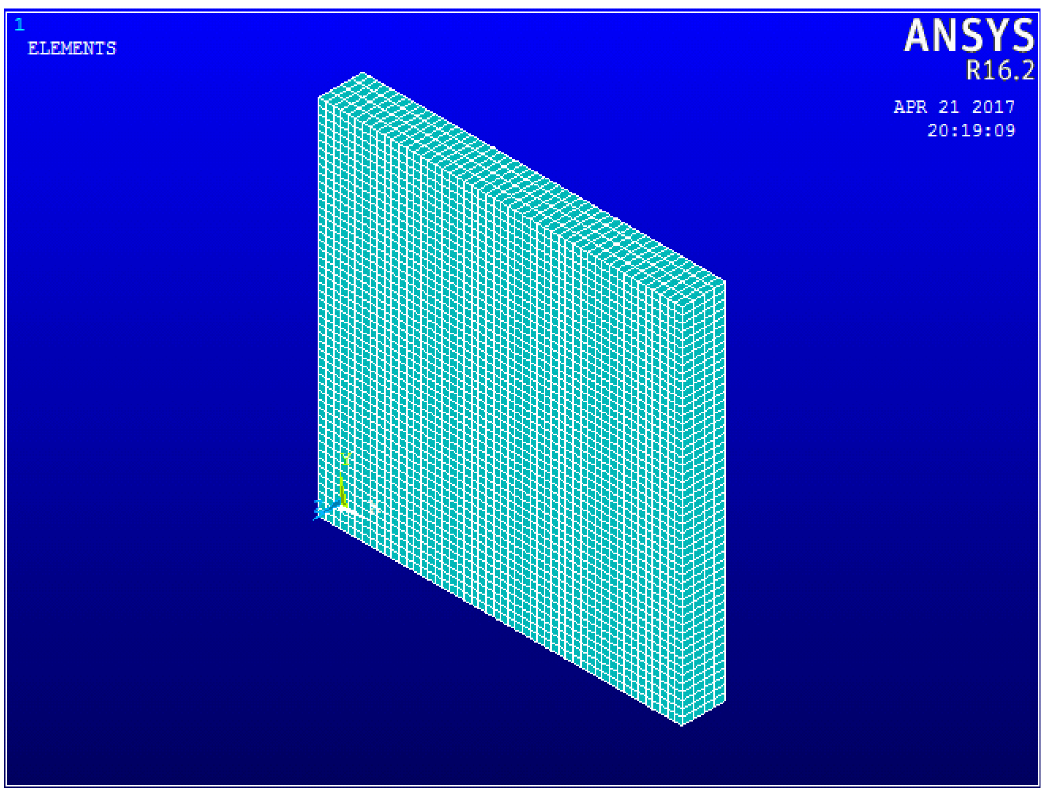


Figure 8.3: 3D Composite Geometry Modeled using SHELL181 Element

8.3. Steps in Modeling of HBCs in ANSYS:

8.3.1. Orthotropic Properties of HBCs:

For modeling of HBCs in ANSYS, orthotropic elastic properties are required. These properties have obtained using ROM and HROM. The HBCs have modeled separately in ANSYS using the properties obtained from ROM and HROM. Table 8.2 shows the orthotropic properties for separate layer of jute and banana fibers determined using ROM and Table 8.3 shows the orthotropic properties of combined layers of jute and banana fibers determined using HROM.

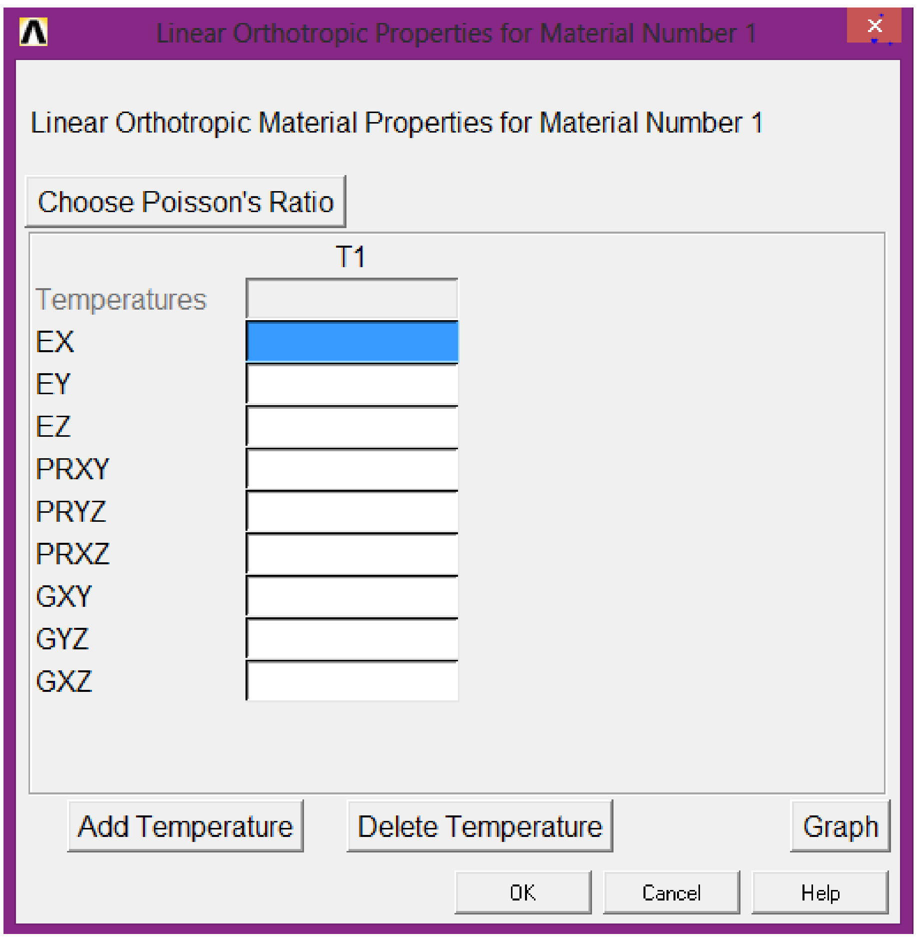


Figure 8.4: Orthotropic Elastic Properties Interface

Table 8.2: Orthotropic Properties for Separate Layer of Jute and Banana Fibers

Orthotropic Properties	Composite Samples							
	JBBJ-1		BJJB-1		JBBJ-2		BJJB-2	
	Jute Fiber	Banana Fiber	Jute Fiber	Banana Fiber	Jute Fiber	Banana Fiber	Jute Fiber	Banana Fiber
E11(MPa)	4861.11	6634.40	2733.33	2918.89	5046.98	6799.27	2923.73	3086.62
E22(MPa)	2988.04	3308.82	2731.79	2881.53	3207.31	3547.01	2918.66	3063.82
υ_{12}	0.31	0.31	0.30	0.31	0.31	0.31	0.31	0.31
υ_{23}	0.19	0.15	0.30	0.30	0.20	0.16	0.30	0.31
G12(MPa)	1148.54	1271.27	1054.70	1102.41	1232.77	1362.68	1117.21	1171.76
G23(MPa)	1256.77	1433.13	1048.71	1104.09	1341.79	1526.90	1118.43	1172.43

Table 8.3: Orthotropic Properties for Combined Layers of Jute and Banana Fibers

Orthotropic Properties	Composite Samples			
	JBBJ-1	BJJB-1	JBBJ-2	BJJB-2
E11(MPa)	8745.51	2885.91	8892.25	3056.36
E22(MPa)	3659.60	2849.16	3918.63	3025.82
υ_{12}	0.32	0.31	0.32	0.31
υ_{23}	0.13	0.31	0.14	0.31
G12(MPa)	1404.83	1086.19	1504.06	1151.62
G23(MPa)	1615.68	1088.53	1719.36	1153.94

Figure 8.6 shows 3D geometry for tensile model and Figure 8.7 shows 3D geometry for flexural model. These geometries have constructed using the above orthotropic properties.

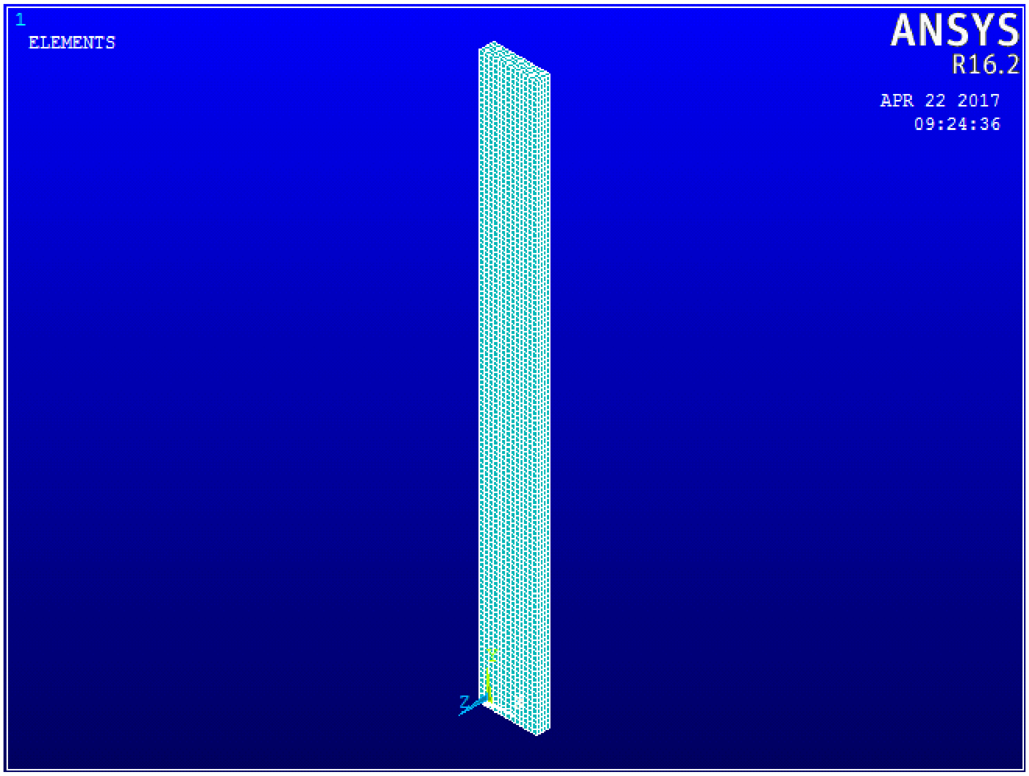


Figure 8.5: 3D Meshed Tensile Test Geometry

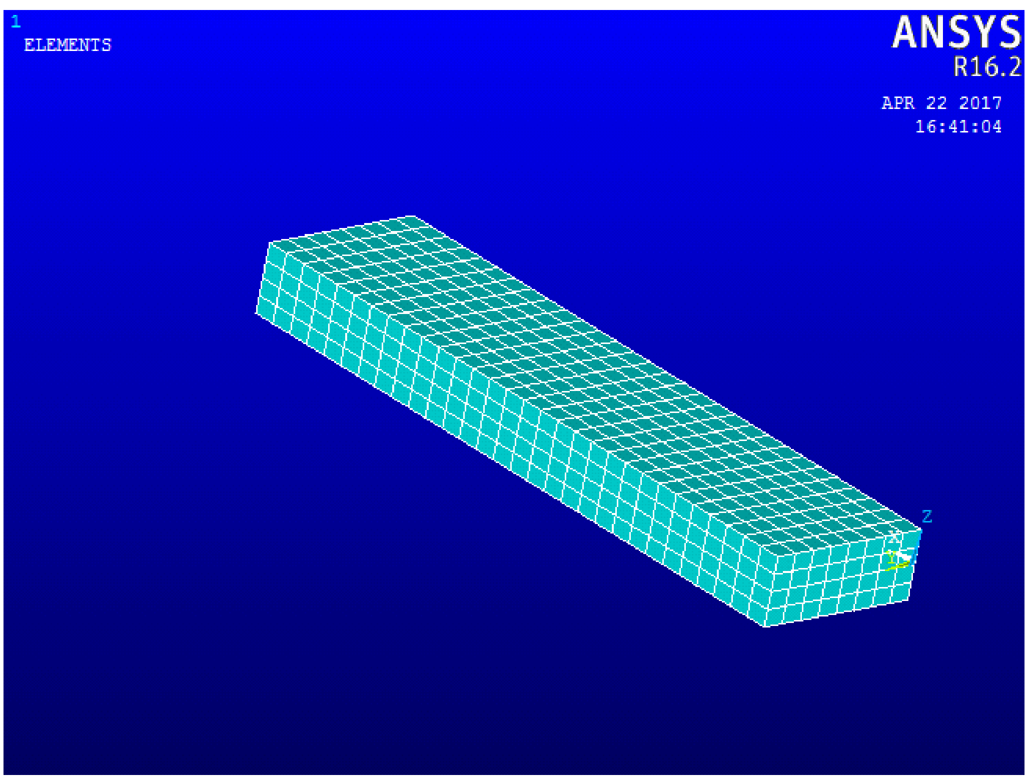


Figure 8.6: 3D Meshed Flexural Test Geometry

Layers in the geometry have created using lay-up editor available in ANSYS APDL. It allows editing the thickness and orientation of each layer.

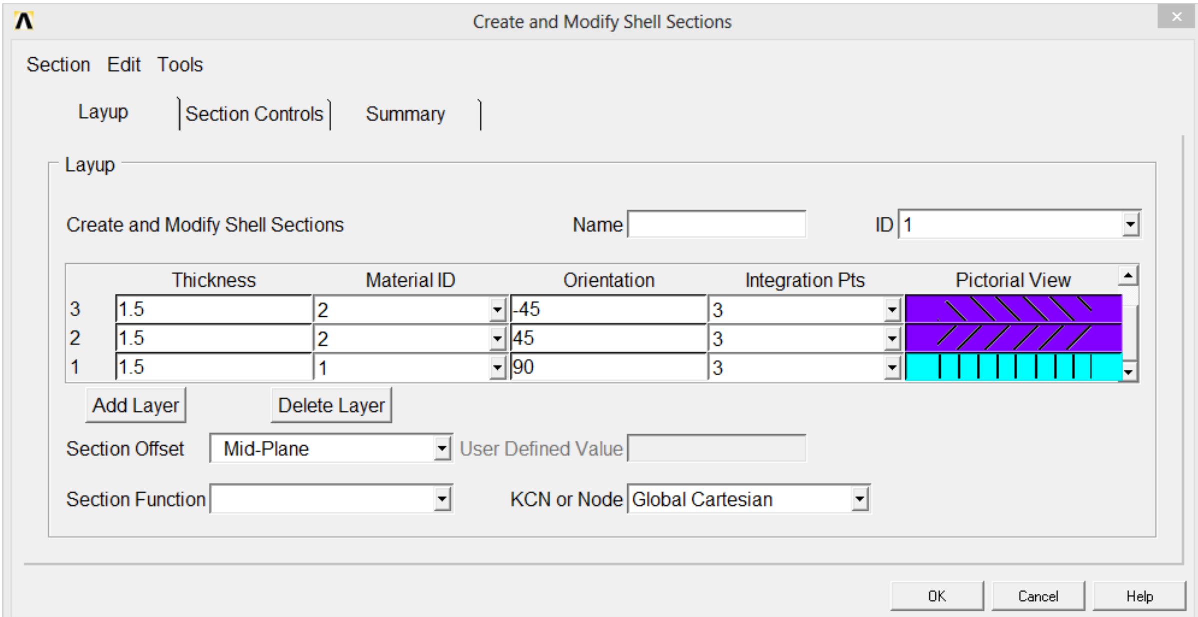


Figure 8.7: Lay-up Editor

8.3.2. Boundary Conditions:

To obtain the desired result, it is must to restrict the number of degree of freedom associated with the body by limiting the count of field variables. These counts of field variables are limited by imposing boundary conditions. For solving the above-mentioned equations, different boundary conditions has imposed depending on the loading conditions.

For Tensile Strength determination boundary conditions used are:

$$at\ y=0,50,200 \rightarrow UX=0\,;UY=0\,;UZ=0\,;ROTX=0\,;ROTY=0\,;ROTZ=0$$

$$at\ y=250 \rightarrow UX=0\,;UY=F\,;UZ=0\,;ROTX=0;ROTY=0\,;ROTZ=0$$

For Flexural Strength determination boundary conditions used are:

$$at\ x=0,60 \rightarrow UX=0\,;UY=0\,;UZ=0\,;ROTX=0\,;ROTY=0\,;ROTZ=0$$

$$at\ x=30 \rightarrow UZ=F$$

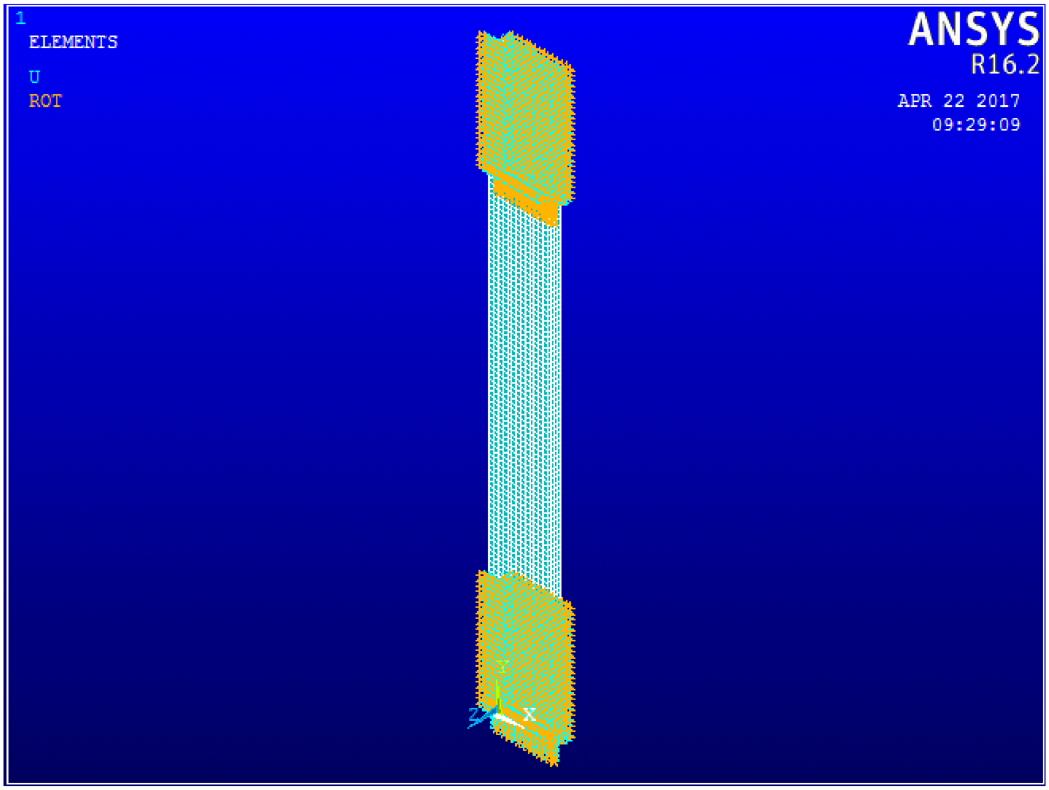


Figure 8.8: Boundary Conditions Imposed on Tensile Test Geometry

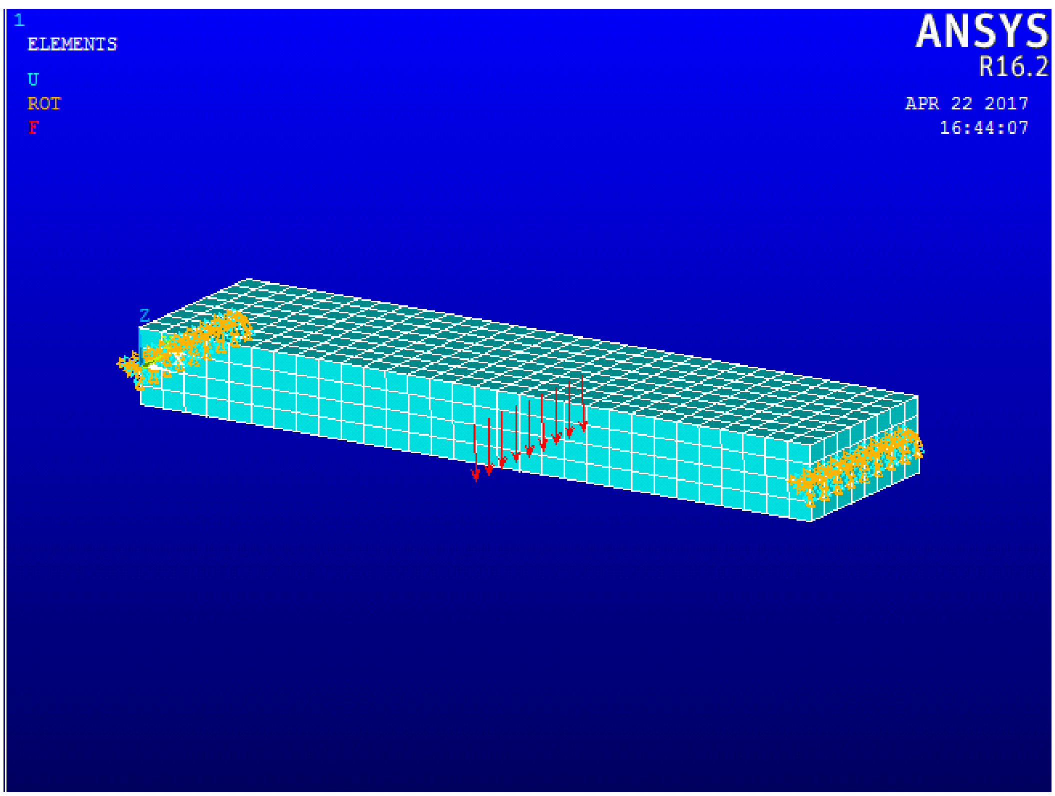


Figure 8.9: Boundary Conditions Imposed on Flexural Test Geometry

8.3.3. Solving the Problem:

This is the final step in FEA procedure. For all the geometries, Von Misses' stresses developed in HBCs under tensile and flexural loading conditions have analyzed. These results have compared with the actual experimentation values.

8.3.4. General Post-processing:

Further calculations have done in this step to obtain the actual shape of the geometry caused due to the deformation in the geometry resulting from the loading and boundary conditions imposed. This step also allows plotting the graphical representation of the deformation behavior of the body.

8.4. Algorithm:

i. Input – Discipline for the Graphical User Interface (GUI), Element type, Material properties.
ii. Enter each ply thickness and angle of fiber orientation, plotting all the layers in GUI.
iii. Enter the co-ordinates of geometry.
iv. Assemble the co-ordinates to produce a 2D geometry.
v. Convert the geometry into area.
vi. Create 'Nodes' through 'Meshing' to impose loads and boundary conditions on the geometry.
vii. Apply loads and boundary conditions on the geometry.
viii. Assemble the stiffness matrix for the complete structure.
ix. Solve the system equations.
x. General post-processing.

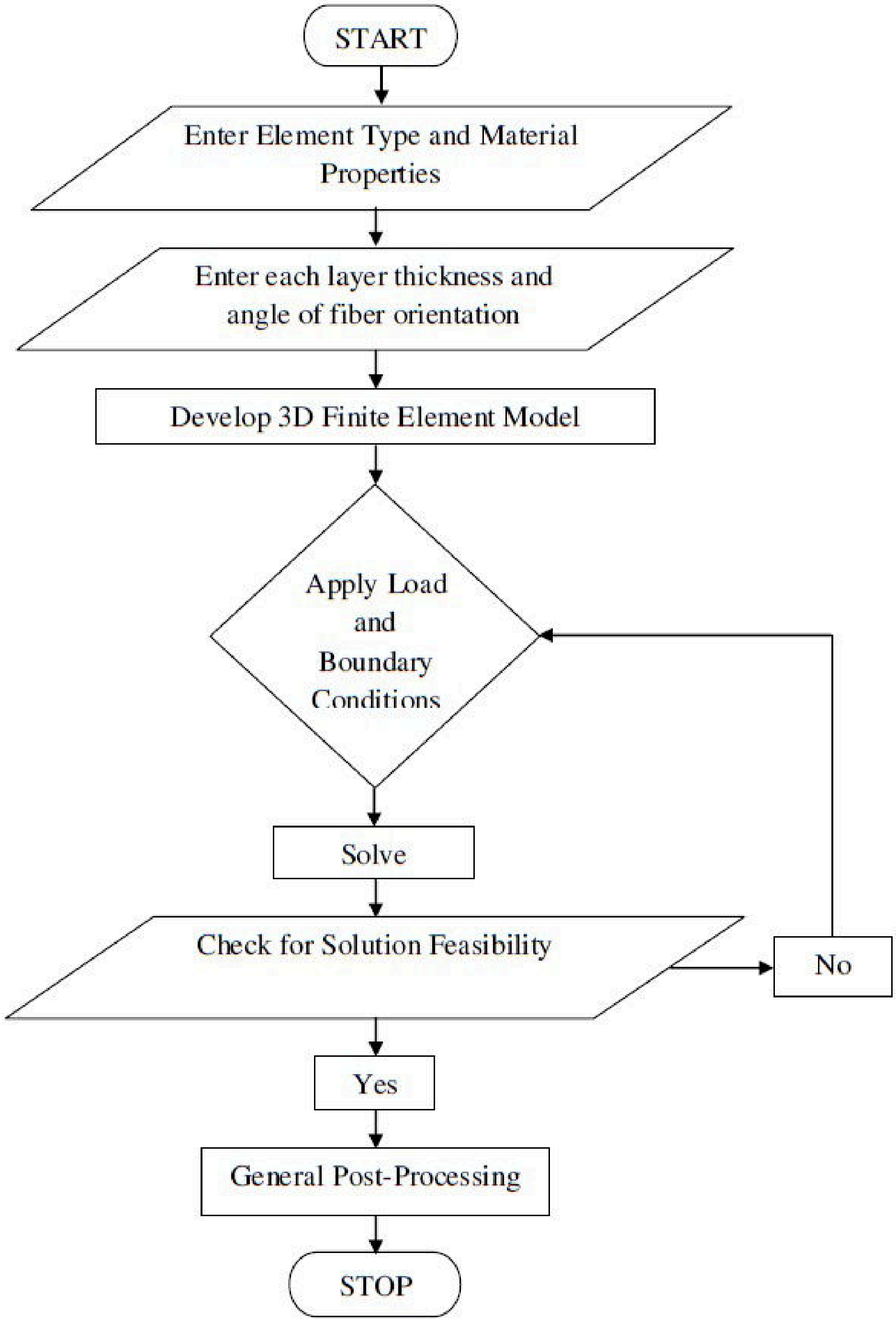


Figure 8.10: Flow-Chart for the Steps in ANSYS

CHAPTER-9

RESULTS AND DISCUSSIONS

The HBCs have subjected to different mechanical and physical characterizations as explained in Chapter-7. The results obtained have detailed in this chapter. The chapter also details the ANSYS simulation results for the various mechanical properties as explained in Chapter-8. Furthermore, the comparison between experimental results and ANSYS simulation results has carried out.

9.1. Experimental Results:

9.1.1 Tensile Properties of the HBCs:

The experimental tensile properties of the HBCs have detailed in Table 9.1.

Table 9.1: Experimental Tensile Properties of the HBCs

Composite Samples	Tensile Strength (MPa)	Tensile Modulus (MPa)
JBBJ-1	27.18	647.12
BJJB-1	20.85	550.62
JBBJ-2	20.54	544.45
BJJB-2	13.79	362.18

The composite sample JBBJ-1 shows the maximum TS on the other hand, the composite sample BJJB-2 shows the least TS among all the HBCs samples.

The composite sample JBBJ-1 has higher TS compared to the composite sample BJJB-1. The composite sample JBBJ-1 shows TS of 27.18 MPa whereas, the composite sample BJJB-1 shows TS of 20.85 MPa.

The composite sample JBBJ-2 shows better TS of 20.54 MPa compared to the TS of 13.79 MPa as shown by the composite sample BJJB-2.

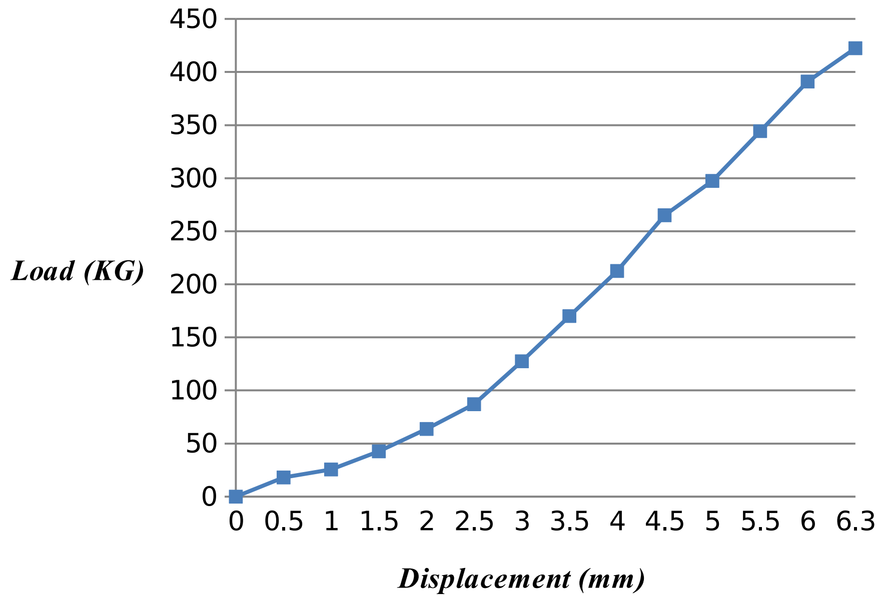


Figure 9.1: Load-Displacement curve for the HBCs Sample JBBJ-1

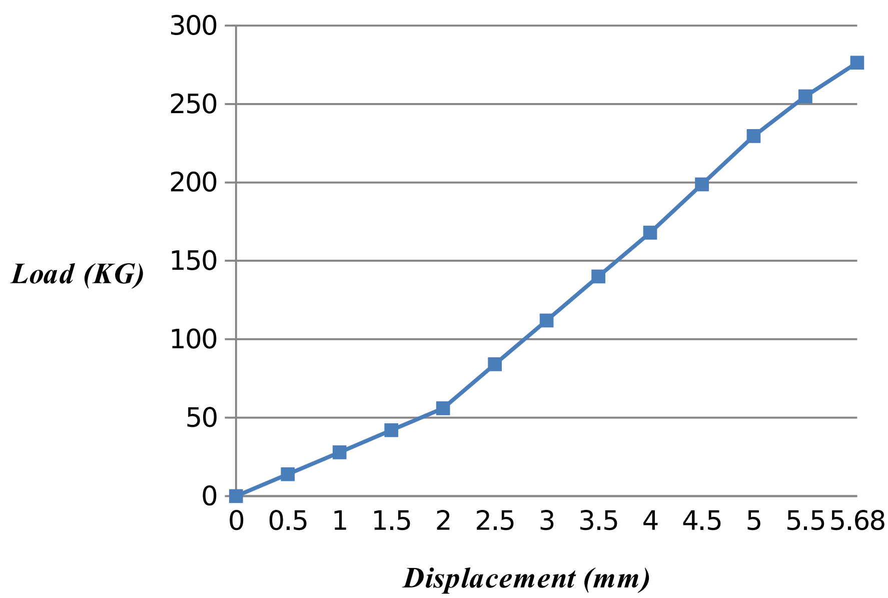


Figure 9.2: Load-Displacement curve for the HBCs Sample BJJB-1

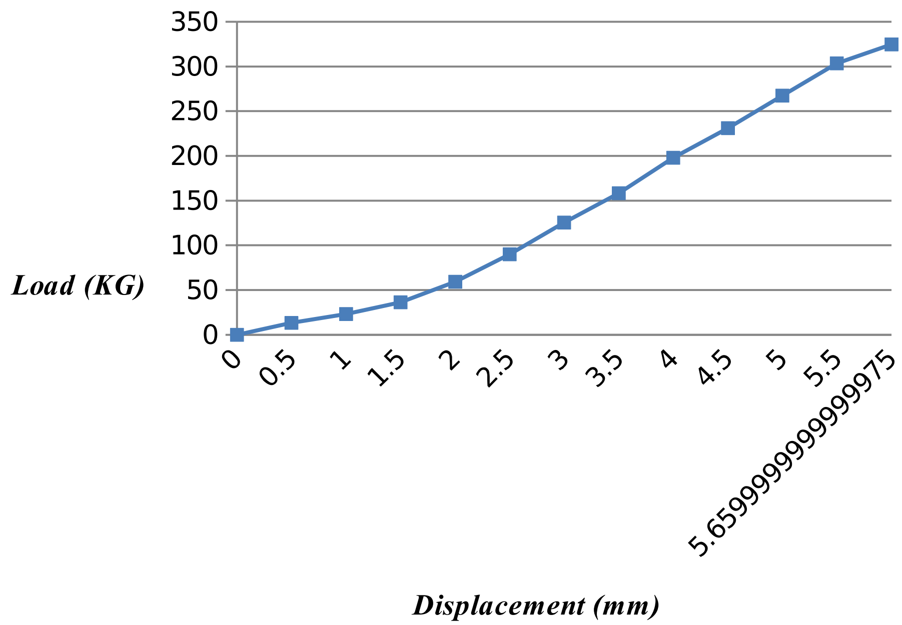


Figure 9.3: Load-Displacement Curve for the HBCs Sample JBBJ-2

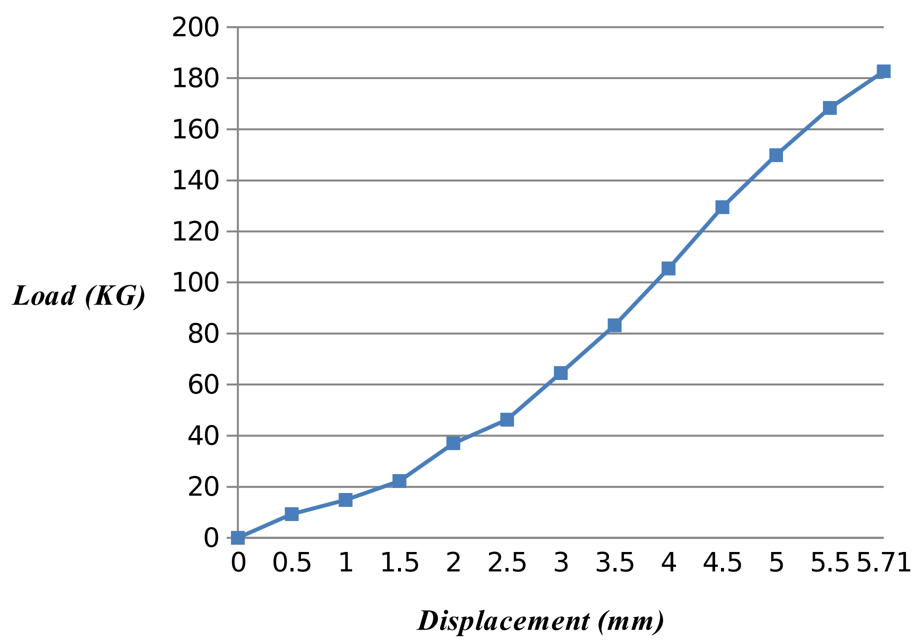


Figure 9.4: Load-Displacement Curve for the HBCs Sample BJJB-2

From the load-displacement curves for the HBCs samples, it also clear that the composite sample JBBJ-1 has the maximum load carrying capacity whereas, the composite sample BJJB-2 has the least load carrying capacity.

The composite sample JBBJ-1 has the load carrying capacity of 423 KG whereas the composite sample BJJB-1 has the load carrying capacity of 276 KG.

Similarly, the composite sample JBBJ-2 show better load carrying capacity of 325 KG compared to the composite sample BJJB-2 which has the load carrying capacity of 183 KG only.

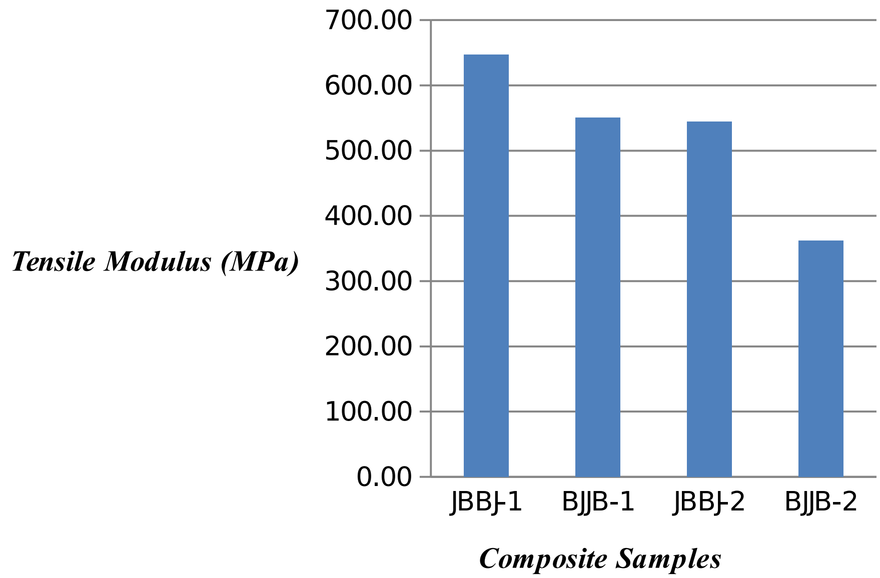


Figure 9.5: Comparison between Tensile Modulus of HBCs

Figure 9.5 shows the TM of the composite sample. The composite sample JBBJ-1 has the maximum TM of 647 MPa compared to the TM of 550 MPa of the composite sample BJJB-1. Similarly, the composite sample JBBJ-2 has higher TM of 544 MPa compared to TM of 362 MPa as shown by the composite sample JBBJ-2

9.1.2. Flexural Properties of the HBCs:

Table 9.2 shows the experimental flexural properties of the HBCs.

Table 9.2: Experimental Flexural Properties of the HBCs

Composite Samples	Flexural Strength (MPa)	Flexural Modulus (MPa)
JBBJ-1	80.48	647.12
BJJB-1	62.38	550.62
JBBJ-2	43.88	544.45
BJJB-2	52.94	362.18

The flexural testing reveals that the composite sample JBBJ-1 has the maximum FS whereas, the composite sample JBBJ-2 has the least strength in bending.

The composite sample JBBJ-1 shows the higher FS compared to the composite sample BJJB-1. The composite sample JBBJ-1 has the FS of 80.48 MPa whereas, the composite sample BJJB-1 has the FS of 62.38 MPa.

Compared to the composite sample JBBJ-2, the composite sample BJJB-2 has better FS. The composite sample JBBJ-2 has the FS of 43.88 MPa only. On the other hand, the composite sample BJJB-2 has the FS of 52.94 MPa.

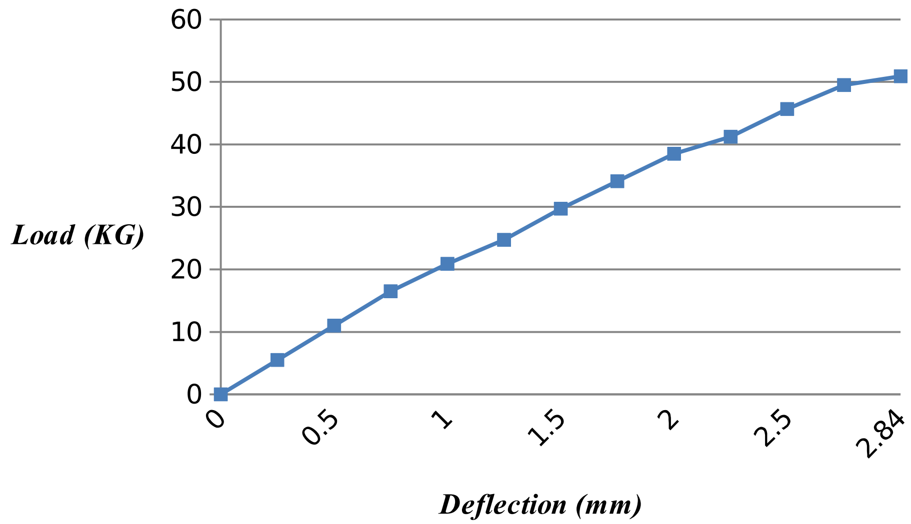


Figure 9.6: Load-Deflection Curve for the HBCs Sample JBBJ-1

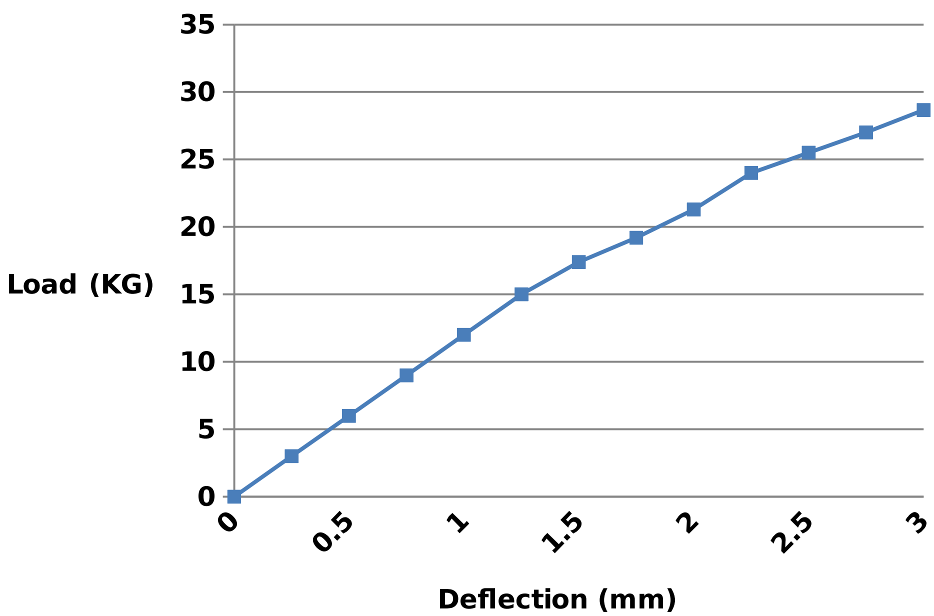


Figure 9.7: Load-Deflection Curve for the HBCs Sample BJJB-1

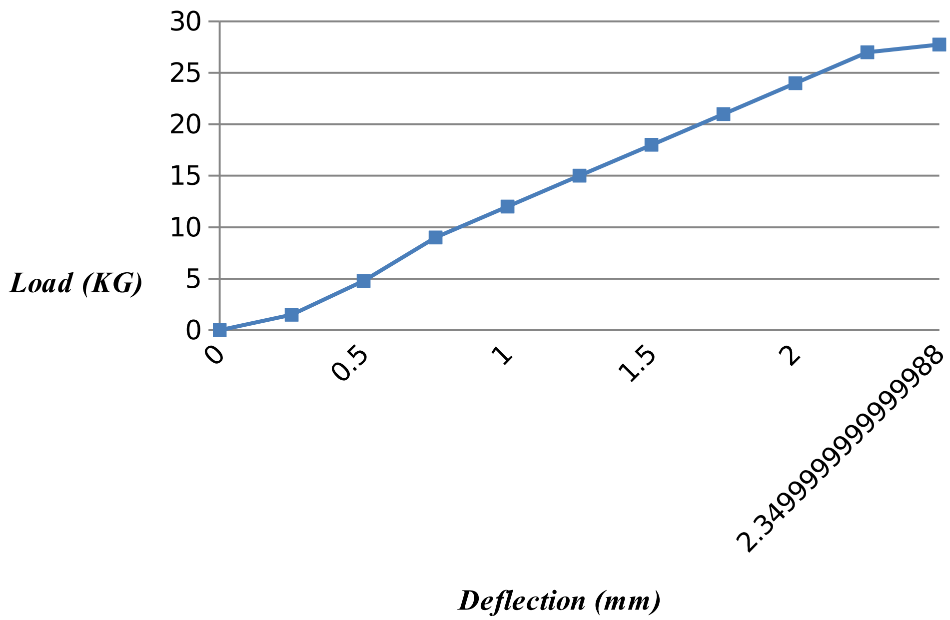


Figure 9.8: Load-Deflection Curve for the HBCs Sample JBBJ-2

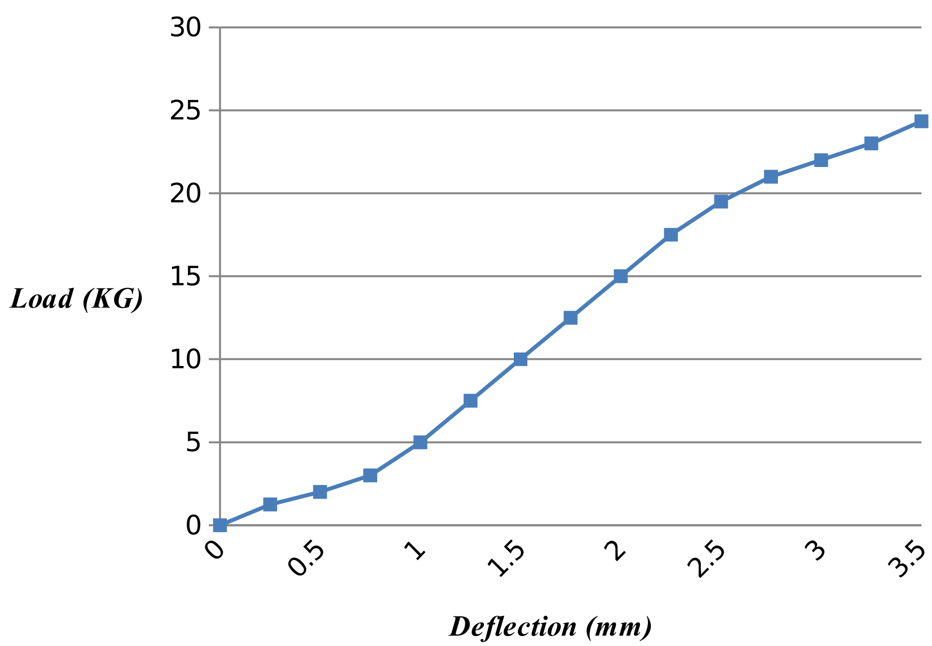


Figure 9.9: Load-Deflection Curve for the HBCs Sample BJJB-2

The load-deflection curves for the HBCs obtained reveals that the composite sample JBBJ-1 has the maximum bending load bearing capacity whereas, the composite sample BJJB-2 has the least bending load bearing capacity.

Compared to the composite sample BJJB-1, the composite sample JBBJ-1 has the maximum bending load bearing capacity. The composite sample JBBJ-1 has the load bearing capacity of 50 KG whereas, the composite sample BJJB-1 can bear the bending load of 28.67 KG.

Similarly, the composite sample JBBJ-2 has the maximum bending load bearing capacity compared to the composite sample BJJB-2. The composite sample JBBJ-2 has the bending load bearing capacity of 27 KG while the composite sample BJJB-2 has the bending load carrying capacity of 24 KG only.

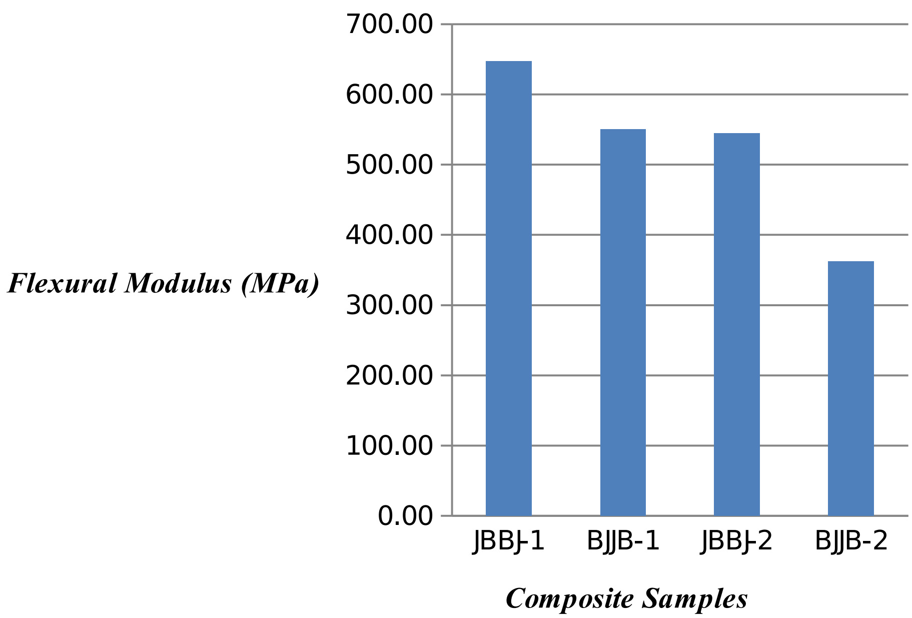


Figure 9.10: Comparison between Flexural Modulus of HBCs

Figure 9.10 shows the comparison between FM of HBCs. The composite sample JBBJ-1 has the maximum FM while the composite sample BJJB-2 has the least FM.

The composite sample JBBJ-1 exhibits maximum FM compared to the composite sample BJJB-1. The composite sample JBBJ-1 shows the FM of 648 MPa while the composite sample BJJB-1 shows the FM of 550 MPa.

Similarly, the composite sample JBBJ-2 has better FM compared to the composite sample BJJB-2. The composite sample JBBJ-2 shows FM of 544 MPa whereas, the composite sample BJJB-2 shows the FM of 362 MPa only.

9.1.3. Impact Properties of the HBCs:

Table 9.3 reveals the IS of the HBCs. Three specimens of each composite sample were tested to determine the IS of the HBCs and the average value for each sample gives the IS of the HBCs.

Table 9.3: Impact Strength of the HBCs

Composite Samples	Impact Strength (Joules)			Average Impact Strength (Joules)
	Trial 1	Trial 2	Trial 3	
JBBJ-1	7	10	8	8.33
BJJB-1	2	4	3	3.00
JBBJ-2	1	1	2	1.33
BJJB-2	0	1	1	0.67

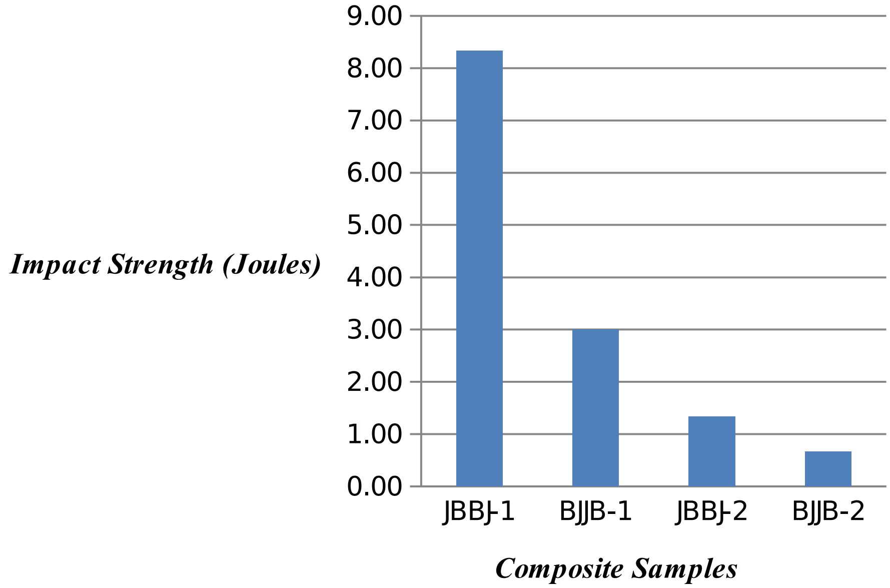


Figure 9.11: Comparison between Impact Strength of the HBCs

Figure 9.11 shows the comparison between the IS of the HBCs. The results reveal that the composite sample JBBJ-1 has the maximum impact energy absorbing capacity. On the other hand, the composite sample BJJB-2 shows least impact energy absorbing capacity. The composite sample JBBJ- 1 exhibits higher IS compare to the composite sample BJJB-1. The composite sample JBBJ-1 has the IS of 8 Joules. On the other hand, the composite sample BJJB-1 has the IS of 3 Joules.

Similarly, the composite sample JBBJ-2 has better IS compare to the composite sample BJJB-2. The composite sample JBBJ-2 has the IS of 1.3 Joules whereas, the composite sample BJJB-2 has the IS of 0.67 Joules only.

9.1.4. Hardness Properties of the HBCs:

Table 9.4 shows the hardness properties of the HBCs. Three specimens of each composite sample have analyzed to evaluate the hardness properties of the samples. The average value of all the specimens gives the hardness value of the HBCs. The hardness values of the HBCs have obtained on B-scale.

Table 9.4: Hardness Properties of the HBCs

Composite Samples	Hardness Rockwell on B-scale (HRB)			Average (HRB)
	Trial 1	Trial 2	Trial 3	
JBBJ-1	60	85	55	66.67
BJJB-1	25	45	30	33.33
JBBJ-2	50	62	50	54.00
BJJB-2	59	52	55	55.33

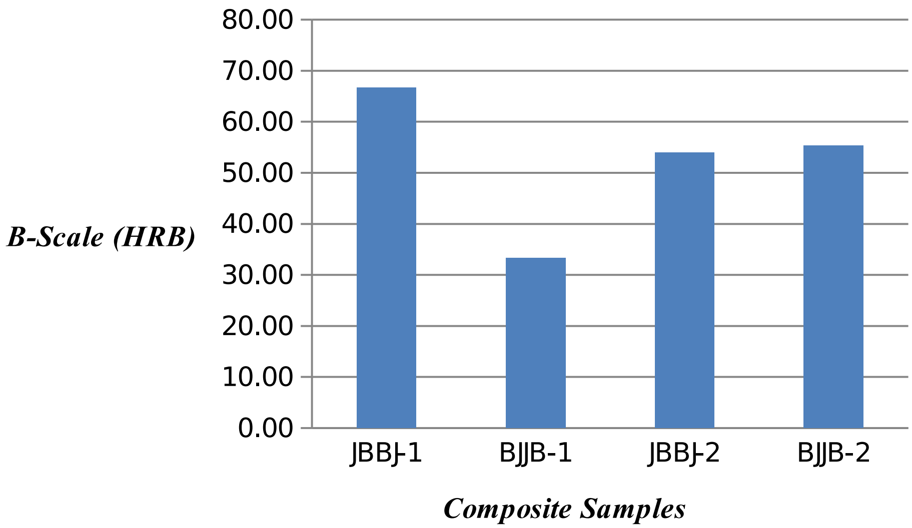


Figure 9.12: Comparison between Hardness Properties of the HBCs

Figure 9.12 gives the graphical comparison between the hardness properties of the HBCs obtained on B-scale. The composite sample JBBJ-1 has the maximum hardness value compared to the composite sample BJJB-1. The hardness values obtained in case of JBBJ-1 and BJJB-1 is 66.67 and 33.33 on B-scale.

The composite sample JBBJ-2 and BJJB-2 exhibits appropriately similar hardness values. The composite sample JBBJ-2 shows hardness value of 54 while the composite sample BJJB-2 shows the hardness value of 55.33 on B-scale.

9.1.5. Water absorption Test:

For water absorption test, three specimens of each composite sample of equal size and equal weight have prepared. The test has performed by recording the initial weight of the specimens and recording the weight of the specimens after removal from water dipped for 72 hours. It has observed that the weight of the composite samples is same in both the conditions.

This test result reveals that the composite samples are perfectly resistant to moisture absorption.

9.2. ANSYS Simulation Results:

For evaluating the mechanical properties of the HBCs in ANSYS, orthotropic elastic properties have obtained using theoretical ROM and HROM. In this section, the mechanical properties of HBCs have evaluated using ROM and HROM separately. The deformed shape of the geometry and Von Misses Stress developed in each case has presented.

9.2.1 ANSYS Simulation of Tensile Properties:

Table 9.5 shows the Von Misses Stresses developed in each case during tensile simulation using ROM.

Table 9.5: Von Misses Stress developed in Tensile Test Geometry using ROM

Composite Samples	Von Misses Stress (MPa)

JBBJ-1	32.11
BJJB-1	20.39
JBBJ-2	20.92
BJJB-2	15.61

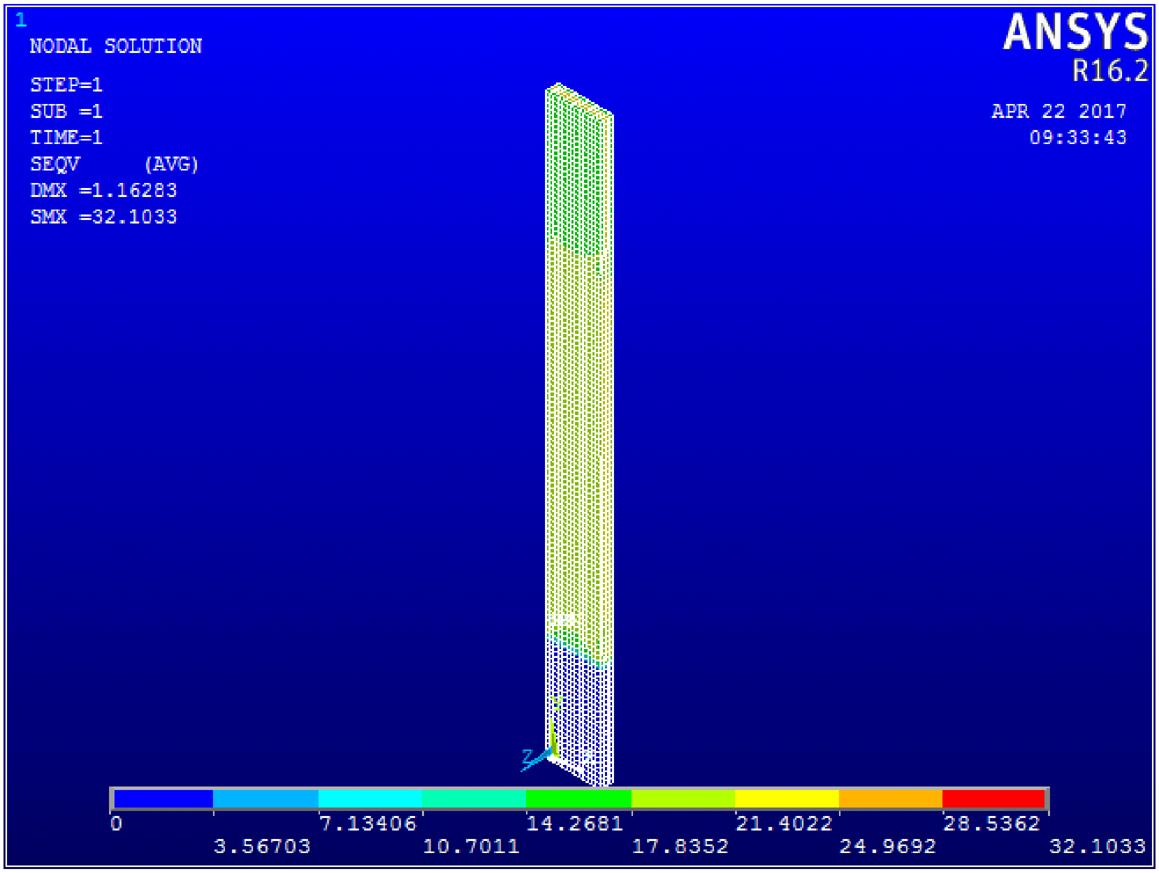


Figure 9.13: Deformed Tensile Shape and Von Misses Stress developed in JBBJ-1 using ROM

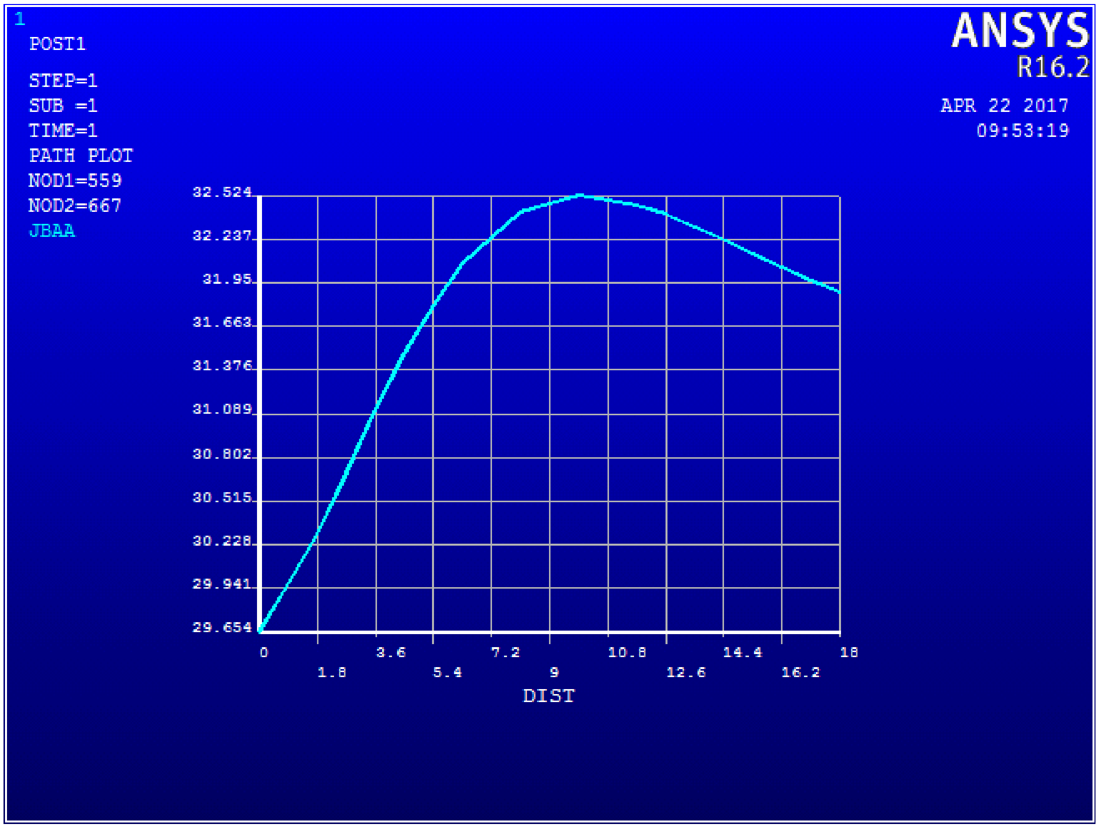


Figure 9.14: Tensile Behavior of HBCs Sample JBBJ-1 using ROM

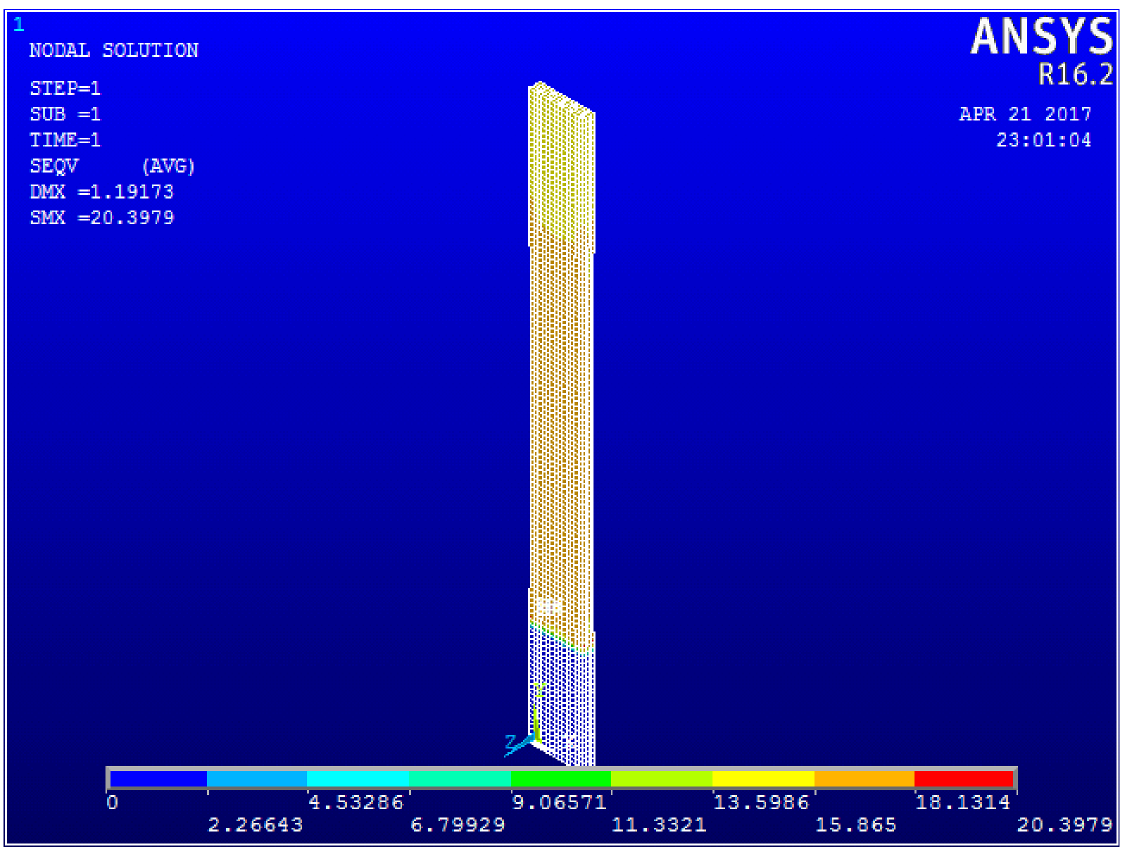


Figure 9.15: Deformed Tensile Shape and Von Misses Stress developed in BJJB-1 using ROM

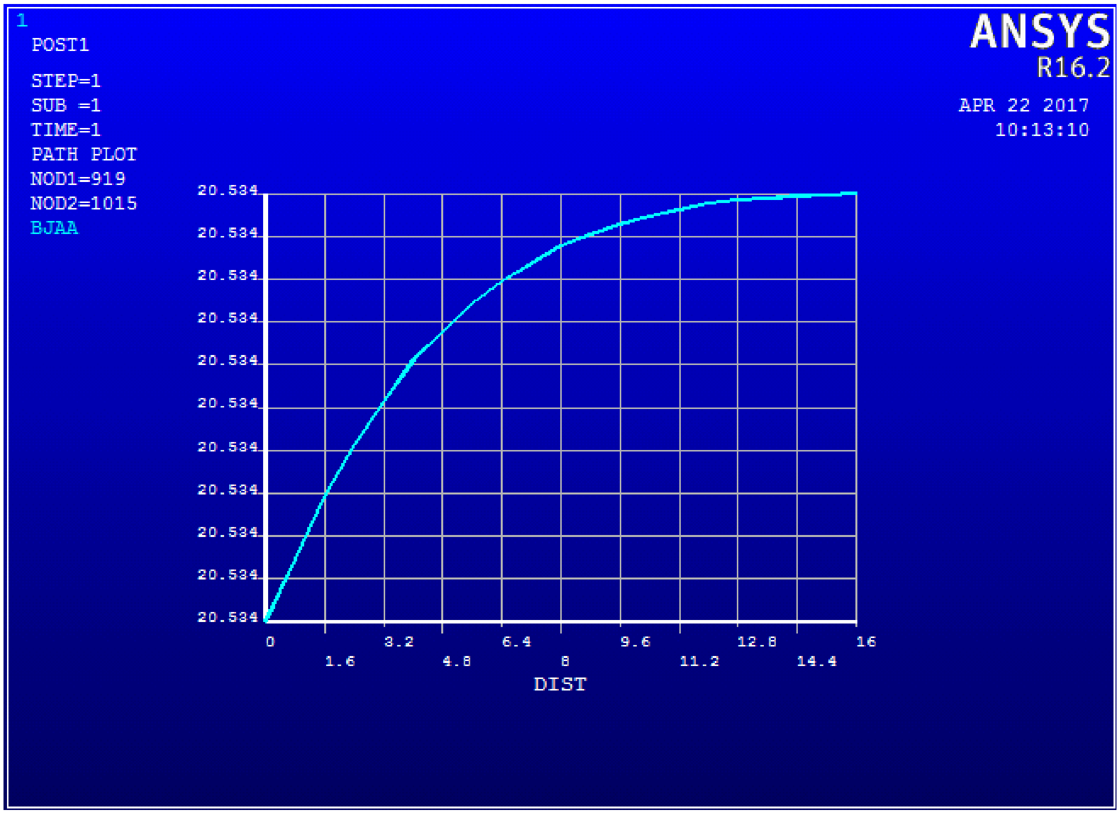


Figure 9.16: Tensile Behavior of HBCs Sample BJJB-1 using ROM

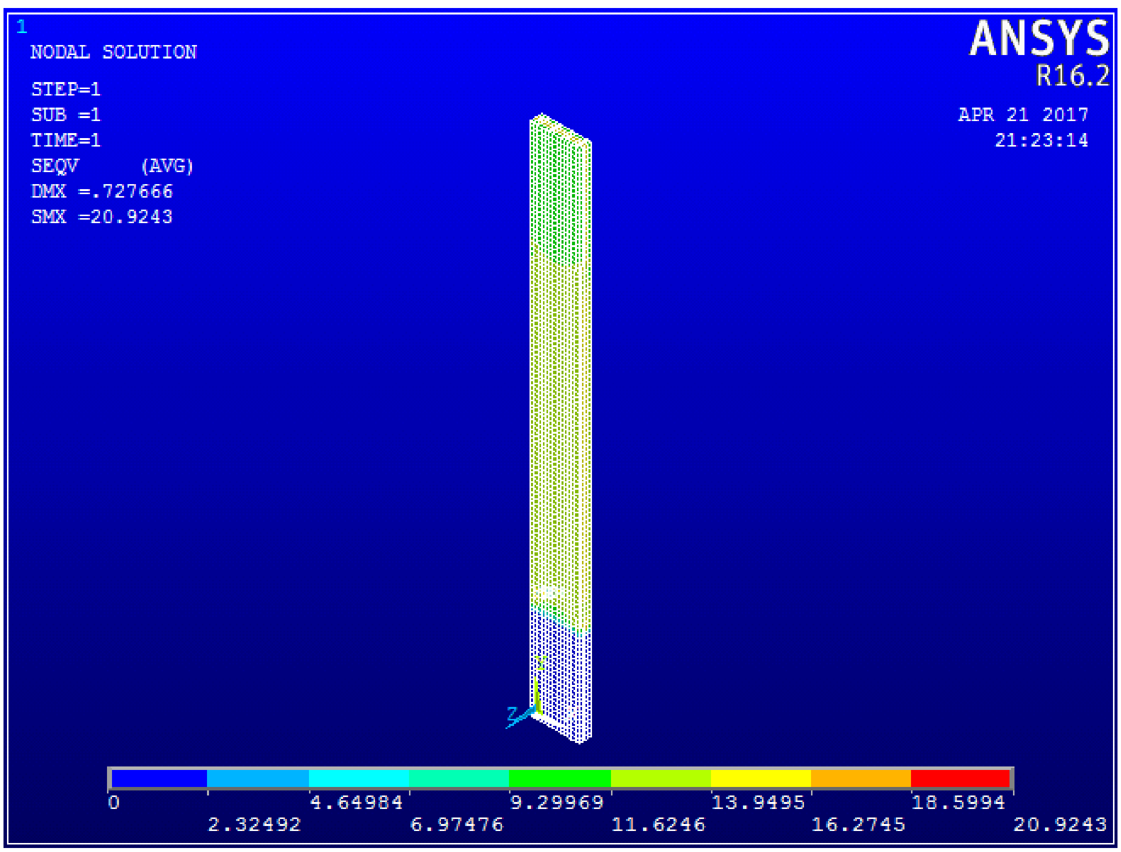


Figure 9.17: Deformed Tensile Shape and Von Misses Stress developed in JBBJ-2 using ROM

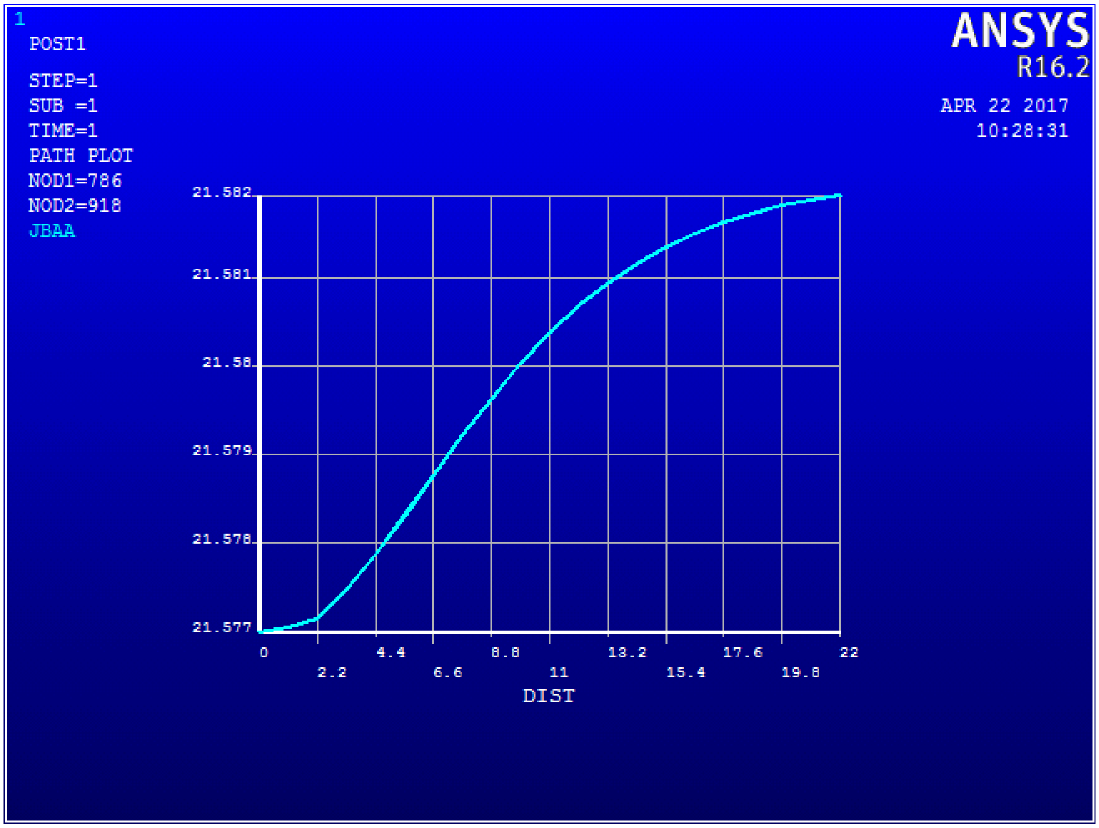


Figure 9.18: Tensile Behavior of the HBCs Sample JBBJ-2 using ROM

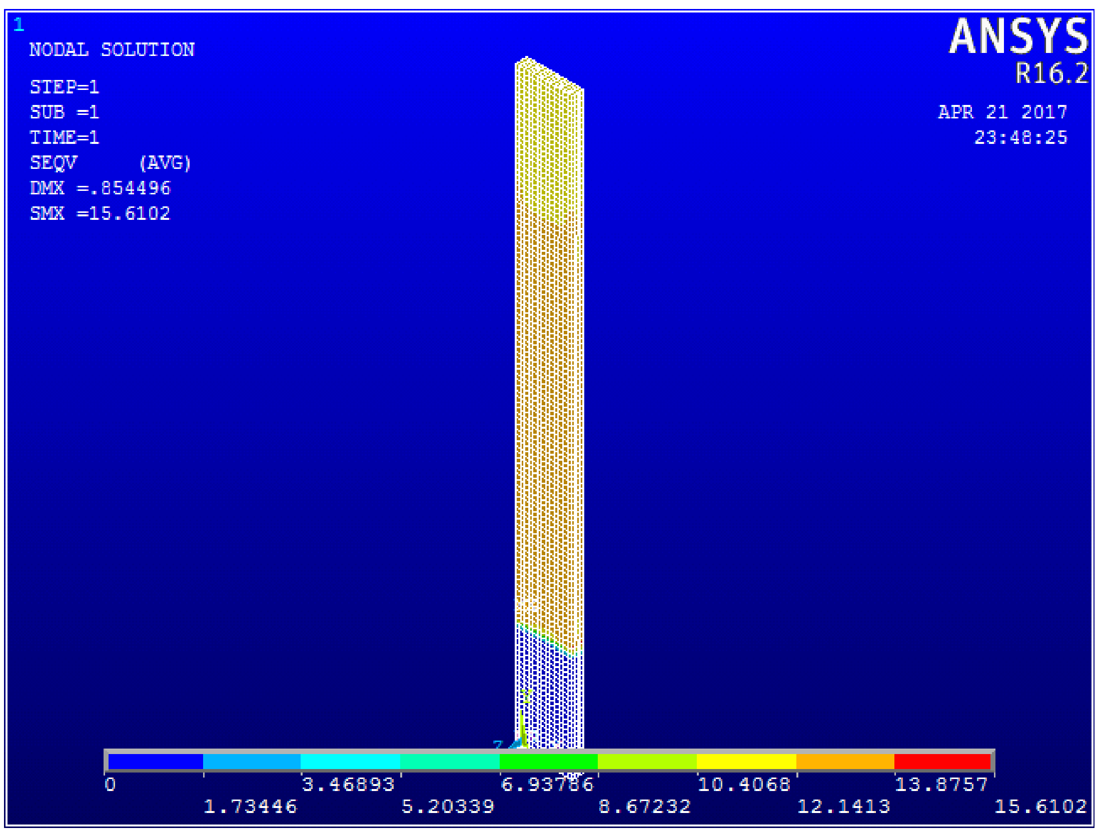


Figure 9.19: Deformed Tensile Shape and Von Misses Stress developed in BJJB-2 using ROM

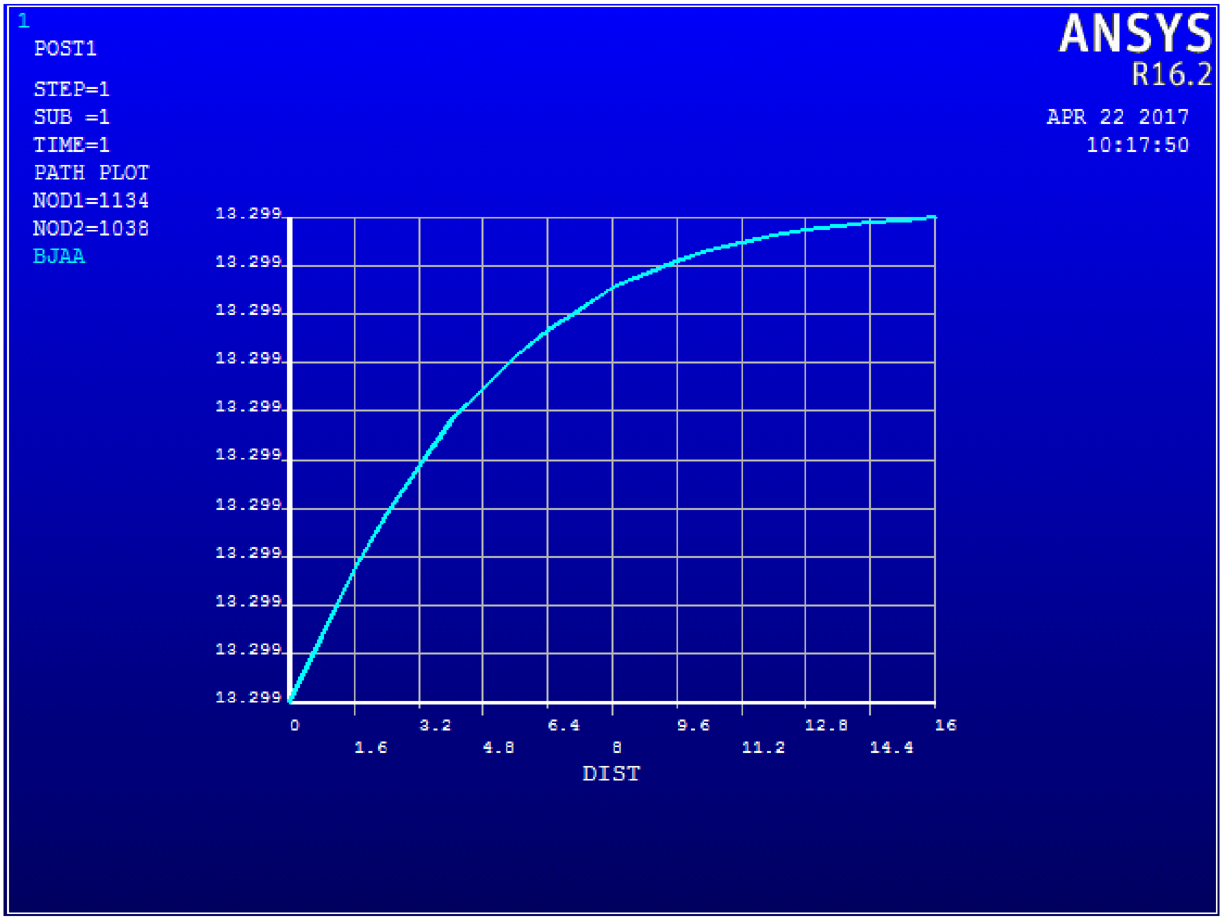


Figure 9.20: Tensile Behavior of HBCs Sample BJJB-2 using ROM

Table 9.6 presents the value of Von Misses Stress developed in each case during tensile testing using HROM.

Table 9.6: Von Misses Stress developed in Tensile Test Geometry using HROM

Composite Samples	Von Misses Stress (MPa)
JBBJ-1	32.79
BJJB-1	21.19
JBBJ-2	23.98
BJJB-2	14.11

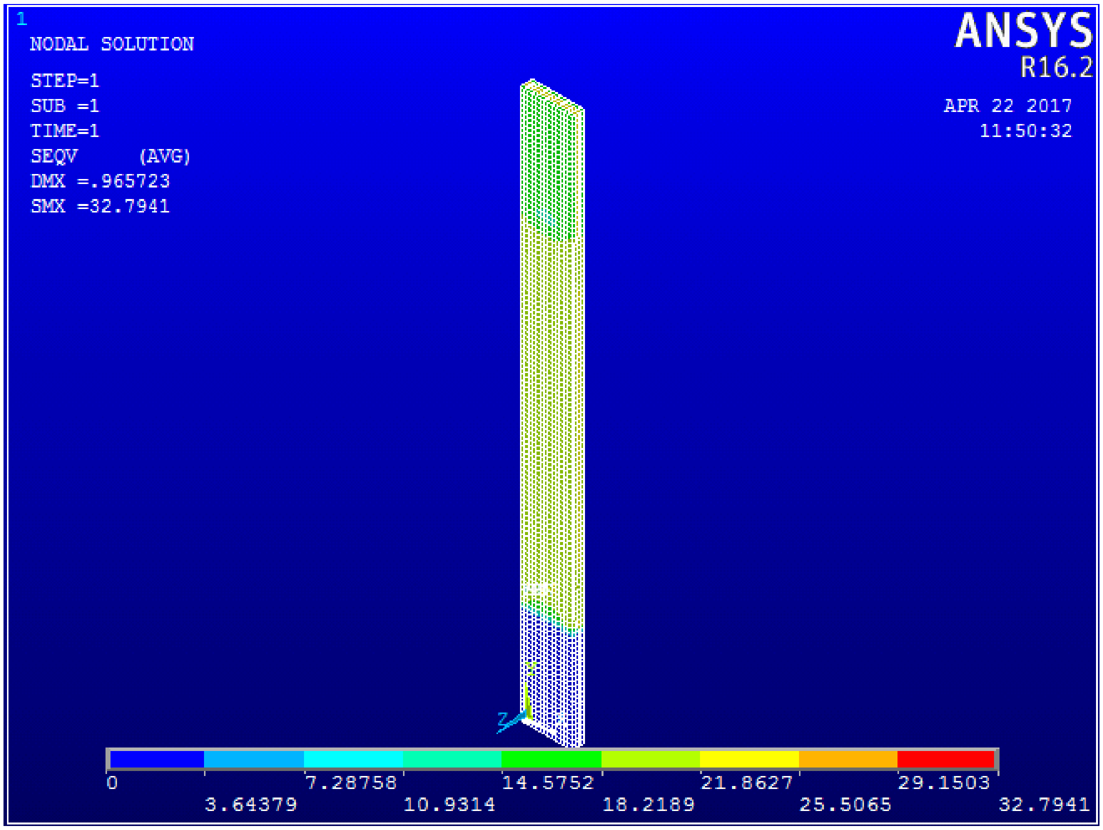


Figure 9.21: Deformed Tensile Shape and Von Misses Stress developed in JBBJ-1 using HROM

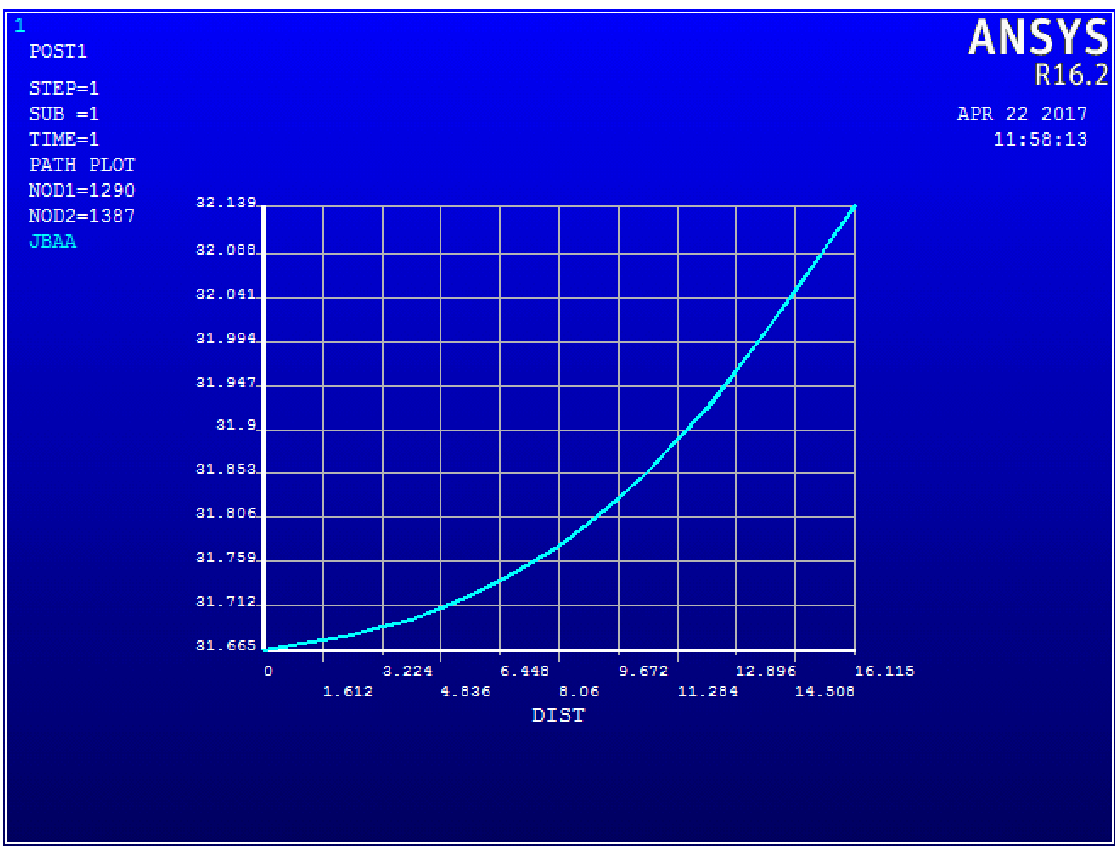


Figure 9.22: Tensile Behavior of HBCs sample JBBJ-1 using HROM

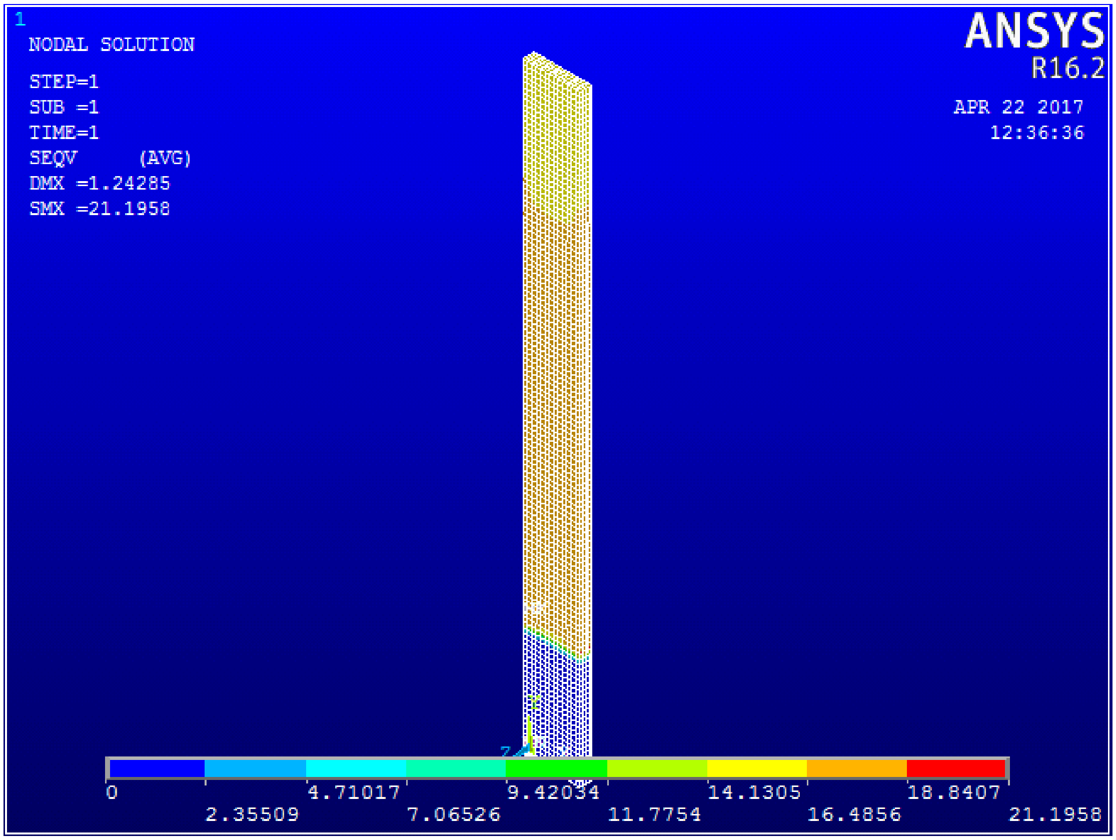


Figure 9.23: Deformed Tensile Shape and Von Misses Stress developed in BJJB-1 using HROM

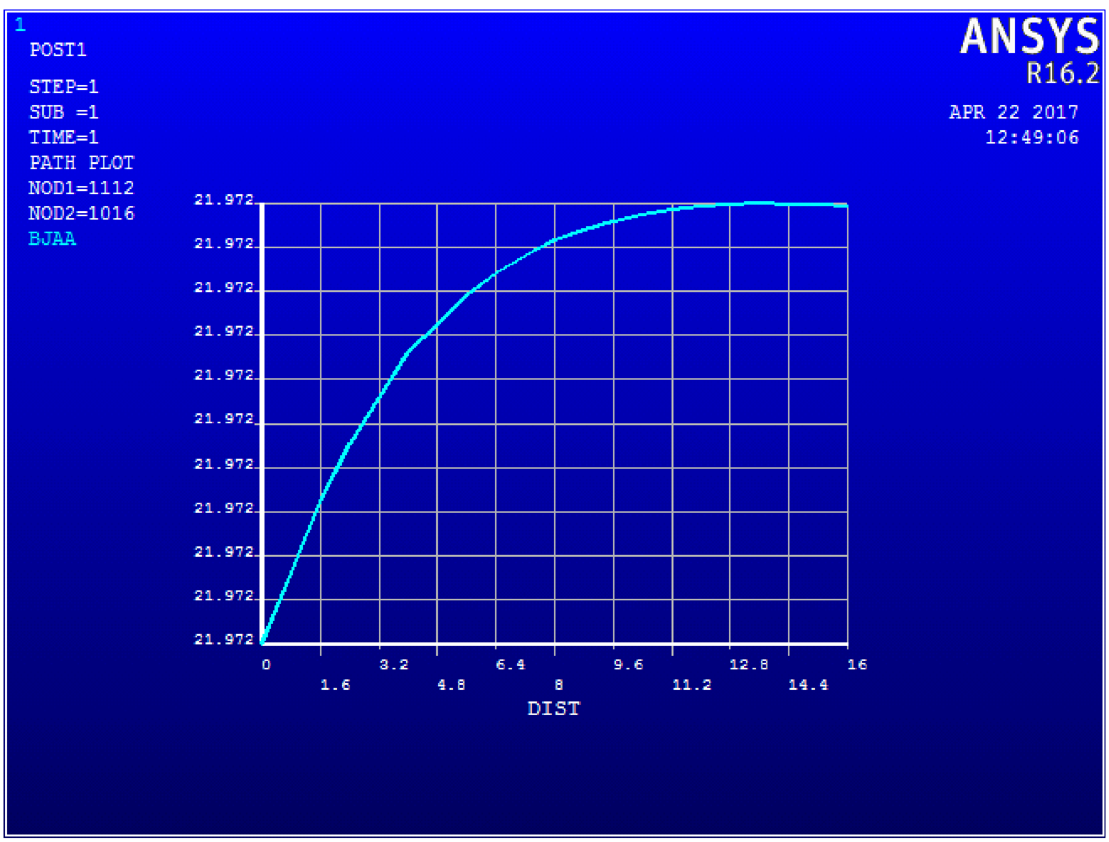


Figure 9.24: Tensile Behavior of HBCs sample BJJB-1 using HROM

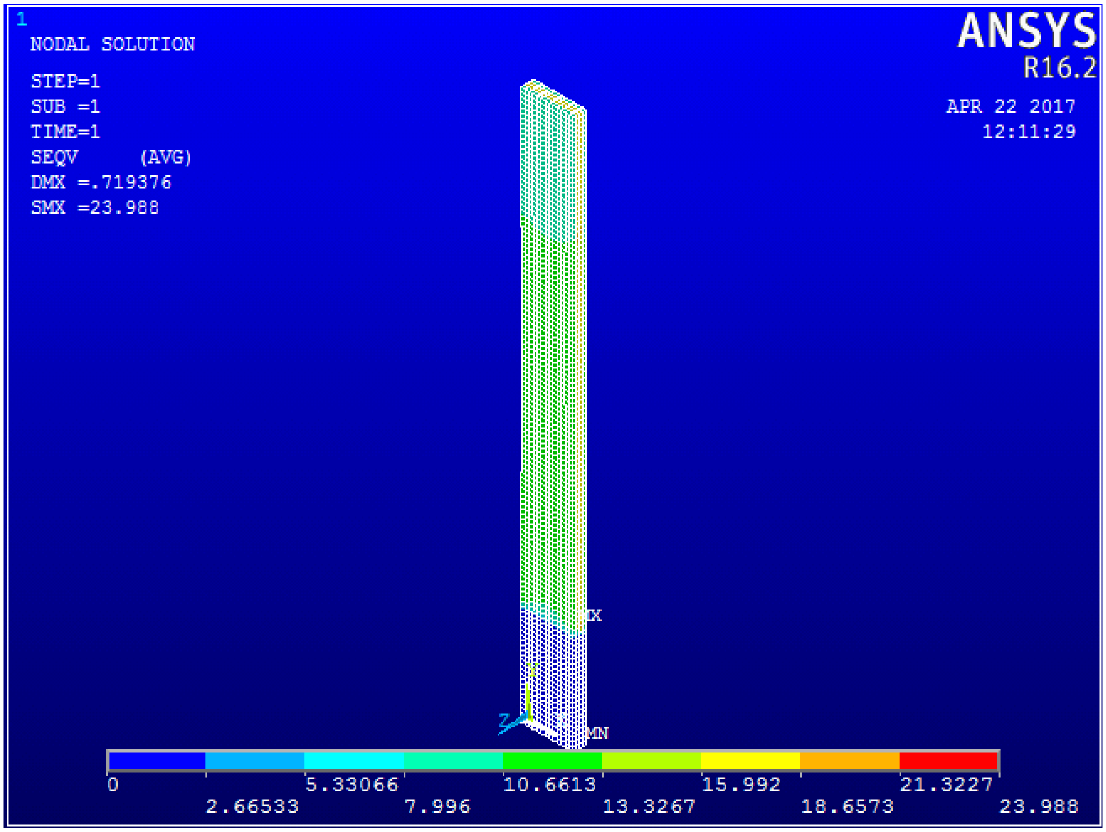


Figure 9.25: Deformed Tensile Shape and Von Misses Stress developed in JBBJ-2 using HROM

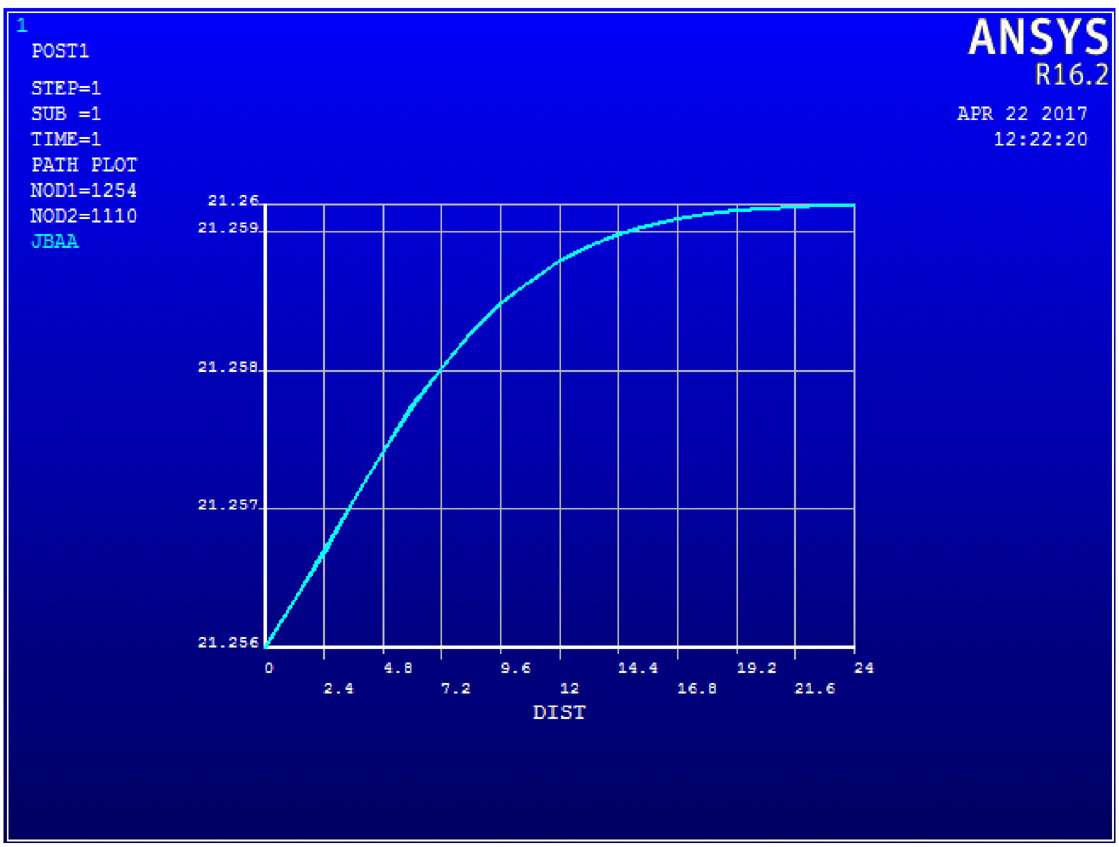


Figure 9.26: Tensile Behavior of HBCs sample JBBJ-2 using HROM

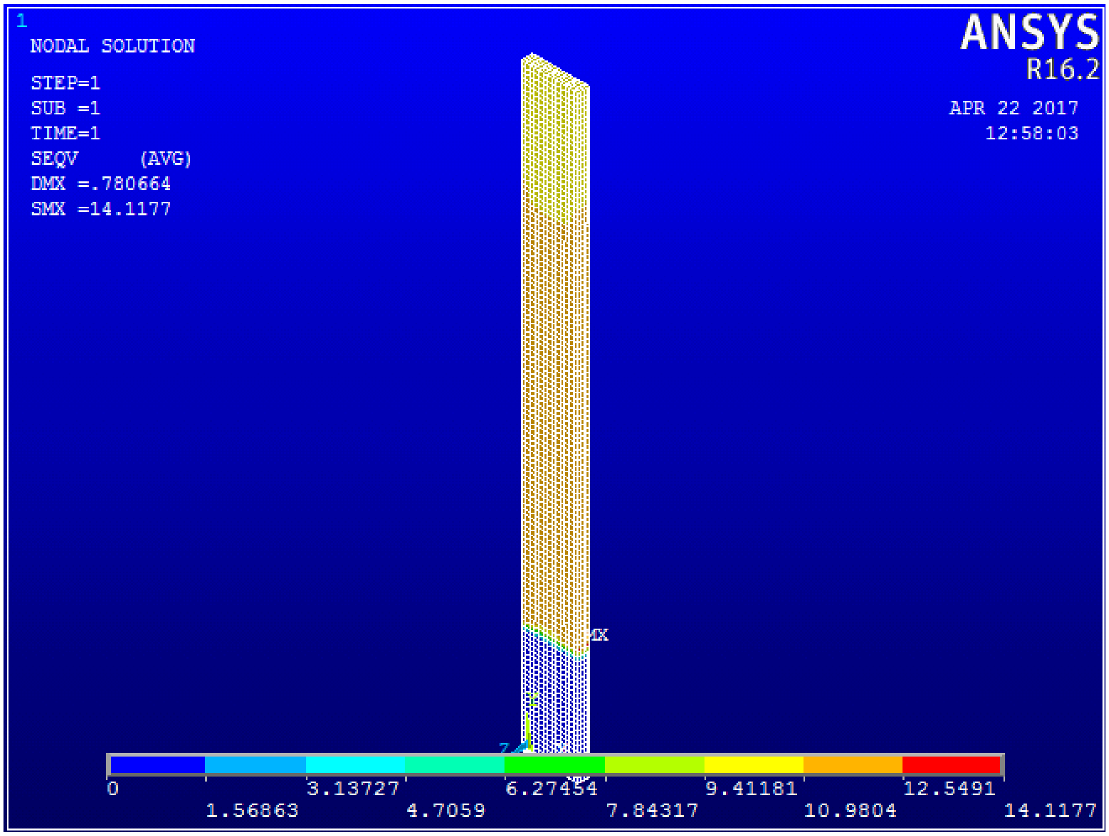


Figure 9.27: Deformed Tensile Shape and Von Misses Stress developed in BJJB-2 using HROM

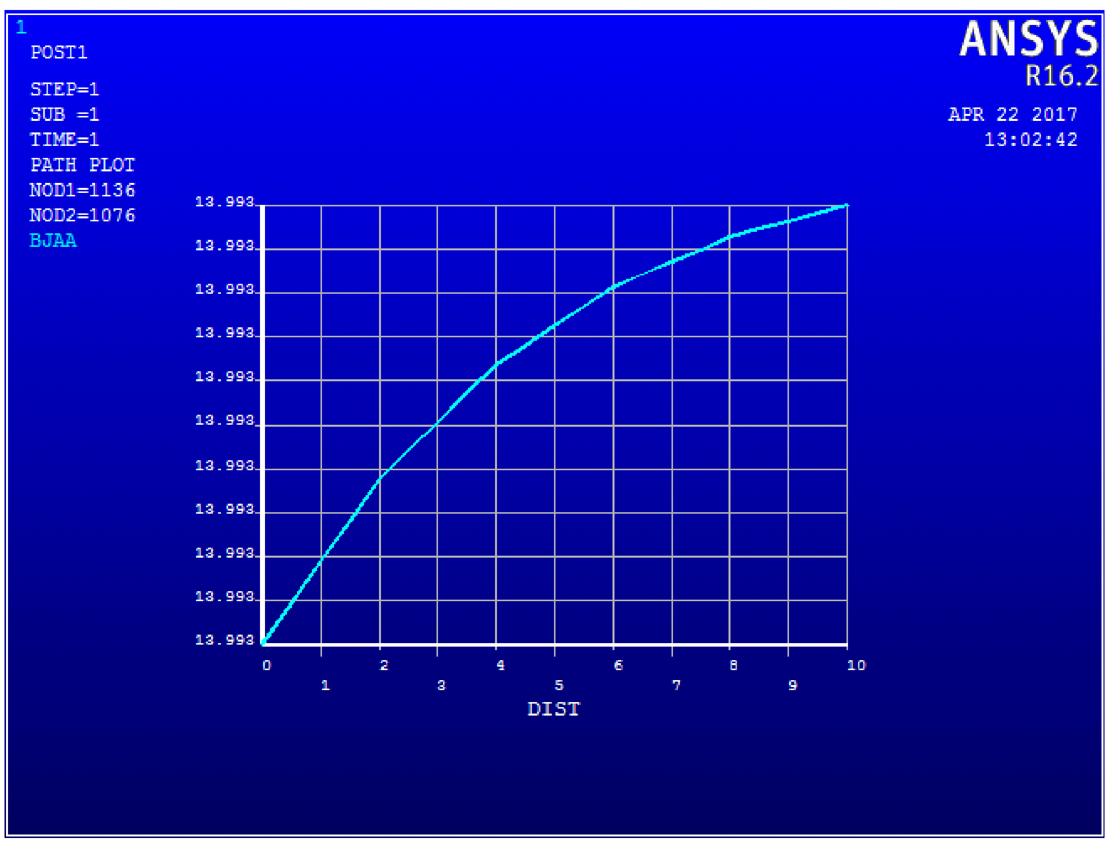


Figure 9.28: Tensile Behavior of HBCs sample BJJB-2 using HROM

9.2.2. ANSYS Simulation of Flexural Properties:

Table 9.7 details the Von Misses Stress developed in each case during flexural simulation using ROM.

Table 9.7: Von Misses Stress developed in Flexural Test Geometry using ROM

Composite Samples	Von Misses Stress (MPa)
JBBJ-1	82.73
BJJB-1	64.75
JBBJ-2	45.65
BJJB-2	54.57

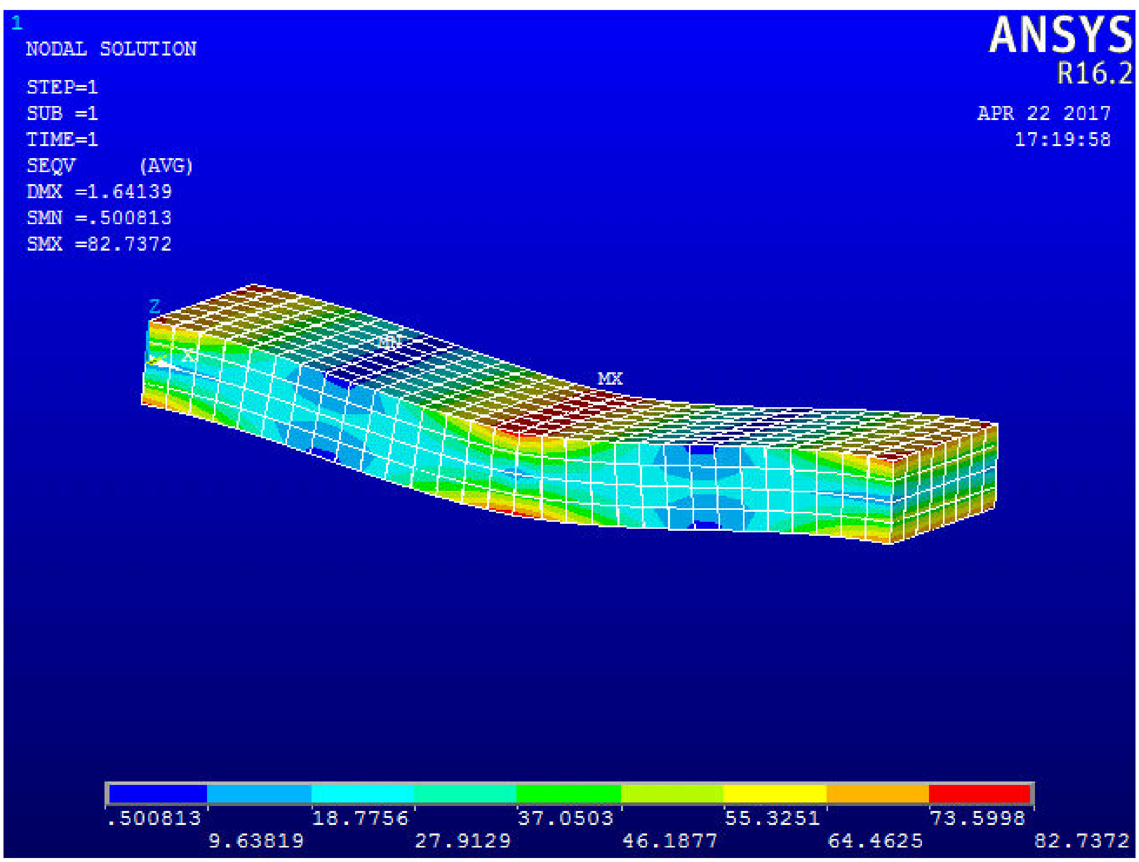


Figure 9.29: Deformed Flexural Shape and Von Misses Stress developed in JBBJ-1 using ROM

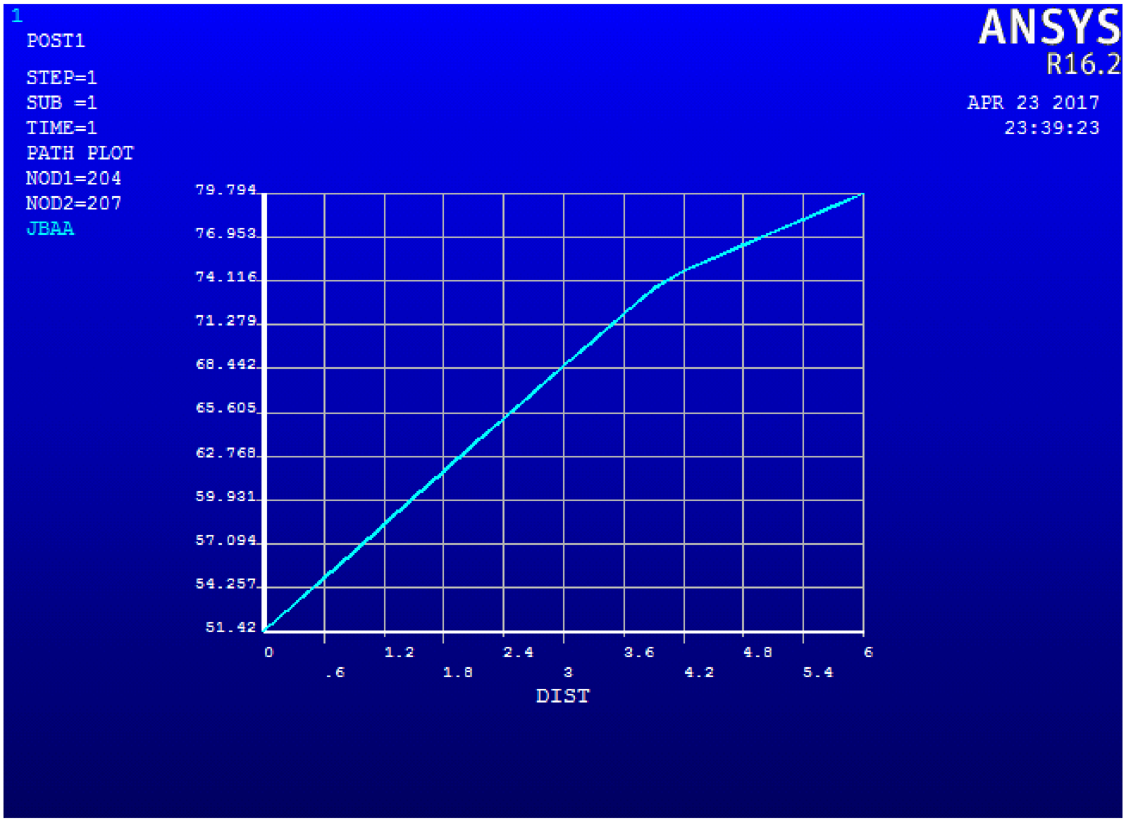


Figure 9.30: Flexural Behavior HBCs sample JBBJ-1 using ROM

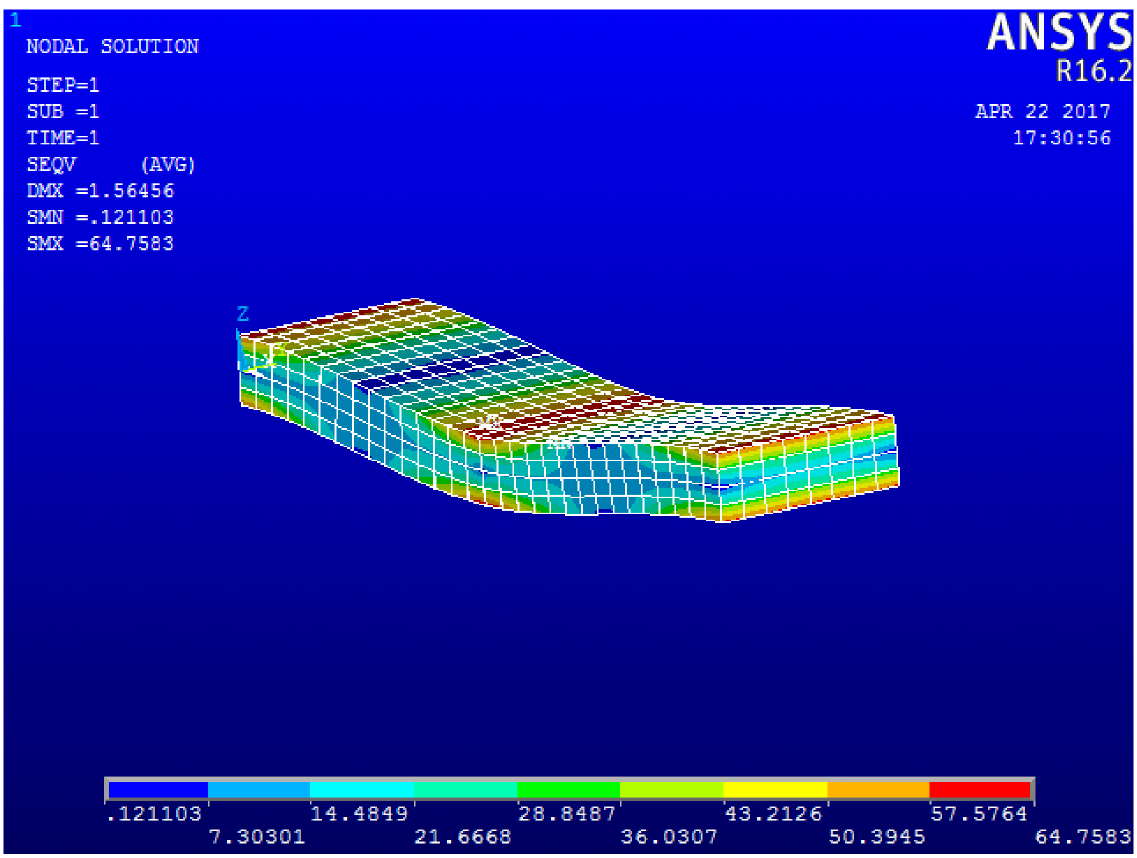


Figure 9.31: Deformed Flexural Shape and Von Misses Stress developed in BJJB-1 using ROM

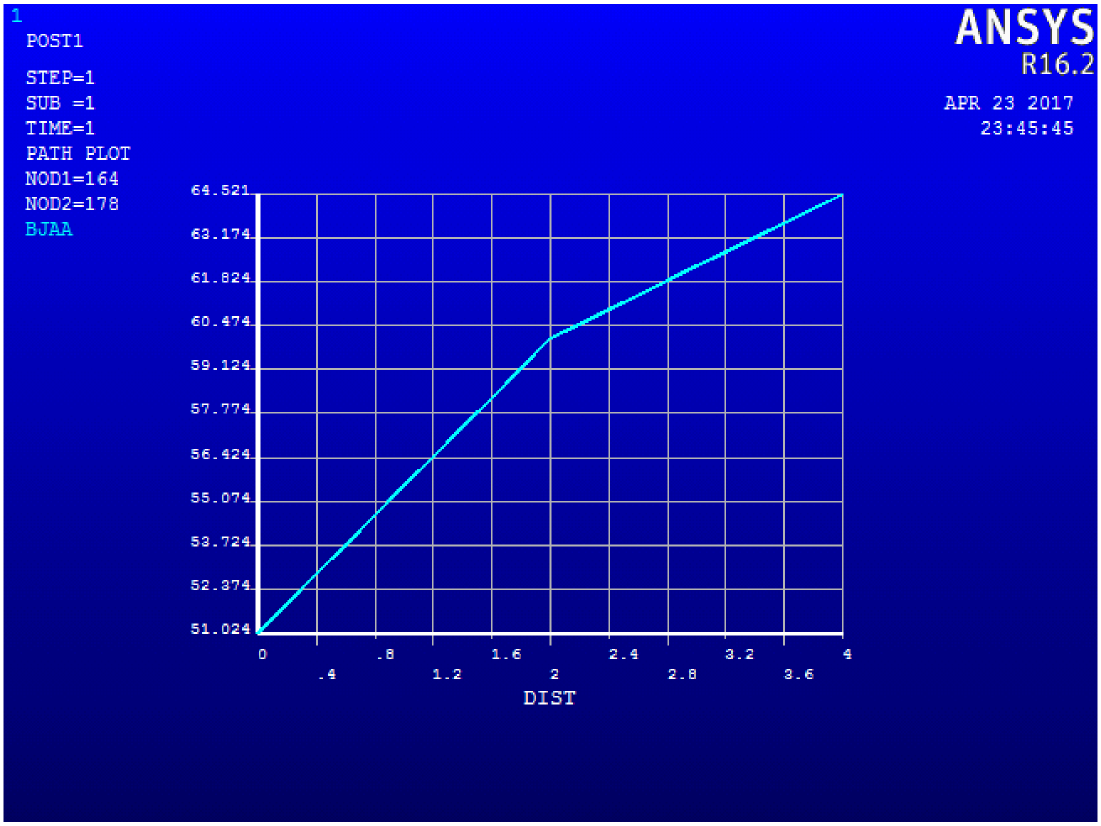


Figure 9.32: Flexural Behavior of HBCs sample BJJB-1 using ROM

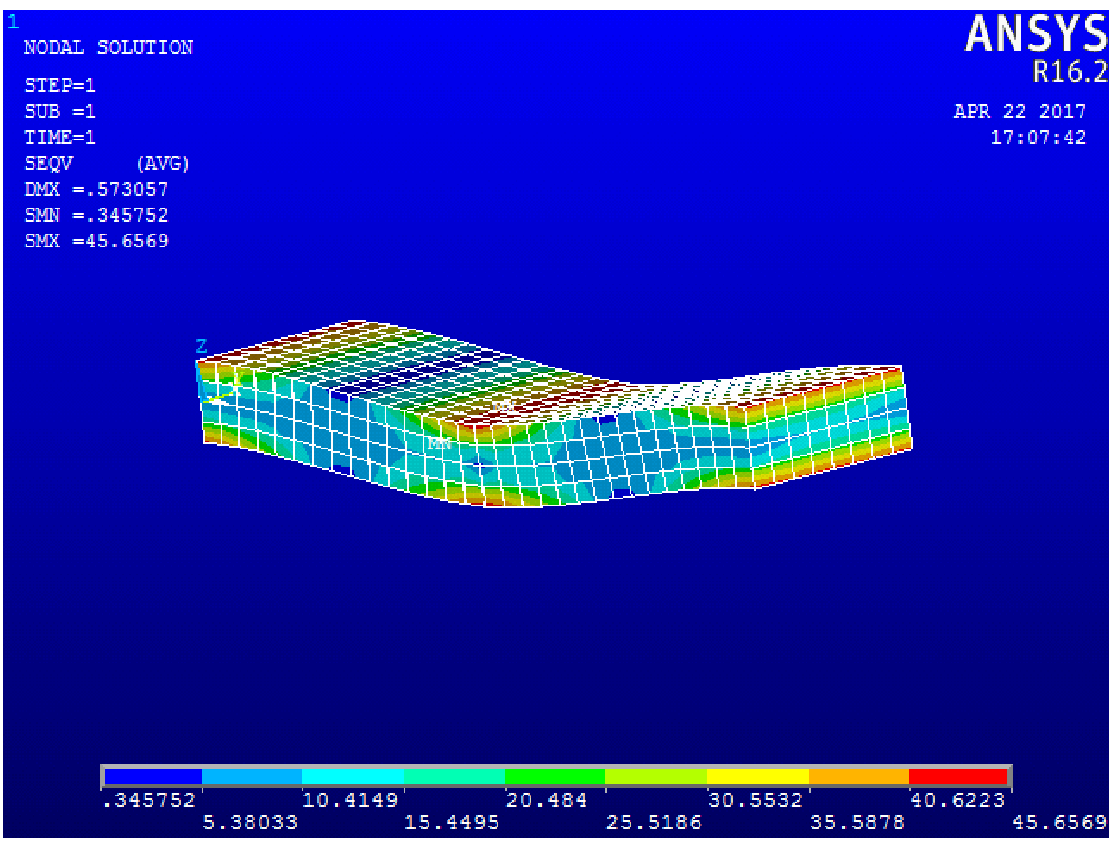


Figure 9.33: Deformed Flexural Shape and Von Misses Stress developed in JBBJ-2 using ROM

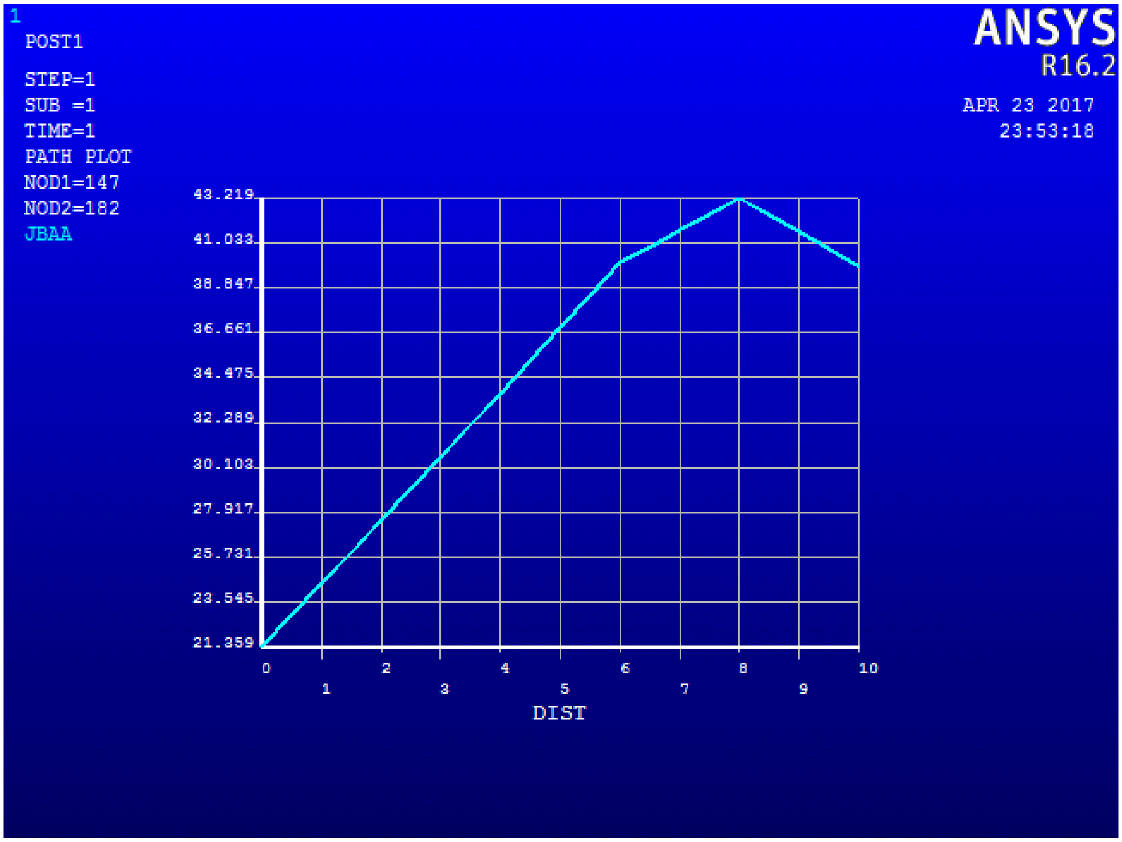


Figure 9.34: Flexural Behavior of HBCs sample JBBJ-2 using ROM

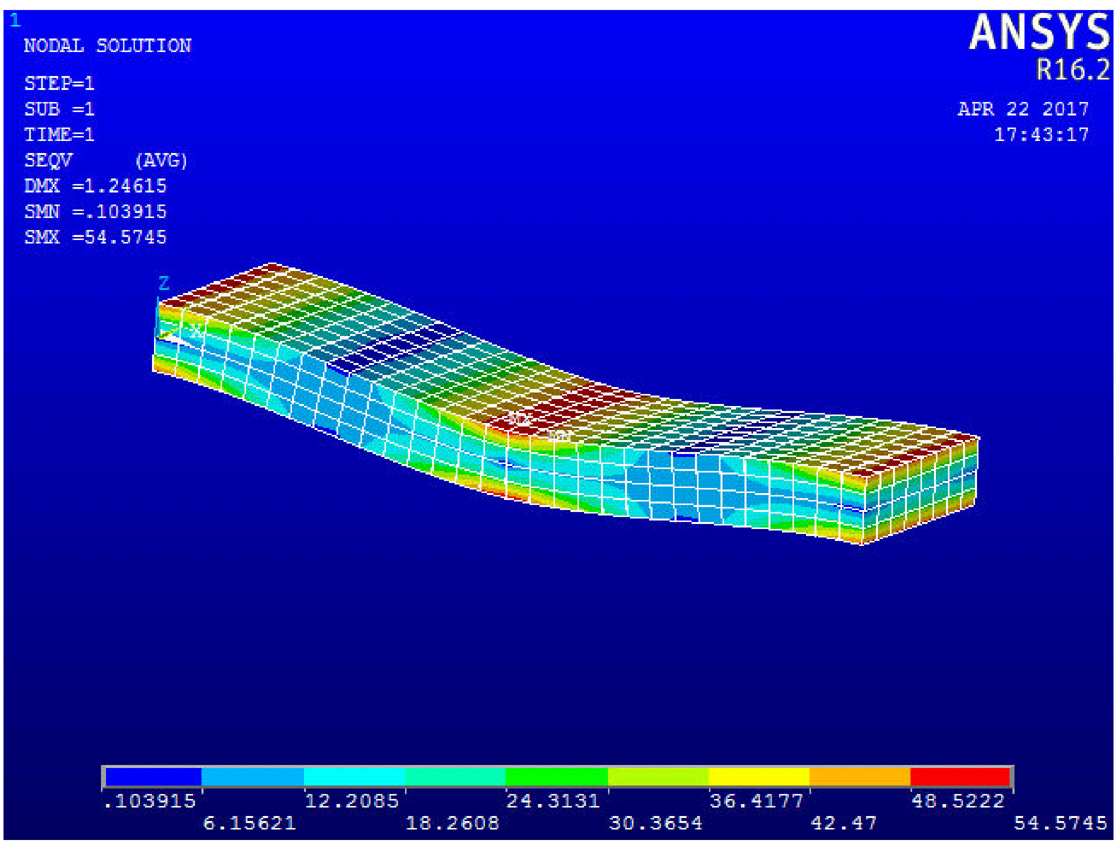


Figure 9.35: Deformed Flexural Shape and Von Misses Stress developed in BJJB-2 using ROM

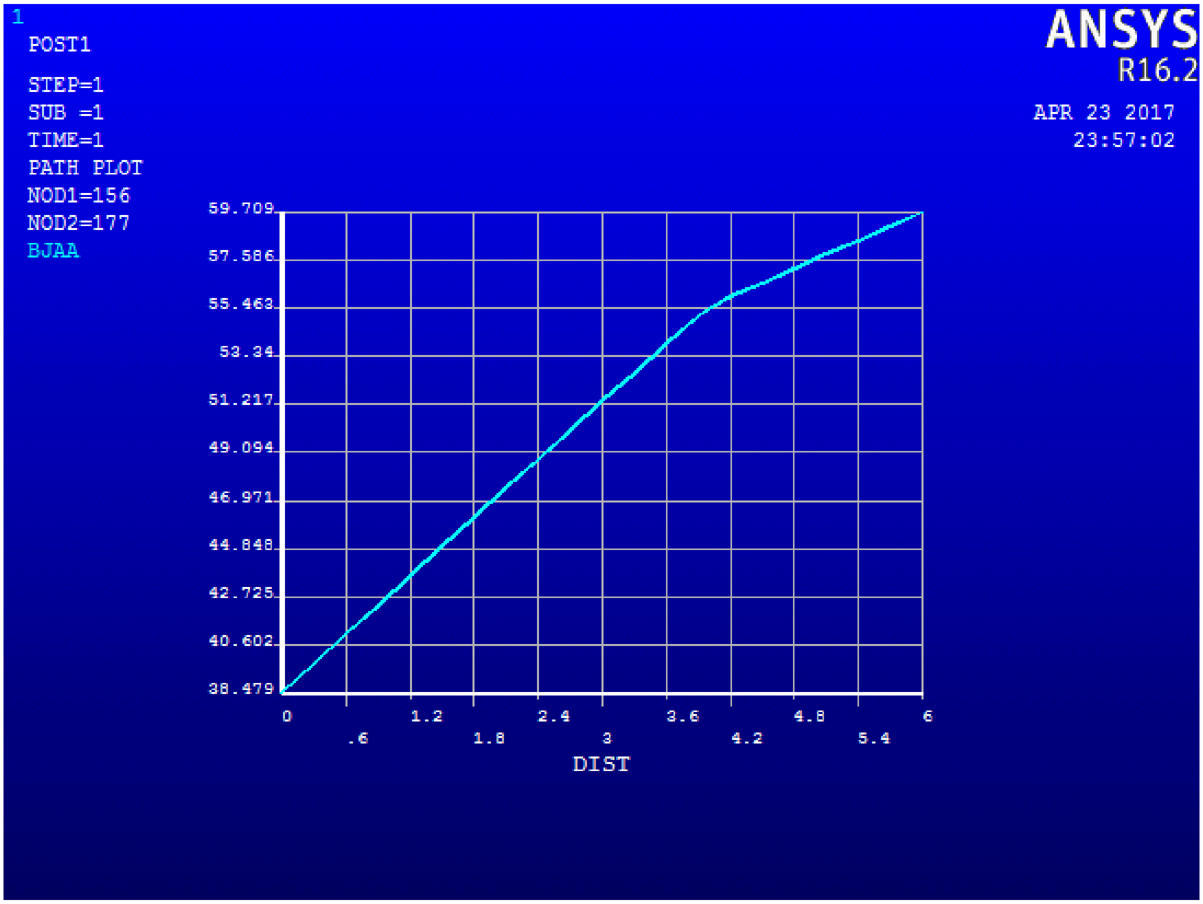


Figure 9.36: Flexural Behavior of HBCs sample BJJB-2 using ROM

Table 9.8 details the Von Misses Stress developed in each case during flexural simulation using HROM.

Table 9.8 Von Misses Stress developed in Flexural Test Geometry using HROM

Composite Samples	Von Misses Stress (MPa)
JBBJ-1	83.45
BJJB-1	64.39
JBBJ-2	45.9
BJJB-2	54.32

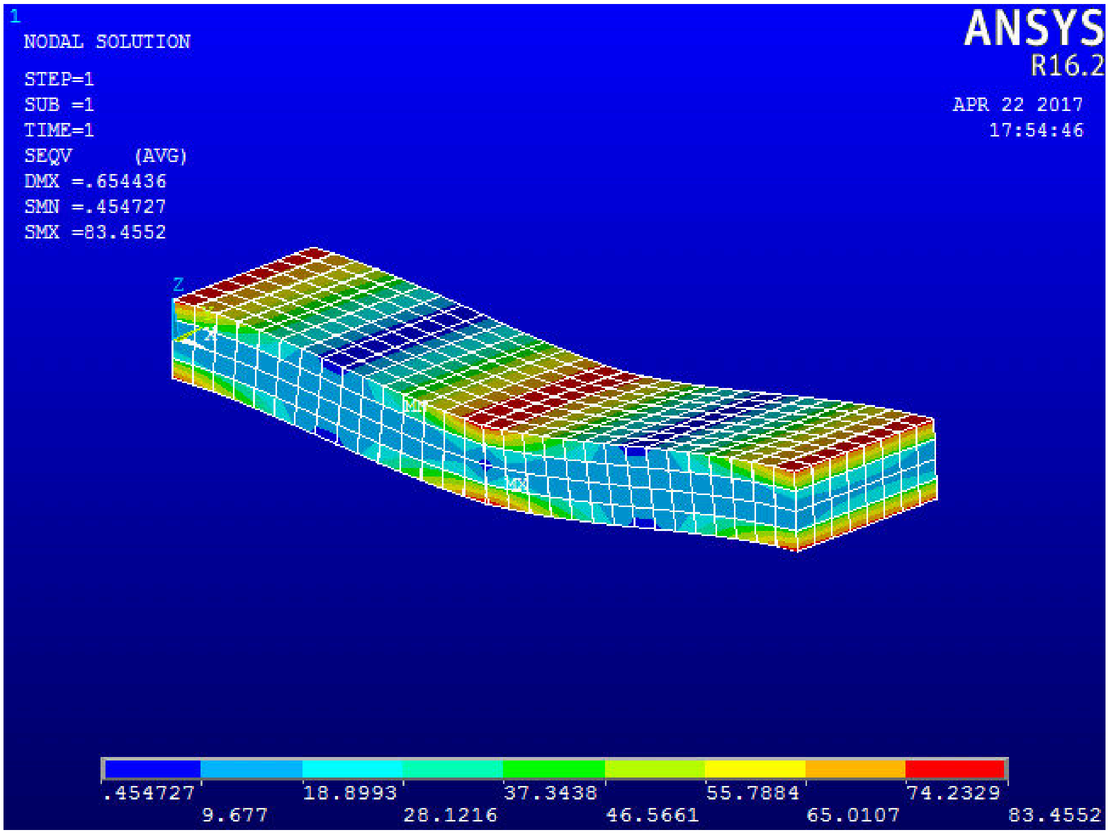


Figure 9.37: Deformed Flexural Shape and Von Misses Stress developed in JBBJ-1 using HROM

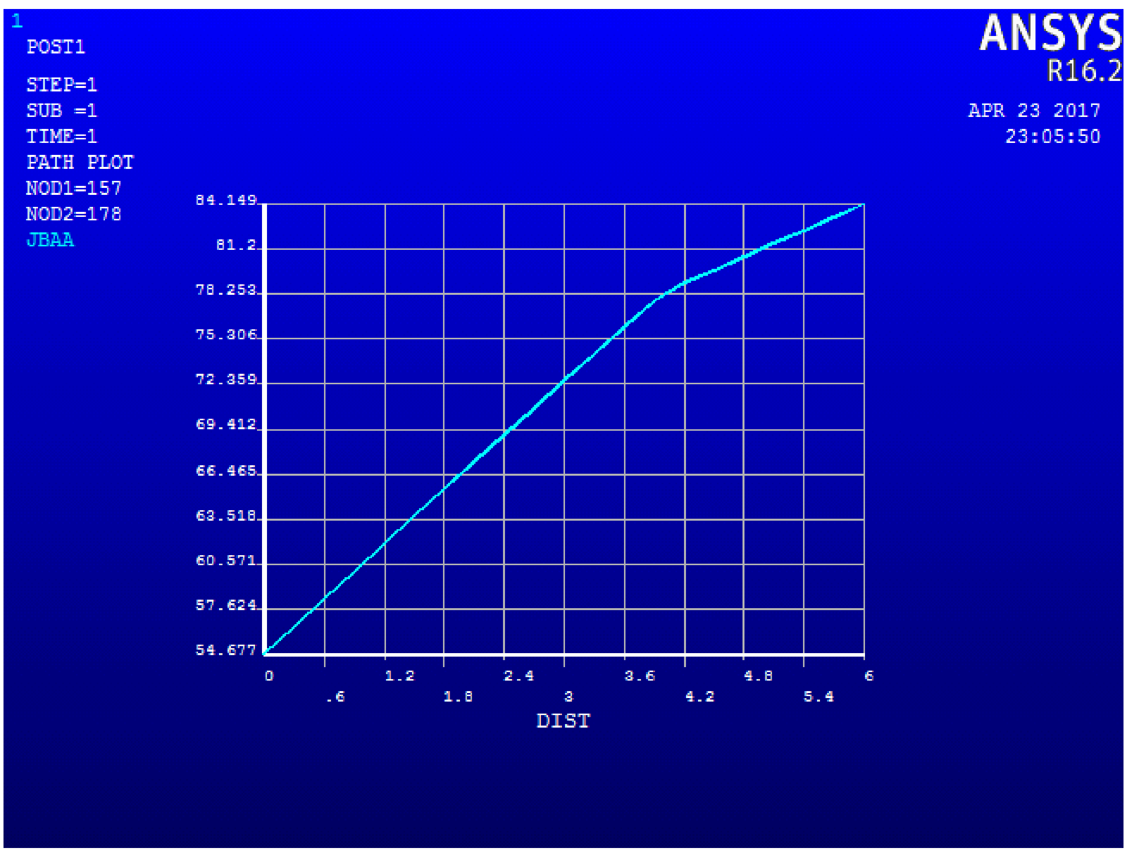


Figure 9.38: Flexural Behavior of HBCs sample JBBJ-1 using HROM

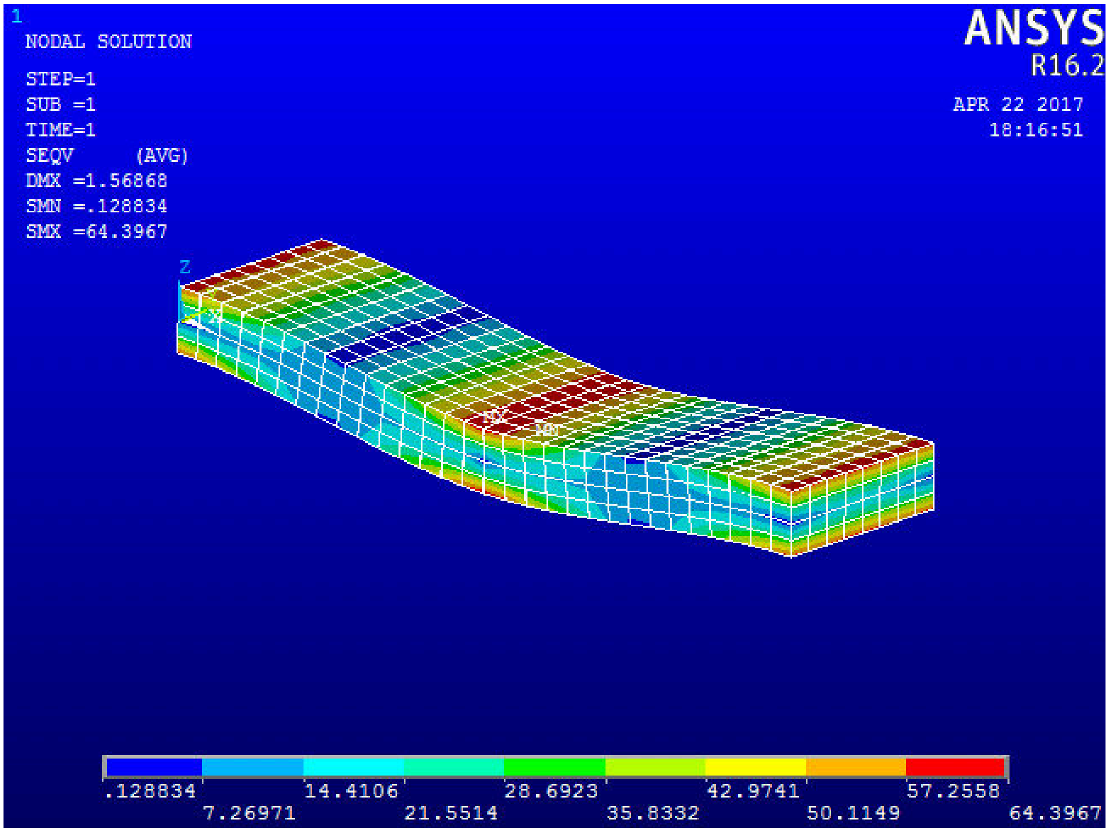


Figure 9.39: Deformed Flexural Shape and Von Misses Stress developed in BJJB-1 using HROM

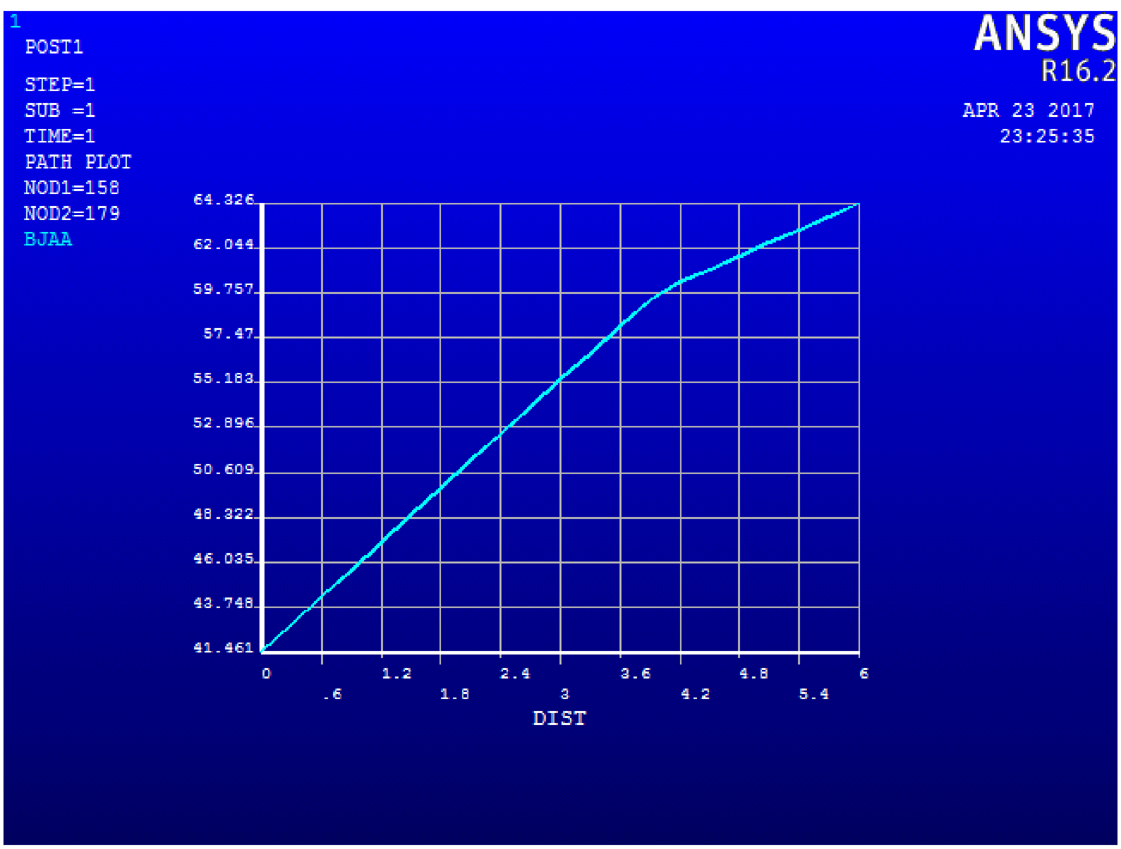


Figure 9.40: Flexural Behavior of HBCs sample BJJB-1 using HROM

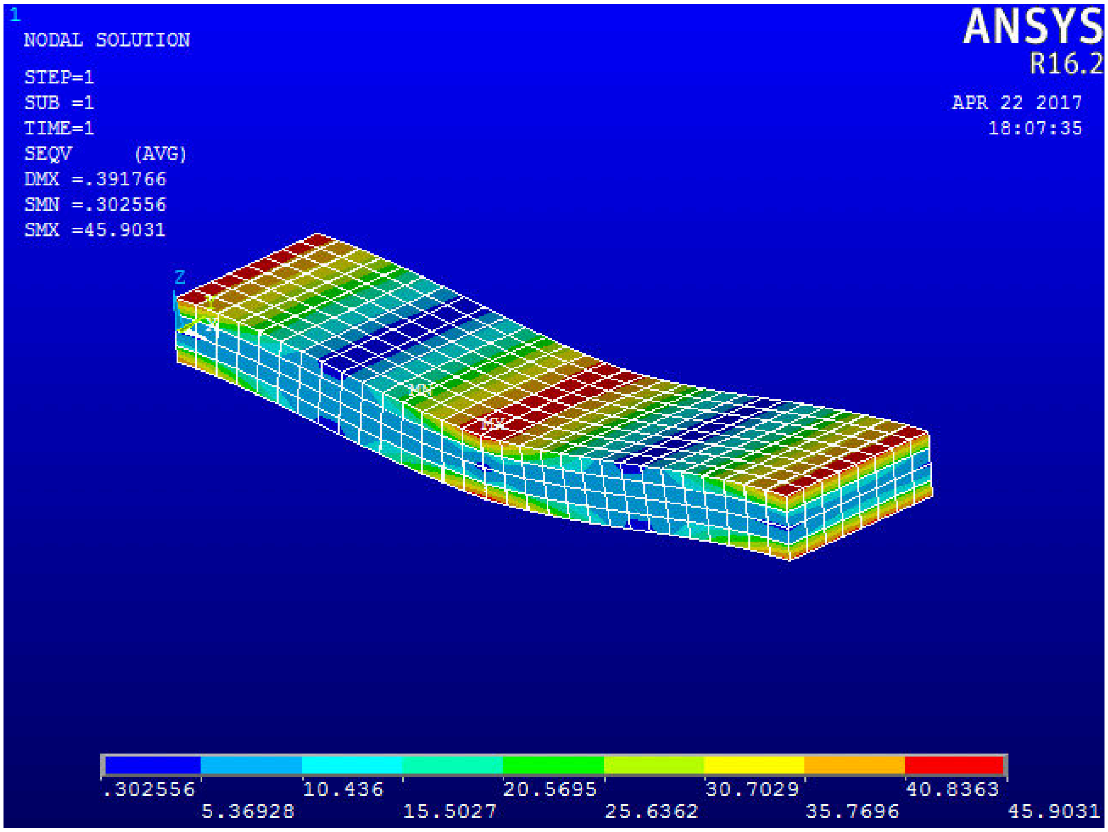


Figure 9.41: Deformed Flexural Shape and Von Misses Stress developed in JBBJ-2 using HROM

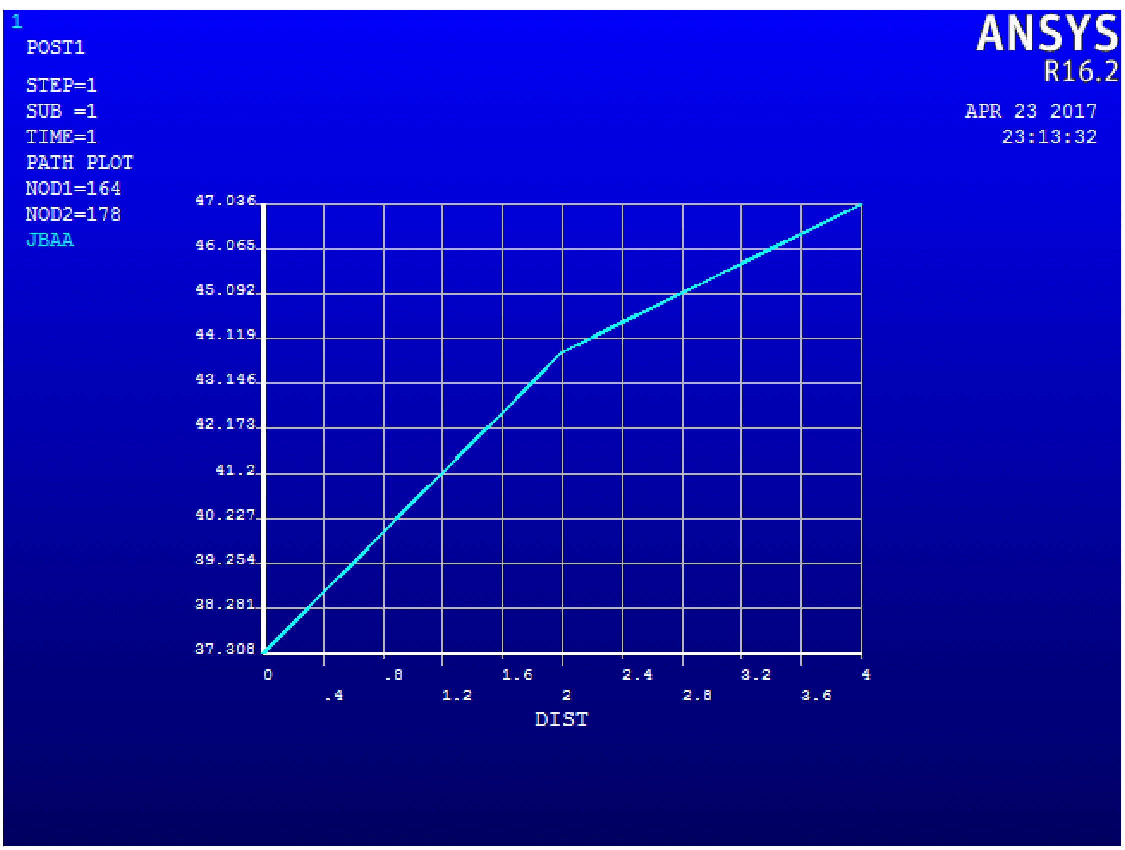


Figure 9.42: Flexural Behavior of HBCs sample JBBJ-2 using HROM

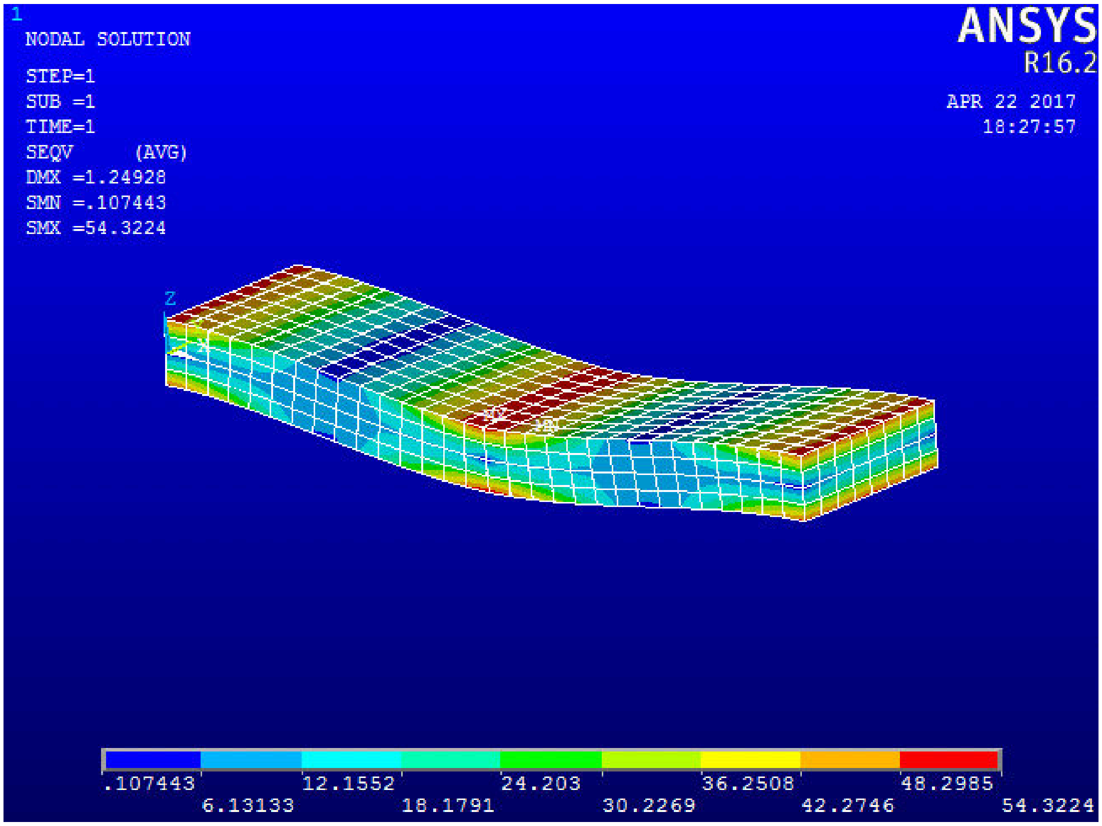


Figure 9.43: Deformed Flexural Shape and Von Misses Stress developed in BJJB-2 using HROM

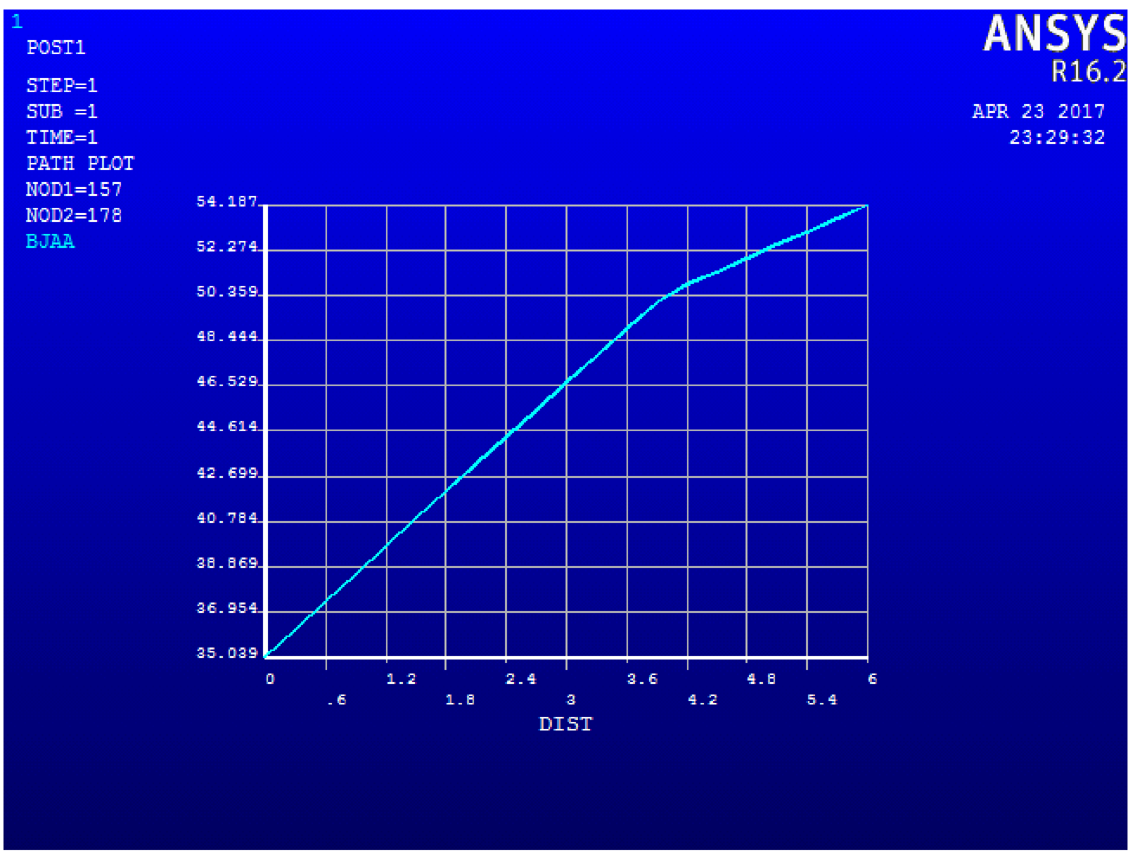


Figure 9.44: Flexural Behavior of HBCs sample BJJB-2 using HROM

9.3. Comparison Between Experimental and ANSYS Results:

This section details the comparison between the experimental results and ANSYS simulation results. Geometries for determining the tensile and flexural properties of HBCs have modeled and analyzed in ANSYS APDL 16.2 using ROM and HROM separately. The graphical comparison for the experimental values and ANSYS APDL values has presented in the figures.

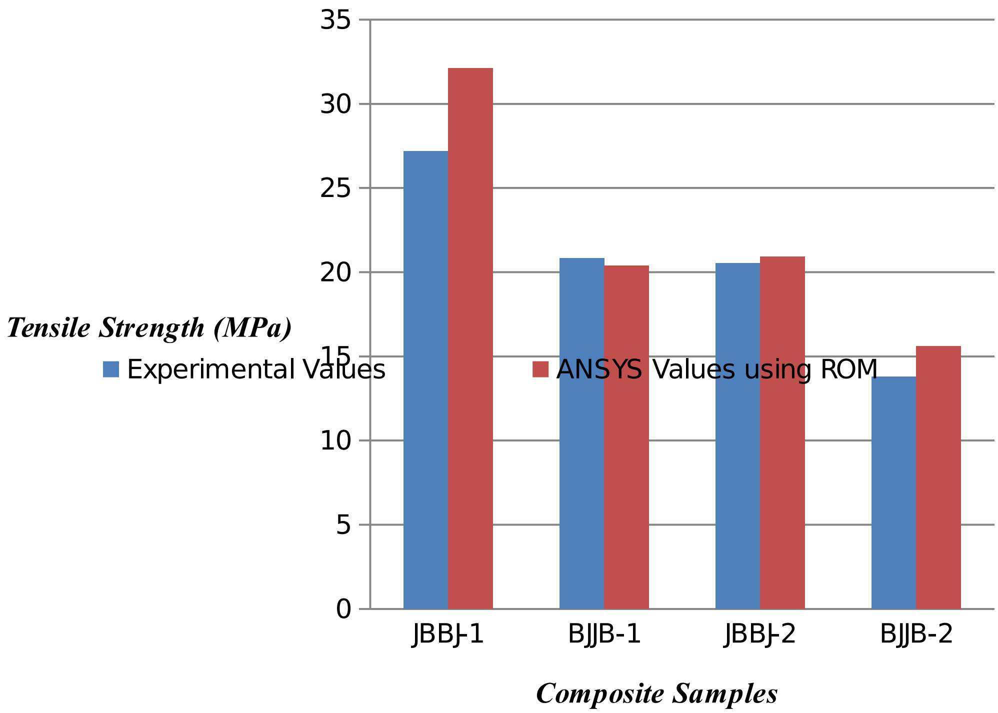


Figure 9.45: Comparison Between Experimental Values and ANSYS Values using ROM for Tensile Properties

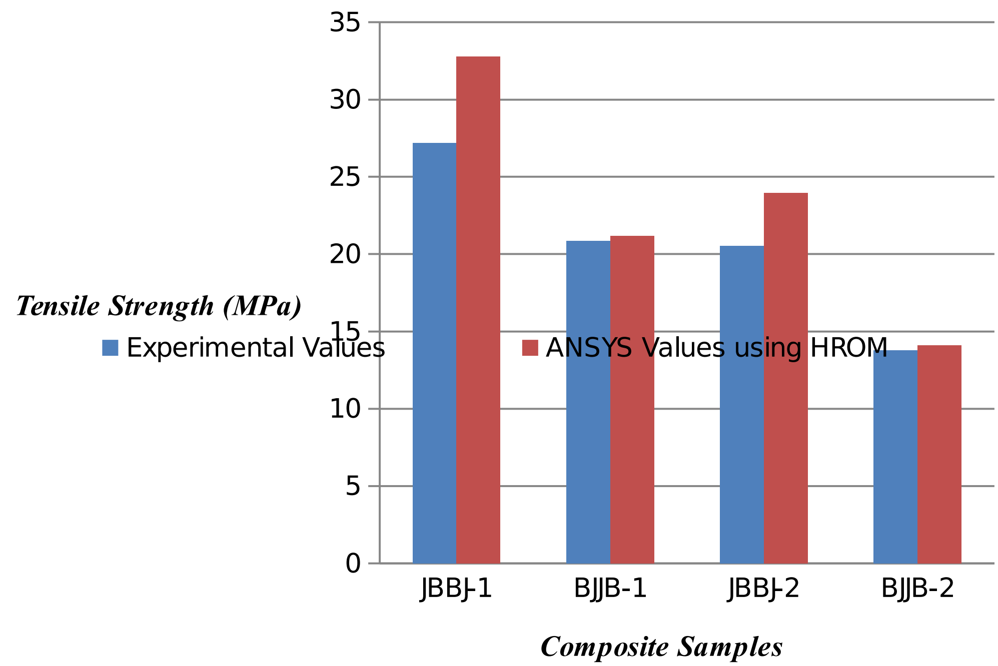


Figure 9.46: Comparison Between Experimental Values and ANSYS Values using HROM for Tensile Properties

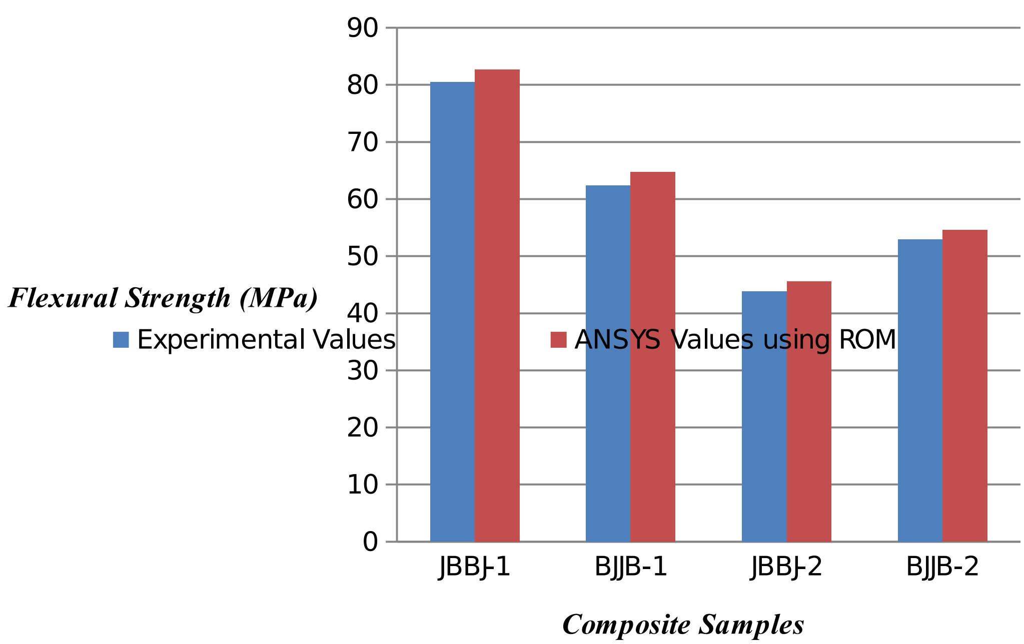


Figure 9.47: Comparison Between Experimental Values and ANSYS Values using ROM for Flexural Properties

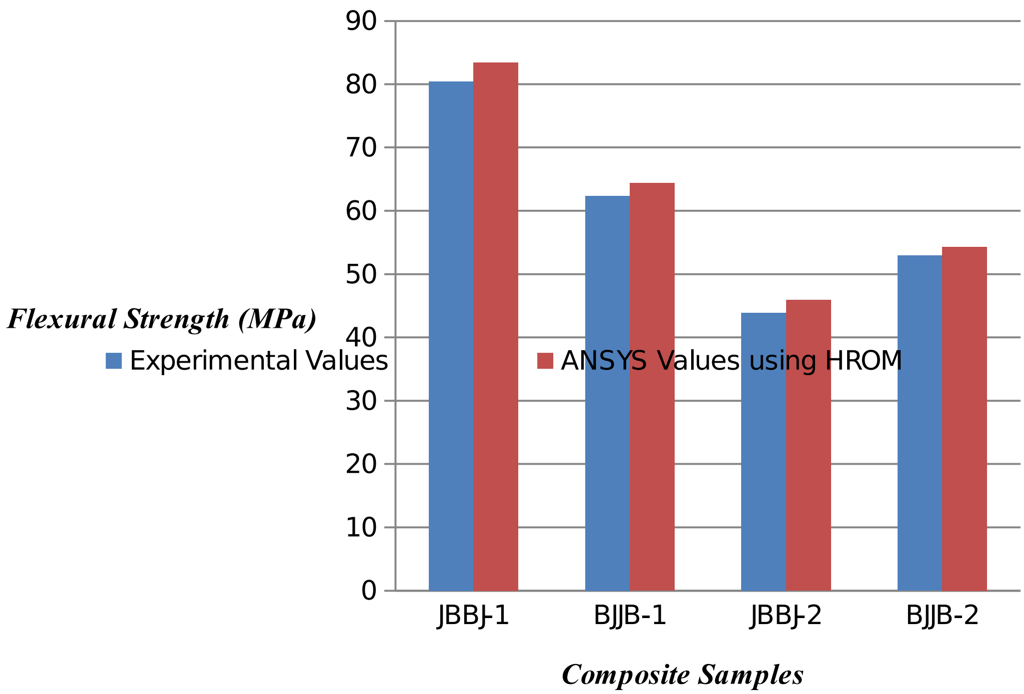


Figure 9.48: Comparison Between Experimental Values and ANSYS Values using HROM for Flexural Properties

The results reveals that the experimental values are in good agreement with the ANSYS values evaluated for each property using ROM and HROM.

9.4. Determination of Percentage Error:

The percentage error is calculated using simple mathematical formula for determining the approximation between the calculated values and the known values. Here, the ANSYS values are the calculated values and the known values are the experimental values. The formula has modified as:

$$Error = \frac{ANSYS\ Values - Experimental\ Values}{Experimental\ Values} \times 100 \qquad (9.1)$$

The percentage error for each case has detailed in this section.

Table 9.9: Percentage Error in Experimental Results and ANSYS Results using ROM for Tensile Properties

Composite Samples	Experimental Values (MPa)	Von Misses Stress (MPa)	% Error
JBBJ-1	27.18	32.11	18.14
BJJB-1	20.85	20.39	2.21
JBBJ-2	20.54	20.92	1.85
BJJB-2	13.79	15.61	13.20

Table 9.10: Percentage Error in Experimental Results and ANSYS Results using HROM for Tensile Properties

Composite Samples	Experimental Values	Von Misses Stress (MPa)	% Error
JBBJ-1	27.18	32.79	20.64
BJJB-1	20.85	21.19	1.63
JBBJ-2	20.54	23.98	16.75
BJJB-2	13.79	14.11	2.32

Table 9.11: Percentage Error in Experimental Results and ANSYS Results using ROM for Flexural Properties

Composite Samples	Experimental Values	Von Misses Stress (MPa)	% Error
JBBJ-1	80.48	82.73	2.80
BJJB-1	62.38	64.75	3.80

JBBJ-2	43.88	45.65	4.03
BJJB-2	52.94	54.57	3.08

Table 9.12: Percentage Error in Experimental Results and ANSYS Results using HROM for Flexural Properties

Compos ite Samples	Experimen tal Values (MPa)	Von Misses Stress (MPa)	% Error
JBBJ-1	80.48	83.45	3.69
BJJB-1	62.38	64.39	3.22
JBBJ-2	43.88	45.9	4.60
BJJB-2	52.94	54.32	2.61

9.5. Summary of Results:

i. The HBCs sample JBBJ-1 exhibits maximum tensile and flexural properties in contrast to the HBCs sample BJJB-1. The HBCs sample JBBJ-1 also shows maximum impact strength compared to HBCs BJJB-1. Similarly, the HBCs sample JBBJ-1 has better hardness properties in contrast to HBCs sample BJJB-1.

ii. The HBCs sample JBBJ-2 shows better tensile and impact strength compared to the HBCs sample BJJB-2. The HBCs sample BJJB-2 shows better hardness and flexural strength compared to HBCs JBBJ-2. However, the HBCs sample JBBJ-2 has the higher flexural modulus compared to HBCs sample BJJB-2.

iii. The HBCs sample JBBJ-1 shows maximum properties whereas, the HBCs sample BJJB-2 shows least properties in each cases.

iv. The water absorption test reveals that all the HBCs samples are perfectly resistant to water absorption. This in one of the important property since NFs composites has distinct applications.

v. The experimental results for the mechanical properties of the HBCs in each case show good agreement with ANSYS APDL simulation results. This is possible by using proper V_f , which enables to determine the orthotropic elastic properties of the HBCs in terms of quantity, quality and arrangement with the help of theoretical ROM and HROM.

Table 9.13: Summary of the Experimental results

Composite Samples	Tensile Strength (MPa)	Flexural Strength (MPa)	Impact Strength (Joules)	Rockwell Hardness (B-Scale)
JBBJ-1	27.179	80.48	8.33	66.67
BJJB-1	20.85	62.38	3.00	33.33
JBBJ-2	20.544	43.88	1.33	54.00
BJJB-2	13.787	52.94	0.67	55.33

Table 9.14: Summary of the ANSYS Results

Composite Samples	Tensile Strength (MPa)		Flexural Strength (MPa)	
	ROM	HROM	ROM	HROM
JBBJ-1	32.11	32.79	82.73	83.45
BJJB-1	20.39	21.19	64.75	64.39
JBBJ-2	20.92	23.98	45.65	45.9
BJJB-2	15.61	14.11	54.57	54.32

CHAPTER-10

CONCLUSION AND FUTURE SCOPE

10.1. Conclusion:

i. For the same V_f, the HBCs samples of jute fibers oriented at 90^0 and banana fibers oriented at 45^0 and -45^0 exhibits higher properties in each case compared to HBCs sample of banana fibers oriented at $90^0$and jute fibers oriented at 45^0 and -45^0.

ii. For the same V_f and similar orientation of jute and banana fibers, HBCs fabricated with resin and hardener ratio of 100:10 exhibits maximum mechanical and physical properties in contrast to the HBCs fabricated with resin and hardener ratio of 100:20.

iii. After evaluation of the properties in each case for all the HBCs samples, it has observed that the composite sample JBBJ-1 performed maximum mechanical and physical properties in each case. Therefore, the optimal results are obtained with the composite sample JBBJ-1, that is the HBCs sample fabricated with jute fibers oriented at 90^0 and banana fibers oriented at 45^0 and -45^0 with resin and hardener ratio of 100:10.

iv. ANSYS is the powerful tool in structural analysis. The experimental results for the mechanical properties of HBCs in each case show good agreement with the ANSYS APDL results.

10.2. Future Scope:

i. The use of appropriate advanced manufacturing techniques of HBCs for limiting the presence of voids in the HBCs. This will improve the overall strength of the HBCs.

ii. The use of coupling agent for matrix modification since matrix modification experiences better interfacial properties by improving the adhesion between NFs and matrix compared to surface treatment of NFs using alkali treatment. This results in overall enhancement of the properties of HBCs.

REFERENCES

[1] Sen T., and Reddy H. N. J. (2011), "Application of Sisal , Bamboo , Coir and Jute Natural Composites in Structural Upgradation," *International Journal of Innovation, Management and Technology,* vol. 2, pp. 186-191.

[2] Mallick, P. K. (1988), "Fiber-Reinforced Composites-Materials, Manufacturing, and Design," New York, NY: Marcel Dekker, Inc.

[3] Ranga P., Singha S., and Singh I. (2014), "A Review Paper on Natural Fiber Reinforced Composite," International Journal of Engineering Research & Technology, vol. 3, no. 2, pp. 467–469, 2014.

[4] Jones R M. (1999), "Mechanics of Composite Materials", 2nd ed. Taylor & Francis.

[5] Koronis G., Silva A., and Fontul M. (2013), "Composites : Part B Green composites : A review of adequate materials for automotive applications," *Compos. Part B*, vol. 44, no. 1, pp. 120–127.

[6] Yusoff R. B., Takagi H., and Nakagaito A. N. (2016), "Tensile and flexural properties of polylactic acid-based hybrid green composites reinforced by kenaf , bamboo and coir fibers," *Ind. Crop. Prod.*, vol. 94, pp. 562–573.

[7] Biswas S., Shahinur S., Hasan M., Ahsan Q. (2015), "Physical , Mechanical and Thermal Properties of Jute and Bamboo Fiber Reinforced Unidirectional Epoxy Composites," *Procedia Eng.*, vol. 105, no. Icte 2014, pp. 933–939.

[8] Essabir H., Bensalah M. O., Rodrigue D., Bouhfid R., Qaiss A. (2016), "Structural , mechanical and thermal properties of bio-based hybrid composites from waste coir residues : Fibers and shell particles," *Mech. Mater.*, vol. 93, pp. 134–144.

[9] Jabbar A., Kale B. M., Rwawiire S., Nawab Y., and Baheti V. (2016), "Modeling and analysis of the creep behavior of jute / green epoxy composites incorporated with

chemically treated pulverized nano / micro jute fibers," *Ind. Crop. Prod*, vol. 84, pp. 230–240.

[10] Deepak K., Vattikuti S. V. P. and Venkatesh B. (2015), "Experimental Investigation of Jute Fiber Reinforced Nano Clay Composite," *Procedia Mater. Sci.*, vol. 10, pp. 238–242.

[11] Saba N., Jawaid M., Alothman O. Y., and Paridah M. T. (2016), "A review on dynamic mechanical properties of natural fibre reinforced polymer composites," *Constr. Build. Mater.*, vol. 106, pp. 149–159.

[12] Ashik K. P. and Sharma R. S. (2015), "A Review on Mechanical Properties of Natural Fiber Reinforced Hybrid Polymer Composites," Journal of Minerals and Materials Characterization and Engineering, pp. 420–426.

[13] Prasad V., Joy A., Venkatachalam G., Narayanan S., and Rajakumar S. (2014), "Finite Element analysis of jute and banana fibre reinforced hybrid polymer matrix composite and optimization of design parameters using ANOVA technique," *Procedia Eng.*, vol. 97, pp. 1116–1125.

[14] Badrinath R. and Senthilvelan T. (2014), "Comparative Investigation on Mechanical Properties of Banana and Sisal Reinforced Polymer Based Composites," *Procedia Mater. Sci.*, vol.5, pp. 2263-2272.

[15] Ramesh M., Atreya T. S. A., Aswin U. S., Eashwar H., and Deepa C. (2014), "Processing and Mechanical Property Evaluation of Banana Fiber Reinforced Polymer Composites," *Procedia Eng.*, vol. 97, pp. 563–572.

[16] Zhao D. and Zhau Z. (2015), "Applications of Lightweight Composites."

[17] B. C. Mitra (2014). "Environment Friendly Composite Materials : Biocomposites and Green Composites," Defence Science Journal, vol. 64, no. 3, pp. 244–261.

[18] Wambua P., Ivens I., and Verpoest I. (2003), "Natural fibers : can they replace glass in fibre reinforced plastics ?," Composites Science and Technology, vol. 63, pp. 1259–1264.

[19] Ray D., Sarkar B. K. and Bose N. R. (2001), "Impact fatigue behavior of vinylester resin matrix composites reinforced with alkali treated jute fibers," Composites, Part, vol. 32, pp. 119–127.

[20] Alves C., Ferrão P. M. C., Silva A. J., Reis L. G., Freitas M., Rodrigues L. B., Alves, D. E. (2010), "Ecodesign of automotive components making use of natural jute fiber composites," J. Cleaner Prod., Vol. 18, pp. 313–327.

[21] Rana A.K., Mandal A. and Bandyopadhyay S. (2003), "Short Jute Fiber Reinforced Polypropylene Composites: Effect of Compatibiliser, Impact Modifier and Fiber Loading," Composites Science and Technology, Vol. 63, pp. 801-806.

[22] Behera A.K., Avancha S., Basak R.K., Sen R., and Adhikari B. (2012), "Fabrication and Characterizations of Biodegradable Jute Reinforced Soy based Green Composites,"Carbohydr. Polym., Vol. 88, pp. 329–335.

[23] Goda K., Sreekala M.S., Gomes A,, Kaji T., Ohgi J. (2006), "Improvement of Plant Based Natural Fibers for Toughening Green Composites—Effect of Load Application During Merce-rization of Ramie Fibers," Composites Part A: Applied Science and Manufacturing, Vol. 37, pp. 2213-2220.

[24] Müssig J., Schmehl M., Buttlar H. B., Schönfeld U. and Arndt K. (2006), "Exterior components based on renewable resources produced with SMC technology – considering a bus component as example," Indust Crops Prod, Vol. 24, pp. 132-145.

[25] Bos H. PhD thesis (2004): "The Potential of Flax Fibres as Reinforcement for Composite Materials," Technische Universiteit Eindhoven: Eindhoven, The Netherlands.

[26] Ochi S. (2008), "Mechanical properties of kenaf fibers and kenaf/PLA composites," Mechanics Mater, Vol. 40, pp. 446-452.

[27] Zampaloni M., Pourboghrat F., Yankovich S. A., Rodgers B. N., Moore J., Drzal L. T., Mohanty A. K. and Misra M. (2007), "Kenaf natural fiber reinforced polypropylene

composites: A discussion on manufacturing problems and solutions," Composites Part A, Vol. 38, pp. 1569–1580.

[28] Li Y., Mai Y. W. and Ye L. (2000), "Sisal fibre and its composites: A review of recent developments," Compos Sci Tech, Vol. 60, pp. 2037-2055.

[29] Oksman K., Wallstrom L., Berglund L. A .and Filho R. D. T. (2002), "Morphology and mechanical properties of unidirectional sisal-epoxy composites," J Appl Polym Sci, Vol. 84, pp. 2358-2365.

[30] Antich P., Vázquez A., Mondragon I., and Bernal C. (2006), " Mechanical behavior of high impact polystyrene reinforced with short sisal fibers," Compos Part A-Appl S, Vol. 37, pp. 139-150.

[31] Arib R. M. N., Sapuan S. M., Ahmad M., Paridah M.T. and Khairul Zaman H. M. D. (2006), "Mechanical properties of pineapple leaf fibre reinforced polypropylene composites," Mater Des, Vol. 27, pp. 391-396.

[32] Stark N. M. and Rowlands R.E. (2003), "Effects of Wood Fiber Characteristics on Mechanical Properties of Wood/Polypropylene Composites," Wood and Fiber Science, Vol. 35, pp.167-174.

[33] Yu Y., Yang Y., Murakami M., Nomura M and Hamada H. (2013), "Physical and mechanical properties of injection-molded wood powder thermoplastic composites," Adv. Compos. Mater., Vol. 22, pp. 425–435.

[34] Dai D. and Fan M. (2014), "Wood fibres as reinforcements in natural fibre composites: structure, properties, processing and applications," in Natural Fibre Composites: Materials, Processes and Properties, chapter 1, pp. 3–65, Woodhead Publishing.

[35] Acha B. A., Reboredo M. M. and Marcovich N. E. (2007), "Creep and dynamic mechanical behavior of PP-jute composites: Effect of the interfacial adhesion," Composites Part A: Applied Science and Manufacturing, Vol. 38, pp. 1507–1516.

[36] Cai, Y., David, S. and Pailthorpe, M., (2000), "Dyeing of jute and jute/cotton blend fabrics with 2: 1 pre metallised dyes," Dye Pigm, Vol. 45, pp. 161–168.

[37] Gassan J and Bledzki A. K. (1999), "Alkali treatment of jute fibers: relationship between structure and mechanical properties," J Appl Polymer Science, Vol. 71, pp. 623–629.

[38] Mwaikambo L.Y and Ansell M. P. (2008), "Chemical modification of hemp, sisal, jute, and kapok fibers by alkalization," J Appl Polymer Science, Vol. 84, pp. 2222–2234.

[39] Gassan J. (2002), "A study of fibre and interface parameters affecting the fatigue behavior of natural fibre composites,"Composites Part A, Vol. 33, pp. 369–374.

[40] Ruys D., Crosky A. and Evans W. J. (2002), "Natural bast fibre structure," Int J Mater Product Technology, Vol. 17, pp. 2–10.

[41] Mishra S., Tripathy S. S., Misra M., Mohanty A. K. and Nayak S. K. (2002), "Novel eco-friendly biocomposites: biofiber reinforced biodegradable polyester amide composites – fabrication and properties evaluation," J Reinf Plast Comp, Vol. 21, pp. 55–70.

[42] Kandachar P. and Brouwer R. (2002), "Applications of bio-composites in industrial products," Mater Res Soc Symp Proc, Vol. 702, pp. 101–12.

[43] Gopinath A., Kumar S. and Elayaperumal A. (2014), "Experimental Investigations on Mechanical Properties Of Jute Fiber Reinforced Composites with Polyester and Epoxy Resin Matrices," Procedia Eng., vol. 97, pp. 2052–2063.

[44] Boopalan M., Niranjanaa M., and Umapathy M. J. (2013), "Study on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites," Compos. Part B, vol. 51, pp. 54–57.

[45] Ku H., Wang H., Pattarachaiyakoop N. and Trada M. (2011), "A review on the tensile properties of natural fiber reinforced polymer composites," Composites : Part B, vol. 42, pp. 856-873.

[46] Stewart D. (2008), "Lignin as a base material for materials applications: chemistry, application and economics," Ind Crops Prod, vol. 27, pp. 202–207.

[47] Mosiewicki M., Rojas O., Sibaja M. R., Borrajo J. and Aranguren M. I. (2007), "Aging study of linseed oil resin/styrene thermosets and their composites with wood floor," Polym Int, vol. 56, pp. 875–81.

[48] Lu Y. and Larock R. C. (2006), "Novel biobased nanocomposites from soybean oil and functionalized organoclay, Biomacromolecules, vol. 7, pp. 2692–2700.

[49] Zhu L. and Wool R. P. (2006), "Nanoclay reinforced bio-based elastomers: synthesis and characterization," Polymer, vol. 47, pp. 8106–8115.

[50] Mosiewicki M., Aranguren M. I. and Borrajo J. (2005), "Mechanical properties of linseed oil monoglyceride maleate/styrene copolymers," J Appl Polym Sci, vol. 97, pp. 825–836.

[51] William G. I. and Wool R. P. (2000), "Composites from natural fibers and soy oil resins," Appl Compos Mater, vol. 7, pp. 421-432

[52] Derksen J. T. P., Cuperus F. P. and Kolster P. (1996), "Renewable resources in coatings technology: a review," Prog Org Coat, vol. 27, pp. 45–53.

[53] Mohanty A. K., Misra M., Drzal L. T., Selke S. E., Harte B. R. and Hinrichsen G. (2005), "Natural fibers, biopolymers and biocomposites an introduction in natural fibers," Biopolym Biocomp, pp. 1–36.

[54] John M. J. and Thomas S. (2008), "Biofibres and biocomposites," Carbohydr. Polym, vol. 71,pp. 343–364.

[55] Liu H., Wu Q. and Zhang Q. (2009), Preparation and properties of banana fiber-reinforced composites based on high density polyethylene (HDPE)/Nylon-6 blends," Bioresour. Technol, vol. 100, pp. 6088–6097.

[56] Rajesh G. and Prasad A. V. R. (2014), "Tensile Properties of Successive Alkali Treated Short Jute Fiber Reinforced PLA Composites," vol. 5, pp. 2188–2196.

[57] Gassan J. and Bledzki A. K. (1999), "Possibilities for improving the mechanical properties of jute/epoxy composites by alkali treatment," Composite Science Technology, vol. 59, pp. 1303–1309.

[58] Gassan J. and Bledzki A. K. (1999), "Possibilities for improving the mechanical properties of jute/epoxy composites by alkali treatment," Composite Science Technology, vol. 59, pp. 1303–1309.

[59] Gassan J. and Bledzki A. K. (1999), "Possibilities for improving the mechanical properties of jute/epoxy composites by alkali treatment," Composite Science Technology, vol. 59, pp. 1303–1309.

[60] Ray D., Sarkar B. K., Rana A. K. and Bose N. R. (2001), "The mechanical properties of vinylester resin matrix composites reinforced with alkali-treated jute fibers," Composites: Part A, vol. 32, pp. 119–127.

[61] Pothan L. A., Thomas S. and Neelakantan N. R. (1997), "Short banana fibre reinforced polyester composites: mechanical, failure and aging characteristics," J Reinforced Plastic, vol. 16, pp. 744– 765.

[62] Mukherjee R. N., Pal S. K., Sanyal S. K. and Phani K. K. (1984), "Role of interface in fibre reinforced polymer composites with special reference to natural fibers," J Polym Mater, vol. 1, pp. 69–81.

[63] Rana A. K., Mandal A., Mitra B. C., Jacobson R., Rowell R. and Banerjee A. N. (1998), "Short jute fibre-reinforced polypropylene composites: effect of compatibiliser," J Appl Polymer Science, vol. 69, pp. 329–338.

[64] Samal R. K., Mohanty M. and Panda B. B. (1995), "Effect of chemical modification on FTIR spectra; physical and chemical behavior of jute fiber," J Polymer Materials, vol. 12, pp. 235–240.

[65] Seshanandan G., Ravindran D., and Sornakumar T. (2016), "Mechanical properties of nano titanium oxide particles - hybrid jute-glass FRP composites," Mater. Today Proc., vol. 3, no. 6, pp. 1383–1388, 2016.

[66] Sanjay M. R. and Yogesha B. (2016), "Studies on Mechanical Properties of Jute / E-Glass Fiber Reinforced Epoxy Hybrid Composites,"Journal of Minerals and Materials Characterization and Engineering, vol. 4, pp. 15–25.

[67] Senthiil P. V. and Sirsshti A. (2014), "Studies on Material and Mechanical Properties of Natural Fiber Reinforced Composites," International Journal of Engineering and Science, vol. 3, pp. 18–27.
[68] Siddika S., Mansura F., and Hasan M. (2013), "Physico-Mechanical Properties of Jute-Coir Fiber Reinforced Hybrid Polypropylene Composites," International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering vol. 7, pp. 60–64.
[69] Mishra V. and Biswas S. (2013), "Physical and Mechanical Properties of Bi-directional Jute Fiber epoxy Composites," Procedia Eng., vol. 51, pp. 561–566.
[70] Ugoamadi C. C. (2013), "Comparison of Cashew Nut Shell Liquid (CNS) Resin with Polyester Resin in Composite Development," NIGERIAN JOURNAL OF TECHNOLOGICAL DEVELOPMENT , vol. 10, pp. 17–21.
[71] Monteiro S. N, Terrones L. A. H., and Almeida J. R. M. D.(2008),"Mechanical performance of coir fiber / polyester composites," Polymer Testing. vol. 27, pp. 591–595.
[72] Harish S., Michael D. P, Bensely A., Lal D. M., and Rajadurai A. (2008), "Mechanical property evaluation of natural fiber coir composite," Mater. Charact., vol. 60, pp. 44–49.
[73] Sapuan S. M., Leenie A., Harimi M. and Beng Y. K. (2006),"Materials & Design Mechanical properties of woven banana fibre reinforced epoxy composites," Materials and Design, vol. 27, pp. 689–693.
[74] Wambua P., Ivens J., and Verpoest I. (2003), "Natural fibers : can they replace glass in fibre reinforced plastics ?," Composites Science and Technology, vol. 63, pp. 1259–1264.
[75] Liu W., Xie T., and Qiu R. (2016), "Improvement of properties for biobased composites from modified soybean oil and hemp fibers : Dual role of diisocyanate," Compos. Part A, vol. 90, pp. 278–285.

[76] Kalita K., Chaudhari R., and Ramachandran M. (2015), "Mechanical Characterization and Finite Element Investigation on Properties of PLA-Jute Composite," International Journal of Computer Applications, vol. 123, pp. 17–21.

[77] Dhakal H. N., Skrifvars M., Adekunle K., and Zhang Z. Y. (2014), "Falling weight impact response of jute / methacrylated soybean oil bio-composites under low velocity impact loading," Compos. Sci. Technol., vol. 92, pp. 134–141.

[78] Merlini C., Soldi V. and Barra G. M. O. (2011), "In fl uence of fiber surface treatment and length on physico-chemical properties of short random banana fiber-reinforced castor oil polyurethane composites," Polym. Test., vol. 30, pp. 833–840.

[79] Donnell A. O., Dweib M. A., and Wool R. P. (2000), "Composites from Natural Fibers and Soy Oil Resins," Applied Composite Materials, vol. 7, pp. 421-432.

[80] Paul V., Kanny K., and Redhi G. G. (2015), "Mechanical , thermal and morphological properties of a bio-based composite derived from banana plant source," Compos. PART A, vol. 68, pp. 90–100.

[81] Bhoopathi R., Ramesh M., and Deepa C. (2014), "Fabrication and Property Evaluation of Banana-Hemp-Glass Fiber Reinforced Composites," Procedia Eng., vol. 97, pp. 2032–2041.

[82] Bismarck A., Mishra S. and Lampke T. (2005), "Plant fibres as reinforcement for green composites," In: Mohanty AK, Misra M, Drzal LT, editors. Natural fibres, biopolymers, and biocomposites. USA: CRC, pp. 37–108.

[83] Takagi H. and Ichihara Y. (2004), "Effect of fiber length on mechanical properties of green composites using a starch-based resin and short bamboo fibers,"JSME Int J A, vol. 47, pp.551–555.

[84] George G., Jose E. T., Jayanarayanan K., Nagarajan E. R., Skrifvars M., and Joseph K.(2012), "Novel bio-commingled composites based on jute / polypropylene yarns : Effect of chemical treatments on the mechanical properties," Compos. Part A, vol. 43, pp. 219–230.

[85] Mathew B., Lopes A., Rodrigues M., Chaves D. M., Ferreira S., Souza D., Sain M., and Narine S. S. (2013), "Environmental ageing studies of chemically modified micro and nanofibril phenol formaldehyde composites," Ind. Crop. Prod., vol. 49, pp. 471–483.

[86] Liu H., Wu Q., and Zhang Q. (2009), "Preparation and properties of banana fiber-reinforced composites based on high density polyethylene (HDPE)/ Nylon-6 blends," Bioresour. Technol., vol. 100, pp. 6088–6097.

[87] John M. J., Francis B., Varughese K. T., and Thomas S. (2008), "Effect of chemical modification on properties of hybrid fiber biocomposites," Composites Part A, vol. 39, pp. 352–363.

[88] Arao Y., Fujiura T., Itani S., and Tanaka T. (2015), "Strength improvement in injection-molded jute-fiber-reinforced polylactide green-composites," Compos. PART B, vol. 68, pp. 200–206.

[89] Kumar A., Avancha S., Kumar R., Sen R., and Adhikari B. (2012), "Fabrication and characterizations of biodegradable jute reinforced soy based green composites," Carbohydr. Polym., vol. 88, no. 1, pp. 329–335.

[90] Reddy N. and Yang Y. (2011), "Completely biodegradable soyprotein – jute biocomposites developed using water without any chemicals as plasticizer," Ind. Crop. Prod., vol. 33, pp. 35–41.

[91] Mistri E., Routh S., Ray D., Sahoo S., and Misra M. (2011), "Green composites from maleated castor oil and jute fibres," Ind. Crop. Prod., vol. 34, pp. 900–906.

[92] Hossain M. K., Dewan M. W., Hosur M., and Jeelani S. (2011), "Mechanical performances of surface modified jute fiber reinforced biopol nanophased green composites," Compos. Part B, vol. 42, pp. 1701–1707.

[93] Hu R., Sun M., and Lim J. (2010), "Moisture absorption , tensile strength and microstructure evolution of short jute fiber / polylactide composite in hygrothermal environment," Mater. Des., vol. 31, pp. 3167–3173.

[94] Donnell A. O., Dweib M. A., and Wool R. P. (2000), "Composites from Natural Fibers and Soy Oil Resins," Applied Composite Materials, vol. 7, pp. 421-432.

[95] Takagi H. and Asano A. (2008), "Effects of processing conditions on flexural properties of cellulose nanofiber reinforced "green" composites," Composites Part A, vol. 39, pp. 685–689.

[96] Tsai J. and Chi Y. (2008), "Effect of fiber array on damping behaviors of fiber composites," Composites Part B, vol. 39, pp. 1196–1204.

[97] Rao S., Jayaraman K., and Bhattacharyya D. (2012), "Micro and macro analysis of sisal fibre composites hollow core sandwich panels," Compos. Part B, vol. 43, pp. 2738–2745.

[98] Bayat M. and Aghdam M. M. (2012), "A micromechanics based analysis of hollow fiber composites using DQEM," Compos. Part B, vol. 43, pp. 2921–2929.

[99] Balac I., Colic K., Milovancevic M., Uskokovic P. and Zrilic M. (2012), "Modeling of the Matrix Porosity Influence on the Elastic Properties of Particulate Biocomposites," FME Transactions, vol. 40, pp. 81–86.

[100] José L., Panzera H., Christoforo A. L., and Durã P. (2012), "Numerical and Experimental Analyses of Biocomposites Reinforced with Natural Fibres," International Journal of Materials Engineering ,vol. 2, no. 4, pp. 43–49.

[101] Le A., Davies P., and Baley C. (2010), "Interfacial bonding of Flax fibre / Poly (L -lactide) bio-composites," Compos. Sci. Technol., vol. 70, pp. 231–239.

[102] Elbadry E. A., Aly-hassan M. S., and Hamada H. (2012), "Mechanical Properties of Natural Jute Fabric / Jute Mat Fiber Reinforced Polymer Matrix Hybrid Composites," Advances in Mechanical Engineering.

[103] Behzad T. and Sain M. (2007), "Finite element modeling of polymer curing in natural fiber reinforced composites," Composites Science and Technology, vol. 67, pp. 1666–1673.

[104] Jayamani E., Hamdan S., Rahman R., and Khusairy M. (2014), “Comparative Study of Dielectric Properties of Hybrid Natural Fiber Composites,” Procedia Eng., vol. 97, pp. 536–544.

[105] Humberto J., Almeida S., Campos S. and Cocchieri E. (2013), “Hybridization effect on the mechanical properties of curaua / glass fiber composites,” Composites : Part B, vol. 55, pp. 492–497.

[106] Li X., Tabil L. G. and Panigrahi S. (2007), “Chemical Treatments of Natural Fiber for Use in Natural Fiber-Reinforced Composites,” J Polym Environ, vol. 15, pp. 25-33.

[107] Pal B. and Haseebuddin M.R. (2012), “Analytical estimation of elastic properties of polypropylene fiber matrix composite by finite element analysis”, Advances in Materials Physics and Chemistry, Vol. 2, No. 1, pp. 23-30.

APPENDIX-A

ANSYS APDL CODING

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1. Preferences

Structural

2. Preprocessor

Element Type

Add/Edit/Delete

Add Element Type

Library of Element Type

Select SHELL181

Options

Storage of Layer Data K8

Enter All Layer + Middle

3. Material Properties

Material Models

(a) For Orthotropic Properties Evaluated using ROM

Material Models Defined

Material Model Number 1

Structural

Linear

Elastic

Enter Orthotropic Properties

Enter Density

Material Model Number 2

Structural

Linear

Elastic

Enter Orthotropic Properties

Enter Density

(b) For Orthotropic Properties Evaluated using HROM

Material Models Defined

Material Model Number 1

Structural

Linear

Elastic

Enter Orthotropic Properties

Enter Density

4. Sections

Shell

Lay-up

Add/Edit

Enter Create & Modify Shell Sections.

Enter Plot Section

5. Modeling

Create

Key points

In active CS

Enter key point number

Enter Location in active CS

Lines

Lines

Straight lines

Draw lines through key points

Areas

Arbitrary

By Lines

Select lines

6. Meshing

Size Control

Manual Size

Areas

All Areas

Enter Element edge length

Mesh

Areas

Free

Click area

7. Solution

Analysis Type

New Analysis

Static

Define Loads

Apply

Structural

Displacement

On Nodes

Select Nodes

Force/Moment

On Nodes

Select Nodes

8. Solve

Current LS

9. General Post processing

Plot results

Contour Plot

Nodal Solution

Stress

Von Misses Stress

Path Operations

Define Path

By Nodes

Select Nodes

Plot Path

Map onto path

Enter user label for item

Stress

Plot Path Item

On Graph

Enter Path item to be graphed