ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School of Mechanical Chemical and Materials Engineering

Mechanical Design and Manufacturing Engineering Program

Experimental investigation on mechanical properties of hybrid composite of polyester matrix reinforced by ceramic particles and jute fiber

A thesis submitted to the Graduate School of Adama Science and Technology University for the Partial fulfillment of the Requirement for the award of degree of Masters of Science in

Manufacturing Engineering

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Submitted in accordance with the requirements for the degree

MASTER OF SCIENCE (M.Sc.)

Approved By Board of Examiners

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Declaration

I hereby declare that the work which is being presented in this thesis entitled "**Experimental investigation on mechanical properties of hybrid composite polyester matrix reinforced by ceramic particles and jute fiber'**. In partial fulfilment of the requirement for the award of the degree of Masters of Science in Manufacturing Engineering is my own work carried out February to December 2019 under the supervision of **Dr.** Moera Gutu, program of Mechanical design and Manufacturing Engineering, Adama Science and Technology University, Adama, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

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This is to certify that above declaration made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

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Advisor	Signature	Date

Abstract

The growing need of eco-friendly, low density, and light weight product manufacturing lead to the development of natural fiber rienforced polymer composites to suit various applications in the field of house hold product and Automobile interior parts. The objective of this work is to fabricate and describe the processing techniques of specimen preparation and conducting experiment to investigate the density, void fraction, water absorption, micro hardness, tensile strength, flexural strength and microstructure test to Al_2O_3/SiC filled jute fiber reinforced polyester composite. Composite laminates were fabricated using the polyester as a matrix and the Al_2O_3, SiC and jute fiber as a reinforcement material with different fiber content, fiber orientation and filler loading according to the ASTM standard by hand lay-up technique in a mold and cured under 35 Kg for 24 hours followed by curing at room temperature for 48 hr. The experimental results showed that the inclusion of filler and fiber in polyester resin improved the physical and mechanical properties of the composites. But, tensile strength of composites found to be decrease with addition of ceramic powder. The mechanical test results indicated that the unidirectional composite samples has high tensile value 42.8 MPa, has high Vickers hardness value 184.53 HV and has high flexural strength value 271.47 MPa. As ceramic powder increase the water absorption of the sample decreases. 6.22% water intake obtained from the chopped fiber orientation and relatively less 2.153% obtained from unidirectional fiber orientations. The interface between ceramic filler, fiber content and matrix is observed through optical microscope analysis revealing that there was good adhesion between fibers and the matrix, and Al_2O_3/SiC powder was distributed uniformly through out laminated composite that produced good mechanical properties of composite. The Taguchi's experimental design (L9 orthogonal array) was used to Characteristics the composites. Results showed that the orientation of jute fiber and concentration of SiC ceramic powder was the most influential fabrication parameter on the tensile strength and Volume fraction of voids (%) of composite materials respectively.

Key word: Ceramic particle, natural fiber, composite material, characterization, mechanical properties

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Nomenclature

Symbol	Property
ρ_a	The actual/measured density of composite
ρ_c	Density of composite
$\rho_{Polyester}$	Density of polyester
ρ_{Jute}	Density of jute fiber
M_{Jute}	Mass of jute fiber
ρ_w	The density of water
F	Applied force for indentation
Mc	Mass of composite (gm)
b	Width of the sample
d	Thickness of the sample
D	Indentation surface
d	Depth of the specimen
$m_{polyester}$	Mass of polyester
M_f	Fiber mass fraction
M_M	Matrix mass fraction
P	Number of factors
P	Load at a given point on the load- deflection curve, N
V_{Jute}	Volume of Jute fiber
$V_{Polyester}$	Volume of Polyester
V_F	Fiber volume fraction
VM	Matrix volume fraction
W %	Percentage of water absorption
W1	Initial weight of sample before immersed
W2	Final weight of sample after immersed
Wa	Weight of the sample in air
W_w	Weight of the sample in water.

List of abbreviations and acronyms

Al_2O_3	Alumina
ANOVA	Analysis of Variance
ASTM	America Society for Testing and Material
BHN	Brinell hardness number
CM	Composite materal
CMMS	Ceramic Matrix Composites
DOE	Design of Experiment
UP	Unsaturated Polyester Resin
FRP	Fiber Reinforced Polymer
GFRP	Glass Fiber Reinforced Polymer
GHG	Greenhouse gas emission
hr	Hour
ILSS	Inter laminar shear strength
ISO	International Organization for Standardization
m	Meter
METEC	Metal and Engineering Corporation
mm	Millimeter
MMCs	Metal Matrix Composites
NaOH	Sodium hydroxide
NFRPC	Natural fiber reinforced polymer composite
NFs	Natural fibers
OA	Orthogonal array
OM	Optical microscope
PE	Polyethylene
PF	Phenol formaldehyde
PFRP	Palm fiber reinforced Epoxy composites
PMCs	polymer matrix composites
PP	Polypropylene

PRP	Particle reinforced polymer composites
PVC	Poly-vinyl-chloride
JFRP	Jute fiber reinforced Polyester composites
Sic	Silicon Carbide
TPO	Thermoplastic Olefins
UTM	Universal Testing Machine
UTS	Ultimate tensile strength or peak stress
UVTM	Ultraviolet Testing Machine
VHN	Vickers hardness Number

CHAPTER ONE

1. INTRODUCTION

1.1. Background and Motivation

Materials are the basis for improving human production and living standards, they are applied for, structural and nonstructural, electronic, environmental, electrochemical, biomedical, thermal, or other applications. From the material point of view, human society has experienced the Stone Age, Bronze Age, and Iron Age [1]. Each age is start with certain materials. The Stone Age used tools made up of stones, the Iron Age brought tools and utensils, the Steel Age brought rails and industrial revolution, and the Space Age brought more advanced materials which is composite materials.

Composite materials are made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The properties of composite materials are functions of the properties of matrix and reinforcement. The matrix material a continuous material which is used for binds the reinforcement, gives the composite shape and determines the quality of the surface. The matrix materials can be metallic, ceramic or polymeric. In composite material the role of the discrete material called reinforcement is increasing the mechanical properties of the matrix material, due to the major portion of the applied load distributed and taken by the reinforcement phase, while the surrounding matrix keeps them in the desired location and orientation, acts as a load transfer medium between them, and protects them from environmental damages due to elevated temperatures and humidity [2]. The reinforcing phase can either be fibers or particulates in nature. Fibers are basically two types, natural and synthetic. The natural fiber are fiber which consist of animal, plant fibers and minerals such as flax, hemp, jute, coir, cotton, wool, bamboo, banana, sisal, and abaca. Nylon, glass, and carbon are some examples for synthetic fibers.

The mechanical properties of polymers are inadequate for many structural purposes, particularly their strength and stiffness lower than ceramics and metals [3]. These difficulties are overcoming by reinforcing other materials with polymers. Reinforcing polymers with ceramics, glasses, metal gives rise to improved mechanical properties and extends their structural applications. Processing of polymer matrix composites doesn't require high temperature and high pressure and also equipment required for manufacturing natural fiber reinforced polymer matrix composites are simpler. For this reason polymer matrix composites developed quickly and almost immediately became popular for structural applications.

Synthetic fibers (SFs) is used to reinforce polymers for a variety of applications in aerospace, automobiles, boats, sporting goods and packaging materials because of their high strength and stiffness. However, synthetic fiber like glass, carbon and boron fiber have serious drawbacks in terms of their no biodegradability, low density, toxicity, initial processing costs, recyclability, energy consumption, machine abrasion, health hazards, cause to environmental pollution problems etc [4]. Natural Fiber-Reinforced polymeric (NFRP) composite are quickly springing up in terms of research and industrial application because they are low cost, easy productivity, their friendly to environment, light weight, renewable, recyclable, available in huge quantities, high specific strength to weight ratio and high specific mechanical performance [5]. Natural fiber reinforced polymer composites have attracted in research area more than synthetic fiber reinforced composites due to growing global energy crisis and ecological risks. Therefore, the material scientists and researchers forced to shift their attention from synthetic fibers to natural fibers due to increasing environmental awareness, to reduce greenhouse gas emissions. This is importance especially in interior transportation applications as it leads to reduction of vehicle weight for higher fuel efficiency, energy saving and reduction in cost.

The difference between natural fiber and synthetic fiber

Polymer composites can be reinforced with synthetic or natural fibers. If the fibers are derived from natural resources like plants or some living species, they are called natural fibers.

Table. 1.1. The difference between natural fiber and synthetic fiber

Natural fiber	Synthetic fiber
All of the natural fiber comes from natural	Synthetic fiber are completely man made
Length of the fiber is natural given	Length of the fiber is controlled by man
Dust and impurities could be in natural fiber	No dust or impurities contain in synthetic fiber
It is not possible to change in fiber structure	It is easy to change in fiber structure
Most of the fiber are hydrophilic in nature	Most of the times, they are hydrophobic
It is easy to dye the fiber	Coloration is not so easy as natural
Most of the cases it becomes ash after burning	It becomes melt in burning
Natural fiber is called environment friendly	Synthetic fibers are not environment friendly
Number of molecular is not limited	Number of molecular is limited

Among natural fiber, jute fibers are extensively used in many industrial applications. Jute fiber is a bast fiber and composed of cellulose, lignin and pectin material. It is a long, soft, shiny fiber that can be spun into coarse, strong threads [6]. Jute fiber has many advantages like high specific properties, low density, renewable, versatile, the fiber has high aspect ratio, high strength to weight ratio. Jute fiber is a low cost eco-friendly, abundantly available and easy to transport. Jute based composites enjoying broader applications in automobiles and railway coaches & buses for public transport system.

Now a day, due to environmental concerns and growing cost of synthetic materials, many traditional materials such as metal, aluminum have replaced by natural fibers reinforced polymers composite, which is free corrosion, better specific stiffness, less weight, capability to manufacture complex shapes, exceptionally grater specific strength, high impact energy absorption in various applications. Natural fiber reinforced polymer composite material in house hold product and automobile body parts was efficiently implemented for the reductions of cost, fuel consumption and vehicle weight [7]. Composites are up to 35% lighter than Aluminum and 60% lighter than steel and the use of composites in automotive can reduce overall vehicle weight up to 10%. Therefore the main goal of automobile factories in the present time is economize fuel energy consumption and vehicles weight reduction by using natural fiber rienforcement and ceramic filler in polymeric composite. Fiber reinforced polymer composites applied in the vehicle interior and external application such as engine sub frame, interior panels, headliners, seat backs, dashboards and frontal bumpers subsystems, because of their high specific strength, modulus and high damping capability, reduce noise and vibration and reduce the vehicle weight [8]. In addition to that, composites have a very high resistance to fatigue and corrosion. And implemented on house hold product for preparing door and windows, chairs, tables, flooring, partition walls, kitchen cabinets and etc. For these reasons, FRP use as substitution for metals in many weight-critical components in aerospace, automotive, and other industries. Ceramic-fillers reinforced polymer matrix composites have the potential to replace traditional materials. The advantages of using fillers as reinforcement in composite improving toughness, mechanical and tribological properties.

In order to estimate physical and mechanical properties, structural materials are subjected to physical and mechanical testing such as density, water absorption, tensile strength, compression strength, hardness and flexural strength. The aim of tests are evaluate the physical and mechanical characteristics of natural fiber and ceramic powder reinforced polymeric composites, and they are very foundation of technical specification of materials and for design purposes, in order to develop numerical and experimental models. It is difficult and time consuming process to obtain parameters such as strength and stiffness from the mechanical testing of composite structures. So, can be somewhat simplified by the testing of simple structures, such as flat coupons. The data obtained from these tests can then be directly related with varying degrees of simplicity and accuracy to any structural shape, [9].

Improvements on mechanical properties of natural fiber reinforced polymer composite are still under research for different applications. Polymer matrix modification is one of the approaches to develop new class of polymer materials. This modification can be done by addition of different ceramic powders of different sizes to achieve the required mechanical properties. In this paper we have modified the polyester matrix by Al_2O_3 and SiC powder in jute fiber reinforced polyester composite to improve the mechanical properties. And study the effect Al_2O_3/SiC content on the performance of jute fiber reinforced polymer composites fabricated with different ceramic particles content, jute fiber content and polymer matrix content and tray to addresses this aspect by adopting a statistical approach called Taguchi experimental design. This technique provides a simple, systematic and efficient methodology for the analysis of the control factors. Hybrid composite of polyester matrix reinforced by ceramic particles and jute fiber has been fabricated by using hand lay-up technique. Physical and mechanical testing like density, percentage of water absorption, tensile strength, hardness flexural strengths are conducted in order to know the properties of fabricated composites.

1.2. Organization of the thesis

In this section, an overview of the tasks involved to accomplishing the overall objective of the study and summary of the contents are given. These tasks are described in detail in the subsequent chapter. This study is organized in five chapters.

Chapter One: Introduces the background of Particulate filled natural fiber reinforced composite materials

Chapter Two: Includes a literature review to provide a summary of the relevant research papers already available involving the issues of interest and this project Problem Statement, objectives, Scope and limitations.

Chapter Three: Includes a detailed description of the raw materials, test procedures, and design of experiments methodology.

Chapter Four: Presents the results of physical and mechanical properties of the composites under study; density, void, water absorption, tensile strength, flexural strength, hardness and microscope observation are discussed in detail.

Chapter Five: Provides specific conclusions drawn from both the experimental and analytical efforts and recommendations for future research.

CHAPTER TWO

2. LITERATURE REVIEW

A review of available literature is to provide background information on the issues to be considered in this thesis. The review is focused on the various aspects of the polymer composites with a special reference to ceramic powder filled jute fiber reinforced polymer composites. This chapter contains review of existing research reports:

- On natural fiber and mechanical properties of natural fiber composites
- On mechanical properties of Jute Fiber Reinforced Polymer Composites
- On Particulate filled Fiber Reinforced Polymer Composites
- On Taguchi Method

At the end of this chapter a research gap in the earlier investigations are presented.

2.1. On Natural Fibers and Mechanical properties of Natural Fiber Reinforced Composites

According to source of origin, natural fiber are classified into different categories such as Vegetable or plant fibers, Animal based (silk, wool, hair), and mineral fibers (wollastonite, asbestos). The Vegetable or plant fibers based natural fibers are given by the tables 2.1.

Table. 2.1. Vegetable or plant fibers source and its varieties [10].

Source	Types (varieties)
Blast	Flax, jute, Hemp, Ramie, Roselle, Rattan, Kenaf, Sugarcane, Banana
Leaf	Sisal, Manila, Abaca, Banana, Palm, Mengkueng, Date palm, pineapple, Agava, Raphia
Wood	Hardwood, soft wood, saw dust
Seed	Kapok, cotton, loofah, milkweed, oil palm seed, Alfalfa
Fruit	Coconut, Betel nut, coir, oil palm
Stalk	Rice, wheat, barley, oat, rye, bamboo, maize
Grass/reeds	Bamboo, bagasse, corn, Sabai, Rape, Esparto, canary

The properties of some of these fibers are presented in Table 2.2. From the table it can be seen that the modulus and specific gravity of natural fibers are comparable to glass fibers but, Tensile strength of glass fiber is higher than natural fibers. These higher specific properties are the major advantages of using NFCs for applications where in the desired properties also include weight reduction.

Table 2.2: Properties of Natural Fibers [11]

Fiber	Density (g/cm^3)	Elongation (%)	Tensile strength (MPA)	Young's modulus (GPa)
Cotton	1.5 – 1.6	7.0 – 8.0	287 - 597	5.5- 12.6
Jute	1.3	1.5 – 1.8	393- 773	26.5
Flax	1.5	2.7 – 3.2	345 - 1035	27.6
Hemp	-	1.6	690	-
Ramie	-	3.6 – 3.8	400 - 938	61.4 - 128
Sisal	1.5	2.02	511 - 635	9.4 – 22.0
Coir	1.2	30.0	175	4.0 – 6.0
Soft wood Kraft	1.5	-	1000	40.0
E- glass	2.5	2.5	2000-3500	70.0
S-glass	2.5	2.8	4570	86.0
Aramide	1.4	3.3 – 3.7	3000 - 3150	63.0 – 67.0
Carbon	1.4	1.4 – 1.8	4000	230.0 – 240.0

Over the last few decades, there has been highly interest in the use of natural fibers to replace synthetic fibers like glass or carbon in composite applications. A number of investigations have been made on the use of various natural fibers such as jute, kenaf, banana, hemp, flax and bamboo as reinforcement for polymer composites and the effect of various factors on physical and mechanical behavior of natural fiber reinforced polymer composites.

Gopalakrishna et al [12] evaluated the physical and mechanical properties of Banana and E-Glass reinforced polyester composites. The density of each of the laminates and water absorption properties are also evaluated. The result indicated that, the maximum tensile strength was pure glass layer laminate (250 MPa) and minimum was pure banana layer laminate (6.45 MPa). They found that the maximum flexural strength, maximum impact strength and maximum hardness was observed in pure glass fabric laminate and minimum in pure banana fabric laminate. Pure E-glass fabric laminate absorbs more amount of water and pure banana fabric laminate absorbs minimum amount of water. They also found that as the glass layer in the laminate increases its mechanical properties enhances. **Hemanth et al [13]** evaluated the mechanical and physical properties, such as tensile strength, flexural strength, impact strength, hardness and scanning electron microscope (SEM) of E-glass and coconut fiber reinforced with polyester and epoxy resin composites. Fiber reinforced composites were synthesized at 18:82 fiber-resin weight percentages. They reported that the coconut fiber reinforced polyethylene composite has good stiffness, but with a limitation in the strength less than glass fiber composite. E-glass reinforced epoxy resin composites showed better mechanical properties.

Alagarraja et al [14] evaluated the mechanical properties such as tensile strength, compression strength, flexural strength and impact strength of sisal – glass fiber reinforced epoxy composites. The interfacial properties, internal cracks and internal structure of the fractured surfaces are evaluated by using Travelling Microscope .The results indicated that the incorporation of sisal fiber with GFRP can improve the properties and used as an alternate material for glass fiber reinforced polymer composites. The Maximum tensile force of the sisal–GFRP reinforced composite was in the range of 24.080 KN. The result indicated that the flexural strength of sisal-GFRP composite higher when compare to glass and sisal fiber separately. The strength of Rockwell hardness and compression test obtained 96.67 HRB and 28.180KN respectively. The microstructure of the fiber is obtained in the breaking point of tensile and impact test of specimen to obtain the interfacial properties, internal cracks and internal structure of the fractured surfaces of the composite materials. **Harish et al** [15] investigated the mechanical properties of coir reinforced epoxy and glass fiber reinforced epoxy composites and Scanning electron micrographs obtained from fractured surfaces were used for a qualitative evaluation of the interfacial properties of coir/epoxy and compared with glass fiber/epoxy. The results indicated that Coir/epoxy composites exhibit average values for the tensile strength, flexural strength and impact strength of 17.86 MPa, 31.08 MPa and 11.49 kJ/m^2, respectively. These values are significantly lower than those measured for GFRP laminate specimens.

Sathish et al [16] studied the effect of volume fraction on mechanical and physical properties such as tensile, flexural, impact, inter laminar shear strength, void content and water absorption of flax and bamboo fibers reinforced hybrid epoxy composites. The results showed that the tensile, impact, flexural and ILSS are maximum for 40:0 (flax: bamboo) hybrid composites. From the result, the maximum flexural strength, impact strength and ILSS was 89.90 MPa, 2.35 J and 3.52 MPa respectively which is hold by the 40% flax fiber and 0% bamboo fiber composites. The void content decreased for 20:20 (flax: bamboo) composites due to tightly packed flax fiber and more compatibility towards epoxy resin. From the SEM micrographs of flexural fracture surface samples, it was reported that fiber matrix adhesion improved due to which fiber pull out is reduced.

Kibret Alemayehu et al [17] investigated the mechanical properties such as tensile, impact, flexural strength of banana fiber reinforced epoxy resin composite. The result indicated that at 50% of fiber volume fraction, the tensile strength is the maximum. At lower volume fractions of banana fiber, the strength of the composite specimen is reduced when compared to the virgin resin. The impact strength decreases when fiber volume gets increased. The morphological study reveals that fibers pull out are occurring on various percentages of unidirectional fibers. **Karthick et al** [18] reported the tensile test, flexural (three-point bending) test, impact test and hardness test of banana fiber reinforced epoxy hybrid composites by increasing the fiber length and fiber loading percentage. The result showed that, the better mechanical properties were found in the composite specimen of 10 mm fiber length and 15% of fiber loading.

Muthu et al [19] investigated the tensile, flexural and Impact properties of Palm fiber reinforced Epoxy composites (PFRP) and compared with Sisal fiber reinforced Polyester composites (SFRP) with different volume fractions. The experimental results showed that the tensile strength, Flexural strength and Impact strength improved with increase in volume fraction of fiber in composites. They also observed that Tensile strength, Flexural strength and Impact strength of PFRP composites are considerably higher than SFRP composites. **Sapuan et al** [20] investigated the tensile and flexural (three-point bending) tests of woven banana fiber reinforced epoxy composites with different geometries. From the results obtained, that the maximum value of stress in x-direction was 14.14 MN/m^2 and in y-direction was 3.398 MN/m^2. For the Young s modulus, the value of 0.976 GN/m^2 in x-direction and 0.863 GN/m^2 in y-direction were computed. As for the case of three-point bending (flexural), the maximum load applied was 36.25 N to get the deflection of woven banana fiber specimen beam of 0.5 mm. Statistical analysis using ANOVA-one way has showed that the differences of results obtained from those three samples are not significant, which confirm a very stable mechanical behavior of the composites under different tests.

Shiva et al [21] investigated the tensile strength and impact strength of jute and sisal fibrous mat reinforced epoxy hybrid composite. They observed that the fabricated composite with [0^0/0^0]

orientation of fibers exhibited higher tensile strength than composite with [$0^0/90^0$] orientation of fibers. The scanning electron microscopy image of the fractured specimens revealed that de-bonding between fiber matrix interface and void nucleation growth were the major factors influencing failure of the material. **Amit Kumar** [22] evaluated the mechanical properties of natural fiber reinforced epoxy polymer resin composites. The result showed that tensile and compressive strength of Bamboo fiber reinforced epoxy composites better than Coir and Jute fiber reinforced epoxy composites. Jute fiber based composite is better tensile and compressive strength than coir fiber based composites.

2.2. On mechanical properties of Jute Fiber Reinforced Polymer Composites

Many materials during its service life are subjected to different loads or forces. Thus, it is very important to understand the mechanical behavior of materials so that the product made from it will not result in any failure during its life cycle. An adequate knowledge of mechanical properties of material helps in selection of its suitable applications. For example lighter and stronger materials are required for vehicles such as bicycles, automobiles, or aerospace applications. Tensile, flexural, inter-laminar shear strength, impact strength and hardness are the important mechanical properties of the FRP composites.

Vivek Mishra et al [23] studied the effect of fiber loading on the physical and mechanical properties of bi-directional jute fiber reinforced epoxy composites. The Results showed that hardness, tensile properties and impact strength of the jute reinforced epoxy composites increases with the increase in fiber loading and also void content decreases with the increase in fiber loading. The properties like flexural strength and inter-laminar shear strength are greatly influenced by the void content of the composites. They found that, the properties of composite materials reduced from 0 wt.% to 12 wt.% fiber loading and improved from 12 wt.% to 48 wt.% fiber loading due to reduction in the void content.

Subhankar et al [24] investigated the physical, mechanical and thermal properties of unidirectional jute and bamboo fiber reinforced epoxy resin void free composites. They reported that bamboo fiber reinforced epoxy had higher tensile strength and jute fiber reinforced epoxy composites had higher flexural strength with transverse fiber distribution in the composites. They also revealed that jute fiber reinforced epoxy composites showed better thermal behavior compared to bamboo fiber reinforced epoxy composites. Scanning electron microscopic analysis showed that morphological changes took place depending on the fiber orientation in epoxy composites. In case of jute fiber composites, some fiber was broken during processing. **Tao et al.** [25] investigated the tensile properties of jute short fiber reinforced PLA and ramie reinforced PLA composites. The fiber loading of jute-PLA and ramie-PLA composites were varied from 10-50 %. It was found that the tensile properties of PLA-based composites increase with the addition of the fiber firstly, and then decrease when the content of fibers is over 30%. The mechanical properties of PLA/ramie are higher than those of PLA/jute because the strength of ramie is higher than that of jute fiber. **Rejaul Hasan et al** [26] investigated the tensile properties of jute woven fabric, jute non-woven mat and jute carded-sliver reinforced with epoxy composites. They found that sliver reinforced composite showed the highest stiffness and non-woven composites showed the lowest stiffness. In terms of strength, non-woven reinforced composite showed the lowest values. The strength of woven and sliver reinforced composites have been found to be almost similar. Woven composites strain was higher (0.016mm/mm) compared to non-woven (0.012 mm/mm) and sliver (0.013 mm/mm).

K. Durga et al [27] investigated the mechanical properties of jute, pineapple leaf fiber and jute-pineapple leaf fiber (Hybrid) reinforced polyester with increase in percentage weight fraction of the fiber. The results indicated that tensile strength, young's modulus, bending strength, bending modulus and impact strength of the composite are increase with increase in weight fraction of the fiber (up to 30%) and decrease with further increase in the weight fraction (35%). And also they found that the Pineapple Leaf Fiber reinforced Polyester composite has maximum young's modulus and tensile strength when compared to the jute reinforced polyester and hybrid fiber composite. The Jute reinforced polyester composite had maximum flexural modulus, flexural strength and impact strength when compared to the Pineapple leaf fiber reinforced polyester and hybrid composite.

Seki [28] studied the effects of chemical treatment on the mechanical properties of alkalized jute fiber reinforced polyester composites. It was found that the siloxane treatment on the alkalized jute fabrics results in an increasing tensile properties, flexure strength and ILSS of jute fiber reinforced epoxy composite and jute fiber reinforced polyester composites, which is related to the interfacial adhesion between jute fiber and polymer matrix.

Stocchi et al. [29] studied the effect of alkali treatment on the tensile behavior of woven jute fabric reinforced vinyl ester composites at two different times of treatment. It was found that significant improvement in stiffness achieved by the composite treated with alkali under biaxial stress for 4 h compared to composites with 24 h alkali treated mats under biaxial stress and untreated mats. On the other hand, irrespectively of the time of treatment, the composites with fabrics treated with alkali under stress showed the highest values of tensile strength.

Rezaur Rahman [30] improved the physical and mechanical properties of jute fiber reinforced Polypropylene composites. Raw jute fiber was oxidized and manufactures composites were post-treated with urotropine to increase the compatibility of the jute fiber with the PP matrix. The results indicated that the Young's modulus, flexural strength, flexural modulus, charpy impact strength and hardness of the composites increased with an increase in the fiber loading. The tensile strength of the composites decreased with an increase in the jute fiber loading. However, there was an increase in the tensile strength of the 20% post-treated jute reinforced composite compared to the PP alone. The tensile strength, Young's modulus, flexural strength, flexural modulus, impact strength and hardness of the urotropine treated jute fiber reinforced composites were higher than those of the raw and oxidized ones. The urotropine post-treatment improved the hydrophilic nature of the jute fiber and the interfacial bonding and wettability between the fiber and matrix. They reported that the 30% jute fiber reinforced PP composites had the optimum set of mechanical properties in comparison with other manufactured composites. **Jochen Gassan et al** [31] studied the influence of fiber surface treatment on mechanical properties of jute fiber reinforced polypropylene composites. They found that flexural strength increased by 40% and flexural modulus by 90%. SEM investigations demonstrated that fiber pull out was reduced after the modification with the coupling agent. The composites without a coupling agent showed a virtually identical behavior as regards dynamic strength, independent of the fiber volume loading. With the application of MAH-PP coupling agent it was possible to reduce the progress of damage and attain an increasing dynamic strength.

Ramesh et al [32] evaluated the mechanical properties such as tensile and flexural properties of hybrid glass-sisal fiber or glass-jute fiber reinforced epoxy composites. Microscopic examinations are carried out to analyze the interfacial characteristics of materials, internal structure of the fractured surfaces and material failure morphology by using Scanning Electron Microscope (SEM). The results indicated that sisal-GFRP composites performing better for tensile loading and can withstand the strength up to 68.55 MPa. The jute-GFRP composite specimen is holding the maximum flexural load of 1.03KN slightly higher than the sisal/GFRP composite sample. The performance of these natural fiber composites is lower than that of the GFRP, it has been used in many application which requires medium strength.

Ajith et al [33] investigated the mechanical properties such as tensile strength, flexural strength, impact strength and hardness of jute fiber reinforced composites with polyester and epoxy resin matrix. The composites were synthesized at 18:82 fiber-resin weight percentages. The results showed that the tensile strength for jute-epoxy and jute-polyester composites was found to be 12.46 N/mm2 and 9.23N/mm2 respectively. The 5% NaOH treated jute fiber reinforced composites had higher tensile strength than 10% NaOH treated fiber reinforced epoxy composite by 18.67 % and for jute fiber reinforced polyester composites it was increase by 16.67 %. The results indicated that the jute epoxy exhibited better tensile and flexural properties. The processing time required for the jute polyester composite is very less compared to jute-epoxy composite. The results of this research indicate better mechanical properties for jute-epoxy, which makes it better suited for the automotive applications rather than jute-polyester composites.

2.3. On Fiber/ Particulate Reinforced Polymer Composites

Incorporating organic or inorganic fillers into a matrix enhances various physical and mechanical properties of the materials. In general, mechanical properties of particulate filled polymer composites depend on size, shape and distribution of filler particles in the polymer matrix [9].

Tapan et al [34] investigated the physical and thermo-mechanical characterization such as void content, water absorption, hardness, tensile strength, impact strength, fracture toughness of silicon carbide filled needle punch nonwoven jute fiber reinforced epoxy composites. The composite materials were prepared by mixing different weight percentages (0–15 wt.%) of silicon carbide in needle punch nonwoven jute fiber reinforced epoxy composites by hand-lay-up techniques. The results indicated that increase in silicon carbide filler from 0 to 15 wt.% in the jute epoxy composites increased the void content by 1.49 %, water absorption by 1.83 %, hardness by 39.47 %, tensile strength by 52.5 %, flexural strength by 48.5 %, and impact strength by 14.5% but on the other hand, decreased the thermal conductivity by 11.62 %. The result also indicated that jute epoxy composites reinforced with 15 wt.% silicon carbide particulate filler presented the highest storage modulus and loss modulus as compared with the unfilled jute epoxy composite.

Priyadarshi et al [35] investigated on the physical and mechanical properties of jute fiber reinforced epoxy composites filled with Al_2O_3 particulate. The composite fabricated with different fiber and filler loading by using simple hand layup technique. The results showed that the presence of Al_2O_3 content significantly influences the physical and mechanical behavior of composites. The tensile strength, flexural strength and hardness of the composites increased with the increase in fiber and filler loading. They observed that composite with 40 wt. % fiber and 15 wt. % filler exhibits maximum hardness value and also composite with 30 wt. % fiber and 10 wt. % filler exhibits maximum tensile strength and flexural value. **Sabeel Ahmed et al [36]** investigated the effect of ceramic fillers like SiC and Al_2O_3 on wear behavior of jute reinforced epoxy composite. The laminates of jute/epoxy composites with fillers in 5%, 10% and 15% based on weight fraction were prepared using hand layup technique. They reported that incorporation of fillers leads to significant improvement in the wear resistance of jute reinforced epoxy composite. It is observed that Al_2O_3 filled composite has better wear resistant than SiC filled.

Sudeep et al [37] investigated the effect of bone and coconut shell fillers on E-glass fiber and jute fiber reinforced epoxy composites with varying concentrations. Mechanical properties such as ultimate tensile strength, flexural strength, inter laminar shear strength (ILSS), tensile modulus, impact strength and hardness of the fabricated composites were tested. The test results of these were compared with unfilled HFRP composites. They found that the mechanical properties of the composites increased with the increase in filler content. Composites filled with 15% volume coconut shell powder exhibited maximum flexural strength, inter laminar shear strength (ILSS), tensile modulus and hardness. Maximum impact strength was achieved by addition of filler (15% Vol.) of bone powder. **Praveen et al** [38] studied the physical and mechanical properties of Silicon carbide filled bamboo/carbon fibers reinforced epoxy composite. They found that the addition of Silicon carbide on bamboo/carbon fibers has improved tensile, flexural strength and micro- hardness. The water absorption tests were performed on immersing specimens into three different water conditions, namely normal, distilled and salt water.

Arpitha et al [39] investigated the mechanical properties of tensile, flexural and impact strength of Sisal and SiC and Glass hybrid composites. They reported that the sisal/Glass composite samples possess good tensile strength and can withstand the strength up to 158.167 N/mm^2.The sisal/Glass fiber filled with 3% of silicon carbide possesses good flexural strength and can withstand the strength up to 558.6 Mpa. The sisal/Glass composites possess good impact strength up to 33.71 KJ/m2 compared to other composites filled with silicon carbide filler. The results indicated that sisal/glass composites without filler showing good tensile strength and sisal/glass with 3% of silicon carbide filler showing good flexural strength compare to other composites and also the composites without filler of sisal/glass performing good impact strength compare to composites filled with silicon carbide filler. The performance of these natural fibers with glass fiber is more than that of composites with silicon carbide filler; it can be used in many applications which needed lower strength.

Devendra et al [40] studied the mechanical properties like ultimate tensile strength, impact strength, flexural strength and hardness of E-glass fiber reinforced epoxy composites filled with varying concentration of aluminum oxide (Al_2O_3), magnesium hydroxide ($Mg(OH)_2$) and silicon carbide(Sic) . The results indicated that Sic filled composites having high impact strength and flexural strength when compared with other filled composites this due to that good bonding strength between filler, matrix and fiber. The results also indicated that composite filled by (10% Vol.) Mg $(OH)_2$ exhibited maximum ultimate strength (375.36MPa) when compared with other filled composites but lower than the unfilled composite this may be due to good particle dispersion and strong polymer/filler interface adhesion for effective stress transfer. Increase in addition of filler materials to composites leads to decrease in ultimate strength this may be due to more filler distribution and filler materials dominated in the materials. They indicated that composites filled by (10%Vol.) Sic exhibited maximum flexural strength (291.55MPa) when compared with other filled composites but lower than the unfilled composites this due to that good compatibility between filler and matrix. Test results showed that increase in addition of Al_2O_3 and Mg (OH_2), enhances the flexural strength this is due to uniform distribution of filler materials and increased in effective bonding between filler materials and matrix and strong polymer/filler interface adhesion. Composite filled by (15 % Vol.) Sic exhibited maximum Brinell hardness number (91.73 BHN) this due to uniform dispersion of SiC particles and decrease in inter particle distance with increasing particle loading in the matrix.

S. Rajesh et al [41] analyzed the mechanical properties like tensile strength, shear strength, impact, hardness and biaxial strength of epoxy and polyester resin composites using aluminum oxide, silicon carbide with different proportion of Al_2O_3 and SiC along with GFRP. The result showed that GFRP composites with epoxy resin have very high tensile strength 36.53MPa. The biaxial stresses are more in GFRP composite with polyester resin of 40.7MPa. The shear strength is also more in the GFRP composite with polyester resin of value 6.45kN. **Prashantha et al [42]** studied the mechanical and physical properties like flexural strength and torsional strength of composite and water absorption behavior like normal water and sea water absorption properties of epoxy composite using aluminum oxide and silicon carbide with different weight properties of Al_2O_3 and SiC along with glass fiber reinforced polymer. The Result showed that addition of filler to polymer matrix significant changes in mechanical and water absorption behavior.

2.4. On Taguchi Method

A Design of Experiment (DOE) is a structured, organized method for determining the relationship between factors affecting a process and the output of that process. Through robust design of experiments the Taguchi method reduce the variation in a process and it was developed by Dr. Genichi Taguchi. He developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels which they should be varied, it allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources [43].

Chrispin et al [44] analyzed the influences of fabrication parameters such as the fiber content, fiber length, alkali concentration and alkali treatment duration on the mechanical properties of Areca fine fiber (AFF)-reinforced phenol formaldehyde (PF) composite by using Taguchi's experimental design (L27orthogonal array). Results showed that the tensile and flexural strength influenced by fiber content and followed by the fiber length and the alkali treatment duration. The interaction between the fabrication parameters also has a significant effect on the tensile and flexural strength of the composite. The optimal combination of fabrication parameters to obtain the maximum tensile and flexural strength was found to be FL = 10 mm, FC = 35 vol%, AC = 6% and ATD = 1 h. Influencing percentages of each fabrication parameter on the mechanical properties were obtained by analysis of variance. **T. Balarami [45]** evaluated the tensile strength of Green Coconut fiber/HDPE composites by adopting Taghuchi's Design of Experiments (DoE) L9 orthogonal array concept. The results showed that tensile strength (TS) composite material is greatly influenced by fiber length as well as fiber volume fraction. Tensile strength of the composite material increases with increase in fiber volume fraction up to 40%, then after decreases slightly and decreases with increase in the fiber length. **Kanthavel et al [46]** investigated the mechanical strength of bagasse fiber-reinforced epoxy composite using a Design of Experiment technique. The parameters of fiber volume percentage, alkali concentration, and treatment time with three levels were considered, and an L27 design matrix was developed using the Taguchi orthogonal array. Statistical analysis indicated that fiber volume and alkali treatment have a significant effect on flexural strength (37.86 MPa).

The literature survey presented above tells the following knowledge gap:

- Much work has been done on a variety of natural fibers polymer composites, very less has been reported on the reinforcing jute fiber based polymer composite for automotive applications.
- Most of the studies are for single filler composites and only very few papers have reported on effect of two different kinds of fillers on the mechanical properties.
- Studies carried out on mechanical behavior of polymer composites with metal or ceramic fillers but only very few reports are available on composites filled with natural fibers and particulates.
- Few papers have been reported on investigation of mechanical properties Al_2O_3/SiC filled natural fiber reinforced polymer hybrid composites, a possibility that the incorporation of both Al_2O_3 and SiC with jute fiber in polyester resin to improve mechanical properties has not been addressed so far.
- Few papers have been reported on using Taguchi method, to understand the influence of fabrication parameters on mechanical properties of natural fiber reinforced composite material.

2.5. Problem statement

In the recent decades, the majority of reaches gives attention to replacing heavier metals and synthetic fiber composite which affects environment after disposal and needs high manufacturing cost by natural fiber composite for house hold products, aerospace, automotive, and marine application due to their advantageous properties. Literature review illustrated that the composite material manufactured by reinforcement of natural fiber with polyester matrix material is expected to reduce and improve all the above mentioned problems. Many studies indicated that jute fiber is a plant having good mechanical properties, biodegradable, renewable and versatile material. However, certain limitations are realized in the natural fibers such as, inferior mechanical strength compared to the synthetic fibers, high moisture absorbing and lower melting temperature. High moisture absorbing property is the major drawback of the natural fibers. This phenomenon reduces the interfacial bonding between the polymer matrix and fiber and cause detrimental effects on the mechanical properties. As a means of solution for problem mentioned above researcher, are fiber pre-treatment, hybridized two or more fibers and adding of different fillers. Filler materials are used in polymer composite for modifying the chemical and physical properties of polymer matrix to improve mechanical behavior of the material. Ethiopia has a excess amount of jute plant, which has a great potential that can be used as structural materials for different application. However the contribution, the performance and application of Ethiopia jute fiber and its composite materials in industrial sector are not investigated well, due to lack of awareness about this plant, unavalability of experimental tools and low manufacturing process capability. A few researchers conducted their study to fabricate composite from jute fiber and ceramic powder. So, this study was elaborated to a great opportuity for our country to produce and characterization of the Al_2O_3/SiC filled jute fiber reinforced composite materials for better strength, long survival time, and reduced water absorption behavior for diferent application as engineering materials and construction materials.

2.6. Objective

2.6.1. General Objectives

The general objectives of this thesis is to investigate the mechanical properties of AL_2O_3/Sic filled jute fiber reinforced polyester resin composite for automotive application.

2.6.2. Specific objectives

- Chemical treatment of jute fibers to improve its interfacial adhesion and stiffness.
- Manufacturing of AL_2O_3/Sic filled jute fiber reinforced polyester resin composite materials with various weight fraction
- Conducting tensile strength, hardness, bending strength tests on composite specimen's
- To determine density and void fraction of composite specimens
- To determine water absorption behavior of composite specimens
- To study the interface and microstructure of the surfaces of the composite specimens
- To study the influences of fabrication parameters (fiber direction, fiber content and filler content) on physical and mechanical properties of composites using Taguchi experimental design.

2.7. Scope of study

In order to achieve the objectives specified the following scopes were settled:-

- Gathering related documents and literatures.
- Gathering raw materials that use for fabrication composite samples
- The fabrication of composite material was conducted by using hand lay-up technique
- Physical and mechanical properties of samples are identified by using convection testing machine
- The study was limited to the evaluation of physical and mechanical properties namely density, void fraction, water absorption, tensile strength, bending strength and hardness.
- The micro structural analysis of these composite materials was carried out using optical microscope (OM)
- To study the influences of fabrication parameters such as fiber content and filler content on composites materials using Taguchi experimental design by Minitab 17 software

2.8. Challenges

The limitation faced during fabrication of jute fiber reinforced polyester composite filled with Al_2O_3/Sic powder filler in this study, the researcher was less difficult to controlling the factors which affect mechanical and physical properties of fabricated composite under hand lay-up technique. Again, obtaining different type of resin, hardener and Al_2O_3/Sic powder needs a long time. To prepare specimen, the cutter which don't affect microstructure of the fabricated composite like abrasive water jet, diamond cutter, etc. are not available. Finding testing machine facilities was another big challenge. It was impossible to get a well-organized laboratory that can test all the required tests. There is no highly competitive laboratory setup for the testing of natural fiber reinforced composite and no fully established workshop for the fabrication of composite material.

2.9. Significance of the study

Due to rapid growth in the manufacturing industries, there is a need for materials which have better properties in terms of strength, stiffness, density, lower cost with improved sustainability. The polymer composite materials are one of the materials which possesses such properties.

This study is helpful for manufacturing industry and society for better use of different manufacturing equipment's:-

- Automotive components such as doors, roof liner, various damping and insulation parts, bonnet insulation, wheel arch, heed rest, bumper, etc.
- Lower embedded energy compared to steel, aluminum etc.
- Low specific weight, and higher specific strength and stiffness than glass fiber.
- Producible with low investment at low cost.
- Low hazard manufacturing process and easy for disposal
- Options for new production technologies and materials.
- Favorable Eco balance for vehicle part production due to weight savings

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Introduction

This chapter describes the materials and methods used for the fabrication of composites under this investigation. For this study the materials such as jute fiber, Silicon Carbide (SiC). Alumina (Al_2O_3), unsaturated polyester resin and hardener are utilized in order to manufacture the composite material specimen. Also sodium hydroxide (NaOH) and distilled water used in order to treat the jute fiber to improve the interfacial adhesive property.

3.2. Materials

3.2.1. Unsaturated Polyester Resin

Low cost natural fiber reinforced composites are successfully fabricated with many thermoset matrixes. Adhesive properties, mechanical properties and degradation from water entrance are the characteristics to choice the resin for composite fabrication. The resin used for this study is Unsaturated Polyester (TOPAZ-1110 Phthalic Anhydride). Unsaturated polyester resin is a thermoset and it capable to being cured from a liquid to solid state when subject to the right condition. Low viscosity for fast wet-out, convenient for hand lay-up applications, low cost, exhibits good mechanical and good chemical resistance, low pressure molding capabilities and capability to cure at room temperature are the advantage of unsaturated polyester when compared to other thermosetting resins. It’s supplied by World Fiber Glass and Water Proofing Engineering. The properties of unsaturated polyester resin are shown in Table 3.1.

Table. 3.1. Physical properties of unsaturated polyester data in cured state (Source: Industrial chemicals and Resin Co Ltd (Technical data sheet)

Properties	**Pure resin**	**Unit**
Viscosity	575-675	Cgs
Specific gravity	1.13	Kg/m^3
Acid value	23-28	KOH
Styrene content	38 ± 3	%weight
Storage stability	4	Months
Peak Exotherm	150-165	C^o

3.2.2. Hardener (catalyst)

The hardener creates a chemical reaction that allows the resin to change from a liquid to a solid state to make polyester resin useful for its intended purpose. This transformation is referred to as "curing" or "polymerization." Topaz-1110 TP; Thixotropic hardener is the chemical hardener used with unsaturated polyester resin. The thickness of the laminate, temperature and humidity or other are considered when estimating the amount of catalyst to add to polyester resin to achieve the curing speed desired. The ratio of catalyst is 2 percent to the total volume of resin to be used. Generally, it is mixed with polyester resin at normal atmospheric temperature. It's supplied by World Fiber Glass and Water Proofing Engineering.

3.2.3. Alumina (Al_2O_3)

Aluminum oxide is a chemical compound of aluminum and oxygen with the chemical formula Al_2O_3.It is commonly called alumina. It has strong ionic inter-atomic bonding and commonly occurs in its crystalline polymorphic phase α-Al_2O_3. Alumina is ceramic material used as the filler in the present investigation were purchased from Bangaiere Fine chem- Bangaiere, India. These Al_2O_3 powder with average particle size of 80-100 micron has a density of 3.65 gm/cm^3. Al_2O_3 is chosen over other ceramics because of it is hard and wear-resistant, has high strength and stiffness and also it serves as filler in plastics.

Table. 3.2. Properties of alumina [47]

Crystal structure	Molar Mass	Density	Melting point	Boiling point	Thermal conductivity	Tensile strength	Compressive strength	Shear modulus	Young's modulus
Values	101.96 g.mol^{-1}	3.95-4.1 g/cm^3	2072^{o}C	2977^{o}C	30W.m^{-1}.k^{-1}	69 to 5500 MPa	690 to 5500 MPa	88-165 GPa	215-413 GPa

Figure 3.1. Alumina

3.2.4. Silicon Carbide (SiC)

Silicon carbide produced using a high temperature electro-chemical reaction of sand and carbon by carbon reduction of silica. It is produced as either fine powder or a large bonded mass, which is then crushed. To purify (remove silica) it is washed with hydrofluoric acid. Silicon carbide is recognized as one of the most promising structural materials due to high temperature strength, good oxidation and thermal shock resistance, high hardness and low specific weight. It is used in abrasive, refractories, ceramic and numerous high performance application. In the present investigation the filler of silicon carbide were purchased from Bangaiere Fine chem- Bangaiere, India. These Sic powder with average particle size of 80-100 micron has a density of 3.21 gm/cm^3.

Table. 3.3. Physical and Mechanical properties of Silicon carbide [48]

Properties	Density	Flexural strength	Elastic modulus	Compressive strength	Hardness	Fracture toughness	Thermal conductivity	Specific heat	Volume resistivity
Values	3.1 g/m^3	550 Mpa	410 GPa	3900 MPa	2800 Kg/mm^2	4.6 Klc	120 W/m ^oK	750 J/Kg^oK	10^2-10^6 Ohm

Figure 3.2. Silicon carbide

3.2.5. Jute fiber

Jute is one of the most promising materials among all the natural fiber-reinforcing materials. Jute is a long, soft, shiny vegetable fiber that can be spun into coarse, strong threads. It is produced from plants in the genus Corchorus, family Tiliaceae [5]. Jute is one of the cheapest natural fibers and is second only to cotton in amount produced and variety of uses. Jute falls into the bast fiber category and primarily composed of cellulose which is major component of plant fiber and lignin which major components wood fiber.

Jute take nearly 3 months, to grow to required height, then cut and bundled and kept immersed in water for "retting" process, then the outer plant gets separated to form fibers. Jute fiber are cheapest material and having low thermal conductivity, ability to be blended with other fibers, moderate moisture regain and manufacture with no skin irritations, There is around 5.6 thousand tons of jute production per year in Ethiopia [49]. Jute fibers used in this work were sourced from the southern part of Ethiopia where it grows mostly and take from Ethiopia fiber (qacaa) factory.

Table. 3.4. Physical properties of jute fiber [50]

Physical property	Jute fiber
Ultimate Diameter of Jute	0.015 to 0.002 mm.
Jute Fiber Length	150 to 300 CM (5 to 12 Feet).
Jute Color	Can be White, Yellow, Brown or Grey.
Specific Gravity	1.48
Strength of Jute	3.5 to 5 G/Den.
Moisture Regain of Jute	13.75 % (Standard).
Elasticity	Breaking Extension 1.8% and Elastic Recovery very low.

Table 3.5. Chemical properties of jute fiber [50]

Chemical property	Range Value
Cellulose	60- 65%
Hemi-cellulose	7- 22.5%
Lignin	6- 11%
Fat and Wax	0.1- 0.3%
Water Soluble Materials	0.5- 1.2%

Figure 3.3. Jute fiber

3.2.6. Sodium Hydroxide (NaOH)

Sodium hydroxide, also known as lye or caustic soda, has the molecular formula NaOH and is a highly caustic metallic base and alkali salt. Pure sodium hydroxide is a whitish solid, which is available in pellets, flakes, granules, and as a 50% saturated solution [51]. Sodium hydroxide is soluble in water, ethanol and methanol. This alkali is deliquescent and readily absorbs moisture and carbon dioxide in air. Sodium hydroxide is used in many industries, mostly as a strong chemical base in the manufacture of pulp and paper, textiles, drinking water, soaps and detergents. In this work we used NaOH in pellets form, purchased from local suppliers with the brand name and code of RANKEM, S0290 respectively and performed chemical treatment of jute fiber.

- To calculate the amount of NaOH in gram required for 5 liter water, we have to follow the following step:-

$$\text{Fiber} - \text{OH} + \text{NaOH} \longrightarrow \text{Fiber} - \text{O} - \text{Na} + H_2O$$

$$\text{ASSUMING PH} = 12$$

$$P^{H} + P^{OH} = 14$$

$$P^{OH} = 14\text{-}12 = 2$$

$$P^{OH} = -\log[OH]$$

$$[OH] = 2\text{x } 10^{-2}\text{ M}$$

$$\text{Morality} = \frac{Number\ of\ mole\ (N)}{Volume\ (V)}$$

$$N = M \text{ x } V$$

$$N = 2 \text{ x } 10^{-2}\text{ M x 5 liter}$$

$$N = 0.02 \text{ x } 5 = 0.1 \text{ mole}$$

$$\text{Mw of NaOH} = 40$$

$$N = \text{mass/ molecular weight} = M/Mw$$

$$0.1 \text{ mole} = m/40$$

$$\text{Mass} = 0.1 \text{ x } 40$$

$$\text{Mass} = 4 \text{ gram}$$

Therefore 4 gram of sodium hydroxide is sufficient to mix 5 liter of water to bring ph-12 which is approaches to strong base.

3.2.6.1. Alkali treatment of jute fiber

The hydrophilic jute fiber is difficult to combine directly with the hydrophobic polyester matrix in jute fiber reinforced polyester composites. The surface of the jute fiber has to be changed from hydrophilic to hydrophobic by subjecting the jute fiber to alkali treatment to bring reinforcing effect. Alkali treatment, named also Mercerization, is a common fiber treatment chemical method that is extensively used by researchers [52]. The aim of the chemical treatment is to improve poor interfacial adhesion between fiber and matrix that lead to the poor wetting of fiber with the matrix , improve bond strength, lowers the water absorption, increase fiber strength and improving mechanical properties of the composite materials. The surface of the jute fibers cleaning with alkali treatment using sodium hydroxide (NaOH) to maximize the efficiency of the fiber as reinforcement However when the percentage of NaOH is increased it affect the fibers properties by reduce the bonding capacity during preparation of the composites. For this study to perform a chemical treatment of jute fiber 4gm of NaOH pellet was mixed with 5 liter of water at ambient temperature. In this process the solution of the jute fiber and NaOH must kept under the vacuum, to reduce absorb moisture in the solution. After soaking jute fiber in solution for four hour the fiber washed by distilled water several time in order to neutralize it. Then, the fibers were allowed to dry in sun light for at least 2 day as shown in figure 3.4.

Figure. 3.4. Alkaline treatment of jute fiber.

3.3. Experimental Sample Preparation Methods

The following steps are used for preparing sample:-

A. The masses of the jute fiber, Silicon Carbide (SiC), Alumina (Al_2O_3) and unsaturated polyester were calculated according to the required weight fractions. The hardener, were added 2 % weight of matrix.

B. The Sic, Al_2O_3 and matrix were mixed for about 5 minute at room temperature continuously and slowly to avoid bubbling during mixing, and then the hardener was added to the mixture with gentle mixing. The mixer is strewed with stirrer for about minutes continuously. The mixing is performed in the mixing containers (Bowl), the bowl is made of Nickel to prevent melting of the Bowl during the exothermic reaction and the mix is done slowly so as to not entrain any excess air bubbles in the resin.

C. The mold was prepared and we pour some mixture after and placed weighted jute fiber according to each weight fraction of composite sample. Above that we pour mixture of fillers and matrix then we press the mold for consolidation and this sample is then left for 24 hours. The composite gets dried up in 48 hours in which the jute fiber and the mixture adheres itself tightly in the presence of hardener.

D. The specimens were cut according to the standard dimensions for each test (tensile, bending, hardness, density, void and water absorption tests) using cutting tools.

E. Water absorption and density test was performed according to ASTM D 570, ASTM D 570 respectively [39]. Tensile strength test, flexural strength test and hardness test was performed according to (ASTM D3039), (ASTM D790) and (ASTM D 2583) respectively [49]. Knowing that all tests were accomplished at room temperature.

Generally, all samples were produced based on the treated fiber filled ceramic powder on different ratios to resin –hardener mixtures. The whole mixing ratio was done based on weight ratios. The procedure to fabricate laminated was described clearly in flow diagram below (Figure. 3.5).

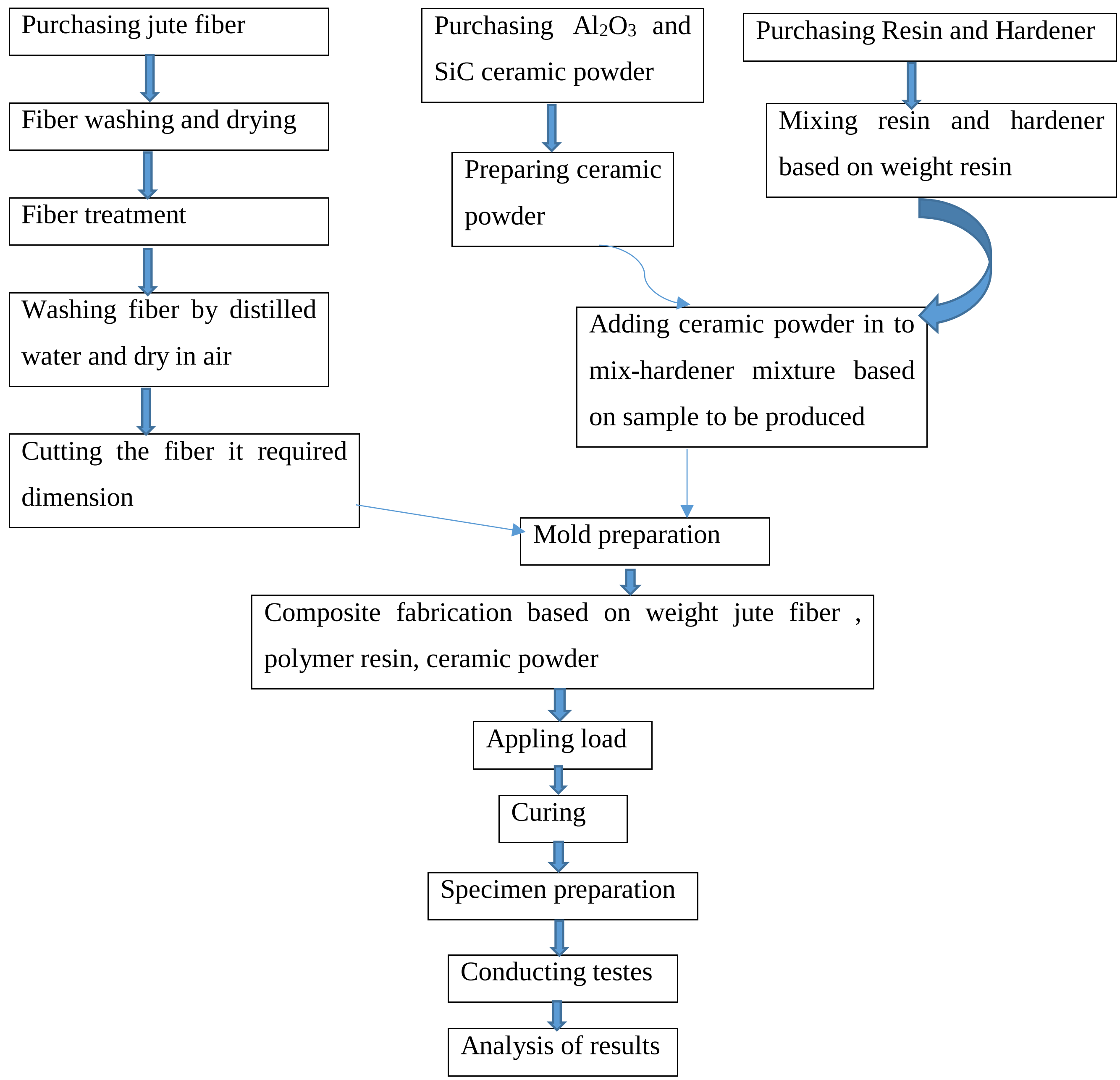


Figure. 3.5. Flow diagram of sample preparation process

3.4. Design of experiment

In the design of experiment (DOE) Taguchi method is commonly used because it is a problem solving tool which can improve the performance of the product, process design and system. DOE is a technique of defining and investigating all possible conditions involving variables, multiple factors and parameters in an experiment. To observe the most influential process parameters in the fabrication of Al_2O_3/SiC/jute fiber reinforced polyester composite namely particle content, jute fiber content, fiber direction at three levels were considered. The selected process parameters, levels and their values at different levels are given in tables 3.9.

Table. 3.6. Process parameters and levels

S.NO	Factors	Parameters Designation	Level 1	Level 2	Level 3
1	Jute fiber content	A	15	25	25
2	Fiber direction	B	Unidirectional	Bidirectional	Chopped
3	Al_20_3 content	C	3	6	9
4	SiC content	D	3	6	9

The selection of a particular orthogonal array was based on the number of levels of various factors, Here, to conduct the experimental 4 factors each at 3 levels were selected.

Now the Degree of Freedom (DOE) can be calculated by the formula as given below.

DOE = P* (L – 1) ………………………….. Equation 3.1.

P = number of factors L = number of levels

DOE = 4 * (3 – 1) = 8

However, total number of experiment of the orthogonal array (OA) should be greater than or equal to the DOE required for the experiment. Thus Lo orthogonal array was selected to make the further experiments are shown in Table 3.10.

Table. 3.7. L9 Orthogonal array center

Expt.no	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Nine different composite were manufactured with different parameters and at different levels. In the Taguchi method the response variation was studied using signal – to- noise and minimization the variation due to uncontrollable parameter. The larger the better S/N ratio used for these responses;

$$S/N = -10 \log \frac{1}{r} \sum_{i=1}^{1} \left(\frac{1}{yi}\right)^2 \text{………………… Equation 3.2.}$$

Here, y = observation, r = total number of observation and yi = ith response. The S/N ratio was calculated for tensile strength and void content in each of the nine trial conditions to see the effect of each parameter on the response.

3.5. Weight fraction of the particulate, fiber and the matrix content of the composite

The mechanical properties of composite significantly influenced by particulate, fiber and matrix materials. These materials can be expressed either as volume fractions or as mass fractions. While mass fractions are easier to obtain during fabrication of composites, volume fractions are handier in theoretical analyses of composites.

Table. 3.8. Composition of particulate, fiber and resin used for specimen preparation

S1	Polyester + bidirectional jute fiber (25 Wt%)
S2	Polyester + Unidirectional jute fiber (15 Wt%) + Al_2O_3 (3Wt%) + Sic (3Wt%)
S3	Polyester + Unidirectional jute fiber (25 Wt%) + Al_2O_3 (6Wt%) + Sic (6 Wt%)
S4	Polyester + Unidirectional jute fiber (35Wt%) + Al_2O_3 (9Wt%) + Sic (9 Wt%)
S5	Polyester + bidirectional jute fiber (15 Wt%) + Al_2O_3 (6Wt%) + Sic (9 Wt%)
S6	Polyester + bidirectional jute fiber (25 Wt%) + Al_2O_3 (9Wt%) + Sic (3Wt%)
S7	Polyester + bidirectional jute fiber (35 Wt%) + Al_2O_3 (3Wt%) + Sic (6Wt%)
S8	Polyester + chopped jute fiber (15Wt%) + Al_2O_3 (9Wt%) + Sic (6Wt%)
S9	Polyester + chopped jute fiber (25Wt%) + Al_2O_3 (3Wt%) + Sic (9Wt%)
S10	Polyester + chopped jute fiber (35Wt%) + Al_2O_3 (6Wt%) + Sic (3Wt%)

Particle, Fiber and matrix mass fraction content of the composites

Total mass of composite = mass of particulate + mass of fiber + mass of matrix

$M_c = M_m + M_f + M_p$

Fiber mass fraction = $\frac{\text{mass of fiber}}{\text{total mass}}$ = M_F = $\frac{Mf}{Mm}$

Particulate mass fraction = $\frac{\text{mass of particulate}}{\text{total mass}}$ = M_p = $\frac{Mp}{Mm}$

Matrix mass fraction = $\frac{\text{mass of matrix}}{\text{total mass}}$ = M_M = $\frac{Mm}{total\ mass}$ and,

MP + MF + MM = 1

Particulate, fiber and matrix volume fraction (V_p, V_F, V_M)

Volume of fiber = $\frac{mass\ of\ fiber}{density\ of\ fiber}$ = V_f = $\frac{Mf}{\mathcal{P}f}$

Volume of Particulate = $\frac{mass\ of\ fiber}{density\ of\ fiber}$ = V_p= $\frac{Mp}{\mathcal{P}p}$

Volume of matrix = $\frac{mass\ of\ matrix}{density\ of\ matrix}$ = V_m = $\frac{Mm}{\mathcal{P}f}$

$V_c = V_m + V_f + Vp$

Fiber volume fraction = $\frac{volume\ of\ fiber}{total\ volume}$ = V_F = $\frac{vf}{vf+vm+vp}$

Particulate volume fraction = $\frac{volume\ of\ particulate}{total\ volume}$ = V_p = $\frac{vp}{vp+vm+vp}$

Matrix volume fraction = $\frac{volume\ of\ matrix}{total\ volume}$ = VM = $\frac{vm}{vf+vm+vp}$

3.5.1. Calculation to find the Mass of the Fiber, particulate and matrix for Specimen

The volume of the composite was calculated by multiplying the length, width and breadth of the mold prepared for molding the composite material Equation 3.3.

Volume of the die = L × w × t …………………………….. Equation ***3.3.***

According to the density of the Jute fiber, polyester resin, aluminum oxide, silicon carbide was taken as following respectively in g/cm^3 (Density= Mass/volume).

- ***Jute fiber = 1.43 g/cm^3***

- ***polyester resin = 1.15 g/cm^3***
- ***Aluminum oxide (Al_2O_3) =3.65 g/cm^{3}Silicon carbide (SiC) = 3.21 g/cm^3***

$V_c = V_{Plyester} + V_{Jute} + V_{Particulate}$ **……………………………..** Equation ***3.4.***

For sample 1

Polyester = 75wt% = 0.75

Jute fiber= 25wt% =0.25

The density of the composite was calculated by the rule of law of mixture method and obtained first by adding the volume fraction of the resin, jute fiber and ceramic particulate for each sample ratio.

$M_c/\mathcal{P}c = m_{polyester}/\mathcal{P}polyester + m_{Jute}/\mathcal{P}Jute$ **……………………………..** Equation ***3.5.***

The density of the composite obtained as shown in eq 3.3.

$1/\mathcal{P}c = \frac{0.75}{1.15} + \frac{0.25}{1.43}$

$\mathcal{P}c = 1.3879 g/cm^3$

$m_c = \mathcal{P}c * Vc$ **……………………………..** Equation ***3.6.***

Volume of the die = L × w × t

=300 × 160 × 5 = 360cm^3

After getting the density of the composite it multiplied by the volume of the composite Equation 3.6 then the mass of the composite obtained.

$m_c = \mathcal{P}c * Vc$

$= 1.387 g/cm^3 * 240 cm^3$

m_c = <u>333.105g</u>

The mass of the composite multiplied by each particulate/fiber/matrix ratio then the mass of each Al_2O_3, Sic, jute fiber and polyester resin obtained.

Mass of Polyester = <u>249.82g</u>

Mass of Jute fiber= 83.27g

For sample 2

Polyester = 79 wt% = 0.79

Jute fiber= 15wt% =0.15

Sic=3* wt% =*0.03

Al_2O_3= 3*wt%=*0.03

The density of the composite was calculated by the rule of law of mixture method and obtained first by adding the volume fraction of the resin, jute fiber and ceramic particulate for each sample ratio.

$$Mc/\mathcal{P}c = m_{polyester}/\mathcal{P}polyester + m_{Jute}/\mathcal{P}Jute + m_{Al2O3}/\mathcal{P}Al2O3 + m_{Sic}/\mathcal{P}Sic$$

The density of the composite obtained as shown in eq 3.2.

$$1/\mathcal{P}c = \frac{0.79}{1.15} + \frac{0.15}{1.43} + \frac{0.03}{3.65} + \frac{0.03}{3.21}$$

$$= 0.69 + 0.1 + 0.008 + 0.009$$

$\mathcal{P}c$= 1.24g/cm3

Volume of the die = $L \times w \times t$

$=300 \times 160 \times 5 = 240cm^3$

After getting the density of the composite the it multiplied by the volume of the composite eq(2) then the mass of the composite obtained.

$m_c = \mathcal{P}c\, Vc$

$= 1.24g/cm^3 * 240cm^3$ = **297.6g**

The mass of the composite multiplied by each particulate/fiber/matrix ratio then the mass of each Al_2O_3, Sic, jute fiber and polyester resin obtained.

Mass of Polyester = 235.104g

Mass of Jute fiber= 44.64 g

Mass of SiC=8.93g

Mass of Al_2O_3= 8.93 g

Table. 3.9. Sample specimen composition by mass for this study

Designation	Composition				Mass (gms)				
	Polyester	Jute	Al_2O_3	SiC	Polyester	Jute	Al_2O_3	SiC	Total
S1	75	25			249.42	83.27			332.69
S2	79	15	3	3	235.10	44.64	8.93	8.93	297.6
S3	67	25	6	6	300.28	119.16	28.59	28.59	476.62
S4	47	35	9	9	162.43	120.96	31.104	31.104	345.58
S5	73	15	6	9	335.16	71.82	28.71	43.09	478.78
S6	66	25	9	3	200.34	79.5	28.62	9.54	318
S7	50	35	3	6	268.12	167.58	14.36	28.72	478.78
S8	73	15	9	6	337.68	72.324	43.41	28.94	488.82
S9	63	25	3	9	301.6	119.7	14.36	43.09	467.28
S10	53	35	6	3	177.94	111.21	19.06	9.53	317.74
Total					2568.07	990.16	217.37	231.53	

***Total* Mass of Polyester = 2568.07 g**

1 liter =1000cm^3

$$V_{polyesyer} = \frac{mp}{\mathcal{P}p} = \frac{2568.07}{1.15} = \underline{2233.10\ cm^3}$$

Total polyester need= 2233.1liter

***Total* Mass of Jute fiber= 990.16g**

Total Mass of SiC= 231.53 g

Total Mass of Al_2O_3= 217.37g

3.5.2. Calculation to find the volume of the fiber, particulate and matrix for specimen

For sample 1

$$\text{Volume of fiber } (V_f) = \frac{mass\ of\ fiber}{density\ of\ fiber} = \frac{Mf}{\mathcal{P}f} = \frac{\mathbf{83.27}}{1.43} = \underline{\mathbf{58.23\ cm^3}}$$

Volume of matrix (V_m)= $\frac{mass\ of\ matrix}{density\ of\ matrix}$ = $\frac{Mm}{\mathcal{P}m}$= $\frac{\mathbf{249.42}}{1.15}$ = **216.89 cm³**

$V_c = V_m + V_f$ = **$275.11\ cm^3$**

For sample 2

Volume of fiber (V_f)= $\frac{mass\ of\ fiber}{density\ of\ fiber}$ = $\frac{Mf}{\mathcal{P}f}$ = $\frac{\mathbf{44.64}}{1.43}$ = **$31.21\ cm^3$**

Volume of matrix (V_m)= $\frac{mass\ of\ matrix}{density\ of\ matrix}$ = $\frac{Mm}{\mathcal{P}m}$= $\frac{\mathbf{235.10}}{\mathbf{1.15}}$ = **$204.43\ cm^3$**

Volume of Al_2O_3 (V_{Al})= $\frac{mass\ of\ \mathrm{Al2O3}}{density\ of\ \mathrm{Al2O3}}$ = $\frac{M\mathrm{Al2O3}}{\mathcal{P}\mathrm{Al2O3}}$= $\frac{\mathbf{8.93}}{3.65}$ = **$2.44\ cm^3$**

Volume of SiC(V_{Si})= $\frac{mass\ of\ \mathrm{SiC}}{density\ of\ \mathrm{SiC}}$ = $\frac{MSi}{\mathcal{P}Si}$= $\frac{\mathbf{18.93}}{3.21}$ = **$5.89\ cm^3$**

$V_c = V_m + V_f + V_{Al} + V_{Si}$ = **$243.97\ cm^3$**

Table. 3.10. Sample specimen composition by volume for this study

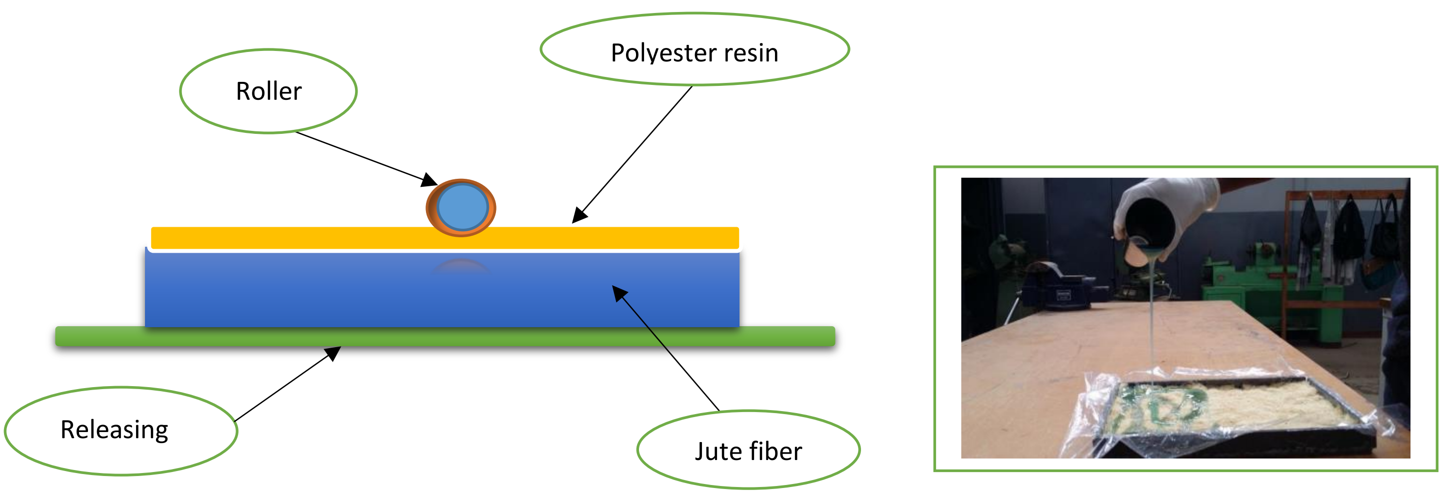
sample	***Composition***				***Volume (cm³)***				
	Polyester	***Jute***	***Al_2O_3***	***SiC***	***Polyester***	***Jute***	***Al_2O_3***	***SiC***	***Total***
S1	***75***	***25***			216.89	58.23			275.11
S2	***79***	***15***	***3***	***3***	204.43	31.21	2.44	5.89	243.97
S3	***67***	***25***	***6***	***6***	261.11	83.32	7.83	8.9	361.16
S4	***47***	***35***	***9***	***9***	141.24	84.56	8.52	9.68	244
S5	***73***	***15***	***6***	***9***	291.44	50.22	7.86	13.42	362.94
S6	***66***	***25***	***9***	***3***	174.20	55.59	7.84	2.97	240.61
S7	***50***	***35***	***3***	***6***	233.21	117.18	3.93	8.94	363.26
S8	***73***	***15***	***9***	***6***	293.63	50.57	11.89	9.01	365.1
S9	***63***	***25***	***3***	***9***	262.26	83.7	3.93	13.42	363.31
S10	***53***	***35***	***6***	***3***	154.73	77.76	5.22	2.96	240.67

3.6. Composite fabrication process

Composite laminate was fabricated by using hand layup composite fabrication methods.

3.6.1. Hand lay-up

Hand lay-up is the simplest method of processing the thermosets based fibers composite. Advantages of hand lay-up are the relatively lower mold costs, the tools required for production are readily available and the molds are easy to maintain. However, hand lay-up is a manual process, and therefore results are very subject to the user that is doing the work. In hand lay-up technique, thin plastic sheets are used on bottom of mold and then a releasing agent is sprayed on it to avoid the sticking of polymer to the surface of mold and to get good surface finish of product. Jute fibers as a reinforcement placed at the upper surface of mold. Then mixture of polyester risen, Al_2O_3/Sic powder and hardener is poured on the surface of fiber already placed in the mold. The polymer is uniformly spread with the help of brush and a roller is used to remove air as well as excess matrix present. The process is repeated for each layer of reinforcement and matrix until the required thickness is achieved. After placing the plastic sheet, release agent is sprayed on the inner surface of the top mold which is then kept on the achieved thickness and during curing a compression load of 35 kg was applied on the mold and the air gaps formed between the jute fiber and mixture was release due to the application of the load. It was kept for one day to get perfect sample, after curing at room temperature, mold is opened and the developed composite part is taken out [53].



(a) (b)

Figure. 3.6. Al_2O_3/SiC filled Jute fiber reinforced polymer composite (a) molding sketch map, (b) Composite molding at manufacturing workshop

3.7. Equipment

The instruments and tools used for characterization of composite material were given as follows:

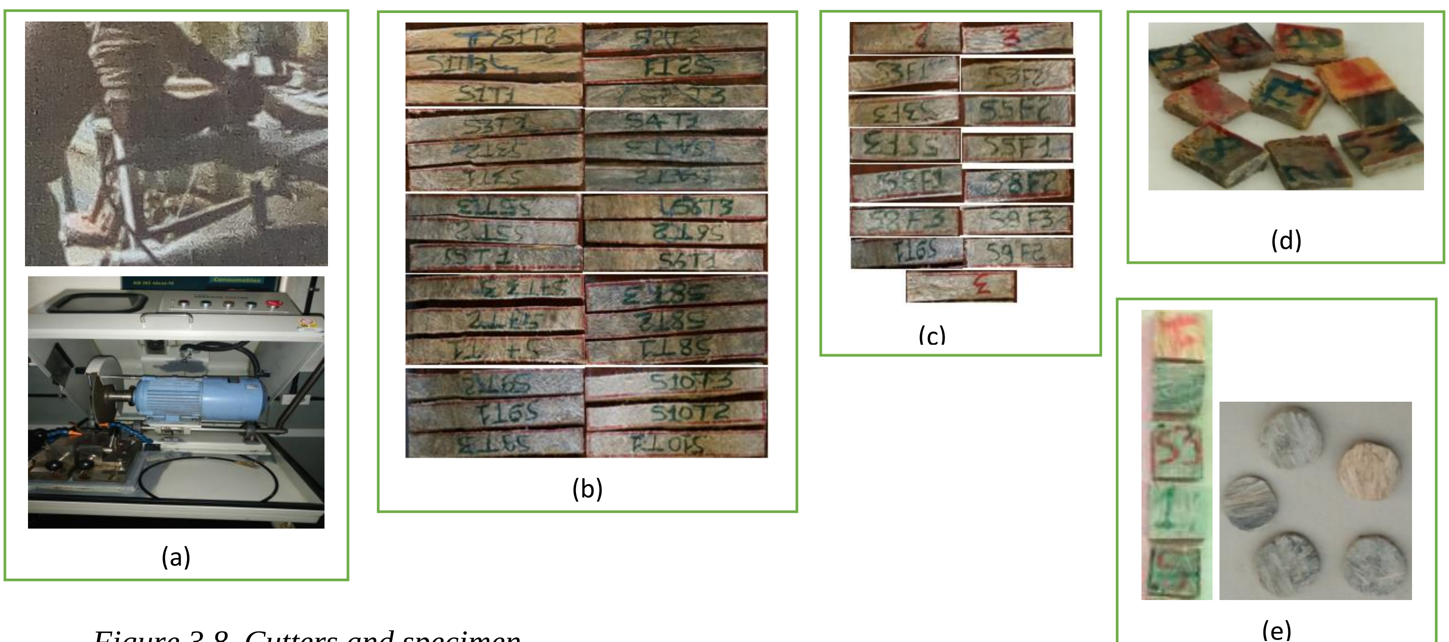
3.7.1. Analytical (digital) balance

The digital mass balance in the ASTU chemistry labs are very sensitive instruments used for weighing substance to the milligram (0.001 g) level. This balance equipment also important to measure while mixing the composites and to characterization physical properties.

Figure. 3.7. Digital balance

3.7.2. Specimen cutter

The prepared specimen was cut using circular cutter and grinder and finally polished by polished paper according to the ASTM standards in to different sizes. For microstructure and micro hardness specimens are produced by using abrasive cutter.



(a) (b) (c) (d) (e)

Figure 3.8. Cutters and specimen

(a) abrasive cutter and circular cutter (b) Tensile Test specimen (c) Bending Test Specimen (d) Water absorption and density specimen (e) Hardness Test specimen

3.7.3. Universal testing machine (UTM)

The universal testing machines are a computer equipped machines used to measure the material mechanical properties under different load conditions. UTM is a machine suitable for conducting tests like the tensile, compression, bending and shear test for all kinds of metals and nonmetals by changing the jaws and modes of operations [54]. The main components of the UTM are, actuator, attachment kit, safety devices frame, engine, and gear, screws, and crosshead grips extensometer, hardware and software control. The control unit is composed of computer and control system, it process stress, strain and displacement control modes, the test data can be stored at will, and the data and curves can be reanalyzed, part amplified and data re- edition, test conditions (specimen, measurement) are programmable. All the mechanical properties can be obtained automatically, and print whole test report and curve.

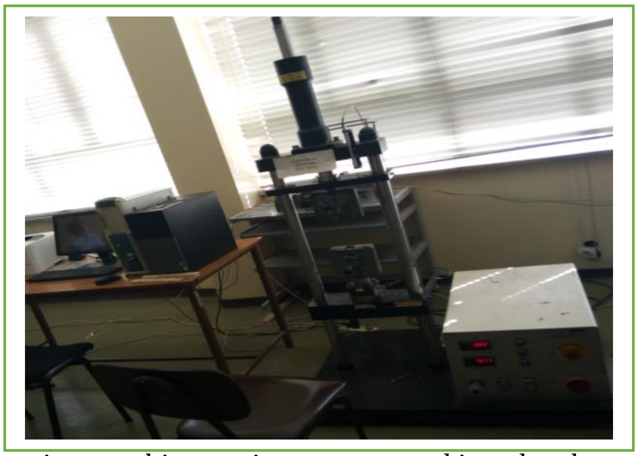


Figure. 3.9. Universal testing machine testing system working sketch map

For this study all the material properties testes was done in Defense Engineering College material Engineering workshop by using Computer Controlled universal testing machine which has a capacity of up to 50 KN.

3.7.4. Vickers Hardness Test

Hardness measurement quantify the resistance of a material to plastic deformation. Indentation hardness tests compose the majority of processes used to determine material hardness, and can be divided in to two class: micro indentation and macro indentation tests. Micro indentation tests typically have forces less than 2N. The term ‘macro indentation’ is applied to tests with a larger test load, such as a10Kg or more force is applied. There are various macro indentation testes, such as Vickers hardness test (HV), knop hardness test (HK), Rockwell test (HR) and others.

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a test force of between 1gf and 100kgf. The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. The Vickers method is capable of testing the softest and hardest of materials, under varying loads.

Figure. 3.10. Micro- hardness measurement under Vickers Hardness Tester (HVS-50)

3.7.5. Optical microscope (OM)

Optical microscope is the type of instrument which is mostly used for visualization and characterization of the fiber microstructure and other [55]. Optical inspections were performed using Huviz HR-300 series. The Huvitz HR-300 series used for this project has Magnification :X50, X100, X200, X500, X1000, with Scanning Area: 104 x 102 mm. Illumination System is 12v, 100w Halogen Lamp and has CCD Sensor: Progressive Scan Digital Camera.

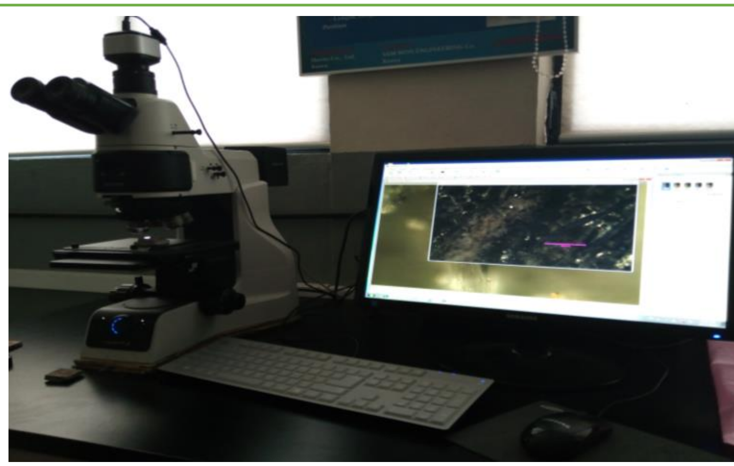


Figure. 3.11. Optical microscope (OM)

3.8. Composite characterization

In order to estimate strength and stiffness, materials are subjected to physical and mechanical testing such as density and void fraction, water absorption, tensile and flexural tests. Evaluating the characteristics of polymeric composites are base for technical specification of materials for design purposes, to develop numerical and experimental models. In this study, fabrication and mechanical property characterization of the Al_2O_3/SiC filled jute fiber reinforced polyester risen composite is the key issue to have the alternative materials for automotive and other industry.

3.8.1. Physical Characterization

3.8.1.1. Density and void fraction

The densities of composite materials are measured using one of three methods: The Archimedes method, the sink-float method, or the density gradient method. For this work, the actual density (ρa) of composite is determined by the Archimedes principle using rain water as the medium. This method is covered in ASTM standard D 570. Archimedes principle states that an object fully or partially immersed in a fluid is buoyed up by a force equal to the weight of that the object displaces [56]. This is demonstrated by simple experiments using graduated beakers.

(a) weight of the sample in air (b) weight of the sample in water

Figure. 3.12. Measuring the actual density of an object

The density of the composite is obtained by using equation Equation 3.7.

$$\mathcal{P}_a = \frac{\mathcal{P}w\, Wa}{Wa - Ww} \quad \text{………………….. Equation 3.7.}$$

Where, ρa and ρw is the actual/measured density of composite and density of water

Wa is weight of the sample in air and

Ww is weight of the sample in water.

The theoretical density of composite materials (ρ_t) in terms of weight fraction can easily be obtained as per the following equation given by Agarwal and Broutman [57].

$$\mathcal{P}_t = \frac{1}{Wf/_{\mathcal{P}f} + Wm/_{\mathcal{P}m} + W\mathcal{P}/_{\mathcal{P}Al2O3} + W\mathcal{P}/_{\mathcal{P}Sic}} \text{ .... Equation 3.8.}$$

$$W_f = \left(\frac{\frac{\mathcal{P}f}{\mathcal{P}c}}{\frac{\mathcal{P}f}{\mathcal{P}c} * vf + vc}\right) * v_f = \frac{mf}{mc} \text{ .... Equation 3.9.}$$

Where, W and ρ represent the weight fraction and density respectively. The suffix p, f and m stand for the particulate filler, fiber and matrix material respectively.

The presence of voids will add to the total volume, but not the weight of the composite. Vv is the void content which is then expressed as:

$$Vv = \frac{\mathcal{P}t - \mathcal{P}a}{\mathcal{P}t} \text{ .... Equation 3.10.}$$

3.8.1.2. Water absorption

Water absorption test is needed to know how much water the specimen can absorb from the surroundings. The water absorption tests of Al_2O_3/SiC/jute fiber reinforced polyester composite were done as per ASTM 570 by immersion in rain water at room temperature. The specimens were dried and measured the weight before immersed in water tank. The composite are submerged in water tank and by 24h interval composites are measured by used analytical precision balance.

Figure. 3.13. Al_2O_3/SiC filled JFRPC sample in the rain water for one day.

The formula used to calculate the water absorption percentage was as follow:

$$W\ \% = \frac{W2 - W1}{W1} * 100\% \text{ .... Equation 3.11.}$$

Where, W % is percentage of water absorption

W1 is initial weight of sample before immersed

W2 is final weight of sample after immersed

Weight balance having accuracy 0.01 g is used to measuring the weight of the sample.

3.8.2. Mechanical characterization

3.8.2.1. Tensile Properties of composite

Tensile testing is one of fundamental tests to know maximum tensile stress that can be developed in the material. The specimens prepared for conduct a tensile test is ASTM D-3039 standards for size and features. During the test the specimens were placed in the grips of UTM and axial load is applied through both the ends of the specimen. Data is collected at pre-determined points or increments during the test. Data include the applied load and change in gage length. The load is generally read from the machine panel in kilograms. For each sample, 3 specimens were tested in each machine. Typical points of interest when testing a material include: ultimate tensile strength (UTS) or peak stress, load-elongation curve, breaking load, % strain at peak stress. The ultimate tensile strength (UTS) is the maximum stress a material can withstand before fracture.

UTS = $\frac{ultimate\ force}{original\ cross\text{-}sectional\ area} = \frac{F}{A}$ …………………….. Equation 3.12.

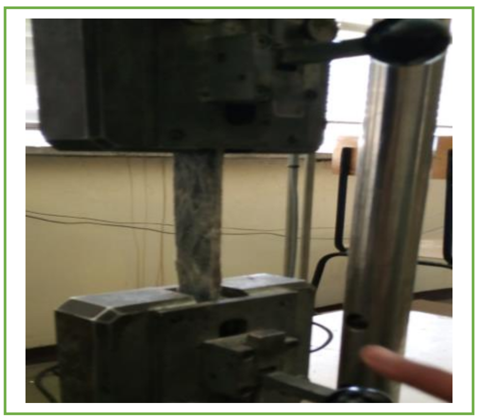


Figure. 3.14. Typical tensile specimen under tensile test.

3.8.2.2. Flexural Strength Test

Flexural strength is defined as a materials ability to resist deformation under load. In flexure, the specimen is typically loaded flat on two solid support rods. A third rod is used for loading. This three-point loading setup helps to act the force from the center loading point to two support rods. The flexural Strength of composites was performed according to ASTM-D790 standard and flexure strength and inter-laminar shear strength calculated based on these data. Flexural strength and inter-laminar shear strength (ILSS) were calculated using equation (3.13)and (3.14) respectively.

Flexural Strength = $\frac{3PL}{2bh2}$ MPa ………………….. Equation 3.13.

ILSS is the parameter which characteristic the jute fiber reinforce polyester composite structure.

ILSS = $\frac{3P}{4bt}$ MPa ………………….. Equation 3.14.

Where P is the maximum load applied on test specimen on test specimen (N), L, the support span (mm), b the width of specimen tested (mm), it the thickness of specimen tested (mm).

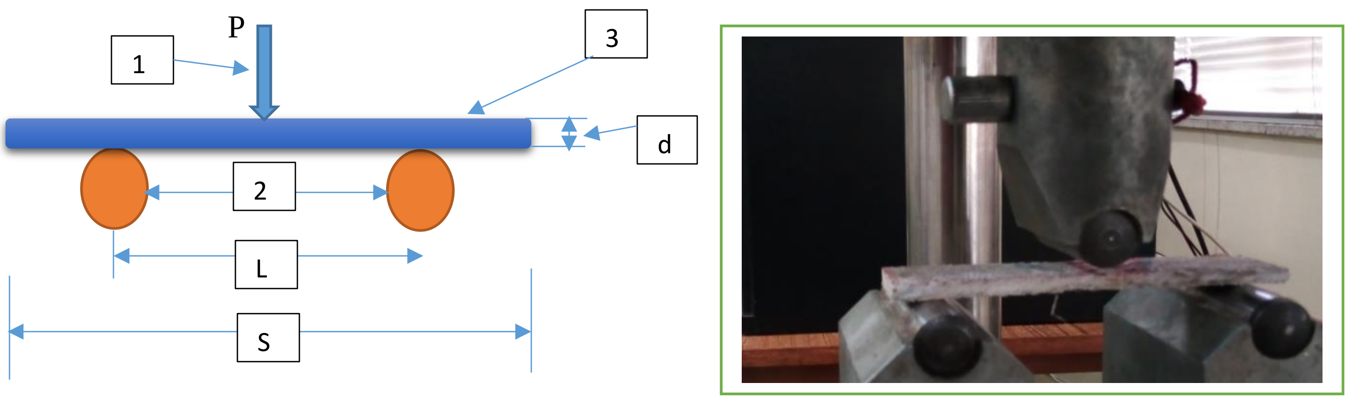


Figure. 3.15. Three-point bending 1- load probe, 2- support, 3- specimen, d- depth of specimen, L- support distance (span) and S- overall length of specimen

3.8.2.3. Vickers hardness test

Hardness tests involve measuring the amount of force required to implant a specified indentation in the surface of a specimen. The Vickers hardness test uses square-based pyramid diamond indenter with an angle of 136^0 between the opposite faces at the vertex, which is pressed into the surface of the test piece using a prescribed force, F.

HV = $\frac{\text{Constant x Test Force}}{Surface\ Area\ of\ Indentation^2}$……………………… Equation 3.15

$$HV = \frac{0.102 * 2F\,(\frac{\sin 360}{2})}{d^2}$$

Where:- HV - Vickers hardness value

F - Load in kgf

d^2 - Arithmetic mean of the two diagonals ($\frac{d1+d2}{2}$), d1and d2 in mm

Equation 13 above was taken from manual of HVS-50 machine of Adama Science and Technology University. The HVS-50 machine used this project has measuring rage 5-2900 HV, Test Force: 9.807,49.03, 196.1, 294.2, 294.2, 490.3 N, maximum height of test piece 180mm, depth of throat, 125mm, magnifications of the measuring system: 125X,250X and minimum scale value of the optical micrometer 0.5µm. load used during hardness test was 10Kg.f on three trial per each sample. The micro – hardness testing machine is shown by Fig. 3.18.

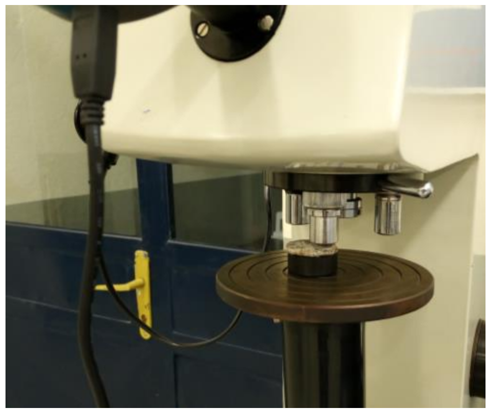


Figure. 3.16: Micro- hardness measurement under Vickers Hardness Tester (HVS-50)

CHAPTER FOUR

4. EXPERIMENTAL RESULTS

4.1. Density and void fraction

Density is a material property which is prime importance in several weight sensitive applications. For their low density in many such applications polymer composites are found to replace materials and conventional metals. Density of a composite depends on the relative proportion of reinforcing and matrix materials and this is one of the most important factors determining the properties of the composites. It is to be noted that the values of theoretical density are not equal to the experimental density of the prepared composites. This difference in the composites is the measure of voids or pores present in it. Higher void contents usually mean lower fatigue resistance, greater susceptibility to water penetration and weathering. The knowledge of void content is desirable for estimation of the quality of the composites. However, presence of void is unavoidable in composite making particularly through hand-lay-up route. The actual density, theoretical density and void of the composite is obtained by using equation 5, equation 6, and equation 8 respectively.

Table. 4.1. Initial weight of sample for rain water

Sample	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
weight of the sample in air (g)	7.56	4.37	6.70	9.31	8.08	8.07	8.56	8.93	5.84	10.42
Weight of the sample in water(g)	1.087	0.761	1.522	2.607	0.910	1.871	1.908	2.097	1.160	2.215

Table. 4.2. Measured and theoretical densities along with the void fractions of the jute - polyester composite with Al_2O_3/SiC fillers.

Composite sample	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
Measured density (gm/cc)	1.168	1.211	1.294	1.389	1.127	1.302	1.287	1.307	1.248	1.270
Theoretical density (gm/cc)	1.211	1.238	1.321	1.417	1.141	1.322	1.318	1.339	1.287	1.321
Volume fraction of voids (%)	3.523	2.135	2.041	1.961	1.238	1.462	2.317	2.343	3.011	3.795

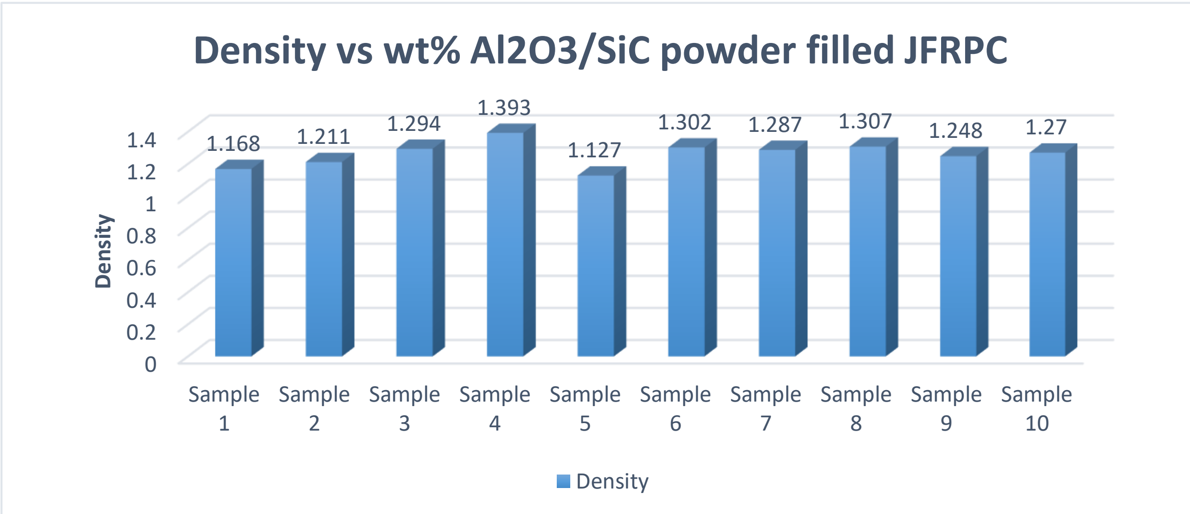


Figure. 4.1. Density vs wt% Al_2O_3/SiC filler and jute fiber reinforced polyester resin composite

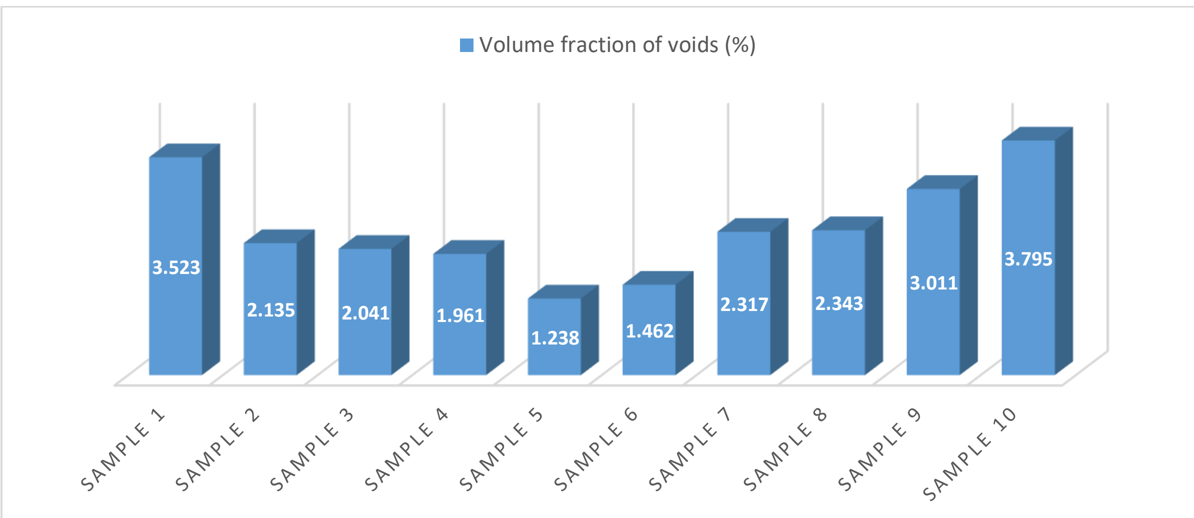


Figure. 4.2. Void vs wt% Al_2O_3/SiC filler and jute fiber reinforced polyester resin composite

4.1.1. Observation

1. It is observed from the figure that the density of composites increase with increasing fiber content and the density of copped fiber reinforced composite increase as compared to uni and bidirectional composites, due to the copped fiber may not be long to cause fiber entanglement which leads to the formation of voids.
2. As shown in the figure, due to presence of large amounts of the hydroxyl group in jute fibers makes them hydrophilic in nature, this hydrophilic nature of jute fiber based polyester

composites results high moisture absorption that leading to increase fiber swelling, density and voids in the fiber-matrix interface.

3. The results showed that the density and void content of composites increases with increase in fiber content as in case of composites without filler. The reason might be the filler reduces the void content of the composites. This is because the Al_2O_3/SiC filler fills the gap between matrix and fiber, due to the dense structure, reduces the chance of air entrapment which reduces the presence of pores and voids.

4.2. Water absorption test

In order to promote the wider use of particles and natural fibers reinforced composites in high-performance applications, it is essential to consider the effect of moisture absorption and water uptake on their physical and mechanical properties and also it is important to composites to define their potential for outdoor working. The water absorption can may results reduction of the mechanical properties and dimensional stability of composites due to water absorption can lead to swelling of the fiber, micro cracks and forming voids at the fiber-matrix interface region. Water absorption test is done to determine the percentage of water absorbed under specified conditions.

The size of the specimen for water absorption was obtained in accordance with ASTM D570 standard. Specimen were immersed in rain water (pH = 7) water at room temperature, and test was conducted different time frames. After specific time intervals specimens were removed from the container, their surface moisture was removed. The content of water absorption by the specimen was measured using a precise digital balance machine. The rain water absorption was carried out for 24, 48, 72, 96, 120 and 144 hours. The formula used to calculate the water absorption percentage as given bellow.

$$W\% = \frac{W2-W1}{W1} * 100\%$$

The test was carried out by measuring the initial weight of the sample using precise weight balancer having accuracy of measuring weight 0.001g.

Table. 4.3. Initial weight of sample for rain water

Sample	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Initial weight (g)	8.20	5.12	6.52	9.61	8.01	8.00	9.64	9.62	6.65	11.18

Weight measurement for each 24hrs difference and water absorption percentage was briefly indicated in the Table 4.4 and Figure 4.3. Water absorption percentage analyzed for each days and averagely for 144hours.

Table. 4.4. Samples results of water absorption percentage in rain water condition (PH = 7)

Sample	Immersion result of water absorption in (%)						Average water absorption result
	24 hrs	48 hrs	72 hrs	96 hrs	120 hrs	144 hrs	
S1	3.38%	4.19%	4.47%	4.49%	4.53%	4.53%	4.265%
S2	2.15%	2.53%	2.74%	3.01%	3.34%	3.41%	2.863%
S3	1.23%	2.61%	2.84%	3.53%	3.57%	3.63%	2.901%
S4	1.46%	1.78%	2.72%	3.47%	3.47%	3.53%	2.153%
S5	1.57%	1.82%	2.01%	2.14%	2.43%	3.29%	2.210%
S6	3.31%	3.67%	3.81%	4.12%	4.49%	5.03%	4.071%
S7	4.24%	4.47%	5.51%	5.74%	6.01%	6.18%	5.358%
S8	2.70%	3.95%	4.13%	4.54%	5.26%	5.32%	4.316%
S9	4.12%	4.43%	4.98%	5.54%	5.81%	6.08%	5.163%
S10	5.23%	5.74%	6.23%	6.41%	6.68%	7.06%	6.225%

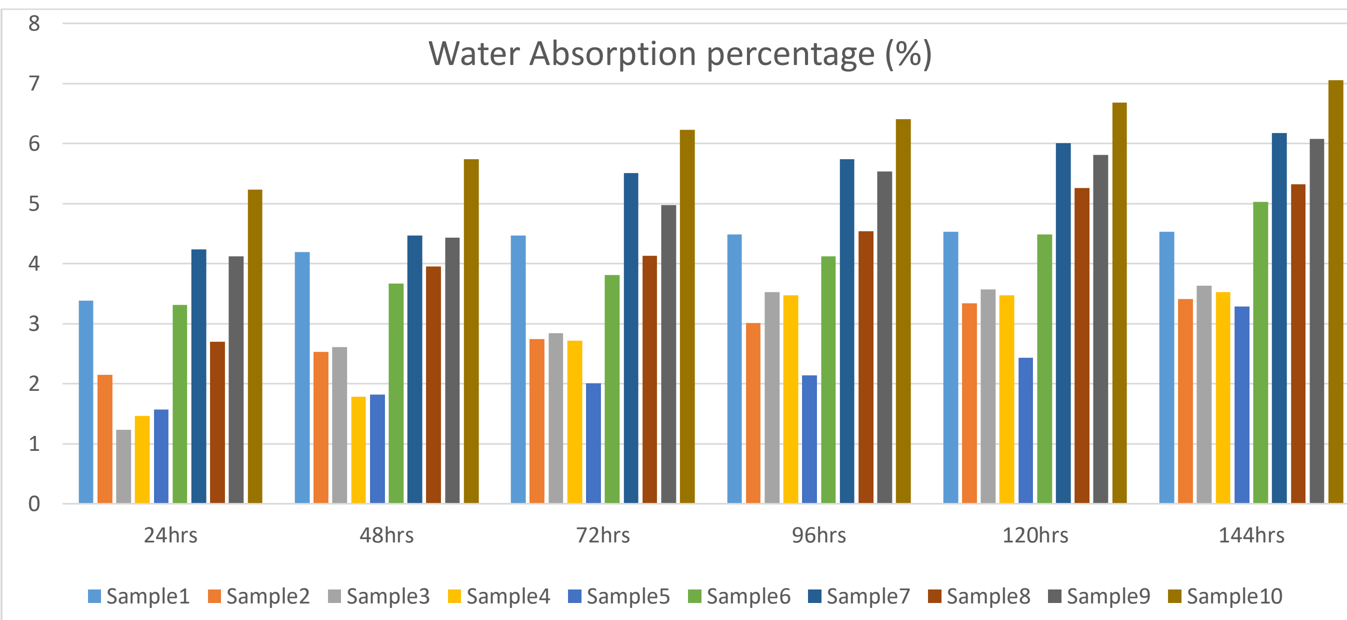


Fig 4.3.Water absorption percentage vs duration for 6 days

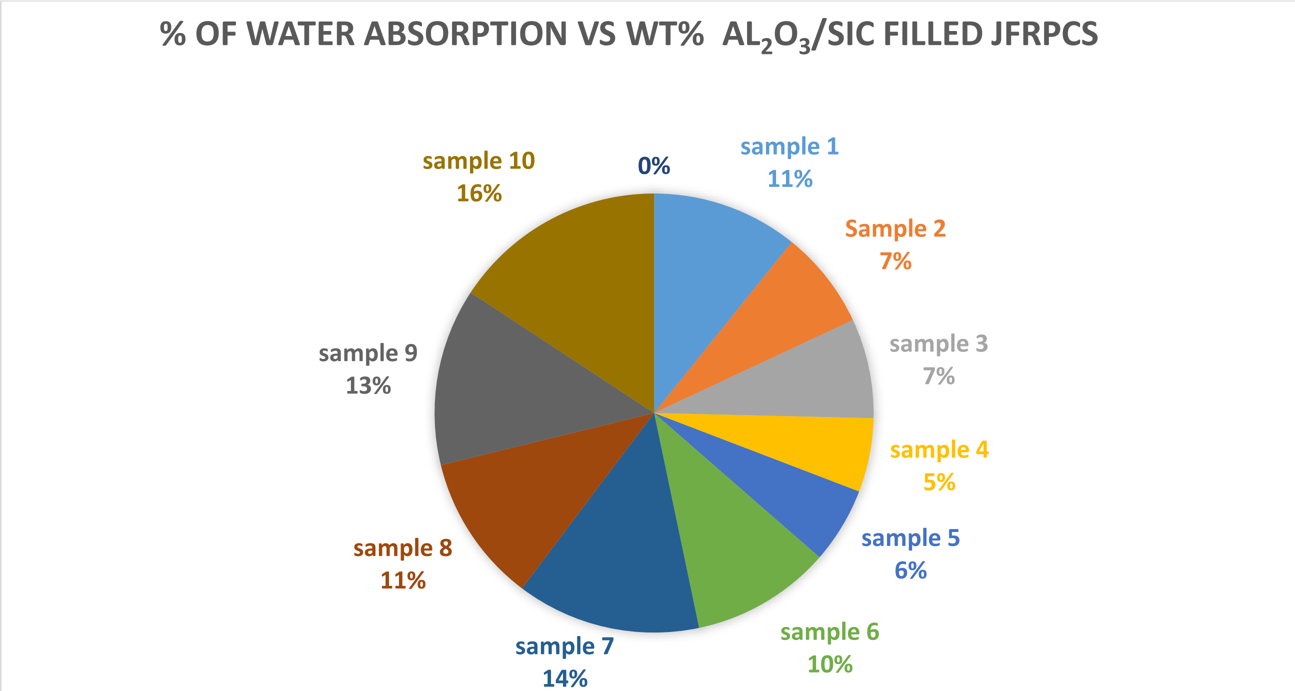


Fig. 4.4. WA% vs wt% Al_2O_3/SiC filled JFRPCS

4.2.1. Observation

1. The result presented in figure 4.3. shows that the water absorption of the specimens almost increase with the immersion time at the starting stage and later keeps less water absorption after that water absorption does not change significantly.
2. It is observed from the figure that the rate of water absorption increases with increase in fiber content. Composites with 35 wt% jute fiber content shows more water absorption rate as compared to 15 wt% fiber content. This increased water absorption percentage may be due to higher hydrophilic nature of cellulosic fibers, presence of voids and micro cracks present inside the composite and also decrease in water absorption percentage with increasing weight fraction of Al_2O_3/SiC filler particles may be due to the filler particles which have a lower water absorption percentage than the jute fiber and polyester resin. Density and void content of composites are greatly affect the rate of water absorption.
3. When compared the uni directional fiber, bi directional fiber and copped fiber, the uni directional jute fiber shows minimum water absorption of 2.153% and copped jute fiber show maximum water absorption of 6.225%.
4. The figure 4.4 showed that the rate of water absorption increase with the increase jute fiber content and decrease with increase Al_2O_3/SiC content in composites. It is also evident from

the figures that the rate of water absorption is less in case of Al_2O_3 filled composites as compared to Sic. 9 wt% of Al_2O_3/SiC filled composites with 15 wt% of fiber content and unidirectional jute fiber shows minimum water absorption rate as compared to all other types of composites under the present study. Lower water absorption are more recommended for automotive body.

4.3. Tensile test

The goal of tensile test was to evaluate the in-plane tensile properties of Al_2O_3/SiC filled jute fiber reinforced polyester composite material. The tensile strength is calculated from the load in Newton (N) required to break the test hour divided by it's the most extreme load a part can withstand before breaking. For tensile strength evaluation, there were 30 specimens under tensile loading for different weight fraction of Al_2O_3/SiC/jute fiber/polyester resin composite specimen. The test results of tensile strength are showed in Table 4.5.

Table. 4.5. Tensile strength and elongation results taken from universal tensile test machine

S. No	Max force (KN)				Tensile strength (MPa)				Elongation (mm)			
					Sample				Sample			
	Tria.1	Tria.2	Tria.3	Aver.	Tria.1	Tria.2	Tria.3	Average	Tria.1	Tria.2	Tria.3	Average
1	5.08	5.10	5.81	5.33	40.64	40.8	46.96	42.8	13.40	10.44	11.93	11.92
2	2.70	3.36	3.06	3.04	21.64	26.88	24.48	24.33	5.41	5.65	5.74	5.6
3	5.81	3.89	5.49	5.06	46.48	31.12	43.96	40.52	12.02	8.45	11.47	10.77
4	4.94	5.86	4.64	5.14	39.52	46.88	37.12	41.14	17.28	23.36	15.85	18.83
5	2.42	3.01	2.49	2.64	19.43	24.1	19.92	21.15	12.14	13.75	12.77	12.88
6	3.38	3.50	2.81	3.23	27.1	28.03	22.48	25.87	15.35	16.25	13.60	15.06
7	2.31	2.40	2.87	2.52	18.48	19.22	22.96	20.22	11.81	14.25	15.91	13.99
8	1.48	1.49	1.13	1.36	11.84	11.92	9.04	10.60	9.09	5.51	4.93	6.51
9	1.01	1.40	1.09	1.16	8.08	11.21	8.76	9.35	5.31	7.77	5.16	6.06
10	1.65	1.32	1.17	1.38	13.20	10.6	9.43	11.07	7.74	6.64	6.39	6.92

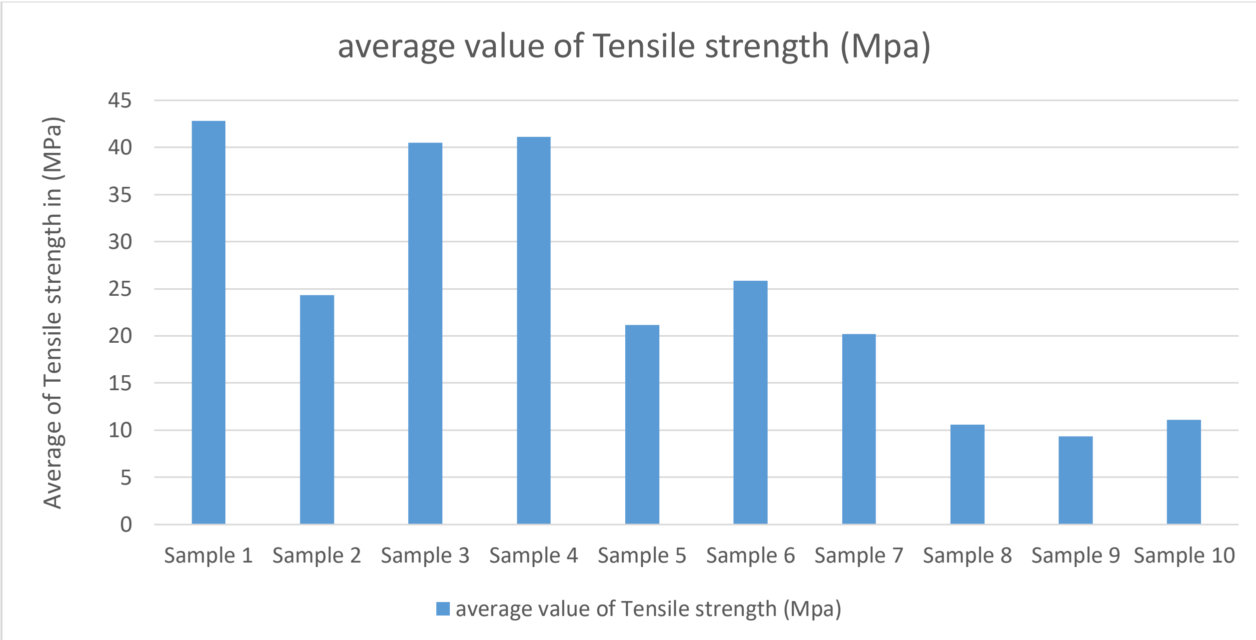


Fig. 4.5. Comparrison of tensile strength between samples

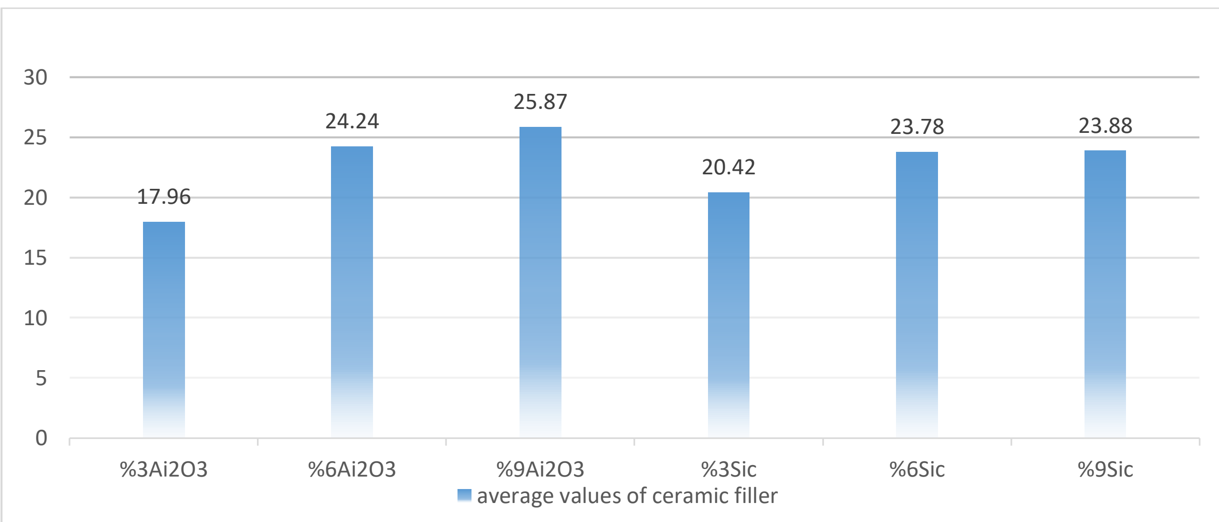


Fig.4.6. Tensile properties vs wt% Al_2O_3/SiC powder filled JFRPCS

4.3.1. Observation

1. It is clearly observed from the Figure 4.5 that as the fiber content increases, the tensile strength in the composite between 15% to 35wt% fiber content is increase. This mean adding of more than 35% of fiber may decrease of tensile strength. This decrease may be due to as the fiber content increases the resin cannot wet the fibers due to non-entrance of resin inbetween the

two adjacent fibers and not be sufficient enough for proper distribution of load. The chances of failure increase with the increase in fiber to fiber interaction.

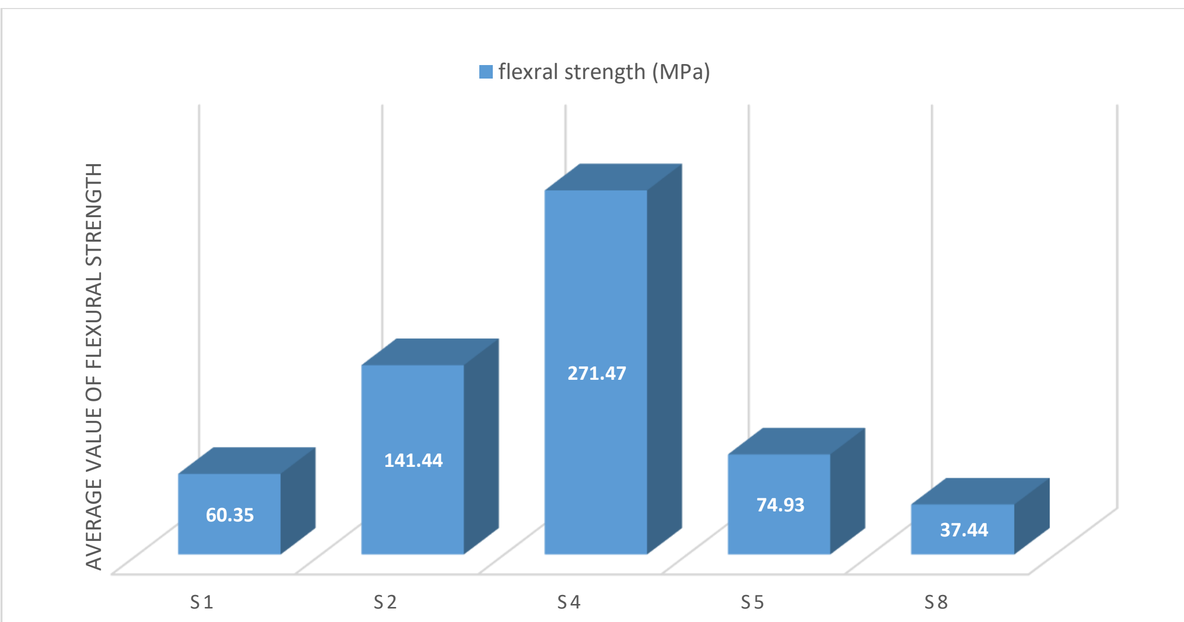
2. The jute fiber orientation affects the tensile strength of the jute fiber reinforced polyester resin composite. Therefore the composite with unidirectional fiber orientation has demonstrated a factor of improvement in tensile strength when compared with the bidirectional and copped fiber orientation.
3. The results showed that incorporation of ceramic fillers lower the tensile strengths of the composites than unfilled one, due to the presence of pores at the interface between the filler particles and the matrix, the interfacial adhesion may be too weak to transfer the tensile stress. From Al_2O_3/SiC filled composite the maximum average value of tensile strength is 41.14 MPa that observed form sample 4 composites with fiber loading of 35 wt% and uni directional fiber. This may be due to good particle dispersion and strong polymer/jute fiber /filler interface adhesion for effective stress transfer.
4. It is observed from figure 4.6 that, the Sic ceramic powder specimen's exhibits lower tensile as the filler content increases in the unsaturated resin. This may be due to the rigidity of the composite increased with increase in content of SiC ceramic powder in the composite.
5. The table 4.5 shows the elongation percentage increase with the increasing weight fraction of jute fiber for all groups of composite materials. This due to elongation percentage at break increase with increasing jute fiber content.

4.4. Flexural test (Three point bending test)

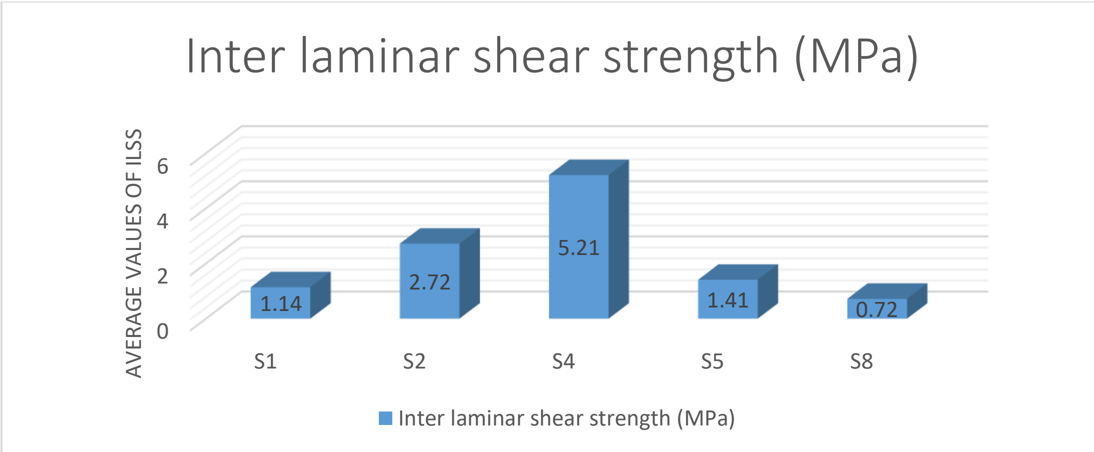
Flexural strength is the ability of the material to withstand the bending forces applied perpendicular to its longitudinal axis. To measure the flexural strength of the composites three point bend test was carried out in accordance with ASTM standard in an UTM machine. The data recorded during the tree point bending test also used to describe the inter laminar shear strength (ILSS). The stresses acting on the interface of the two adjacent laminae in a layered composite are called inter-laminar stresses. These stresses cause relative deformations between the consecutive laminae and if these are sufficiently high they may cause failure along the mid-plane between two adjacent laminae. It is therefore of considerable interest to evaluate inter-laminar shear strength through tests in which failure of the laminates of the composite initiates in a shear mode. The results of Flexural strength and ILSS are showed in Table 4.6.

Table. 4.6. Flexural strength and inter laminar shear strength value

	Peak load to (N)			FS (MPa)				ILSS (MPa)			
Type of bamboo sample	t-1	t-2	t-3	t-1	t-2	t-3	Ave.	t-1	t-2	t-3	Ave.
Polyester + bidirectional jute fiber (25 Wt%)	*200*	*200*	170	62.40	62.40	53.04	**60.35**	1.2	1.2	1.02	**1.14**
Polyester + Unidirectional jute fiber (15 Wt%) + Al_2O_3 (3Wt%) + SiC (3Wt%)	360	440	560	112.32	137.32	174.72	**141.44**	2.16	2.64	3.36	**2.72**
Polyester + Unidirectional jute fiber (35Wt%) + Al_2O_3 (9Wt%) + SiC (9 Wt%)	970	859	780	302.64	268.00	243.36	**271.47**	5.82	5.15	4.68	**5.21**
Polyester + bidirectional jute fiber (15 Wt%) + Al_2O_3 (6Wt%) + SiC (9 Wt%)	260	230	217	81.12	71.76	67.70	**74.93**	1.56	1.38	1.30	**1.41**
Polyester + chopped jute fiber (15Wt%) + Al_2O_3 (9Wt%) + SiC (6Wt%)	100	140	120	31.20	43.68	37.44	**37.44**	0.6	0.84	0.72	**0.72**



(a)



(b)

Figure. 4.7. Comparison of flexural and inter laminar shear strength between samples: (a) flexural strength (b) inter laminar shear strength

4.4.1. Observation

1. The maximum flexural strength of jute fiber reinforced composite at 15 wt% of jute fiber (141.44 Mpa), at 25wt% (60.35 Mpa) and at 35wt% (271.47 Mpa) this is due to good interfacial bonding between Al_2O_3/SiC, jute fiber and polyester resin.
2. The figure shows the highest value of flexural strength and ILSS are seen in the case of jute composites laminates with unidirectional fiber orientation. The value of flexural strength decrease from unidirectional fiber orientation to bidirectional and copped fiber orientation. The best orientation of composition in terms of maximum flexural strength and ILSS is unidirectional jute reinforced composite (271.47Mpa).
3. It is observed that, there is improvement of ILSS of jute-polyester resin composites with Al_2O_3/SiC particulate filling. Incorporation of Al_2O_3/SiC particulate is seen to have caused the substantial increase in the inter-laminar shear strength.
4. It is shown from figure that improvement in flexural strength is observed in Al_2O_3/SiC particulate filled jute fiber polyester composites as compared to the unfilled one. The increase in flexural strength may be also due to the high elastic modulus of the filler material compared with that of the matrix material. In case, the flexural strengths improve with 9wt% of filler content due to increase in the wettability with polyester matrix, leading to good interfacial bonding and uniform distribution of the particles. The composite material containing SiC filler particles has shown a greater bending strength than the Al_2O_3 filler particles.

4.5. Micro-hardness

The hardness test was conducted using the standard Vickers hardness tester 10 Kgf. Depending on this force the hardness test was conducted to different weight fraction of Al_2O_3/SiC filled jute fiber reinforced polyester hybrid composite. The results of VH are showed in table 4.7.

Table. 4.7. Vickers hardness test results using 10 Kgf

No.	Sample	Vickers hardness values with 10 Kgf			Average Vickers hardness value
		Tria.1	Tria.2	Tria.3	
1	**Polyester + bidirectional jute fiber (25 Wt%)**	44.1	37.3	48.7	43.36
2	**Polyester + Unidirectional jute fiber (25 Wt%) + Al2O3 (6Wt%) + SicC (6 Wt%)**	88.8	117.9	93.2	99.96
3	**Polyester + Unidirectional jute fiber (35Wt%) + Al_2O_3 (9Wt%) + SiC (9 Wt%)**	122.1	315	116.8	184.53
4	**Polyester + bidirectional jute fiber (15 Wt%) + Al_2O_3 (6Wt%) + SiC (9 Wt%)**	116.5	82.2	99.2	99.3
5	**Polyester + bidirectional jute fiber (25 Wt%) + Al_2O_3 (9Wt%) + SiC (3Wt%)**	75.9	91.5	72.6	80
6	**Polyester** + chopped **jute fiber (25Wt%) + Al_2O_3 (3Wt%) + SiC (9Wt%)**	39.6	57.8	60.6	52.66

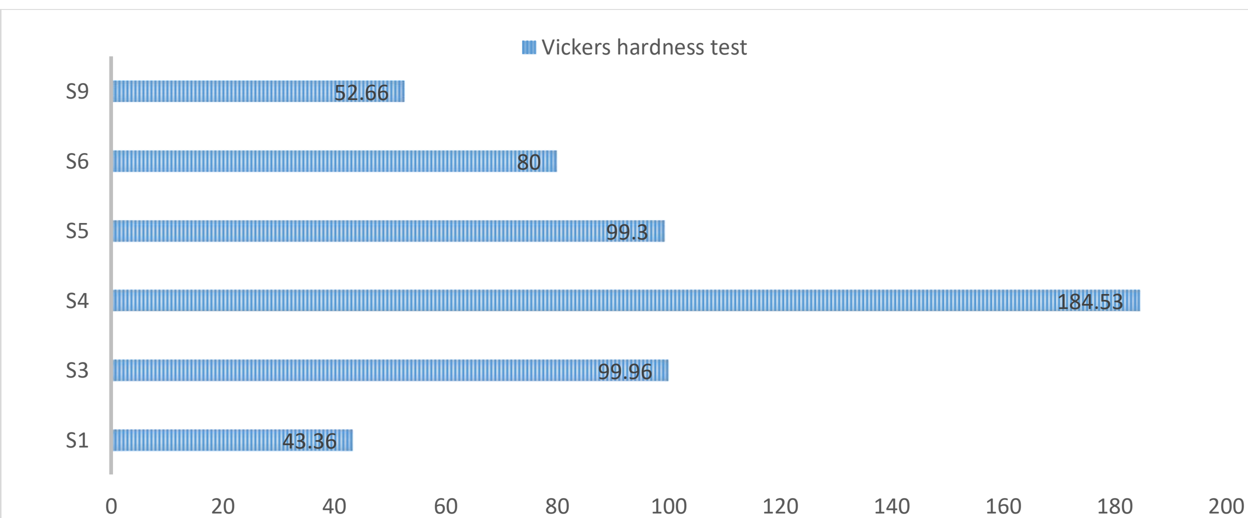


Figure. 4.8. Average Vickers hardness test results using 10Kgf

4.5.1. Observation

1. It is observed from the figure 4.8 that as the weight percentage of fiber content in the composite increases, the hardness of composite also increases.
2. The Vickers hardness test shows that the uni-directional jute fiber reinforced by polyester composite have highest Vickers hardness number average values of 184.53 HV. This is due to polyester resin and fiber has high hardness in the longitudinal direction. From the synthesized composite material the bi directional jute fiber reinforced polyester composite has the less value. This is a rise from the fiber properties has less hardness in the transverse direction.
3. It is also evident from the figure that the improvement in hardness property with the increasing weight fraction of filler particles. The addition of filler content increases the hardness of composite material due to increase in the resistance strength of polymer to plastic deformation, increasing wettability (interaction) between the matrix and the filer particles and solid filler phase would be pressed together and touch each other more tightly. The maximum hardness value of 184.53 HV is observed from composites with 35wt% fiber loading and uni-directional fiber orientation. Here, also the composite material containing SiC filler particles has a higher hardness when compared to the Al_2O_3 filler particles.

4.6. Optical microscope (OM) analysis

The interaction between ceramic filler and matrix determine the properties of composite materials. In order to evaluate this interaction, the microstructure of the composites including the dispersion of the Al_2O_3/SiC particles in the polyester matrix is observed under Optical Microscope. The microstructure results for the samples are described in figure below based on their weight percentage Al_2O_3/SiC and jute fiber.

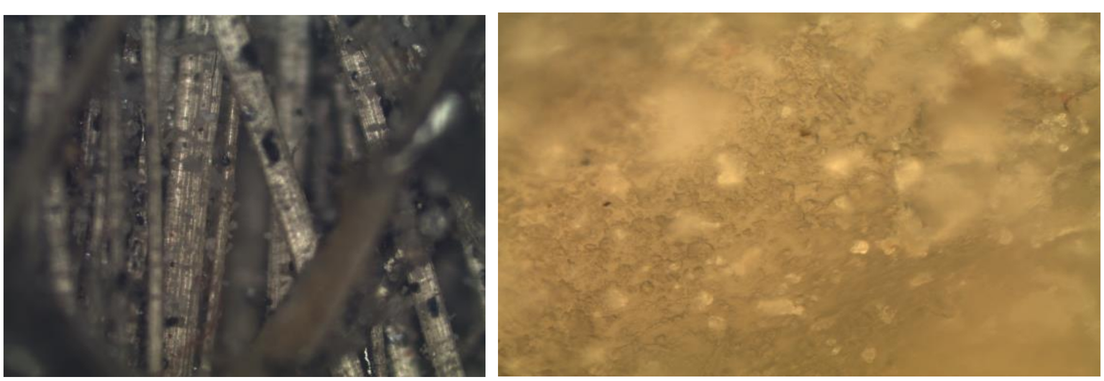


Figure 4.9. Microstructure of Sample 3

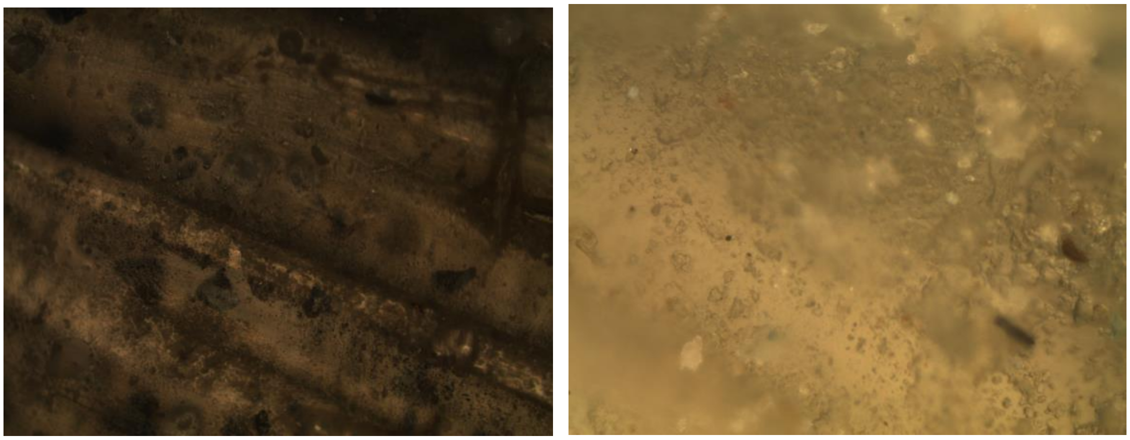


Figure 4.10. Microstructure of Sample 4

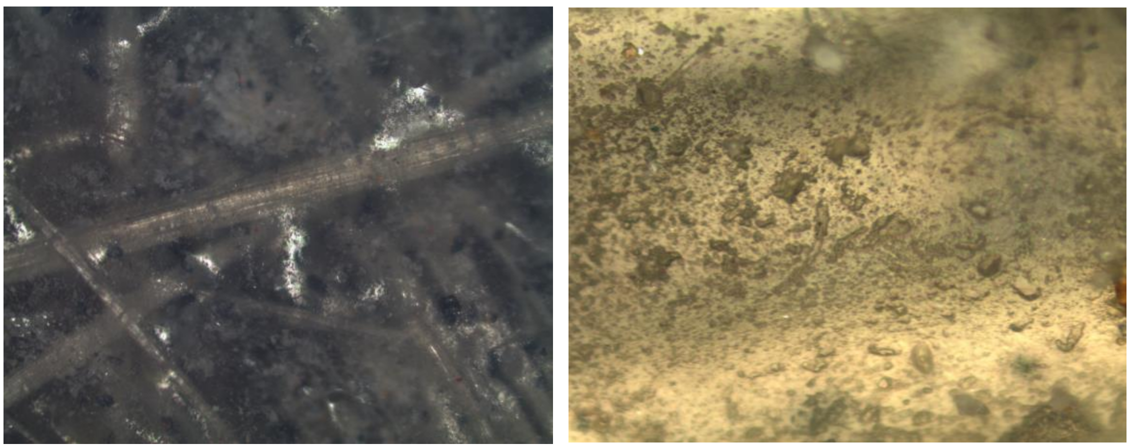


Figure 4.11. Microstructure of Sample 6

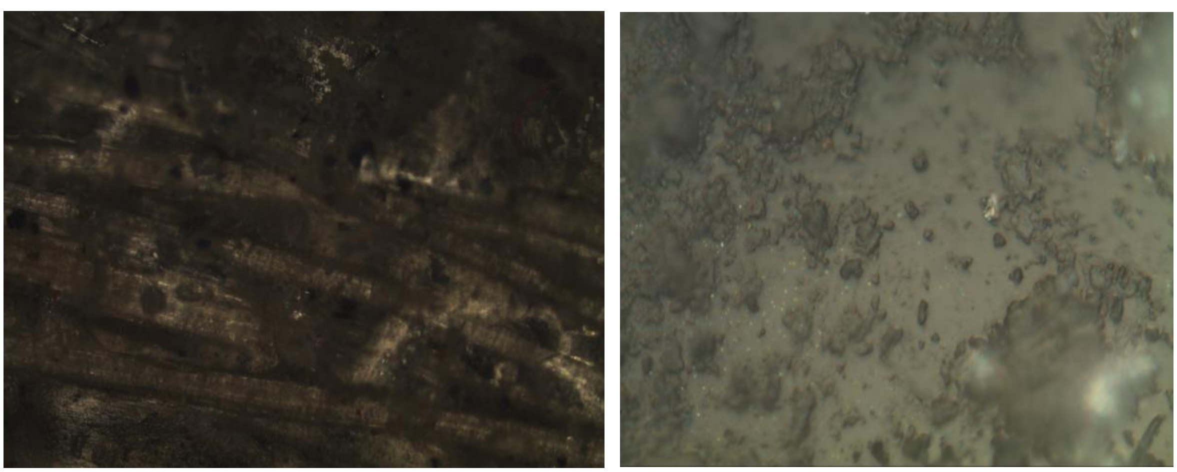


Figure 4.12. Microstructure of Sample 8

4.6.1. Observation

- OM analysis showed that the interfacial bonding adhesion between the fiber and polyester matrix considerably good. Fiber pullout is visible, this is due to wet ability problem and increase of void fraction content which is reduce the strength of the composite.
- The OM image of composite show that the Al_2O_3/SiC powder are uniformly distributed in the composite with low porosity or defect in fabrication of composite that produced good mechanical properties of the composite. From jute fiber reinforced polyester resin composite the microstructure of Al_2O_3/SiC powder filler was seen by white and black point boundary. As Al_2O_3/SiC wt% increases the boundary of mixtures clearly shown. It have better microstructure mixture.
- It is clear from the OM image that the composite is uniform mixing with Al_2O_3/SiC particle reinforced as compared to short and long jute fiber reinforcements.
- Form figure 4.11 the OM image of composite shows that poor Al_2O_3/SiC filler-matrix interface bonding with micro voids which explains the lower mechanical strength and modulus and the figure 4.10 shows the higher strength of composites (sample 4) can be explain by the perfect wettability of the surface in the polyester matrix, compared to the other composites. It has already been established that unstable interfacial adhesion between fiber/filler and matrix often results in fiber pullout, fiber delamination and matrix deboning are being more possible in the case of natural fibers than for their synthetic counterparts [58].

4.7. Comparison with the previous works

Table. 4.8. Comparison with previous works to current work

Composition of materials (%)			Methods of fabrication	Flexural strength (Map)	Tensile strength (MPa)	Hardness test	Reference
Resin/fiber	Ceramic filler	Fiber orientation					
Polyester/jute fiber	Al_2O_3/Sic	Unidirectional	Hand lay up	271.47 MPa	41.14	184.53 HV	Current work
Epoxy/Sisal-GF	-	Unidirectional	Hand lay up	298.75 MPa	24.08 MPa	96.67 HRB	K. Alagarraja et al [14]
Flax/bamboo	-	Unidirectional	Compression molding	89.90 MPa	34.27 MPa	-	Sathish et al [16]
Polyester/jute fiber	-	Bidirectional	Hand lay up	44.71 MPa	12.46 MPa	44 HRm	Ajith et al [33]
Epoxy/Jute fiber	Al_2O_3	Unidirectional	Hand lay up	69.56 MPa	48.25 MPa	53.24 HV	Priyadarshi Tapas et al [35]
Epoxy/Sisal/Glass fiber	Sic	-	Hand lay up	467.75 MPa	91.331	-	Arpitha et al [39]

The table 4.8 is indicates the detail of tensile, bending, Vickers hardness test and proportions of the materials to produce composite materials by previous researchers.

4.8. Effect of process parameters on Al_2O_3/SiC filled jute fiber reinforced composite

Volume fraction of the fibers, fiber length, fiber aspect ratio, fiber-matrix adhesion, concentration distribution and orientation of the reinforcement, stress transfer at the interface, shape, particle size and filler content are the parameters that influence the physical and mechanical properties of composite material. In the present study, Al_2O_3/SiC filled jute fiber reinforced polyester resin hybrid composite were fabricated with different fiber direction, jute fiber content, content of ceramic powder to understand this effect of process parameters on the composite. The fiber direction, jute fiber content, content of ceramic powder plays a vital role in determining the physical and mechanical properties of the composites.

4.8.1. Taguchi Design of Experiments

Taguchi's orthogonal arrays are highly fractional orthogonal designs. Orthogonal array designs focus primarily on main effects. These designs can be used to estimate main effects using only a few experimental runs. Taguchi signal – to- Noise rations (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimization results. Table 4.9 presents the process parameters selected for optimization and their levels.

Table. 4.9. The experimental results and operating conditions for each parameter and level

Exp .No	Casting parameters				Tensile strength in (MPa)	Volume fraction of voids (%)
	Fiber direction	Jute Content	Al_2O_3	SiC		
	A	B	C	D		
1	Unidirectional	15	3	3	24.33	2.135
2	Unidirectional	25	6	6	40.52	2.041
3	Unidirectional	35	9	9	41.14	1.961
4	Bidirectional	15	6	9	21.15	1.238
5	Bidirectional	25	9	3	25.87	1.462
6	Bidirectional	35	3	6	20.22	2.317
7	chopped	15	9	9	10.60	2.343
8	chopped	25	3	6	9.35	3.011
9	chopped	35	6	3	11.07	3.795

S/N Ratios

In Taguchi method, response variation is studied with the help of signal- to noise (S/N) ratio. The uncontrollable parameters are affected quality of the characteristics. The undesirable parameter values are expressed as "noise" (standard deviation) and desirable parameters values are termed as "signal" (mean). Specimens are prepared based on L9 orthogonal array and the S/N ratio are calculated using MINITAB 17 software. From the S/N ratio for "larger is better" is used to identify the optimum parameter for tensile strength of composite and for "smaller is better" is used to identify the optimum parameter for void content of composite. Compared the S/N ratio for each experiment to maximize the response values, create response table, and determine the parameters that have the highest and lowest effect on the tensile strength and Void content.

4.8.1.1. Presents the S/N ratio response values for tensile strength

Table. 4.10. Tensile strength signal to noise ratios (larger is better)

Experiment number	Fiber direction(A)	Jute fiber content(B)	Al_2O_3 (C)	SiC (D)	S/N.ratio
1	1	1	1	1	27.72
2	1	2	2	2	32.15
3	1	3	3	3	32.28
4	2	1	2	3	26.50
5	2	2	3	1	28.25
6	2	3	1	2	26.11
7	3	1	3	2	20.50
8	3	2	1	3	19.41
9	3	3	2	1	20.88

Example calculation is shown for factor B (Jute fiber content).

$S/N_{B1} = \frac{27.72 + 26.50 + 20.50}{3} = \mathbf{24.90}$ $S/N_{B2} = \frac{32.15 + 28.25 + 19.41}{3} = \mathbf{26.60}$

$S/N_{B3} = \frac{32.28 + 26.11 + 20.88}{3} = \mathbf{26.44}$

Table. 4.11. Tensile strength response table (Larger is better)

Level	Fiber direction(A)	Jute fiber content(B)	Al_2O_3 (C)	SiC (D)
1	30.72	24.91	24.42	25.62
2	26.96	26.61	26.51	26.26
3	20.27	26.43	27.02	26.07
Δ	10.45	1.70	2.60	0.64
Rank	1	3	2	4

The effect of this factor is calculated by determining the range:

$\Delta = \text{Max} - \text{Min} = 30.72 - 20.27 = 10.45$

Jute fiber direction has the largest effect on the tensile strength and SiC ceramic particular has the smallest effect on the tensile strength.

4.8.1.2. Presents the S/N ratio response values for Volume fraction of voids (%)

Table. 4.12. Volume fraction of voids (%) of signal to noise ratios (Smaller is better)

Experiment number	Fiber direction(A)	Jute fiber content(B)	Al_2O_3 (C)	SiC (D)	S/N.ratio
1	1	1	1	1	-6.58
2	1	2	2	2	-6.19
3	1	3	3	3	-5.84
4	2	1	2	3	-1.85
5	2	2	3	1	-3.29
6	2	3	1	2	-7.29
7	3	1	3	2	-7.39
8	3	2	1	3	-9.57
9	3	3	2	1	-11.58

Example calculation is shown for factor C (Al_2O_3 content).

$S/N_{C1} = \frac{-6.58 - 1.85 - 7.39}{3}$ = **-5.27** $S/N_{C2} = \frac{-6.19 - 3.29 + -9.57}{3}$ = **-8.23**

$S/N_{C3} = \frac{-5.84 - 7.29 - 11.58}{3}$ = **-4.35**

Table. 4.13. Volume fraction of voids (%) response table (Smaller is better)

Level	Fiber direction(A)	Jute fiber content(B)	Al_2O_3 (C)	Sic (D)
1	-6.21	-5.27	-7.82	-7.15
2	-4.15	-6.35	-6.54	-6.96
3	-9.51	-8.24	-5.51	-5.75
Δ	5.36	2.96	2.30	1.39
Rank	1	2	3	4

The effect of this factor is calculated by determining the range:

Δ = Max – Min = -2.96 + 8.24 = 2.96

Sic ceramic powder has the largest effect on the Volume fraction of voids (%) and the fiber direction has the smallest effect on the Volume fraction of voids (%).

Tensile strength S/N ratio values using MINI TAB 17 software

The S/N ratio values at different levels for the responses of tensile strength and Volume fraction of voids (%) are analyzed using MINITAB 17 software.

Table. 4.14. Optimal parameter values

S. No	Fiber direction n(A)	Jute fiber content(B)	Al_2O_3 (C)	SiC (D)
Tensile strength	Unidirectional jute fiber	25 wt %	9 wt%	6 wt%
Volume fraction of voids (%)	Bidirectional jute fiber	15 wt%	9 wt%	9 wt%

Fiber direction, fiber content and Al_2O_3/SiC content plays a vital role in determine the physical and mechanical properties this composite. In both tables (4.11) and (4.13), it was found that the jute fiber orientation contributes a larger impact on tensile strength and SiC ceramic powder is the optimum parameter that affect the Volume fraction of voids (%) of the composites.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In this research work, fiber reinforced polymer matrix composites were developed from Al_2O_3/SiC ceramic powder, jute fiber and unsaturated polyester resin using hand lay-up techniques. Also starting from fabrication of composite sample, physical and mechanical characterization process was briefly presented and discussed. The physical and mechanical properties of composites (water absorption, void content, tensile, hardness and flexural properties) were determined using laboratory experiment. Based on experiment data studies in this work, it can be concluded as follows:

- NaOH alkali treatment is an effective chemical treatment in improving interfacial adhesion between jute fibers and polyester resin. Wax, oil and impurities were removed from the surfaces of the fibers by the chemicals treatment.
- Fabrication of composites has been done successfully using Hand Lay-up technique and mechanical property characterization was done using universal testing machine. From the results, it observed that 9% of Al_2O_3/SiC filled with 15% of jute fiber reinforced polyester composite material has a good mechanical property (Average tensile strength value is 41.14 MPa ,Average flexural strength value is 271.47 MPa, and Average Vickers hardness value is 184.53) basically in the unidirectional jute fiber. However, it has moderate mechanical properties in the bi-directional and copped jute fibers reinforced polyester resin.
- The presence of Al_2O_3/SiC fillers in these composites improves their density, tensile, flexural, ILSS, hardness strengths and this improvement depends on the weight content of the filler and fiber content.
- The void content of this composites increases with the increase in fiber content and void fraction decreases with increase of filler loading (AL_2O_3 /SiC). This is because the filler fills the gap between the fiber and the matrix, due to the dense structure, the chances of entrapment of air reduces. However, presence of void is unavoidable in composite making particularly through hand-lay-up techniques.
- The water absorption behavior of composites significantly influenced by the fiber parameters, filler and immersion time. The rate of water absorption is less in case of Al_2O_3/SiC filled

composites as compared to unfilled one. 9 wt% Al_2O_3/SiC filled composites with 15 wt% jute fiber content and unidirectional fiber showed minimum water absorption rate as compared to all other types of composites.

- The addition of filler content increases the hardness of composite material due to the polymeric matrix phase and the solid filler phase would be pressed together and touch each other more tightly. From the hardness experimental test results it is found that composites with filler content 18 wt% shows better hardness value as compared to other filler content. Better hardness value is obtained in unidirectional fiber orientation.
- The tensile strength of composites increases with increase in the fiber content and due to the improper adhesion delays it is decreases with further increase in the fiber content. Tensile strengths of the composites decrease with incorporation of particulate fillers due to the presence of pores at the interface between the filler particles and the matrix and the interfacial adhesion may be too weak to transfer the tensile stress. The maximum tensile strength (42.8 MPa) is obtained in unidirectional jute fiber and minimum tensile strength (9.35 MPa) is obtained in chopped jute fiber.
- It is seen that in case of Al_2O_3/SiC filled jute reinforced polymer composites there is improvement of flexural strength and ILSS with increasing filler and fiber content but further increase the strengths are to be decreasing. The maximum bending strength and ILSS was observed for composites with unidirectional fiber orientation.
- OM analysis indicated that there was good adhesion between fibers and the matrix, and Al_2O_3/SiC powder was distributed uniformly throughout laminated composite that produced good mechanical properties of composite.
- Characteristics of the composites using Taguchi methodology have been analyzed. Significant control factors affecting the void content and tensile strength have been identified through successful implementation of this technique. Bidirectional jute Fiber and SiC ceramic powder are found to be significant for maximizing tensile and void content of composites properties respectively.

5.2. Recommendation for potential application

The Al_2O_3/Sic filled jute fiber reinforced polyester composites fabricated and experimented upon in this investigation are found to have adequate potential for a wide range of applications. In the same way many researchers around the world conducted many works on the jute fiber depending on the species available around them, most of the time, materials used for the Automotive and industrial application the difficulty in production cost and not eco-friendly. From all the results and comparisons we can conclude that the fabricated composite material can be a potential to substitute synthetic fiber such as fiber glass in light weight Automotive application for preparing interior panels, headliners, seat backs and dashboards which does not need a very high mechanical performance and minimum energy absorption. And also substitute different construction as well as house hold product like frame for door and windows, chairs, tables, honey comb selling, flooring, partition walls, kitchen cabinets and etc exported from other countries.

5.3. Future work

The present research work leaves a wide scope for future investigation. Few recommendations for the future investigation include:

- The present study has been carried out using simple hand lay-up technique. However, the research work can be extended further by considering other methods of fabrication and similarly the effect of manufacturing techniques on the performance of composites can be analyzed.
- The present study can be extended further by the development of hybrid composites using hard particulate fillers along with jute fiber or other natural fibers to improve the strength.
- In this study, the mechanical experimental property characterization was done using only the universal testing machine. However the experimental testing should be done using appropriate universal testing machine that strain gauge was installed on it in order to attain a precise results.
- Testing like Fatigue test, shear test, Impact test, thermal test and tribological test.
- Cost analysis of these composites to assess their economic viability in domestic/industrial applications.

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APPENDIX

Appendix I

Tensile strength S/N ratio values using MINITAB 17 software

The S/N ratio values at different levels for the responses of tensile strength and void content are analyzed using MINITAB 17 software.

Taguchi Design

```
Taguchi Orthogonal Array Design

L9(3^4)

Factors:  4
Runs:     9


Columns of L9(3^4) Array

1 2 3 4
```

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7
	Fiber direction	Fiber content	Al2O3 content	SiC content	Average values of TS(Mpa)	SNRA1	MEAN1
1	1	1	1	1	24.33	27.7228	24.33
2	1	2	2	2	40.52	32.1534	40.52
3	1	3	3	3	41.14	32.2853	41.14
4	2	1	2	3	21.15	26.5062	21.15
5	2	2	3	1	25.87	28.2559	25.87
6	2	3	1	2	20.22	26.1156	20.22
7	3	1	3	2	10.60	20.5061	10.60
8	3	2	1	3	9.35	19.4162	9.35
9	3	3	2	1	11.07	20.8830	11.07

Figure 4.13: Tensile strength orthogonal array by MINITAB 17 software

Taguchi Analysis: uts versus Fiber direction, Fiber content, Al2O3 content, SiC content

```
Response Table for Signal to Noise Ratios
Larger is better

          Fiber    Fiber    Al2O3      SiC
Level  direction  content  content  content
1          30.72    24.91    24.42    25.62
2          26.96    26.61    26.51    26.26
3          20.27    26.43    27.02    26.07
Delta      10.45     1.70     2.60     0.64
Rank           1        3        2        4
```

Figure 4.14. Main effect plot for S/N ratios

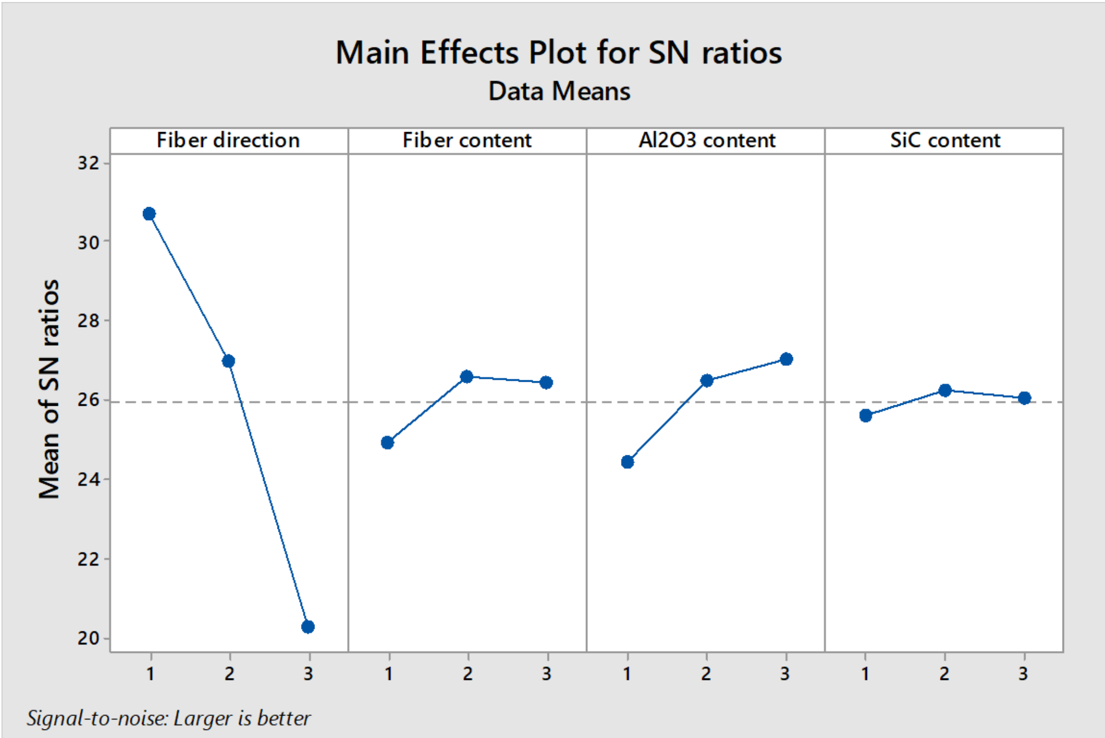
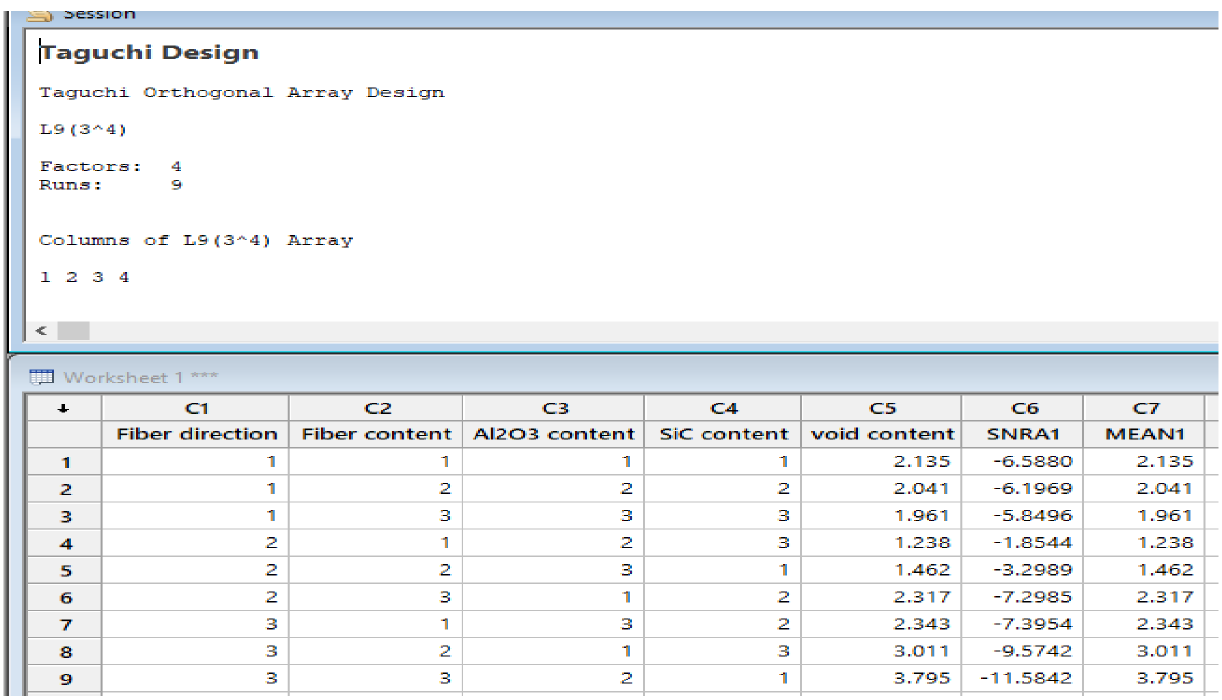


Figure 4.15 S/N ratio plot for tensile strength

Void content of S/N ratio values using MNITAB 17 software


Session

Taguchi Design

Taguchi Orthogonal Array Design

L9(3^4)

Factors: 4
Runs: 9

Columns of L9(3^4) Array

1 2 3 4

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7
	Fiber direction	Fiber content	Al2O3 content	SiC content	void content	SNRA1	MEAN1
1	1	1	1	1	2.135	-6.5880	2.135
2	1	2	2	2	2.041	-6.1969	2.041
3	1	3	3	3	1.961	-5.8496	1.961
4	2	1	2	3	1.238	-1.8544	1.238
5	2	2	3	1	1.462	-3.2989	1.462
6	2	3	1	2	2.317	-7.2985	2.317
7	3	1	3	2	2.343	-7.3954	2.343
8	3	2	1	3	3.011	-9.5742	3.011
9	3	3	2	1	3.795	-11.5842	3.795

Figure 4.16: Void content orthogonal array by MINITAB 17 software

Session

Taguchi Analysis: Void content versus Fiber direct, Fiber conten, Al2O3 conten, SiC content

Response Table for Signal to Noise Ratios
Smaller is better

Level	Fiber direction	Fiber content	Al2O3 content	SiC content
1	-6.211	-5.279	-7.820	-7.157
2	-4.151	-6.357	-6.545	-6.964
3	-9.518	-8.244	-5.515	-5.759
Delta	5.367	2.965	2.306	1.398
Rank	1	2	3	4

Figure 4.17. Main effect plot for S/N ratios

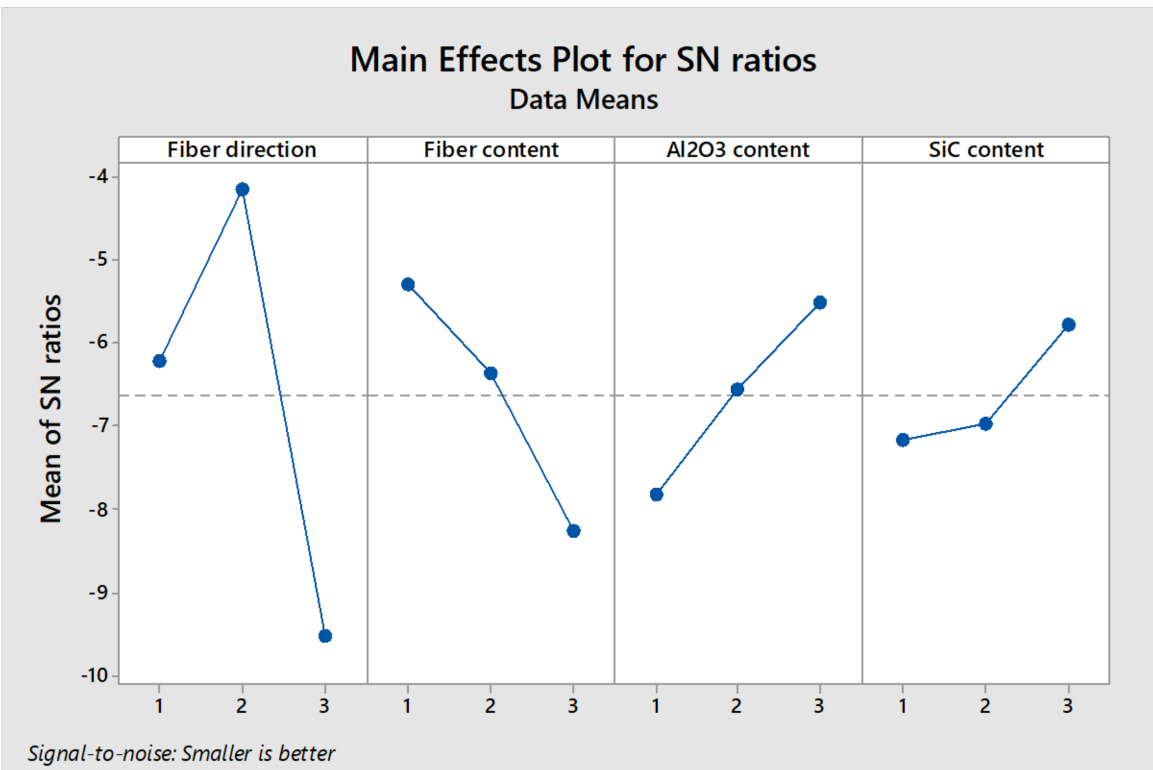
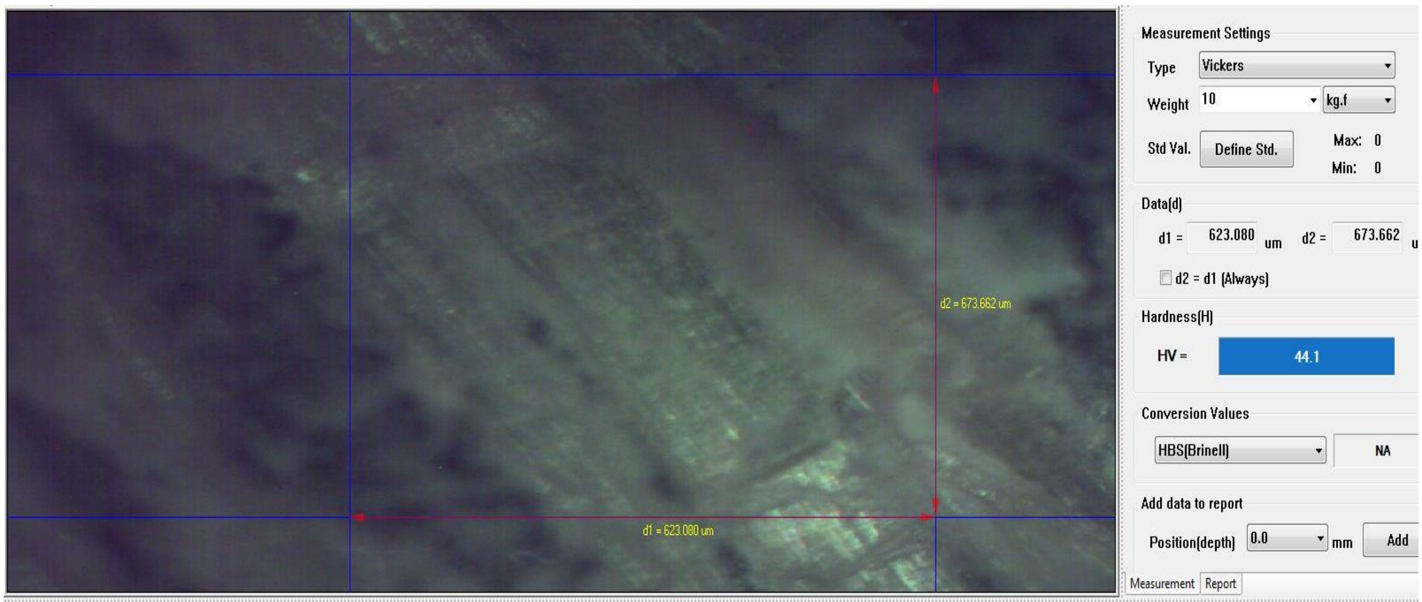


Figure 4.18 S/N ratio plot for void content

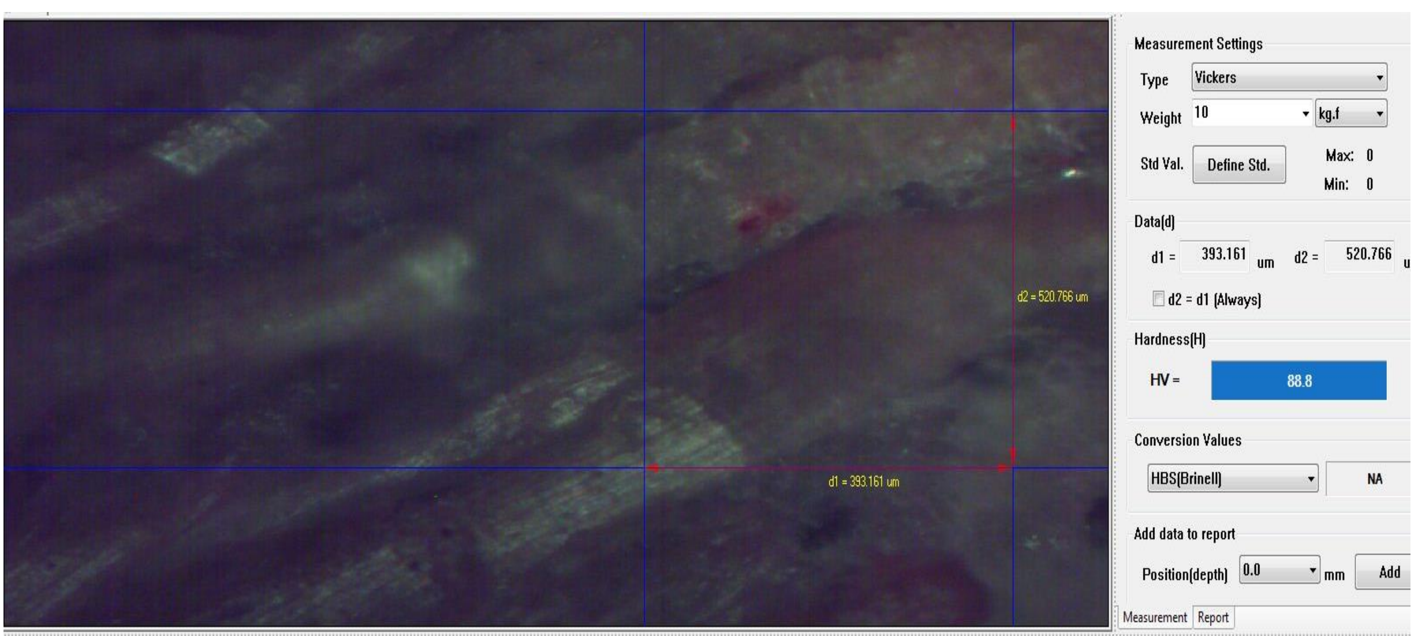
Appendix II

Micro hardness results of all samples

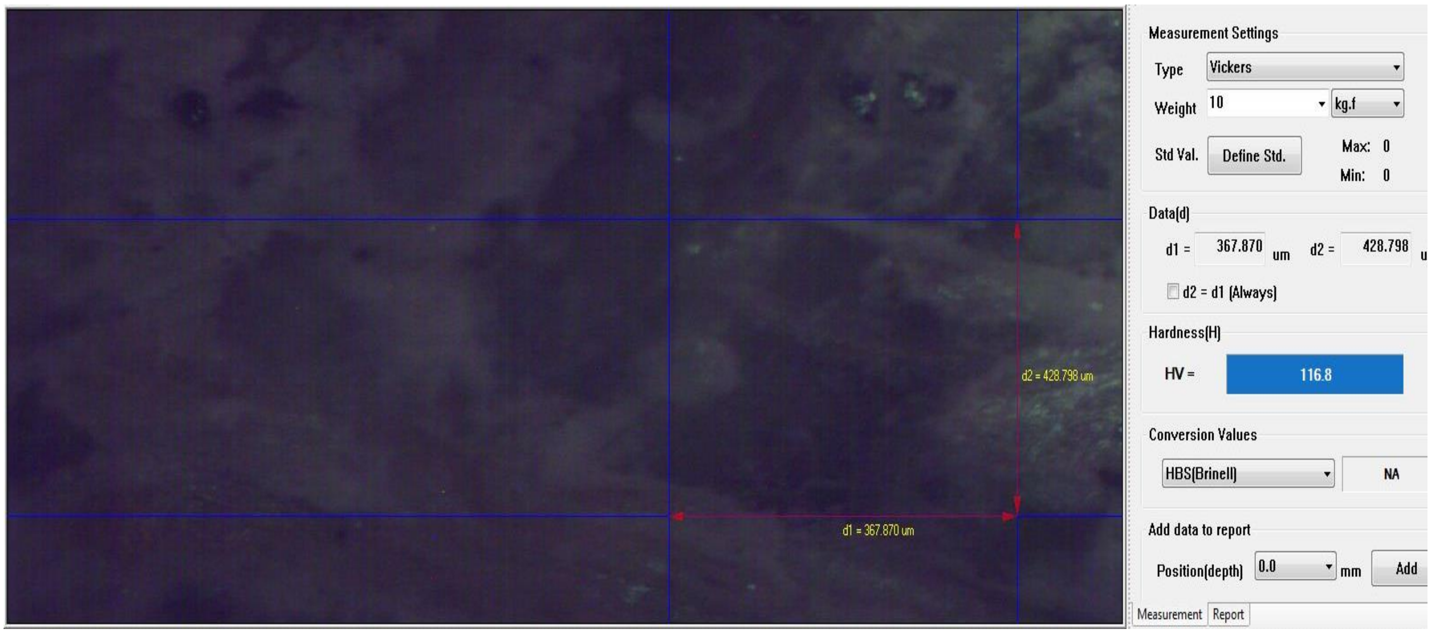
Sample 1: Micro – hardness result:



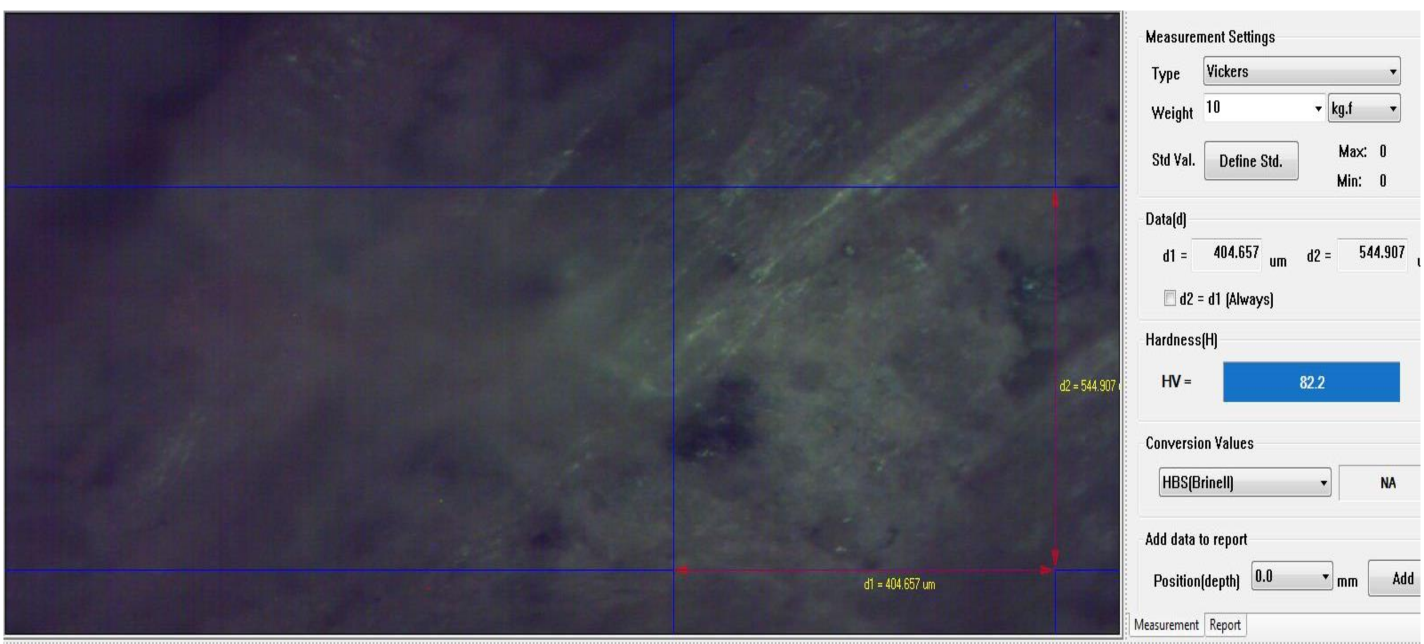
Sample 3: Micro – hardness result:



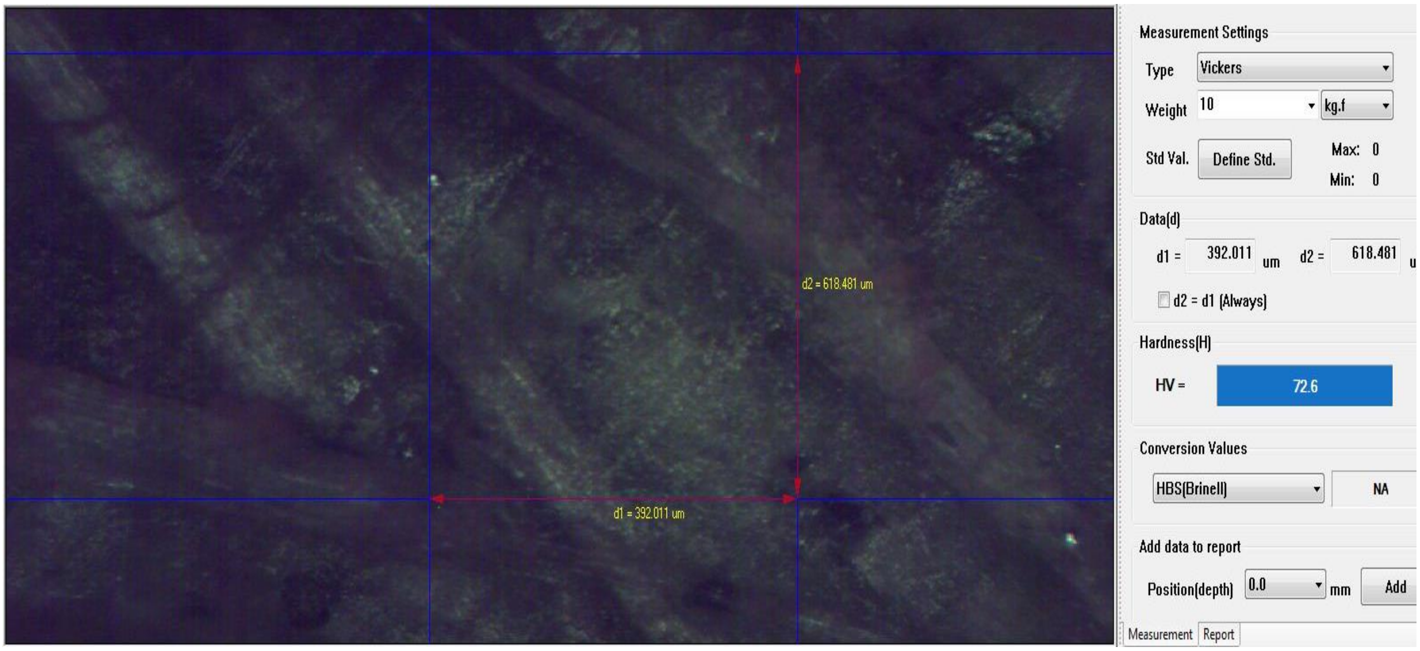
Sample 4: Micro – hardness result:



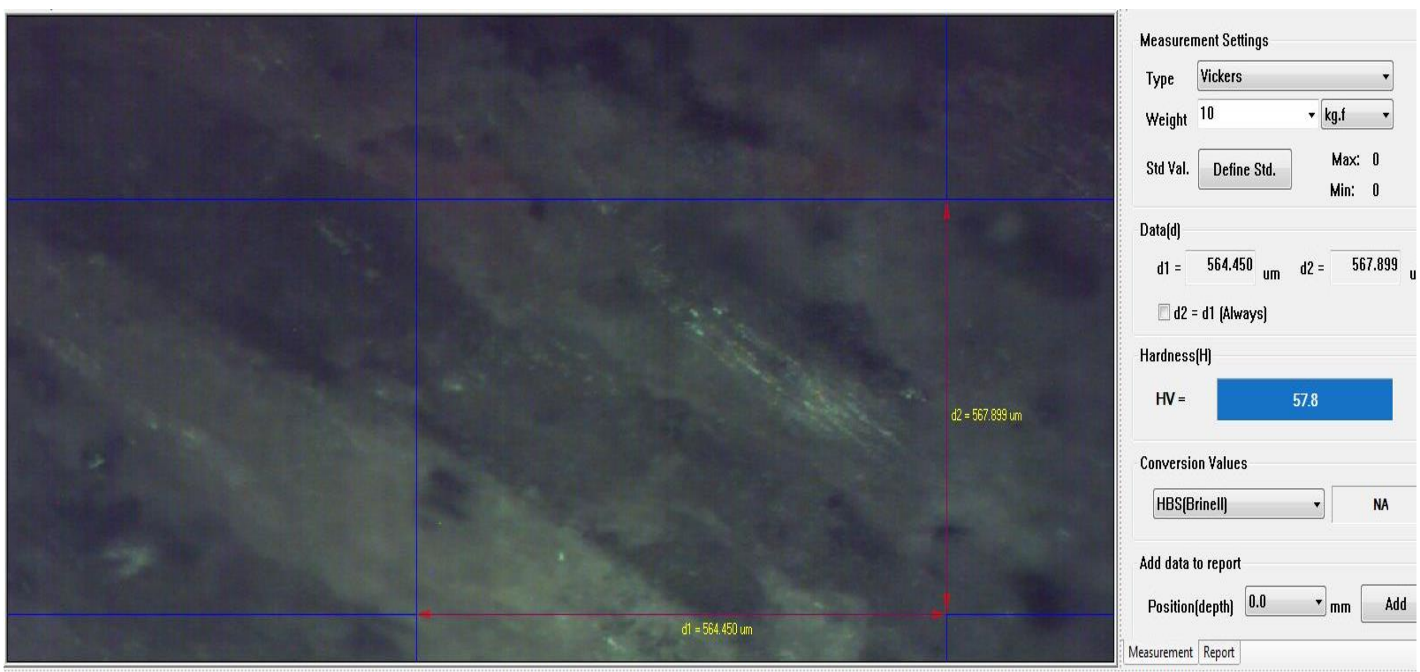
Sample 5: Micro – hardness result:



Sample 6: Micro – hardness result:



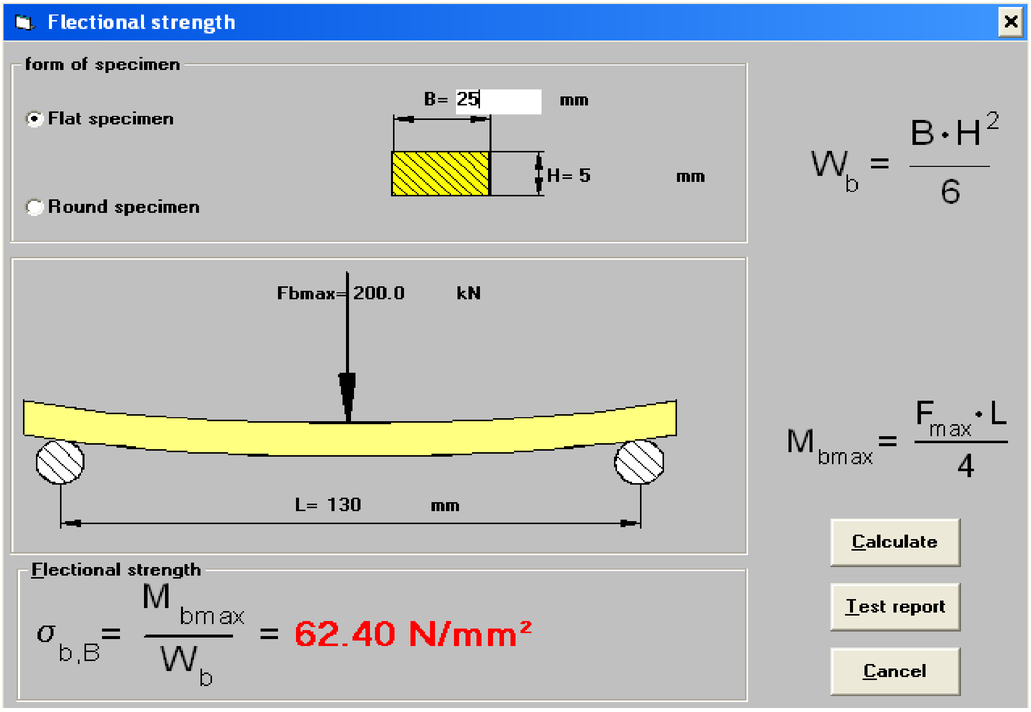
Sample 9: Micro – hardness result:



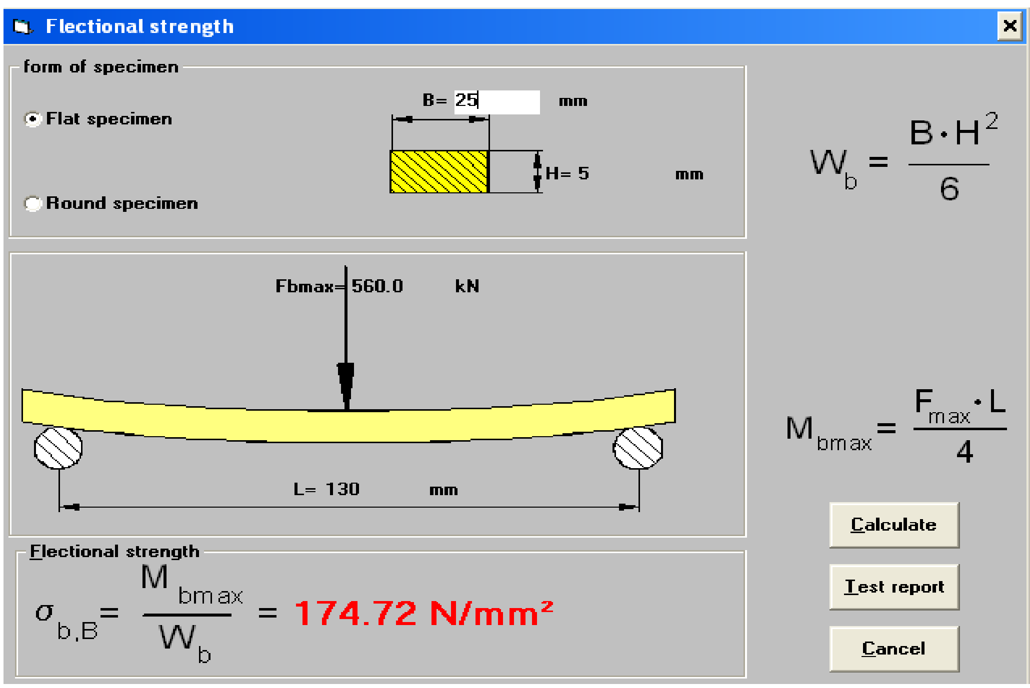
Appendix III

Flexural strength results of all samples

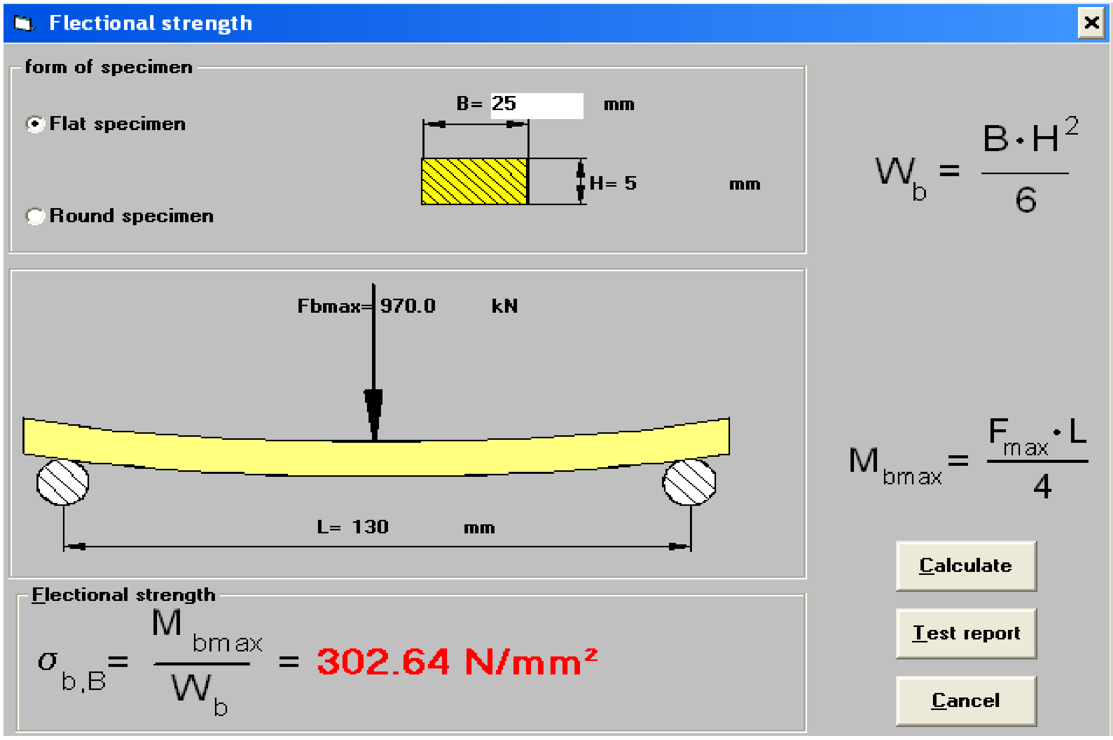
Flexural test result for sample 1.



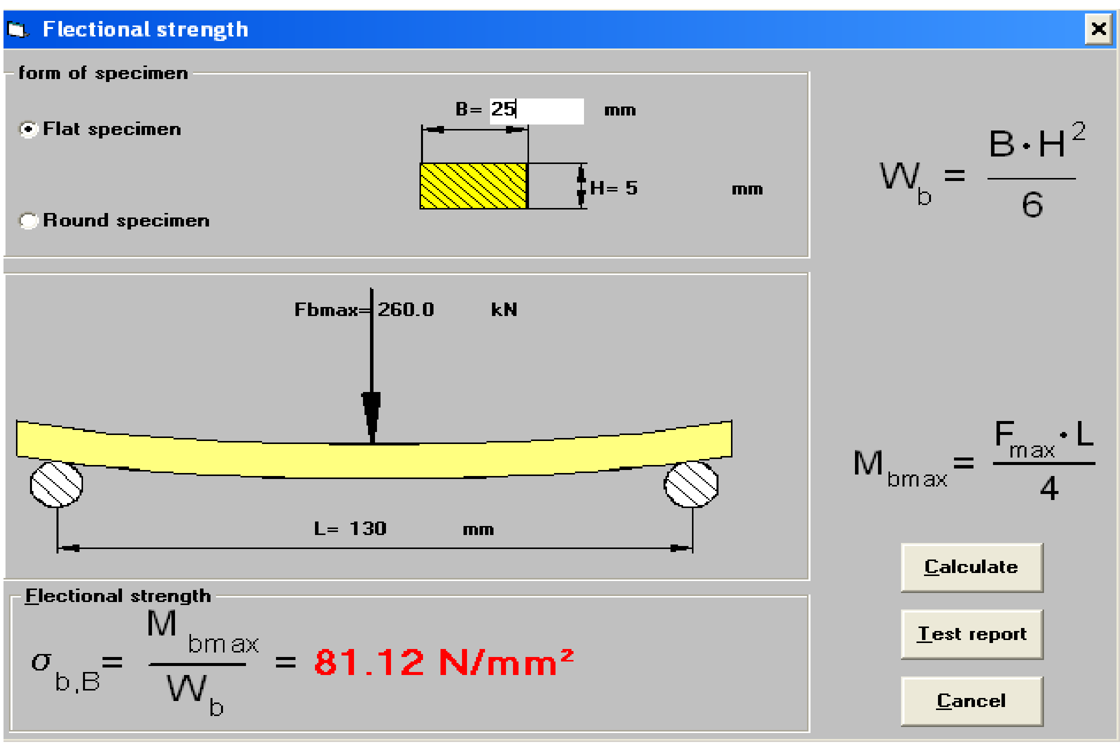
Flexural test result for sample 2.



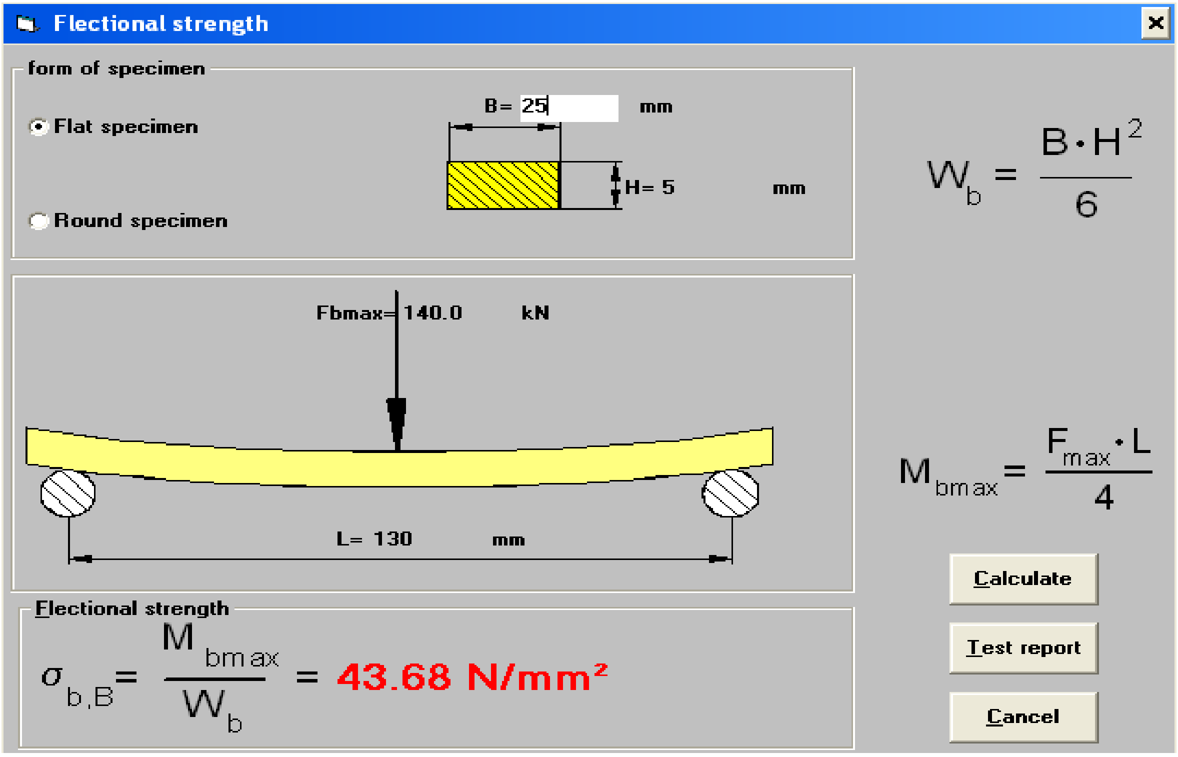
Flexural test result for sample 4.



Flexural test result for sample 5.



Flexural test result for sample 8.



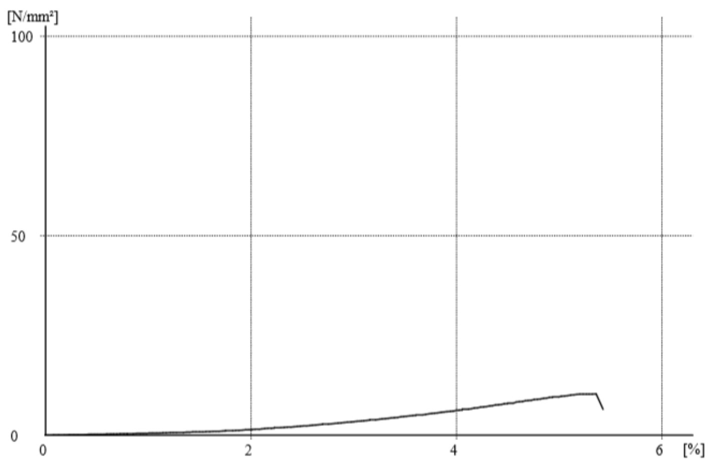
Appendix IV

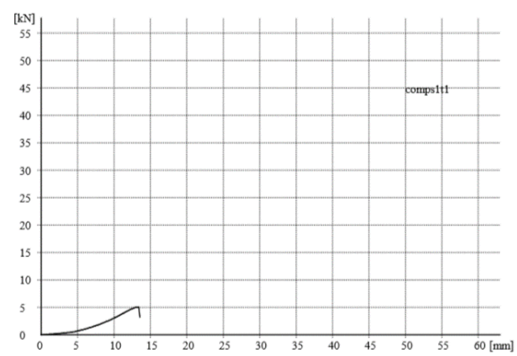
Tensile test result for sample 1.

Stress-elongation-diagram for tensile specimen

Material: comps1t1
Free Text:
Initial measurement length: 250mm
Specimen diameter: 25mm
Date: 23.09.2019

Force-elongation-diagram for tensile test specimen



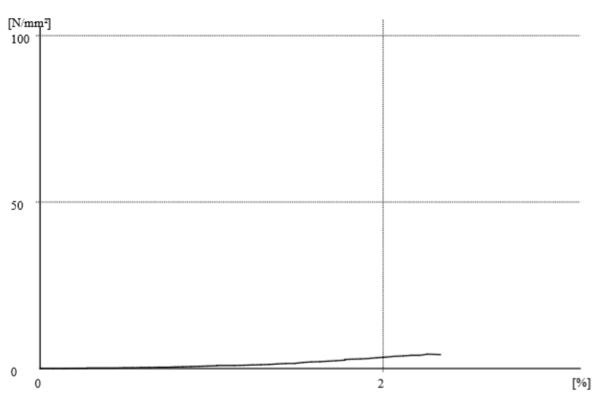


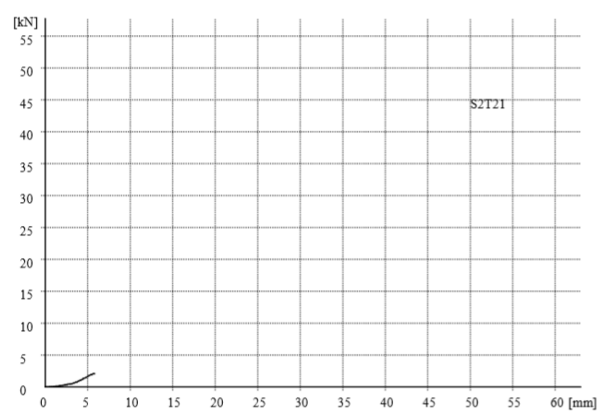
Tensile test result for sample 2.

Stress-elongation-diagram for tensile specimen

Material: S2T22
Free Text:
Initial measurement length: 250 mm
Specimen diameter: 25 mm
Date: 30.09.2019

Force-elongation-diagram for tensile test specimen

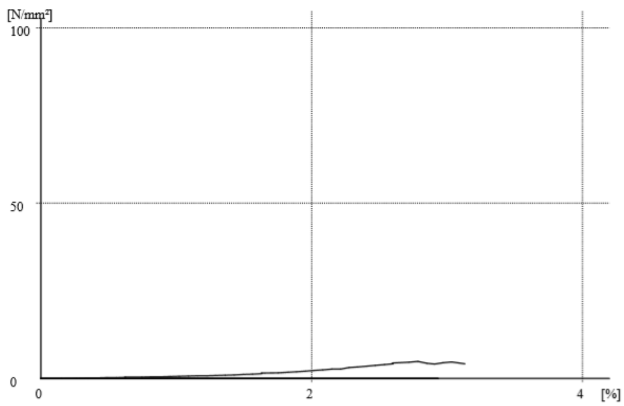




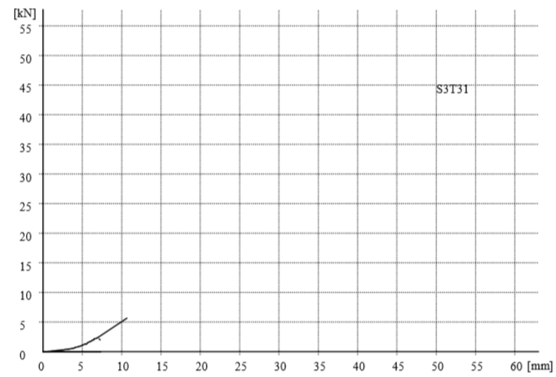
Tensile test result for sample 3.

Stress-elongation-diagram for tensile specimen

Material: S3T32
Free Text:
Initial measurement length: 250 mm
Specimen diameter: 25 mm
Date: 30.09.2019



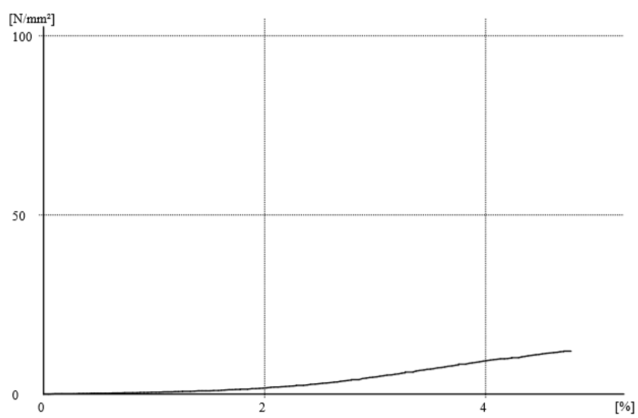
Force-elongation-diagram for tensile test specimen



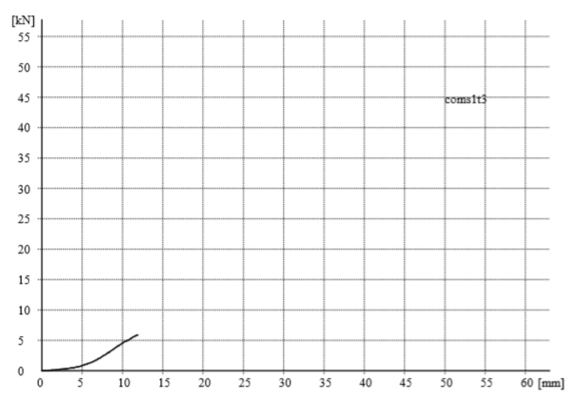
Tensile test result for sample 4.

Stress-elongation-diagram for tensile specimen

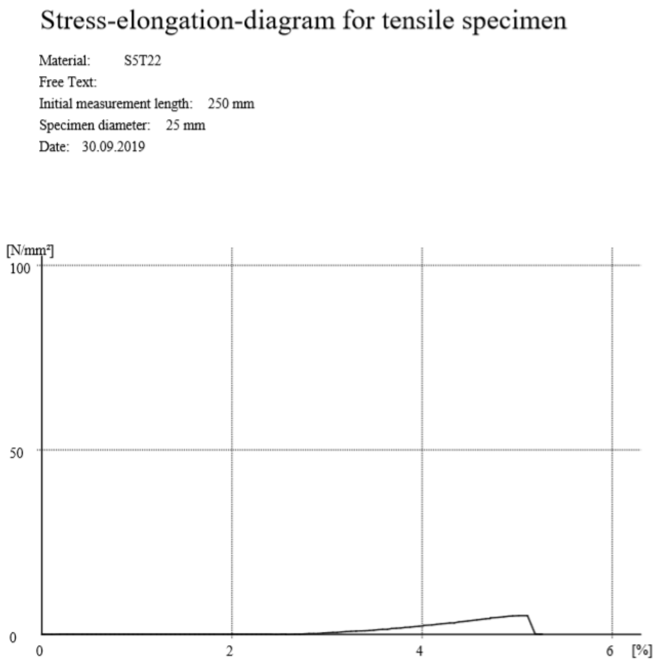
Material: coms1t3
Free Text:
Initial measurement length: 250mm
Specimen diameter: 25mm
Date: 23.09.2019

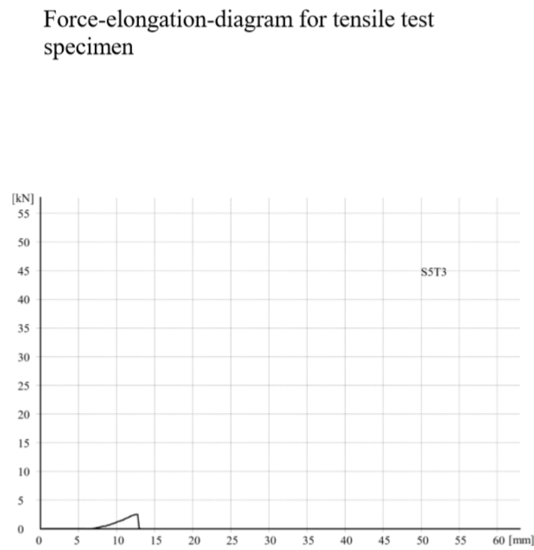


Force-elongation-diagram for tensile test specimen

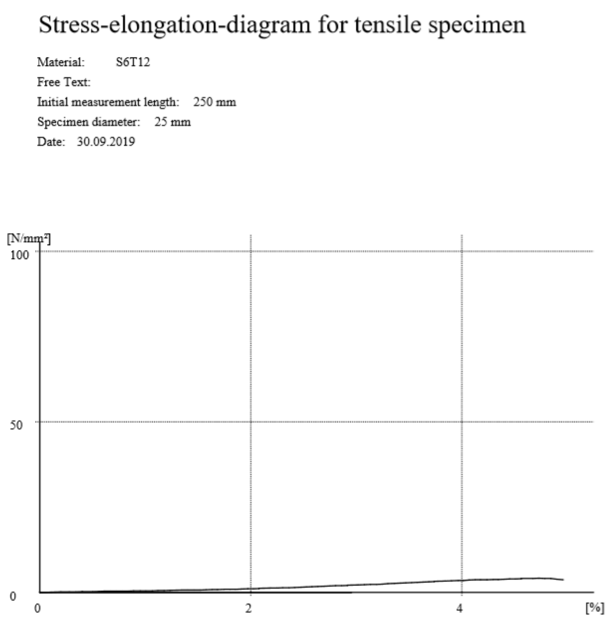


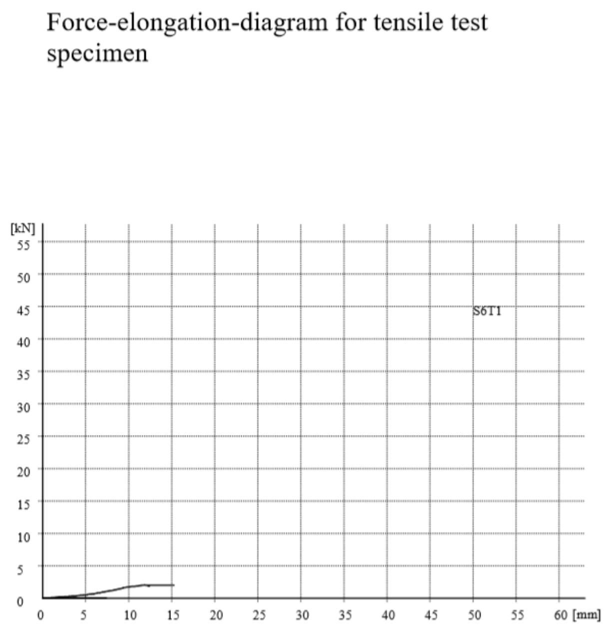
Tensile test result for sample 5.





Tensile test result for sample 6.



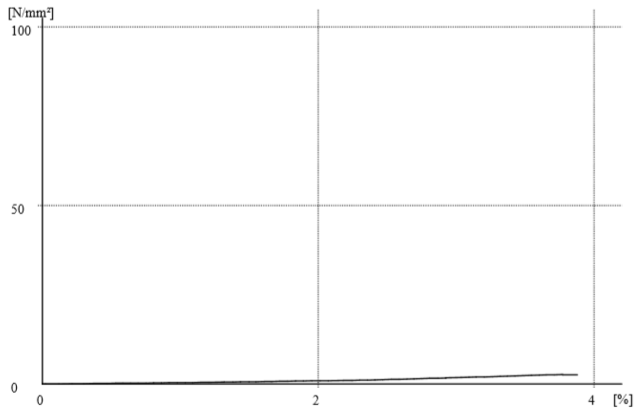


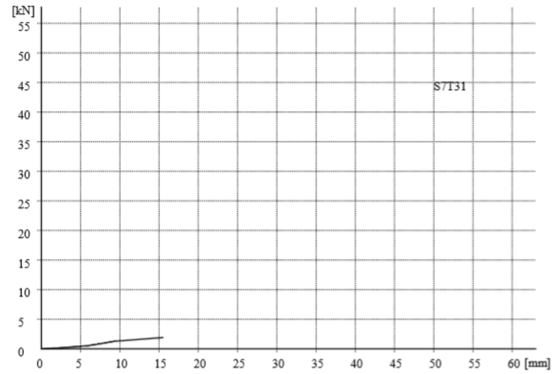
Tensile test result for sample 7.

Stress-elongation-diagram for tensile specimen

Material: S7T32
Free Text:
Initial measurement length: 250 mm
Specimen diameter: 25 mm
Date: 30.09.2019

Force-elongation-diagram for tensile test specimen



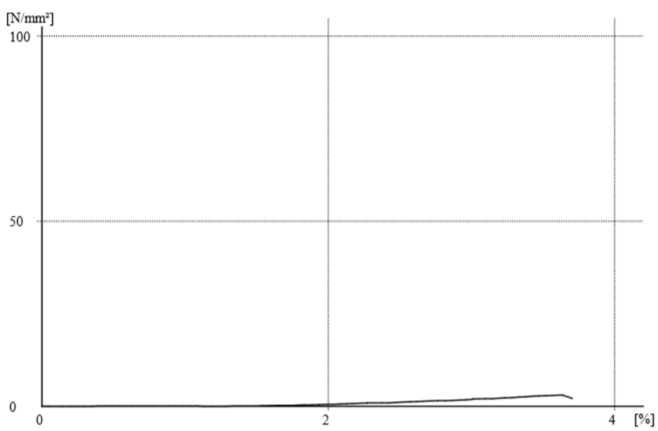


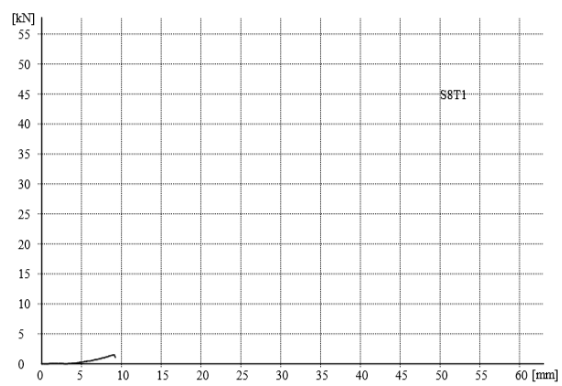
Tensile test result for sample 8.

Stress-elongation-diagram for tensile specimen

Material: S8T1
Free Text:
Initial measurement length: 250mm
Specimen diameter: 25mm
Date: 23.09.2019

Force-elongation-diagram for tensile test specimen

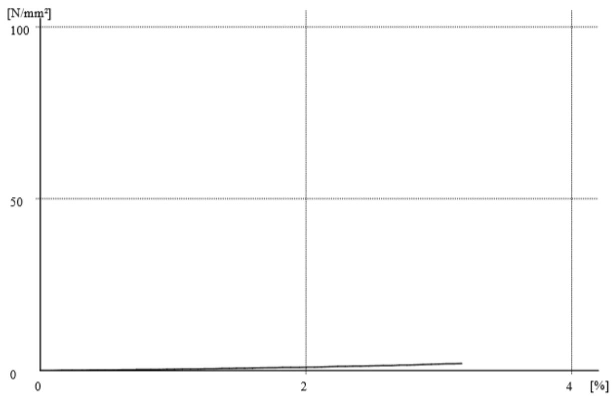




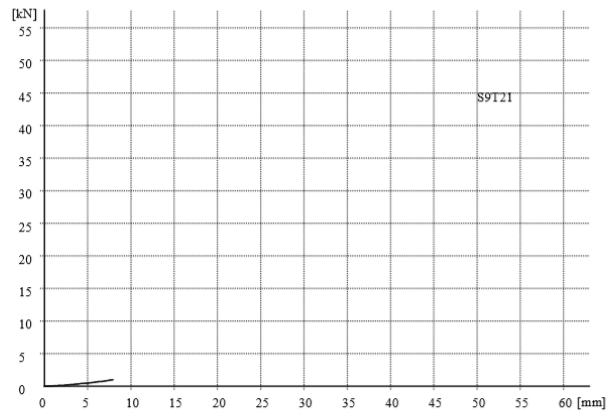
Tensile test result for sample 9.

Stress-elongation-diagram for tensile specimen

Material: S9T22
Free Text:
Initial measurement length: 250 mm
Specimen diameter: 25 mm
Date: 30.09.2019



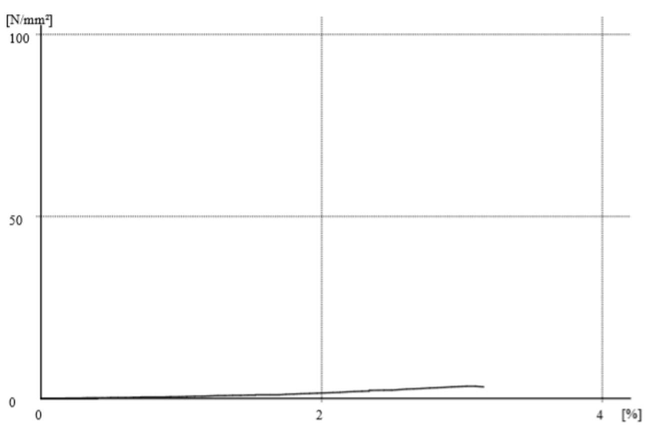
Force-elongation-diagram for tensile test specimen



Tensile test result for sample 10.

Stress-elongation-diagram for tensile specimen

Material: S10T12
Free Text:
Initial measurement length: 250 mm
Specimen diameter: 25 mm
Date: 30.09.2019



Force-elongation-diagram for tensile test specimen