Adama Science and Technology University
School of Mechanical, Chemical and Materials Engineering
Mechanical Design and Manufacturing Engineering Program

Fabrication and experimental analysis of banana fibers reinforced polymer composite filled with Aluminium-powder filler for automotive body

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 Master of Science in

Manufacturing Engineering

By: Robson Balcha Wakeyo

(GSR/0096/09)

Advisor: Dr. J Bhaskaran (PhD)
Assistant Professor

Co-Advisor: Dr. Perumalla Janaki Ramulu (PhD)
Associate Professor

Adama, Ethiopia

July, 2018

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIAL ENGINEERING

DEPARTMENT OF MECHANICAL DESIGN AND MANUFACTURING ENGINEERING

Fabrication and experimental analysis of banana fibers reinforced polymer composite filled with Aluminium-powder filler for automotive body

BY

Robson Balcha (GSR/0096/09)

Approved by Board of Examiners

____________________	________	______
Chairman, Department Graduate Committee	Signature	Date
____________________	________	______
Major Advisor	Signature	Date
____________________	________	______
Co-Advisor	Signature	Date
____________________	________	______
Internal Examiner	Signature	Date
____________________	________	______
External Examiner	Signature	Date

Candidate declarations

I hereby declare that the work which is being presented in thesis entitled "***Fabrication and Experimental analysis of banana fiber reinforced polymer composite filled Al-powder filler***" in partial fulfillment of the requirements for the award of the degree of Masters of Science in Manufacturing Engineering is genuine best of my own work carried out since November 2017 to May 2018 under supervision of **Dr. J Bhaskaran** and co-supervision of **Dr. Perumalla Janaki Ramulu**, program of Mechanical Design and Manufacturing Engineering, Adama Science and Technology University, 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 accordingly acknowledged.

Robson Balcha Wakeyo ______________________ ______________

Candidate Signature Date

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

Dr. J Bhaskaran ______________________ ______________

Advisor Signature Date

Dr. Perumalla Janaki Ramulu ______________________ ______________

Co-Advisor Signature Date

Acknowledgement

Above all, I give special thanks to the Almighty Allah for everything of the merits is due to his gracious and merciful.

It gives me enormous pleasure to express great thanks to my advisor ***Dr. J Bhaskaran*** and co-advisor ***Dr. Perumalla Janaki Ramulu*** for their continuous support, correction, supervision and constructive comments greatly help me during doing this thesis work.

I would like to thank **Mr. Danye Addisu** lecturer at School of Chemistry Hawassa University for his guidance and advice during conducting fibers chemical treatment at their school laboratory.

I am greatly thankful my close friend **Mr. Diriba Tilaye** former lecturer and chairman of school of Mechanical and Electromechanical Engineering at Hawassa University and PhD candidate at University of Kassel, Germany for purchasing and sending me Al-powder filler that I used for this study.

Again, it is a great pleasure for me to acknowledge my beloved wife ***Damu Bedane*** and my lovely daughters ***Iman*** and ***Sumeya Robson,*** and also to my mother ***Bunda Huluka***, my father **Balcha Wakeyo** and my entire family for their moral, financial and endless support and encouragement during my thesis work. Thank you again!

Lastly, I would like to give thanks to my friends and classmate those support me during fiber extraction and composite fabrication i.e., ***Nuguse Hamu, Maru Denebo, Murtessa Debasa, and Robsen Gena.***

Abstract

The rising concern of environmental related issues and attention given to green and clean composite materials and the need of finding realistic alternative to replace heavy metals have led researchers to find for alternative natural fiber reinforced polymer composites. The main objective of this study was to introduce new green composite materials from abundant waste resource of banana stem that have high mechanical and physical properties fiber used for automotive companies. The composite was fabricated from banana fiber filled Al-powder filler through resin-hardener mixture by simple hand lay-up technique followed by compression molding technique to obtain high mechanical and physical properties. The samples fabrication procedure carried out on fixed weight percentage of banana fibers by varying Al-powder filler weight percentage to see its effect of mechanical and physical properties. Four samples i.e., Banana fiber reinforced polymer composite (sample A), banana fiber reinforced polymer filled 5wt% of Al-powder filler (sample B), banana fiber reinforced polymer composite filled 10 wt% Al-powder filler (sample C) and banana fiber reinforced polymer composite filled 15 wt% Al-powder filler (Sample D) was produced by fixing banana fibers 10 weight ratio and 0 wt%, 5 wt%, 10 wt% and 15 wt% of Al-powder filler respectively. Then, tensile strength, density, micro hardiness, water absorption percentage and Microstructure were conducted according to ISO and ASTM standards. The results show that steady tensile strength increment is obtained by adding Al-powder up to 10wt%. Beyond this wt% of Al-powder tensile strength decreased. Density of composite samples filled Al-powder increases as the wt% of Al-powder increase. Microstructure of sample C exhibits superior distribution of Al-powder than other samples. As Al-powder increase the water absorption of the samples decreases. Micro structure of the fabricated samples shows best Al-powder distribution throughout the composites. Overall optimal mechanical and physical properties obtained at sample C with highest tensile stress, less water absorption, moderate density, microstructure and micro-hardness when compared to other samples.

Keywords: Banana fibers; Aluminum Powder; Resin; Mechanical Properties

Table of Contents

List of Figures

List of Tables

Abbreviations and Acronyms

Al	Aluminium
ASTM	American Society of Testing Materials
DMA	Dynamic Mechanical Analysis
EDTA	Ethylene diamine tetra acetic acid
FRPCs	Fiber reinforced polymer composites
FRPs	Fiber reinforced polymers
GHG	Greenhouse gas emission
ISO	International Organization for Standardization
MMCs	Metallic matrix composites
PMC	Polymer matrix composites
PP	Polypropylene
PVC	Poly-vinyl-chloride
SEM	Scanning electron Microscope
UTM	Universal Testing Machine
UV	Ultraviolet radiation
VHN	Vickers hardiness Number

CHAPTER ONE

INTRODUCTION

1.1 Background

According to Bakri *et al.* (2017) increasing consideration towards sustainable progress and environment awareness forces scholars to discover more on the green biodegradable materials based on agricultural trashes. The rising environmental concerns, global warming, waste controlling concerns, declining fossil resources, as well as escalating oil prices have resulted in increase in research for innovative materials that are friendly to our health besides environmental concern. Green products are being increasingly promoted for sustainable development (Singh *et al.* (2017)).

A new trend in engineering research is to replace heavy metals with polymer material reinforced with natural fibers such as different plants, animal and wood fibers. Many researchers have focused to replace heavy metals by some materials with low density and high strength. Thus the use of polymers in various applications has grown rapidly. Now a day the application of polymer grounded products can be found from household utilities to aerospace applications (Haldar *et al*., 2017). According to reports of (Arpitha and Yogesha, 2017), (Mehamud *et al*., 2016) and (Bhatnagar and Senthilvelan, 2015) the sources of natural fibers are from plant, animal and minerals. Some examples of natural fibers are: banana, abaca, hemp, wood fiber, bamboo, cotton, coir, flax, jute, rice husks, straw wheat, coconut, coir, henequen, sisal, ramie, water pennywort, kapok, pineapple leaf fiber, grass reeds, oil palm empty fruit bunch, cotton, bagasse, alpaca, angora, bisdown, camelhair, chasmere, acetate, triacetate, art silk, asbestos, etc.

Moreover, automotive as well as packaging companies are demanding a change of their design from oil-derived polymers and mineral underpinning materials to natural materials focusing the recyclability or else biodegradability of ‘‘green’’ products at the termination of life (Alves *et al*., 2010). Agricultural waste derived natural fibers can play a vigorous role in producing composites based products in addition to reducing environmental problems. Natural fibers are affordable, degradable, manageable, recyclable, and renewable (Bakri *et al*., 2017).

Fragassa, (2017) reported that the furthermost important benefits of natural fibers relate to environmental issues: they are biodegradable as well as carbon positive, subsequently they absorb more carbon dioxide than they produce (Bogoeva-Gaeva *et al*., 2007). Other important advantages are shown in terms of specific material properties: using natural fibers in place of synthetic ones, it is possible to reduce the mass of a composite material by up to 40%, and it is also possible to increase flexural strength, stiffness and ductility (De Paola *et al*., 2013). The fibers from the natural sources provide certain advantages over synthetic reinforcement fibers for instance low cost, non-toxicity, comparable strength, small density; also minimum waste disposal problems (Ramesh *et al*., 2014). Natural fiber reinforced thermoplastic composites exhibits supremacy over conventional materials outstanding to ease of processing, fast fabrication cycling and low tooling cost, thus making them most suitable materials for automobile and electrical industries (Paul *et al*., 2008). In comparison with synthetic fibers, natural fibers exist low in cost, low density, and have very much specific property (Satyanarayana *et al*., 2007).

It was created that natural fiber composites have superior electrical resistance, virtuous thermal as well as acoustic insulating properties and higher confrontation to fracture. Natural fibers have many benefits related to synthetic fibers, for instance low weight, low density, low cost, acceptable specific properties, recyclable and biodegradable in nature. They are also renewable and have somewhat high strength and stiffness and cause no skin irritations. On the other hand, there are also some drawbacks, such as moisture absorption, quality variations and low thermal stability (Venkateshwaran *et al*., 2012). According to (Prasad *et al.*, 2014) report high level of moisture absorption, poor wettability, inadequate adhesion and de-bonding are the main disadvantages of natural fibers reinforced composites. Natural fibers are also having some draw backs, such as large variations in mechanical properties, sensitivity to humidity and UV radiation plus low resistance to impact (Benitez *et al*., 2013).

The word banana comes from Arabic and it means ‘finger’. There are about 300 species of banana and about 20 are used for consumption. In order to obtain the best fiber, the plants are cut when they are almost at the flowering stages, before any fruit has formed (Pujari *et al*., 2014). Banana fibers have good specific strength properties comparable to those of conventional materials, similar to glass fibers (Sapaun *et al*., 2006). Ethiopia as a country whose economic sector depends on agricultural products has abundant potential to develop and utilize fiber derived from Agricultural waste. Banana and false banana fibers which are important by-products of farmer food processing are discarded as waste in Gurage zone (Raj *et al*., 2016)**.** The surplus by-products of agricultural products are abundant and quantitatively beneficial in a country like Ethiopia with its massive agricultural resources. Reducing natural assets, regulations on using synthetic resources, increasing environmental awareness and economic attentions are the major motivating forces to utilize annually renewable resources such as biomass for various industrial applications (Temesgen and Sahu, 2014).

By product of the rotting process is methane gas which is some of the greenhouse gases (a pollutant). Utilization of the banana stalk fibre not only benefits the environment, but it will also reduce the overall resource consumption while sustaining national economic growth and introduction of green technology to the rural areas (Baharin, *et al* ., 2016). According to (Amir *et al*., 2017) banana fiber possesses good unambiguous tensile strength properties comparable to those of conventional materials like glass fibre (Herrera-Estrada *et al*., 2008).

Benitez *et al*., (2013) report shows that the structure and chemical composition of natural fibers are greatly dependent on climatic condition, soil type, and age of plant and the individual characteristics of each plant variety. According to (Jordan and Chester 2017) report mechanical properties of lignocelluloses fibers may also vary greatly, even from same plant. This is due to several factors during the plant's life cycle, including growing circumstances, the maturity of fibers during harvesting; the ways and means used to extract the fibers, and the transportation and storage of fibers over time (Dittenber and Gangarao 2012). Alkali treatments have exist recognized effective in removing contaminations from the fiber, reducing moisture absorption and permitting mechanical bonding, and thereby improving matrix-reinforcement interaction (Edeerozey *et al*., 2007).

Pujari *et al*., 2017 clearly reported that the use of natural fibers reduces weight by 10% and lowers the energy consumption needed for production by 80%, while the cost of the component is 5% lower than the comparable fiber glass-reinforced component (Geethamma *et al*., 1998). According to (Raj *et al*., 2016) composites, the wonder material with light -weight, high strength to weight ratio and stiffness properties have come a long approach in replacing the conventional materials like metals, woods etc. The replacement of steel with composites can save 60% to 80% of component weight and 20% to 50% with the Aluminum components. The polymer fabricated composite materials use is increasing because of their light weight as well as good mechanical responses.

Recent environmental issues related to global weather change and greenhouse gas releases have encouraged automotive manufacturers to emphasis on the development of lightweight and fuel efficient vehicles. Greenhouse gas emissions (GHG) related with highway transport vehicles account for 27% of all collective emissions in USA which decodes into 1800 million metric tons of CO_2 correspondent. Now it's a common thoughtful that a 10% discount in vehicle weight has possible to save 6% to 8% fuel consumption and ever since lighter thing needs less energy to get faster compared to heavy ones, clearly lightweight materials be responsible for a better opportunity to enhance vehicle's fuel economy and alleviate GHG emissions (Pervaiz et al., 2016). The most important advantages of using composites in automotive is the weight reduction as the composites are up to 35% lighter than Aluminium and 60% lighter than steel and the use of composites in automotive can clues to an overall vehicle weight reduction of up to 10%. Other classes of light weighting materials used in automotive for the "greening" of automotive industry are natural fiber reinforced composites. Replacement of glass fibers with natural fibers allows lighter components as the density of natural fibers (1.5 g/cm^3) are lower compared to glass fibers (2.5 g/cm^3) while simultaneously increasing the proportion of renewable resource content within the vehicle (Pervaiz *et al*., 2016). Composites are materials that embrace strong load carrying material (known as reinforcement) set in in weaker materials (known as matrix). Reinforcement is responsible for strength and rigidity, helping to support structural load. The matrix or binder (organic or inorganic) upholds the position, orientation of the reinforcement and transfers the peripheral load to the reinforcement (Pujari *et al*, 2014).

1.2 Statement of problem

A process of meeting human need in manufacturing technology aims to ensure and provide the ecosystem services to the natural resources upon which the society and economy depend is called sustainable development. To ensure this; natural fiber as a means of usable material to engineering application is a key element. In developing country most of the time the body and spare part of automotive were imported from abroad. In Ethiopia also, the spare part and body of automotive were imported from developed country. These imported materials are heavy in weight, high in cost and have an adverse impact on the environment. On other hand Ethiopia is known as agricultural dependent country. Among many source of agricultural product banana is one of the major sources of fruit with unusable stem of banana which is disposed as a waste in case of our country's trend, because the source of fiber in Ethiopia is related only to false banana and sisal. Therefore, the preparation of natural fibers composite using banana in aligned with automotive application will plays a vital role in manufacturing sectors. Many researchers carried out their study on natural fibers as a replacement source of material for heavy metals and glass fibers. A few researchers conducted their study to fabricate composite from natural fibers and metallic powder filler. So, this study was elaborated to a great opportunity for our country to produce automotive body from Aluminum filled banana fibers as reinforcement for better strength, long survival time, and reduced water absorption behavior of banana fibers.

1.3 Objective

1.3.1 General objective

The general objective of this study is to fabricate and analyze the mechanical and physical properties of banana fibers reinforced polymer composite filled by Al-Powder filler for automotive application.

1.3.2 Specific objectives

The specific objectives of this study are:

i. To fabricate composite of banana fiber reinforced polymer composite filled Al-powder filler by hand lay-up with compression molding technique from banana fiber, resin and aluminum-powder filler for better mechanical bonding.

ii. To evaluate mechanical and physical properties i.e., tensile stress, density, water absorption percentage, micro-hardness and micro structure of composite fabricated from treated banana fibers filled aluminum-powder filler for the automotive body application.

iii. To analyze and recommend better weight ratio of banana fibers filled aluminum-powder filler samples and evaluate against previous literature.

1.4 Scope of Study

The scope of this study was limited to fabrication of banana reinforced polymer composite from banana fibers filled with Al-powder filler suitability for automotive body.

- ☞ Gathering related documents and literatures.
- ☞ Extraction of banana fiber was done by manual method.
- ☞ Samples and specimens preparation was carried out.
- ☞ Convectional testing machine was used to identify samples mechanical and physical properties.
- ☞ Density and water absorption percentage was identified by using digital balance and water immersion method.
- ☞ The result was analyzed by using mini tab and other Engineering software and recommending better weight fraction.
- ☞ Conclusion, recommendation and future research area was addressed by researcher.

1.5 Challenges

During prefabrication of banana fiber reinforced polymer composite filled with Al-powder filler the limitation face the researcher is: banana fiber is extracted from banana stem by traditional method that needs skill to obtain smart fiber and longer time. Then, during fabrication of composite material controlling factors those affect mechanical and physical properties of fabricated composite are more or less difficult under hand lay-up technique. Again, obtaining different type of resin, hardener and Al-powder are needs a long time. Finally, to prepare specimen the cutter those don't affect microstructure of the fabricated composite i.e., abrasive water jet, diamond cutter, etc. are not available. Additionally, to conduct test like flexural, bending and surface morphology machines are not easily available. And also, machine calibration error controlling is also difficult on manual controlled test machine.

1.7 Thesis organization

This thesis has five chapters:

Chapter One: addresses clearly about background of the study, general and specific objectives, statement of problem, scope of the study, significance of the study, limitation, and organization of the thesis study

Chapter Two: literature review based on journals those related to this study is written. The background and general results, discussion and conclusion of previews researcher work are summarized in this chapter.

Chapter Three: delivers methodology and materials those used in this project. The fiber extraction method, chemical treatment system, sample fabrication procedure, specimen preparation procedure, tests conducting procedure and machines used for tests are clearly provided by this chapter.

Chapter Four: addresses the results of tensile test, compression test, density, micro hardness, water absorption percentage and microstructure are analyzed. The comparison among each fabricated samples was done.

Chapter Five: provides conclusion, recommendation and future research area based on the study results and finding.

CHAPTER TWO

LITERATURE REVIEW

2.1. Reinforced Fibers and Matrices used for Composite fabrication.

Composites are materials made up of two or more chemically separate constituents, on a macro-scale, having a distinct boundary separating them. One or more broken phases therefore, are inserted in a continuous phase to form a composite. The discontinuous part is usually harder as well as tougher than the continuous phase which known as reinforcement, whereas, the continuous phase is named the matrix. The matrix material can be metallic, polymeric or else ceramic. When the matrix is a polymer, the composite is called polymer matrix composite (PMC). This reinforcing material can be fibrous or non-fibrous (particulates) in nature. If the fibers are unoriginal from plants or some other living types, fiber are known as natural-fibers. The fiber reinforced polymers (FRPs) be made up of fibers of high strength and modulus united to a matrix with a distinct border stuck between them. In this form, both fibers and matrix hold their physical as well as chemical identities. In general, fibers are the foremost load carrying supporters, whereas the matrix holds onto them at the preferred location as well as orientation, acts as a load transmission intermediate between them, and defends them from environmental damage (Boopalan *et al*., 2013).

Composite material is made of two or more materials joined in such a way that the distinct materials are easily differentiable. Reinforcements mainly come in three forms which are particulate, continuous, and discontinuous fiber. Matrix materials are commonly certain type of plastic. The most common plastic matrices are epoxy and polyester and vinyl-ester resins (Fragassa, 2017). Matrix plays a minor in the case of tensile loading of the composites. However, compressive, in plane shear and interlaminar strengths are highly influenced by the variety of matrix used (Senthilkumar *et al*., 2018).

The properties of natural fiber based composites are mainly influenced by fiber content and amount of filler (Badrinath and Senthilvelan, 2014). Fiber reinforced polymer constituents are composites consisting of great strength fibers (reinforcement) embedded in polymeric matrices. Fibers are the load-carrying components and provide strength and rigidity, despite the fact the polymer matrices sustain the fibers alignment, orientation and position and protect them against the environment and imaginable damage. A pure polymer does not frequently have mandatory mechanical strength for application in various fields. The reinforcement by high strength fibers be responsible for the polymer substantially improved mechanical properties and makes the fiber reinforced polymer composites (FRPCs) appropriate for a large number of various applications ranging from aerospace to sports apparatus (Begum and Islam, 2013).

The bonding at the fiber matrix interface plays a most important role in the mechanical behavior of composite materials. In polymer matrix composites the most important role of the matrix is to distribute the applied stress among the fibers. The applied stress must be transferred across the fiber/matrix interface, transverse, longitudinal, shear strength of polymer matrix composite depend heavily on the interfacial bond strength. Thus bonding must be exploited if the full strength of reinforcing fiber is to be realized, making perfect characterization of interfacial tie in composite materials (Badrinath andSenthilvelan, 2014).

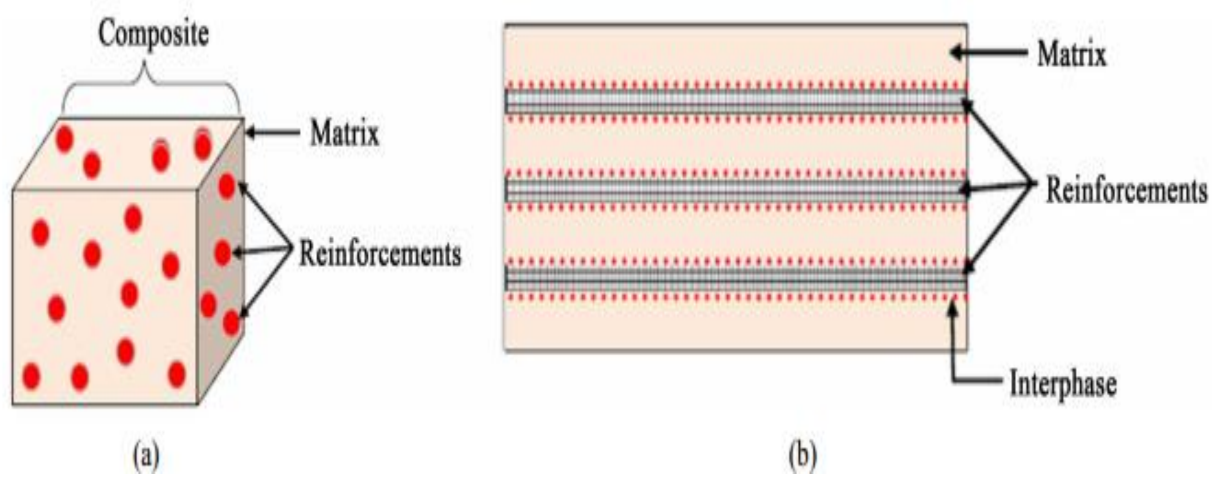


Figure 2.1: (a) Pictorial presentation of laminate which include resin as a matrix and fiber as reinforcement and (b) shows inter-phase of matrix and reinforcement (Ashik and Sharma (2015))

The reinforcing capability of lingo cellulosic fibers in polymer matrices is strongly dependent on the properties and structure of the component phases, their relative concentrations and parameters such as orientation , diameter, distribution and fiber length (Merlini *et al*., 2011), (Saliba *et al*., 2005).

2.1.1. Natural Fibers

Natural fibers have an appeal to the attention to researchers, engineers, professionals as well as scientists all over the world as an another reinforcement, for the reason that have superior properties such as high specific strength, low cost, low weight, fairly good mechanical properties, eco-friendly non-abrasive, and bio-degradable physical characteristics (Elanchezhian *et al*., 2018).

Natural fiber composites are an alternative for substituting environmentally dangerous synthetic materials and help control greenhouse gasses problems. Natural fiber composites possess better electrical resistance, good thermal and acoustic insulating properties, good mechanical properties and higher resistance to fracture (Ramnath *et al*., 2014). It can be categorized into two types namely animal and plant-based fibers (Lau *et al*., 2018) but other litratures categorizes natural fibers into three based on sources of extaction as: Animal based (silk, wool, hair), mineral based (asbestos) and cellulose/lignocellulose based fibers. The cellulose/ligno cellulose based natural fibers are given by the Tables 2.1.

Table 2.1: Cellulose/Lignocellulose fibers source and its varieties

Source	Types (varieties)	Source
Blast	Flax, Jute, Hemp, Ramie, Roselle, Rattan, Kenaf, Sugarcane, Banana	(Rathore and Pradhan, 2017)
Leaf	Sisal, Manila, Abaca, Banana, Palm, Mengkueng, Date Palm, Pineapple, Henequen, Agava, Raphia	(Ashik and Sharma, 2015)
Wood	Hardwood, Softwood, 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	

2.1.2. Physical properties of Banana Fibers

Fibers with the highest aspect ratio will show highest tensile properties deliver high surface area which are valuable for reinforcement purposes (Bhatnagar *et al*., 2015).

Table 2.2: Physical properties of Banana Fibers

No:	Properties	Value	Source
1	Moisture	10-11%	(Ramesh *et al*., 2014)
2	Density	1-1.5 g/cm^3	

2.1.3. Chemical Properties of Banana Fibers

It is well-known that cellulose is the key essential of plant fibers followed by hemicelluloses and lignin interchangeably and pectin respectively. Cellulose is also the reinforcement for lignin, hemi cellulose and Pectin (Bhatnagar *et al*., 2015).

Table 2.3: Chemical Properties of Banana Fibers

No:	Properties	Range Value	Source
1	Cellulose	60-65%	(Bhatnagar *et al*., 2015)
2	Hemi Cellulose	6-19%	
3	Lignin	5-10%	
4	Pectin	3-5%	
5	Ash	1-3%	
6	Extractives	3-6%	

2.1.4. Mechanical Properties of Banana Fibers

The mechanical property of natural fibers differs from fibre to fibre. The mechanical properties of fiber are influenced by origin, age, type of fibre, volume fraction physical properties, various structure, environmental conditions as well as processing methods. Different matrix systems have not the same properties. Natural fibers have well approaching as reinforcements in polymer composites (Arpitha and Yogesha, 2017). According to (Venkateshwaran *et al*., 2012) report the main parameters which affect the mechanical properties of the composites are fiber length, fiber orientation, weight ratio, and interfacial bond between fiber and matrix (John K, 2004). Mechanical properties of short banana fiber was reported by (Srinivasan *et al*., 2014) indicates that: the volume fraction of the short banana fibre significantly influences the dynamic mechanical properties of the fibre reinforced polyester composites. It is also originated that the properties like flexural and impact strength of banana composite are superior to hybrid composite (Pothan *et al*., 2003)

Table 2.4: Mechanical Properties of Banana Fibers

No:	Properties	Value	Source
1.	Tensile Strength	529-914 MPa	(Bhatnagar et al., 2015) (Arpitha and Yogesha, 2017)
2.	Impact Strength	13.25 kJ/m^2	(Arpitha and Yogesha, 2017)
3.	Flexural Strength	57.33 MPa	
4.	Flexural Modulus	8.9 GPa	
5.	Failure strain	1-3%	(Bhatnagar *et al.*, 2015)
6.	Diameter	80-250 µm	
7.	Length	1000-5000 mm	
8.	Aspect Ratio (l/d)	150	
9.	Young's Modulus	20 GPa	(Ramesh *et al.*, 2014)
10.	Micro fibrillar angle	11^0	
11.	Lumen size	5 mm	

2.2. Fiber Orientations

Different fiber orientation used to fabricate composite are mentioned as given by following Figure 2.2.

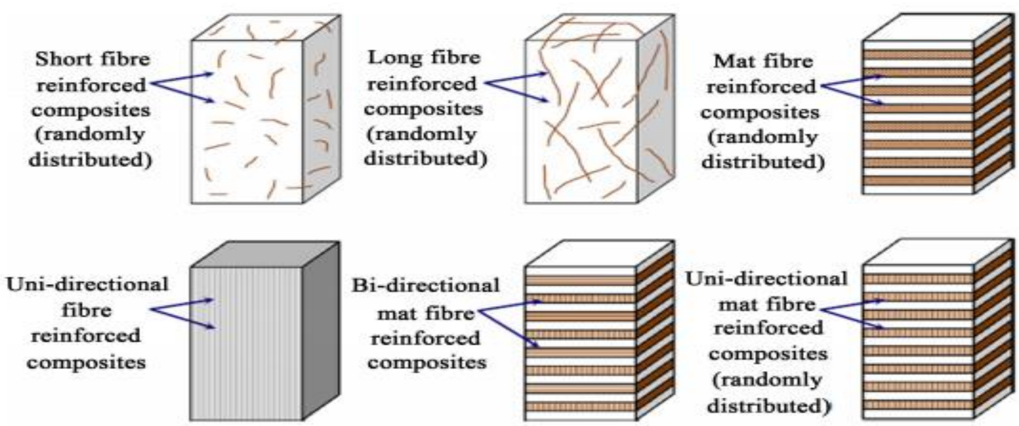


Figure 2.2: Different type of fiber orientation used for the laminate manufacturing (Ashik and Sharma, 2015)

2.3. Filler /Aluminum Powder Filler Properties

Pujan Sarkar *et al.*, (2017) reported that Aluminium has low weight, easy machining, high strength, and superior ductility, and superb corrosion resistance, good thermal and electrical conductivity. Aluminium is also very easy to recondition. Mechanical properties including dimension accuracy, hardness, and thermal conductivity improved by combination of Aluminium powder with epoxy resin. It is also proven that on decreasing the particle size, mechanical properties increase more. The application of Aluminium matrix composite materials are raising continuously in the field of automotive and aerospace for the reason that they have superior physical and mechanical tribological properties as compared to base alloy. Composite materials with metal matrix materials like Aluminium or Magnesium are finding comprehensive level applications in many industries because of their high hardness, lower density, better wear as well as corrosion resistance, high strength to weight ratio, good formability, high thermal shock resistance, high fatigue strength high modulus etc. Aluminium based composites reinforced with micro/nano Sic, Al_20_3, TiB_2, ZrO_2, B_4C, and SiO_2 and graphite particles, changes the micro-structural characteristics that develop superior mechanical as well as physical properties for automotive/aerospace applications (Koli *et al*., 2015).

As reported by (Dasari *et al*., 2018) the low density of Aluminium permits its usage within numerous MMCs applications. Furthermore, it is inexpensive in comparison to commonly used low density metals such as Ti and Mg. High corrosion resistance and better formability makes Aluminium a material used for automobile applications over other alternatives, including ferrous metals.

In case of Aluminium particulate composites, Aluminium powder is added to the epoxy resin first then, mixed well in continuous stirring manner then the hardener is added with the Aluminium epoxy mixture (Sarkar *et al*., 2017).

Saba *et al*., (2016) obtained that addition of 3% of Nano oil palm empty fruit bunch fiber (OPEFB) filler into kenaf epoxy composites considerably improves the mechanical and morphological properties.

2.4. Fabrication Process

To date, a number of manufacturing approaches have been explored to produce composites, such as film stacking, vacuum infusion, hand lay-up, compression moulding, filament winding, manual winding, resin transfer moulding, injection moulding, and pultrusion to name a few (Sajay *et al*., 2018).

According to (Bakri *et al*., 2017.) samples fabrication processes were prepared on two samples which divided into two parts, untreated and treated. For the untreated samples, the banana fibers were washed with distilled water and dried in an oven at 60 °C for 48 hours. For the treated samples, the banana fibers were submerged in 5wt % sodium hydroxide solution at the room temperature for 24 hours. Immersing the fibers with NaOH solution helps to eradicate impurities and increased the surface roughness of the fibers. Later, the wrapped up banana fibers in the sodium hydroxide solution were cleaned with distilled water and dried in an oven at 60 °C for 48 hours. (Mehamud et al., 2016) prepared four sets of samples; one set is 5% banana fiber with 95% epoxy resin, second set is with 10% banana fiber with 90% epoxy resin, third set is 15% Banana fiber with 85% of epoxy resin and fourth set is 20% Banana fiber with 80% of epoxy resin, all of the specimens are on 0/90 degree (straight unidirectional) orientation fibers are linearly increasing percentage of banana fiber indicate the optimum condition of the experiment. First mix LY5560 resin and hardener in the ratio 10:1 and apply on the mould. Place banana fibers on 90 degree orientation. Again apply resin and hardener over the fiber. The trapped air bubbles are removed carefully with a sliding roller and the mould is closed for curing at a temperature of 30°C for 24 hour at a constant load of 50kg.

Stirring of the mixture continues for a certain duration based on the exothermic reaction. The inner sides of the mould is enclosed with very thin tear resistant plastic film of few microns thickness to carry out the similar function of releasing agent to escape the possibility of infusion of releasing agent into the glass fiber. Epoxy (resin and hardener) or Aluminium mixed epoxy is lap up on the woven fibers uniformly and at that point the wetted fibers are placed one above the other into the mould. The entire assembly is pressed in a hydraulic press (20 kg) and is left for 24 (twenty four) hours at room temperature. The compression confirms that the entrapped air bubbles are absolutely removed with the excess resin. After de-moulding post curing is prepared at room temperature for 48 hour to complete the fabrication process (Sarkar *et al*., 2017).

The composite are made-up by hand lay-up technique. The mould used for producing the composite is prepared up of Aluminium with a debonding agent applied on the inner flank. The inner cavity dimension of the mould is 150mm x 150mm x 10mm. The fiber is immersed in the resin and make straight in the mould where the resin is also poured. The fiber fraction used was fixed 30%. The upper side is pressed using a roller in less than room temperature until the matrix is set properly. The setup is left to cure for 24 hours at room temperature. The prepared composite were cut for testing obey the dimensions of the specimen as per ASTM standards (Santhosh *et al*., 2014).

To analyze mechanical properties, the materials used were jute fibers and aluminum powder. The jute fibers were prepared by washing as well as drying it and cutting it into 10mm to12mm. The composites were produced by the hand lay-up process, as shown in Figure 2.3 and they have taken the several volume percentage (8% and 16%) of the jute fibers and aluminum powder (Rafiquzzaman *et al*., 2016).

Figure 2.3: Jute fiber, Al Powder, Epoxy resin and hardener (Rafiquzzaman *et al*., 2016)

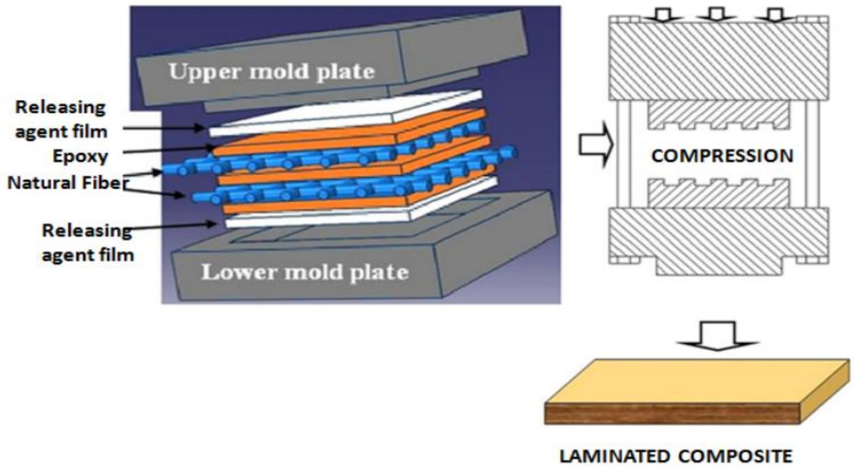


Figure 2.4: Schematic of hand layup and compression molding method for fabrication of laminate composite (Singh *et al*., 2017)

One of the methods of making biocomposites is by lamination. Lamination will ensure that the distribution and the alignment of the fiber can be controlled accurately in the biocomposites. Fiber orientation plays important role in biocomposites for the reason that the properties measured along the fibre orientation are usually higher that the properties measured in the perpendicular direction. Biocomposites of uniform properties can certainly be produced by crossing the fibre orientation in the different layers of the laminates (Baharin *et al*., 2015).

2.5. Treatment needed for Natural Fibers

Bakri *et al*., (2017) reported that as there were many approaches for treating the natural fibers. The methods used may be either in single or mixture of physical, chemical, thermal, and mechanical treatment. Among those approaches, alkaline treatment is generally used chemical treatment for natural fiber composites. The alkaline treatment caused alteration in the network structures of hydrogen bond due to reaction by means of alkaline based solution, such as NaOH, especially on the internal and external structure of fibers. This also caused deviations in the surface roughness, removal of smelly odors and change in the color of the natural fibers. Alkaline treatment improves the natural fiber and polymer bonding, which created strong structural fiber composites due to the removal of oil, wax and impurities on the cell wall surfaces of the fibers.

Jordan and Chester, (2017) reported some common chemical treatments used in natural fibers i.e., silane treatment, peroxide treatment, alkali treatment, permanganate treatment, isocyanate treatment, and a polymer coupling agent such as maleic anhydride.

Collected fibers were treated with alkali then; process of neutralization was done by treating the fiber with 5% acetic acid solution. The jute and banana fibers were cut to 60cm of length and soaked in a 5% of NaOH solution separately at 30 ^{0}C for 4 hours. The fibers were then washed numerous times with distilled water to remove any NaOH piercing to the fiber surface, neutralizing it with dilute acetic acid and washed again with distilled water. Final pH value maintained was 7. The fibers were then dried at room temperature for 48 hours, followed by oven drying at 100 ^{0}C for 6 hours for the removal of moisture content (Pujari *et al*., 2017).

Various mechanical properties of natural composites like Young's modulus, hardness, flexural modulus, and impact strength can be enhanced by treating it by Maleic Anhydride (Mishra *et al*, 2000). The treatment of physically and chemically are needed to enhance interfacial bonding between fiber and matrix and elimination of no-fibrous substances such as pectin and lignin, waxes and other water-soluble substances (Benitez *et al*., 2013). Chemical modifications have upgraded the mechanical properties of banana fibre reinforced polyester composite and upon various chemical treatments simple alkali treatment with 1% NaOH proved to be more effective (Pothan *et al*., 2002). The chemically treated banana fibers reinforced composites showed superior mechanical properties than untreated fiber reinforced composites (Ramesh *et al*., 2014). The interface adhesion between nano particles and matrix evaluated, using the dynamic mechanical analysis (DMA) method, using the visco-elastic behavior of the composite that NaOH treatment has the improved the storage modulus value of the composite at all frequencies (Nagendra et al., 2017)**.** The fibers were treated with 5% of NaOH for 1 hour. The fibers are then washed carefully with distilled water. Fibers are then dried in oven for 2 hours at 100°C to remove the moisture content in fiber (Santhosh *et al*., 2014).

Alkali treatment of jute and banana fibre reinforced composites with 5% NaOH increases the mechanical properties of composites. Improvement of interfacial bond is important in improving mechanical properties (Prasad *et al*., 2014). The treated banana fiber composites revealed higher tensile strength in addition young's modulus values than the untreated composites, due to the stronger interfacial interactions among the treated fibers and the polyurethane matrix. These effects happened due to the morphological and chemical changes in the treated fiber surfaces which encourage better adhesion between fibers and the polyurethane matrix (Prabu *et al*., 2014). The bonding between banana fibers and matrix are done by chemical treatment. The chemical treatment needed for natural fibers are as listed in Table 2.5.

Table 2.5: Chemicals used to treat natural fibers (Sood and Dwivedi, 2017).

Name of Treatment	Chemicals used	Strength of Chemical
Alkali Treatment	Sodium Hydroxide	5%, 10%, 15%
Acetylation Treatment	Siliane	5 wt% in Methanol
Benzoylation treatment	Benzoyl Chloride	-
Cyclohexane modification	Cyclohexane/Ethanol	1:1 vol/vol
Etherification	Dodecane bromide, NaOH, Isopropanol	12 mol Dodecane bromide into Isopropanol solution
Fluorocarbon treatment	Derigurard UFC	50g/l
Isocyanate treatment	Carbon tetra chloride and dibutyl tin dilaurate	-
Modification with Alkyl Ketene dimer	Alkyl Ketene Dimer	3-5% Alkyl ketene dimer in n-hexane
Modification with maelic anhydride	Maelic Anhydride	20 wt% solution into Acetone
Permanganate treatment	Potassium permanganate	0.005% in Acetone
Peroxide treatment	Benzoyl peroxide or Dicumyle peroxide	6% solution in Acetone
Silicon treatment	Perisoft MSA	20g/l
Stearic acid treatment	Stearic acid	1% solution in ethyl alcohol
Sulfuric acid treatment	Sulfuric Acid	1% (wt/vol)
Treatment with Ethylene diamine tetra acetic acid (EDTA)	EDTA	Solution of 5g/l
Treatment with flexible epoxy resin	Flexible epoxy resin	1g resin: 200ml Acetone

2.6. Natural Fibers Application

Ramesh *et al*., (2014) reported that natural fibers are non-abrasive, renewable, and bio-degradable, possess a good calorific value, exhibit excellent mechanical properties and can be burn up for energy recovery have low density and are cheap. This good environmental friendly feature makes the materials very widespread in engineering markets such as the automotive and construction industry.

Common application of natural fibers-reinforced composites includes interior paneling for aircraft, and automobiles, household Tables, chairs, window frames, laptop cases, and other consumer items. Natural fibers composite are appreciated for their sustainability and light weight compared to similar conventional composites, which makes them especially popular in the automotive industry (Jordan and Chester, 2017). Aerospace applications of advanced composites increase for about 50% of current sales and sporting goods, for instance golf clubs and tennis rackets, increasing account for another 25%. Automobiles and industrial equipment are manufactured using polymer matrix composites. The next main challenge for polymer matrix composites is used in large military and commercial transport aircraft. Because of their resistance to corrosion, they may also be good-looking for marine structures. In space, a variety of composites may possibly be used in the suggested Aerospace plane, and polymer matrix composites are being considered for the tubular frame of the NASA space station (Badrinath and Senthilvelan, 2014).

Natural fiber composites are nowadays being used in numerous engineering applications to increase the strength and to optimize the weight and the cost of the product (Santhosh *et al*., 2014).

It is used in fabrication of vehicle body; this reduces the weight of the vehicle and as a result reduces CO_2 emissions and fuel consumption to the required target in the transportation sector (Onyedum *et al*., 2015), (Metu *et al*., 2015).

The motives for the application of natural fibers in the automotive industry include:

- Low density
- Acceptable mechanical properties, good acoustic properties
- Favorable processing properties, i.e., low wear on tools, etc.
- Options for new production technologies and materials.
- Favorable accident performance, great stability, less splintering
- Favorable eco-balance for part production
- Favorable eco-balance during vehicle operation due to weight savings
- Occupational health benefits compared to glass fibers during production

- No off gassing of tonic compound
- Reduced fogging behavior
- Price advantages both for the fibers and the applied technologies (Tudu, 2009).

According to (Arthanarieswaran *et al*., 2014) report natural fiber composites are normally used in automobiles, aerospace, packaging industries and construction sector. Fiber can be used for fabrication of light weight apparatuses used in housing sector, automobile body building, packaging industry, and partition panels. The alternatives of the conventional material for curved pipes are succeeded by natural (hemp) and glass fiber together with 20% cost reduction and 23% weight reduction (Cicala *et al*., 2009).

It is estimated an increase of the use of natural fibers in automotive parts at about 54% per year, since European as well as American car makers have been previously using them to achieve environmental directives. In USA automotive companies are taking on natural materials: about 1.5 million of vehicles are even now using vegetable fibers such as jute, hemp, kenaf as reinforcement of thermoplastic and thermosetting polymers (Alves *et al*., 2010).

Today's car designers are antagonized with a number of challenges (increasing fuel efficiency, enhancing performance, improving safety, and confortable) and a number of structure materials to decide on (steel, Aluminium, as well as thermoset and thermoplastic composites to name a few (Osborne, 2013). Vehicle's light weighting is doubtfully the most strongly talk over topic in today's automotive industry. The cars that roll off the company production lines in the future need to grow into lighter to encounter global emissions targets that are fast approaching and focus on strict fuel efficiency as well as CO_2 emissions targets. Global vehicle production estimated to increase from 88.7 million in 2015 to more than 110 million units by 2015 (Spinks, 2017). The applictain of polymeric materials allows more freedom in design and approximately 82% of an average vehicle's weight gets recycled. The main characteristic in choosing the high performance plastic materials in relation to other materials used in automotives are the design of automobiles, their functionality and more economic manufacture, as well as reduced fuel consuption. It is estimated that every 10% reduction in vehicle weight result in a 5-7% reduction in fuel usage (Patil *et al*., 2017).

Table 2.6: Application of natural fiber composites in different automotive manufacturer companies

Manufacturer	Vehicles Model	Parts made from Natural Fibers	Source
Audi	A2, A3, A4, A4 Avant, A6, A8, Road Star, Coupe	Seat backs, side and back door panel, boot lining, hat rack, spare tire lining	(Faruk, 2015), (Pervaiz *et al*., 2016), (Akova, 2013)
BMW	3, 5 and 7 Series and others	Door panels, headliner, boot lining, seat back, noise insulation panels, molded foot and well linings	(Faruk, 2015), (Pervaiz *et al*., 2016), (Akova, 2013)
Citroen	C5	Interior door paneling	(Akova, 2013)
Daimler-Chrysler	A, C, E, and S class	Door panels, windshield/dashboard, business Table, pillar cover panel	(Faruk, 2015) (Pervaiz *et al*., 2016)
	A class, Travego Bus, Evo Bus	Exterior under body protection trim	
	M class	Instrumental panel	
FLAT	Punto, Brava, Marea, Alfa, Romeo 146, 156		(Faruk, 2015) (Akova, 2013)
Ford	Mondeo CD 162, Focus	Door panels, B-pillar, boot liner	(Faruk, 2015) (Pervaiz *et al*., 2016), (Akova, 2013)
LOTUS	Eco Elise	Body panels, Spoiler, seats, interior carpets	(Akova, 2013)
Mercedes-Benz	Trucks	Internal engine cover, engine insulation, sun visor, interior insulation, bumper, wheel box and roof cover	(Pervaiz *et al*., 2016)
Mitsibushi	Space star	Door panels	(Faruk, 2015)
	Colt	Instrumental panels	
Opel	Astra, Vectra, Zafira	Headliner panel, door panels, pillar cover panel, instrumental panel	(Faruk, 2015)
Peugeot	New model 406	Seat backs, parcel shelf	(Faruk, 2015) (Akova, 2013)
Renault	Clio, Twingo	Rear parcel shelf	(Faruk, 2015) (Akova, 2013)
Rover	Rover 2000 and others	Insulation, rear storage shelf/panel	(Faruk, 2015) (Akova, 2013)

Saab		Door panels	(Faruk, 2015)
SEAT		Door panels, seat back	(Faruk, 2015) (Akova, 2013)
Toyota	Brevis, Harrier, Celsior, Raum	Door panels, seat backs, and spare tire cover	(Akova, 2013) (Pervaiz *et al.*, 2016)
Volkswagen	Golf A4, Passat, Variant, Bora, Fox, Polo	Door panel, seat back, boot liner and boot lid finish panel	(Faruk, 2015), (Pervaiz *et al.*, 2016), (Akova, 2013)
Volvo	C70, V70	Seat padding, natural foams, cargo floor tray	(Faruk, 2015) (Pervaiz *et al.*, 2016), (Akova, 2013)

The following natural fiber used in automotive body described in Figure 5-8 are taken from (Faruk, 2015) report to illustrated how it was applicable and suitable for this sector.

Figure 2.5: Automotive door in-liner, instrumental panel made from wood fiber reinforced composites

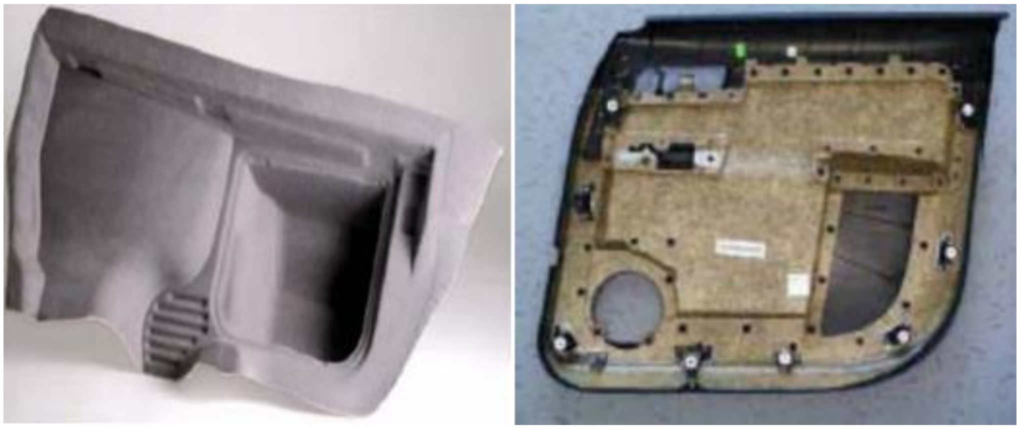


Figure 2.6: Automotive door-in-liner made from jute, flax, hemp, sisal fiber reinforced composite

Figure 2.7: Under floor protection trim of Mercedes A Class made from Banana fiber reinforced composite

Figure 2.8: Newest Mercedes S Class Automotive components made from different bio fiber reinforced components

The amount of natural fibers that used for fabrication automotive body components are summarized by Table 2.7.

Table 2.7: Fibers average weight to fabricated automotive body (Faruk, 2015).

Automotive Component	Typical Weight of fibers (kg)
Front door liners	1.2-1.8
Rear door liners	0.8-1.5
Boot liners	1.5-2.5
Parcel shelves up to	2.0
Seat backs	1.6-2.0
Sunroof sliders up to	0.4
NVH material min	0.5
Headliners average	2.5

2.7. Summary of Literatures

The summary of finding and conclusion of different literatures those related to this study are addressed as following to clearly indicate applicability of natural fibers.

Sarkar *et al.*, (2017) concluded that density and void fraction of glass epoxy composite increase with the incorporation of Aluminium powder. Density increase when weight percentage of Aluminium Powder increases. With the presence of Al-Powder filler up to 10 wt%, Micro-hardness of the composite is improved as compared to unfilled glass epoxy and with further addition of Aluminium up to 15 wt%, Micro-hardness decrease. It is found that, there is a gradual drop in tensile strength within Aluminium content. It is observed that the tensile modulus of glass epoxy composites improve significantly with 10 wt% of Al-powder content. But in the case of 5 and 15 wt% Al-powder filled glass epoxy composites, it decreases with respect to unfilled glass epoxy composite. The highest improvement of flexural strength with 5 wt% of Aluminium content is recorded whereas 15 wt% Aluminium filled glass epoxy composites shows the lowest strength even lower than the unfilled composite.

Adhikari and Gowda, (2017) studied that: the tensile strength, flexural strength, and impact strength of short randomly oriented banana/jute hybrid polyester composite. They had taken 25%, 20%, 15%, 10% and 5% fiber volume fraction by maintaining banana/jute volume in 1:1

ratio. The specimens were prepared for 3mm as well as 5mm thickness. The optimum fiber volume fraction for tensile as well as flexural strength is found to 15% and impact strength increase in fiber loading continuously up to 25%. The mechanical properties slightly increase with the increase in thickness of specimen.

The samples with various percentages were cut as per ASTM standards using water jet machining for conducting physical and mechanical tests such as tensile strength, flexural, impact strength test. The comparison of tensile strength reveals that 05% banana 90^{o} orientation fiber/ epoxy composite has 67.5MPa higher tensile strength than 20% banana bidirectional fiber 47.4MPa, fiber concentration decreases the tensile strength also increases. Impact tests reveal that 05% banana fiber / epoxy and 10% banana bidirectional fiber possess higher impact strength than other fiber samples. The flexural strength of 05% banana fiber/ epoxy exhibits improved flexural strength of 390.442MPa than other banana fiber permutations. The morphological study reveals that fibers pull out occurred on various percentages of bidirectional fiber, Epoxy resins are well bonded than bidirectional fibers which results in weak interfacial bonding on fiber percentage and 5% banana 90% orientation fibers (Raj *et al*., 2016).

With a fixed wt% of fiber reinforcement, and different wt% Aluminium powder filler, glass epoxy composites are fabricated in convectional hand lay-up technique followed by light compression moulding process. Results show steady decrease of tensile strength with Aluminium powder addition (Sarkar *et al*., 2018)

Venkateshwaran *et al*., (2011) concludes that: addition of sisal fiber in banana/epoxy composites of up to 50% by weight results in increasing the mechanical properties and decreasing the moisture absorption property.

The comparison of tensile strength reveals that 20% banana fiber and 80% epoxy on 90^{0} orientation fiber/ epoxy composite has 56.5MPa exhibit higher tensile strength than 15% banana unidirectional fiber 47.4MPa. Whereas 10% banana unidirectional fiber/epoxy composite has exhibit better tensile strength of 42.6MPa than 5% banana unidirectional fiber which has only 37.8MPa. When fiber concentration increases the tensile strength also increases. Impact tests reveal that 20% banana fiber /epoxy unidirectional and 15% banana unidirectional possess higher impact strength than other fiber samples. The flexural strength of 20% banana fiber/epoxy unidirectional exhibits better flexural strength of 340.625MPa than other banana fiber percentage (Mehamud *et al*., 2016).

Merlini *et al*., (2011) concluded that: The tensile strength and Young's modulus improved with increasing fiber volume fraction and length for the untreated and treated banana fiber polyurethane composites. On the other hand, the treated banana fiber composites showed higher tensile strength and Young's modulus values than the untreated fiber composites, due to the stronger interfacial interfaces between the treated fibers and the polyurethane matrix. These effects ensued due to the morphological and chemical changes in the treated fiber surfaces which endorse better adhesion between the fibers and the polyurethane matrix.

Both treated and untreated banana fiber are in use for the development of the hybrid composite material. The untreated banana fiber is treated by NaOH to increase the wettability. The untreated banana fiber and sodium hydroxide treated banana fiber are used as strengthening material for both epoxy resin matrix and vinyl ester matrix. Coconut shell powder is used alongside with both untreated and treated banana fiber as a reinforcing material. The variations in mechanical properties are considered and analyzed (Santhosh *et al*., 2014).

Study different natural fibers like jute, banana and sisal have been used as reinforcement and epoxy as matrix to make the natural fiber reinforced polymer unidirectional composite with the help of hand lay-up as well as compression molding. Mechanical properties alike flexural strength, tensile strength, and impact strength for treated and non-treated natural fiber reinforced polymer unidirectional composites have been examined and compared. It has been found that tensile strength of the composites has enhanced due to incorporation of natural fibers to polymers. Further a considerable increase in tensile and flexural strength has been observed with the use of surface treatment method; nonetheless impact strength has been extremely decreased with the use of surface treatment. It has also been found that the jute reinforced polymer composite shows the highest tensile strength (Singh *et al*., 2017).

Two different chemical treatments considered to encourage the interfacial bonding between banana fibers and an LDPE matrix: peroxide treatment and permanganate treatment are used. The sound effects of the treatments on the tensile properties of individual banana fibers were explored, with peroxide treatment improving the tensile properties and permanganate treatment having an inadequate effect. Some interesting outcomes from composite processing are concisely explored, leading to peroxide treated fibers being omitted from composite testing. Untreated banana fibers provided a measurable increase in composite properties, especially in tensile stiffness. Permanganate treated fibers delivered little to no advantage in composite properties compared to their untreated counterparts, even with post-fracture analysis showing enhanced interfacial bonding (Jordan and Chester, 2017).

Banana fiber reinforced epoxy composites are fabricated and the mechanical properties of these composites are calculated based on 40%, 50% and 60% banana fiber with 60%, 50% and 40% epoxy resin. The composite samples with different fiber volume fractions were prepared by using the hand lay-up process and apply pressure at room temperature. The samples were exposed to the mechanical testing such as tensile, flexural and impact loading. Scanning electron microscope (SEM) analysis is carried out to estimate fiber matrix interfaces and investigate the structure of the fractured surfaces. They observed that 50% banana fiber and 50% epoxy resin polymer composites are performing better than other composite combination tested. 60% banana fiber and 40% epoxy resin polymer composites are performing better than other composite tested regarding flexural load. Impact strength observed that, the 60% banana fiber and 40% epoxy resin polymer composites are performing better than other composite combinations tested (Ramesh *et al.*, 2014).

The banana fibers were gained from agricultural field after banana fruit has been matured. And it experienced an alkaline treatment using 5wt % of NaOH. The composites were prepared with various fiber loadings, extending from 5wt %, to 20wt %. The effects of alkaline treatment on the mechanical, morphological, as well as spectral properties were inspected and evaluated using, universal testing machine, light/optical microscope, scanning electron microscopy, and Fourier transform infrared spectroscopy. Based on the results obtained, it is observed that a lot of factors involved in affecting the characteristics of the natural composites, for instance density, fiber amount, and structure agglomeration. From the results obtained, treated fiber composites have superior properties as related with untreated fiber composites. The alkaline treatment on the fibers makes happen better adhesion of epoxy in the banana epoxy composites. It created surface roughness, which improved the bonding between fiber and matrix that created enhanced tensile and yield strength (Bakri *et al*., 2017.)

Generally, majority of reachers gives attention to replacing heavier metals and glass fibers those affects environment after disposal and needs high manufacturing cost for any industrial application by cheap and environmentally friendly biodegradable natural fibers. As a means of solution for problem mentioned above many researcher had done their study on individual fibers variety source, by hybridization of two or more fibers and adding of different fillers. But, in developing country abudant fiber sources including banana are disposed as a waste. And also, almost there is a limited knowledge and skill to use fibers that obtained from banana stem considered as waste in Ethiopia for automotive body application and other purpose. Instead sisal and false banana are used as a source of fiber for different purpose throughout the country. Additionally, trends of adding metallic materail with natural fiber is not such much known for different application in construction, manufacturing and automotive industries. So, the aim of this study is to utilize unutilized banana stem resouce and to satisy unstasfied labor force of our country by conducting study on this research gap for country future income generation source and environmental protection.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Introduction

The main objective of this study was to fabricate a new composite from banana fiber filled by Al-Powder filler and analysis its mechanical and physical properties. The samples were fabricated based on weight fraction. The procedure to fabricate laminated composite was described clearly in flow chart below.

- Banana fiber was extracted and collected from Hawassa City area. These fibers washed repeatedly by down runner water and dried in air. Banana fiber was treated by using 5% NaOH in Chemistry department laboratory, Hawassa University, Ethiopia. The pH for this amount of NaOH was measured. Then, treated fiber was washed three times till it becomes neutral by means of down runner water. Finally, it was washed by distilled water and dried in air for 48 hours.
- Unsaturated polyester resin and hardener (Catalysts) was bought form World Fiber Glass and Water Proofing Engineering Company, Addis Ababa, Ethiopia.
- Aluminum Powder filler was purchased from Germany Country online market.
- Musk, brush, gloves, roller, wax, string wood, and scissors were purchased from local pharmacy and market centers.
- Mold was prepared form Aluminium sheet to fabricate samples.
- Simple hand lay-up composite production method was used that followed by compression molding for 24 hours to remove excess resins and air bubbles.
- Treated banana fibers without/with Aluminum Powder filler was produced layer by layer through using resin by hand lay-up system and rolled by roller.
- The curing process was taken at room temperature for 48 hours.
- The fabricated sample was cut into specimens based on tests standard to obtain their mechanical and physical properties by using convectional testing machines.
- The results were analyzed and the optimal composite fabrication weight ratio was identified.

Unsaturated polyester resin and hardener was mixed based on the weight ratio. Then Al-Powder filler was added to mixture of resin and hardener according to samples based on wt% requirement. To obtain the influence of Aluminum Powder filler on banana fiber matrix weight fraction to resin-hardener mixture was carried out.

Generally, all samples were produced based on the treated fiber filled Aluminum Powder filler on four (4) different ratios to resin-hardener mixtures. The whole mixing ratio was done based on weight ratios.

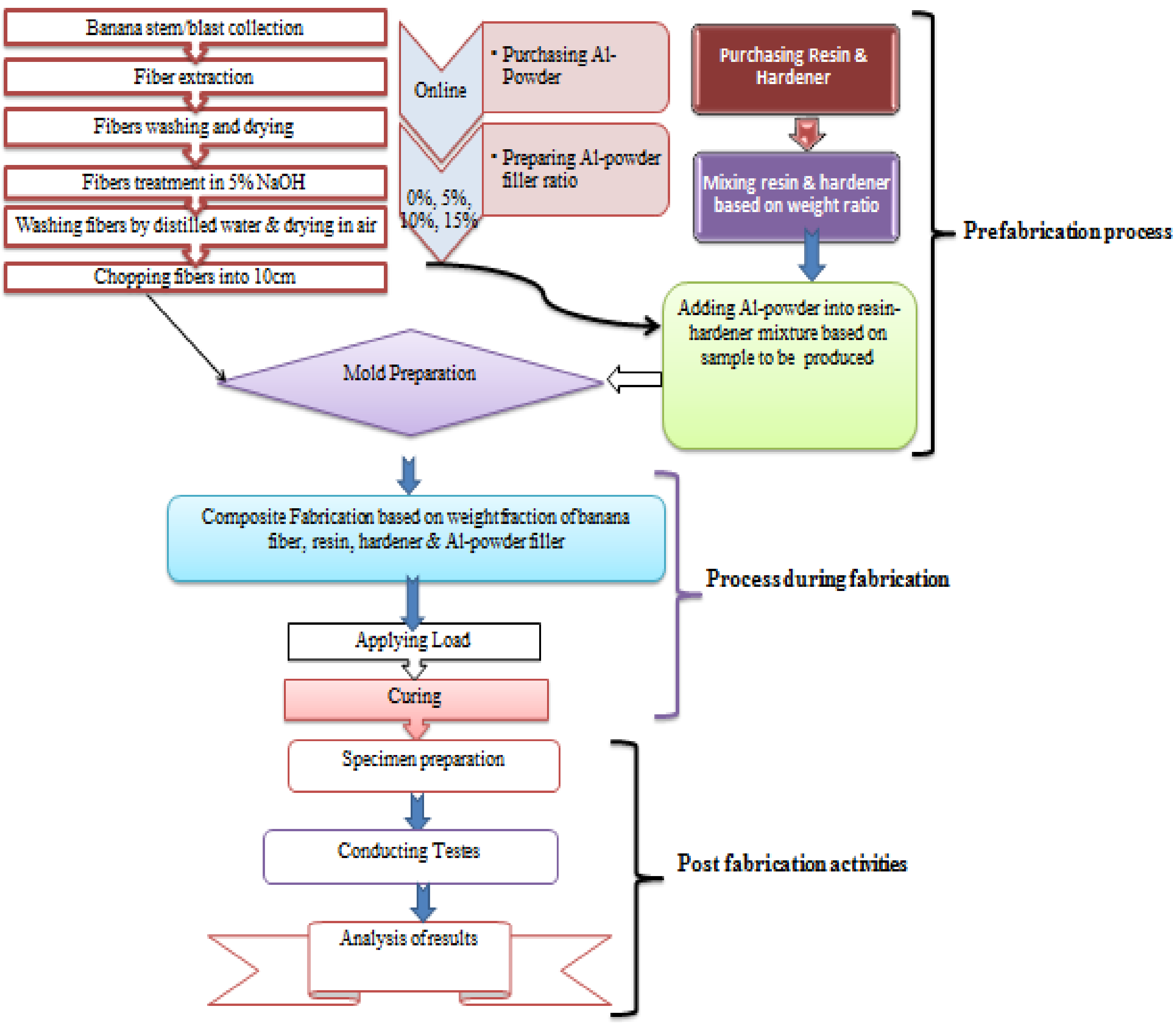


Figure 3.1: Flow diagram of sample prefabrication, during fabrication and post fabrication process

3.2. Materials

Materials those used to form composites are: banana fibers, Aluminium Powder filler, unsaturated polyester resin, hardener (catalyst), and NaOH.

The equipment used to remove impurities and for mixing resin, hardener and Aluminium mixtures are comb, musk, roller, gloves and stirring wood.

3.2.1. Banana Fibers

Banana fibers were extracted from Banana stem and the extraction was done by manual/traditional method. The extracted banana fibers was washed by down runner water and dried in Air. Combing was carried out to remove dirty and impurities. Then Banana fibers were treated by 5% NaOH to improve physical, chemical and mechanical properties of the fibers. Again, it was washed by down runner water and distilled water to neutralize the chemicals and dried in air for further process.

Figure 3.2: Banana fiber extraction by traditional means from Hawassa City area, Ethiopia

3.2.2. Aluminum Powder Filler

99.9% pure Aluminium powder of 56µm was purchased from online, Germany. It was added to resin and hardener based of weight percentage of resin and hardener mixture needed to produce laminated composite for this study. To analyze its mechanical properties effects on natural fibers; it was conducted by adding Aluminium Powder filler of 5%wt, 10%wt and 15%wt by measuring it's mass on digital balance at Chemical Engineering laboratory, ASTU, Ethiopia.

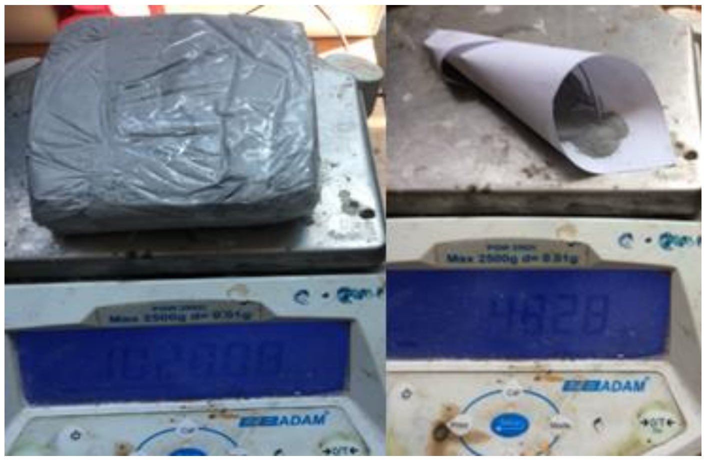


Figure 3.3: Al-powder filler measuring on digital balance based on weight ratio

3.2.3. Matrix and Hardener

Generally, polymers can be classified into two classes; thermoplastics and thermosetting. Thermoplastic materials currently control, as matrices for bio-fibers; the most frequently used thermoplastics for this purpose are polypropylene (PP), polyethylene, and poly -vinyl-chloride (PVC); while phenolic, epoxy and polyester resins are the most commonly used thermosetting matrices (Raj *et al*., 2016). Matrix plays vigorous role in composite material for keeping secure grip on fibers and transferring the load in between broken fiber. Similarly, it acts as barrier from harmful environmental contact in order to protect fibers (Dhakal and Gowda, 2017). The matrix acts as a load transfer intermediate between fibers, and in less ideal cases where the loads are difficult, the matrix may even have to stand loads transverse to the fiber axis. The matrix is more ductile than the fibers and acts as a source of composite toughness. The matrix also serves to protect the fibers from environmental damage before, during and after composite processing (Elanchezhian *et al*., 2018).

Unsaturated polyester resin and Catalyst were purchased from World Fiber Glass and Water Proofing Engineering Company, Addis Ababa, Ethiopia. The weight fraction of each sample resin-hardener mixture was done on digital balance at Chemical Engineering laboratory, ASTU, Ethiopia. For each sample the amount of resin-hardener used was described in Table 3.1.

Figure 3.4: Resin and hardener measurement on digital balance by weight fraction

To obtain best mixture of resin-hardener and Al-powder filler mixture using measured amount of each composition play a great role. To fabricate each sample mixing resin-hardener that filled Al-powder filler was recommended based on the sample type and production amount.

Table 3.1: Mix batch of resin and hardener based on wt% composite

S. No:	Date	Sample	Batch No: Quantity (grm)			Cup Mass (grm)	Gross Mass (grm)
			Resin	Hardener	Al-powder (grm)		
1.	14/05/2018	A	985.84	8.86	0	5.75	1,000.45
2.	14/05/2018	B	936.55	8.37	49.292	5.75	999.962
3.	16/05/2018	C	887.26	8.87	98.584	5.75	1000.46
4.	16/05/2018	D	838.08	8.38	147.76	5.75	999.97

3.2.4. Chemical Treatment of Fibers

Influence of surface treatment on natural fibres improves the interfacial bond between fibre and resin thereby increases its mechanical properties. Alkali treatment of jute and banana fibre reinforced composites with 5% NaOH improves the mechanical properties of composites. Alkali treatment removes the lignin and hemicellulose content in the fibre, also decreases the spiral angle so as to increase the molecular alignment thus increasing the elastic modulus of fibre. Improvement of interfacial bonding is significant in improving mechanical properties. Alkali treatment provides finer fabric, increase crystallinity, reduction in amount of defects, superior bonding and reduced moisture absorption (Haldar *et al*., 2017).

Chemical treatment is needed to improve the mechanical properties of natural fibers. Most of the researchers use 1-10% NaOH to improve the properties. For this study 5% NaOH was used to improve Mechanical properties. Then, it was washed by down running water. Finally, it was by distilled water and cured in air for 48 hrs.

Figure 3.5: Banana fiber treatment in 5% NaOH solution and its PH measurement

3.3. Sample Preparation Methods

Usually with an increase in the fiber content in the composition, the tensile and flexural property gradually improves. Beyond certain limit of the fiber content, however, depending on the method of processing, the adhesion between the resin and the fiber decreases resulting in the decrease in the strength of final products (Begum and Islam, 2013). (Boopalan *et al*., 2013) concluded that addition of banana fiber in jute/epoxy composites of up to 50% by weight results in increasing the mechanical and thermal properties and decreasing the moisture absorption property.

The sample preparation was based on 10% fixed weight ratio of banana fiber to resin-hardener mixture. Majority of researchers focused on volume ratio of natural fibers to matrix compositions. But, some of them uses weight fraction. Again, some of them used different weight/volume fraction of natural fibers to matrix ratio; while few researchers uses fixed volume/weight ratio of natural fibers to matrix to see their effect on mechanical properties. In this study, the basic focus was to see Al-powder filler effect on mechanical and physical properties of composites. So, this study was carried out on fixed weight ratio of banana fibers to variable resin-hardener- Al-powder filler composition. Adding more weight ratio of banana fiber causes porous on fabricated composite and lowering weight ratio below 10 wt% reduces fiber utilization. Based on this 10 wt% of banana fiber was taken for this thesis work. Shortly, it was indicated by the following Table 3.2.

Table 3.2: Fabrication of composites samples

Sample Code	Composition (wt %)
A	Resin-hardener (90 wt %) +Banana Fiber (10 wt %)+ Aluminium powder filler (0 wt%)
B	Resin-hardener (85wt %) +Banana Fiber (10wt %) + Aluminum Powder filler (5wt %)
C	Resin-hardener (80wt %) +Banana Fiber (10wt %) + Aluminum Powder filler (10wt %)
D	Resin-hardener (75wt %) +Banana Fiber (10wt %) + Aluminum Powder (15wt %)

Note: A represented for: Banana fiber reinforced Polyester matrix composite

B= Banana fiber reinforced Polyester matrix filled by 5wt % Al-powder composite.

C= Banana fiber reinforced Polyester matrix filled by 10wt % Al-powder composite.

D= Banana fiber reinforced Polyester matrix filled by 15wt % Al-powder composite.

Generally, to obtain high mechanical properties of composite, considering cause-effect plays great role. In this study, causes and parameters are considered to produce sample from banana fibers. Among many factors those affects the results of fabricated composite; I have clearly focused on some of them. The causes/parameters those should be taken into consideration during fabrications of laminated composites are as I have tried to show by below cause-effect fishbone diagram. The cause/parameters those controlled at hand lay-up process gets attention in one or more way to obtain quality product that show better mechanical and physical properties.

The produced mold for sample producing were cleaned by releasing agent (wax) and dried before pouring resin-hardener mixture/resin-hardener-Aluminum powder mixture on it. The mixed resin-hardener mixture/resin-hardener-Aluminum mixture based on weight percentage which stirred manually poured on the clean mold. The treated banana fibers were distributed uniformly over resin poured on the mold in non-woven orientation. Again, resin-hardener mixture/resin-hardener-Aluminum powder was poured on the banana fiber layer. The excess resin and air bubble was removed from the composites by using hand roller. It was also used to uniformly distribute mixture of resin-hardener/resin-hardener-Aluminum powder through the composites. Then, banana fiber and mixtures of resin are added till the required thickness and samples are produced. Then, it was compressed under 50kg for 24hrs to remove excess resin mixture and air bubble.

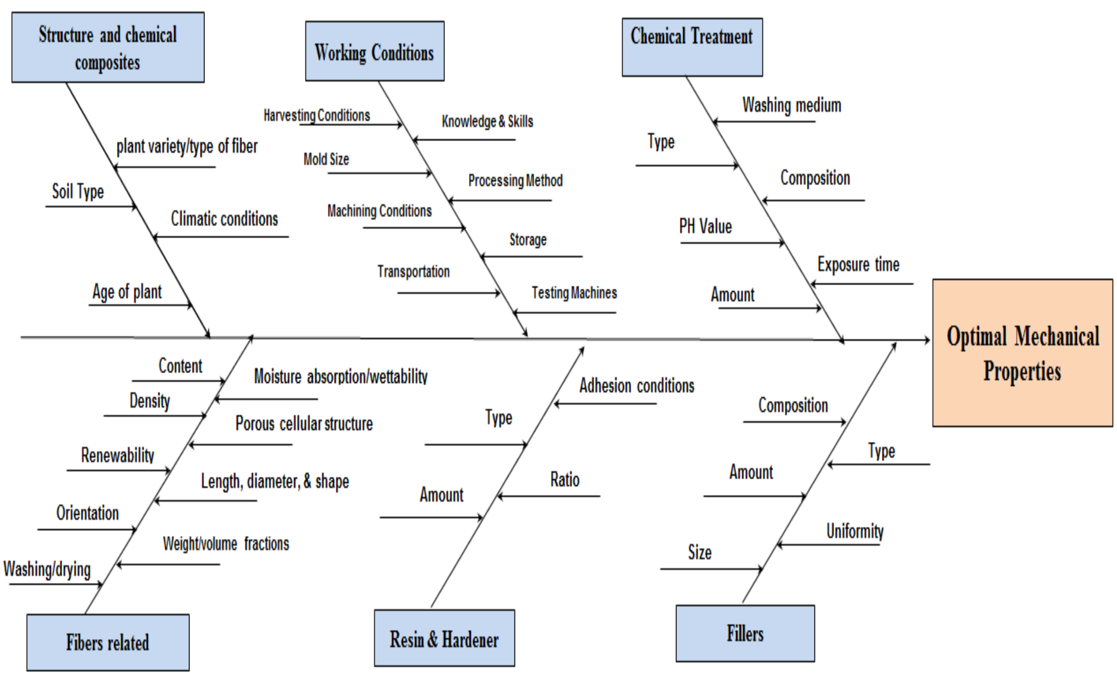


Figure 3.6: Fish-bone diagram of factors those affects the mechanical properties of Natural fiber reinforced composites

By considering some of these six causes those play a great role to obtain laminated composite fabricated from banana fiber reinforced polymer composite filled Aluminium powder filler optimal mechanical properties; the procedure to fabricate sample was as shown in Figure 3.7.

Figure 3.7: Banana fiber reinforced polymer composite fabrication procedures

3.3.1. Mould Preparation

The mold was fabricated from Aluminum sheet of 30cmx25cmx6mm size by bending machine as shown in Figure 3.8. The fourth direction was closed by sheet Aluminium of 5mm to obtain uniformly distributed laminated composite sample.

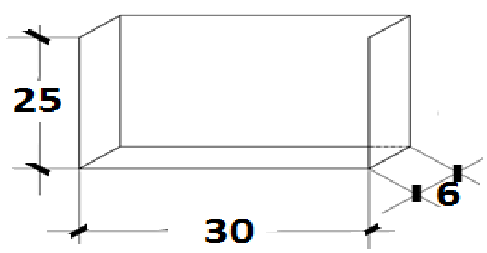


Figure 3.8: Mould dimension to fabricate laminated composite

3.3.2. Preparation of Banana Fibers reinforcement-resin-hardener mixture filled Al-powder filler based on weight fraction

The fiber orientation selected for this study was chopped short randomly distributed (non-woven mat) fashion because one can be fabricate easily any product from waste banana stem by this method. The fiber was chopped into 8-10cm length and randomly distributed over 120cm x 75 cm areas based on 10 wt% to resin-hardener/resin-hardener-Al-powder filler mixture. After equally distributed over the area, load was applied over fiber to hold fibers on distributed location and then chopped by scissors for four (4) samples to be produced. Each sample has three layer of banana fibers and four layers of resin-hardener/resin-hardener-Al-powder mixture. Mix by weight ratios are recommended for accuracy, especially for smaller batches of composite like this study. The mixing of small test batch is familiar to mixing and curing process before applying the whole mixture needed to produce the composite. The test batch verify that resin: hardener to Al-powder filler ratio is accurate each time. The mix by weight method is more preferable for small batch of resin to hardener that determines the proper mixing ratio for this thesis purpose. Then the proper amount of resin to hardener was added to pure and clean containers. During pouring of resin and hardener into the container; adding of the correct amount of hardener to achieve an accurate ratio was carried out. Then mixture was stirred well and cure to scrapes the sides and bottom of the container. It was stirred until the mixture is no longer hazy. Mixing takes place a few minutes depending on the batch sizes amount of Al-powder filler used per sample. 2-4 minute mix was done till uniform in color and viscosity. Then, the stirred and well mixed resin-hardener/resin-hardener-Al-powder filler was poured on mold. The banana fiber was added over matrix and rolled well by roller. Again resin-hardener/resin-hardener-Al-powder filler was poured over banana fiber layers. By the same fashion all samples was done till the required thickness was obtained.

3.4.Experimental setups and Procedures

Specimen for Mechanical and physical tests are prepared according to dimension requirement and machines standard. Then average values are taken for analysis. For density measurement also three specimens are taken from each sample and an average result was used for analysis. Micro hardiness and water absorption tests are done on single specimens of each sample. All specimens are cut by circular cutter, grinder and Abrasive cutter.

3.4.1. Specimen preparation procedure for all Samples

Specimen for each sample was prepared based on the dimension requirements of the mechanical and physical properties test that was conducted for this study. The dimension requirement for tensile strength test on 2000kN UTM of Ethiopian Conformity Assessment Enterprise based on ISO 6892-1 was indicated by Figure 3.9 below. Three specimens per sample was prepared by using circular cutter and grinder and finally polished by polishing paper. Specimen for compression strength test was also cut by circular cutter and grinder based on the dimension requirement. For microstructure and micro-hardness specimens are produced by using abrasive cutter.

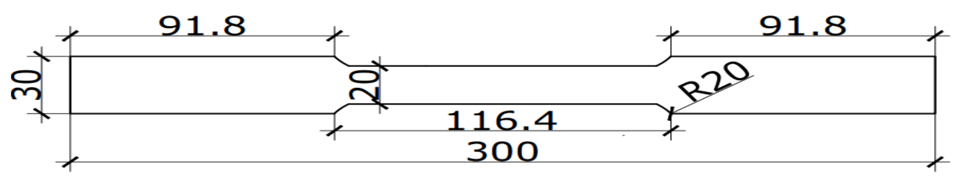


Figure 3.9: Specimen dimension for tensile stress measurement on UTM-2000kN machine

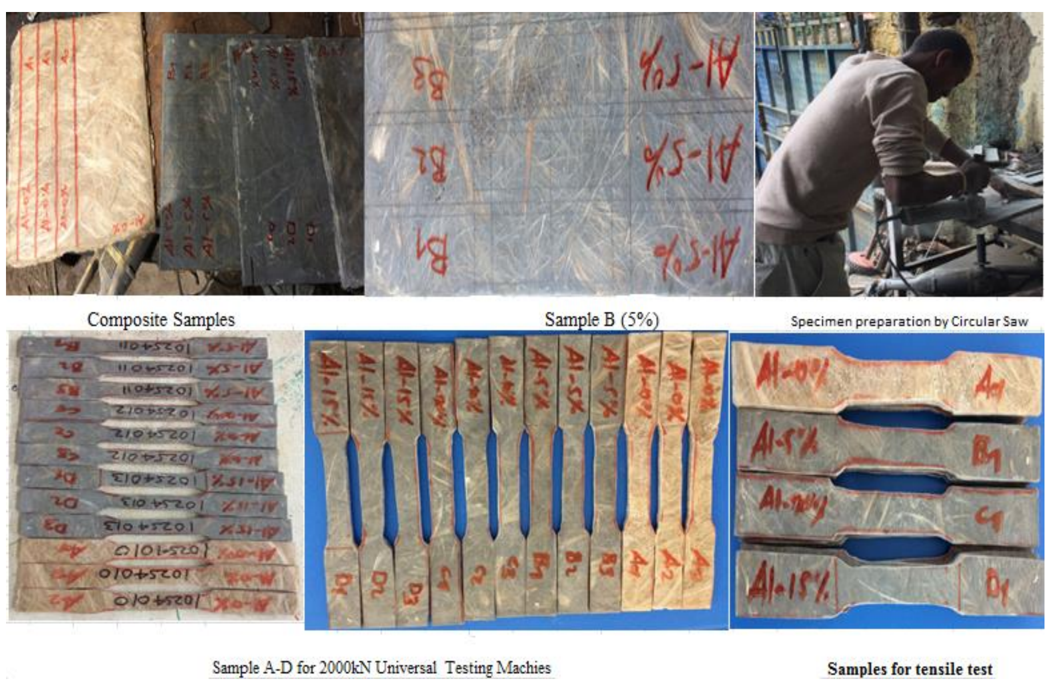


Figure 3.10: Specimen identification codes (User's code) for tensile test on UTM-2000kN

3.4.2. Testing procedure of Specimens

The test procedure of sample was conducted by preparing specimen based on the kind of test conducted. The mechanical and physical properties test conducted in this study is indicated by Table 3.3 given below.

Table 3.3: Tests and machine on which tests was conducted

S.No	Name of the test	Name of the Machine
1	Tensile Strength	UTM-2000kN
2	Density	Water immersion method
3	Micro Hardness	Vickers Hardness Tester (HVS-50)
4	Moisture Absorption	Water immersion Method
5	Microstructure	Metallurgical Microscope

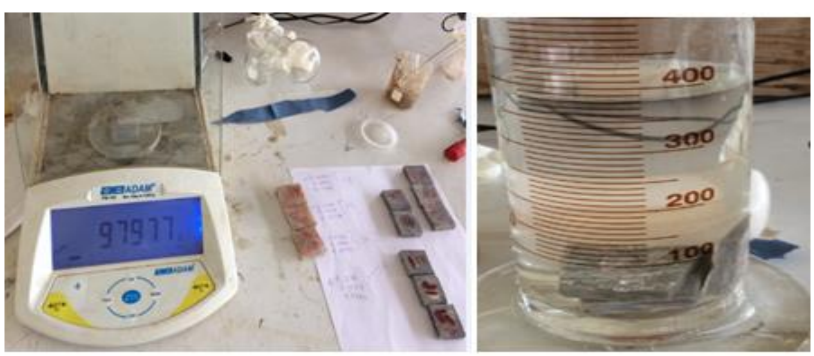
3.4.2.1. Tensile strength

Tensile stress test was done at Ethiopian Conformity Assessment Enterprise on UTM 2000Kn as shown in Figure 3.11. It determines tensile properties of banana fiber polymer composite filled Al-Powder filler in the prepared sample plane. For all samples three specimens are prepared and average results was used for comparison of the results. The specimens were designed as: $\mathbf{A_1}$**,** $\mathbf{A_2}$**,** $\mathbf{A_3}$**,** $\mathbf{B_1}$**,** $\mathbf{B_2}$**,** $\mathbf{B_3}$**,** $\mathbf{C_1}$**,** $\mathbf{C_2}$**,** $\mathbf{C_3}$ and $\mathbf{D_1}$**,** $\mathbf{D_2}$**,** $\mathbf{D_3}$ based on Aluminium powder filler content and trial number for each sample.

Figure 3.11: UTM-2000kN used to test tensile stress

3.4.2.2. Density measurement

Actual density (ρ_{ce}) of the composite is determined experimentally by simple water immersion technique with the use of the sample of 30mmx30mm dimensions. Three specimens were tested per each sample and average value was taken for density analysis of each samples. Each sample is measured on digital balance at Chemistry department, Hawassa University, Ethiopia. The volume of each sample was obtained from displaced water level during immersion of composite into water. Figure 3.12 shows the density measuring method for fabricated banana fiber reinforced polymer composite samples.



Mass measuring digital balance   Volume measuring method

Figure 3.12: Density measuring method for fabricated banana fiber reinforced polymer composite samples

3.4.2.3. Micro-hardness test

Hardness is the resistance of a material to deformation, indentation or scratching. The basic goal of hardness testing is to quantify the resistance of a material to plastic deformation. The indentation value has high importance for technical applications which reflects the resistance to deformation which is a complex property and related to modulus, strength, elasticity, plasticity and dimensional stability of a material. 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= Constant x Test Force/Surface Area of Indentation

$$= \frac{0.102*2F(\frac{\sin 136^0}{2})}{d^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Equation 3.1 above was taken from manual of HVS-50 machine of Adama Science and Technology University. The HVS-50 machine used for this project has measuring rage: 5-2900 HV, Test Force: 9.807, 49.03, 98.07, 196.1, 294.2, 490.3N, 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 hardiness test was 49.03 N (10kg.f) on three trail per each sample. Average result was used for comparison of HV value of all samples. The micro-hardness testing machine and abrasive cutter is shown by Fig. 3.13.

Figure 3.13: Abrasive cutting in action (RB-203), Micro-hardness measurement under Vickers Hardness Tester (HVS-50)

3.4.2.4. Water Absorption percentage

According to literatures' source moisture absorption was conducted in accordance with ASTM D570-98. Single specimens of each composite are cut and their weights are taken as per their samples. All samples were immersed into water for 8 days. Then the specimen are removed from water and cleaned by dry materials and their weights are measured within 24hrs difference. The measurement was taken immediately after the specimens removed from immersed water, dried by dry materials and exposed to air. The specimen size prepared was 30mmx30mm. the following equation was obtained from (Haldar *et al*., 2017) report.

$$\% \text{ Water Absorption} = \frac{Wt-Wo}{Wo} * 100 = \frac{mw-ma}{ma} * 100 \ldots\ldots\ldots\ldots\ldots\ldots \text{(3.2)}$$

where; w_t is weight of wet sample

w_o is weight of dry sample

m_w is mass of wet sample

m_a is mass of dry samples

The mass recording and water immersion procedure is shown by Fig 3.14. After removal form water all time immediate mass of samples are recorded.

(a) (b) (c)

Figure 3.14: (a) ad (b) shows Sample immersed in distilled water and (c) mass measurement of sample after removed from water (Moisture Absorption Test)

3.4.2.5. Microstructure observation

The Microstructure of Banana fiber reinforced filled by Al-powder filler was observed by using Metallurgical Microscope of model: Huvitz HR-300 series, magnification: X50, X100, X200, X500, X1000, scanning area: 104x102mm, illumination system: 12v, 1000W halogen lamp. The specimens for Microstructure were cut by Abrasive cutter (RB 203 Abcut-M) at Material Engineering lab, ASTU, Ethiopia. All, samples are seen at (x50) magnification for this thesis work as shown on Fig. 3.15 to see only microstructure of fibers. The lowest magnification was used to observe micro structure without addition of etching acid medium on leveled surface of fabricated composite.

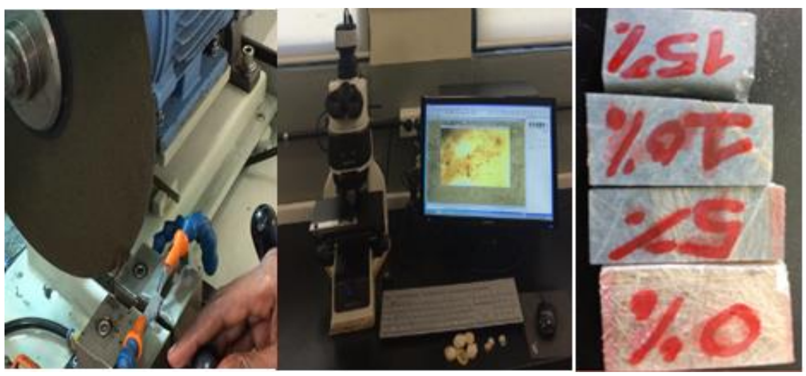


Figure 3.15: Abrasive cutting in action (RB-203), Microscopic study under Metallurgical Microscope

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Introduction

Based on the objectives and methodology of this study the results of mechanical properties and physical properties are described by Table 4.1. The interpretation and analysis was done by Minitab software. The better composition of the sample was discussed based on result obtained from experiment.

Table 4.1: Samples result finding of tensile strength and density

Sample code	Tensile strength (MPa)	Density (g/cm^3)
Treated banana fiber composite with unsaturated polyester resin (90wt %) +banana fiber (10wt %)		
A_1	28.1	1.031
A_2	19.8	1.098
A_3	23.7	1.079
Average	**23.87**	**1.069**
Treated banana fiber composite with unsaturated polyester resin (85wt %) +banana fiber (10wt %) + Aluminum Powder (5wt %)		
B_1	32.8	1.096
B_2	32.3	1.095
B_3	23.7	1.096
Average	**29.6**	**1.096**
Treated banana fiber composite with unsaturated polyester resin (80wt %) +banana fiber (10wt %) + Aluminum Powder (10wt %)		
C_1	42.1	1.075
C_2	24.7	1.138
C_3	32.4	1.239
Average	**33.07**	**1.151**
Treated banana fiber composite with unsaturated polyester resin (75wt %) +banana fiber (10wt %) + Aluminum Powder (15wt %)		
D_1	25.3	1.154
D_2	35.6	1.178
D_3	30.9	1.244
Average	**30.6**	**1.192**

In Table 3.1 contains individual results of each samples specimen for tensile strength, compression strength and actual density are tabulated. For results analysis the average value of each test was taken. The analysis for tensile strength, compression strength and density was carried out individually as below.

4.2. Analysis of Tensile strength

Based on fabricated composite average tensile stress value sample C (banana fiber reinforced polymer composite filled 10 wt% Al-powder filler) has higher tensile stress. It was clearly seen as Al-powder filler increase upto 10 wt% tensile strength increases. But adding more wt% Al-powder filler results to decrease the tensile strength of the composite. Sample A (banana fiber reinforced composite polymer) has lower tensile strength than Al-powder filled composites. Shortly, from this study point of view Sample A (banana fiber reinforced composite that do not have Al-powder filler) exbits lower tensile stress. Sample B and Sample D have moderate tensile stress when compared to unfilled banana fiber reinforced polymer composite.

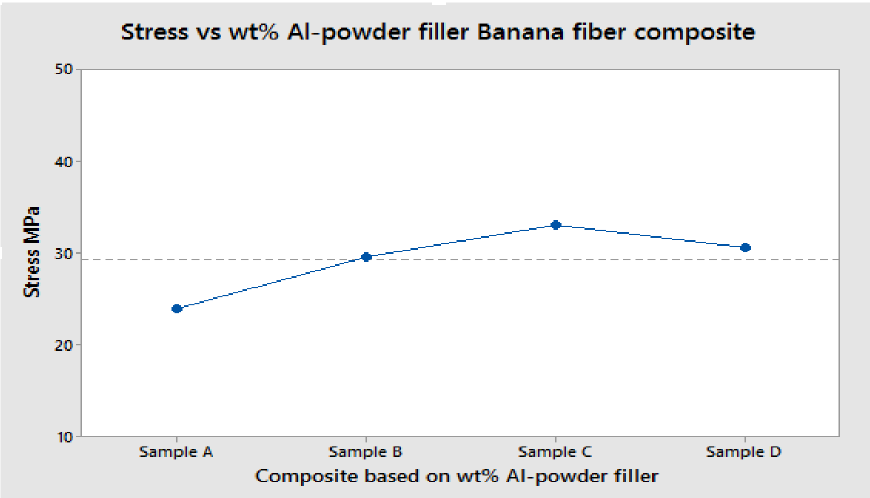


Figure 4.1: Tensile stress vs composite samples based on wt% of Al-powder filler

4.3. Density

Density of banana fiber reinforced composite increases as wt% of Al-powder filler increases. The result of Sample D (banana fiber reinforced polymer composite filled 15 wt% Al-powder filler) indicates higher density than other sample results. Sample A has lower density than other composite samples those filled Al-powder based on wt% Al-powder filler. Sample B and Sample

C have medium density. As the main objective of the study is reducing the weight and density of automotive body component, increasing Al-powder filler beyond some wt% is not recommended.

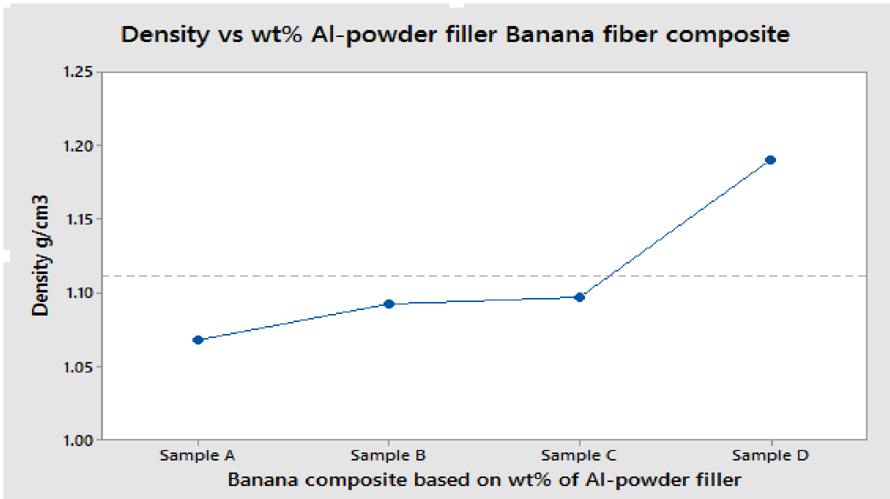


Figure 4.2: Density vs wt% Al-powder filler Banana fiber composite

4.4. Micro-hardness

The result of micro-hardness of each sample was tabulated by table 4.2 and the result was attached to appendix.

Table 4.2: Samples micro-hardness results of banana fiber reinforced polymer composite filled Al-powder filler

Composite	Trial 1	Trial 2	Trial 3	Average
A	293.8	212.4	198.3	234.83
B	136.6	191.0	207.5	178.37
C	132.0	206.1	148.4	162.17
D	133.2	123.2	207.3	154.57

The comparison for each sample is analyzed by taking average value of three trial value of specimens. The result of micro hardiness indicates that as wt% Al-powder filler increases the micro hardiness of samples was dicreases. Sample A has higher micro hardiness value while sample D has the lower HV value. So, as the Al-powder filler wt% increase the micro hardiness of composite fabricated from 10 wt% of banana fiber decreases in this study. The resistance to load decrease by increasing Al-powder wt% amount.

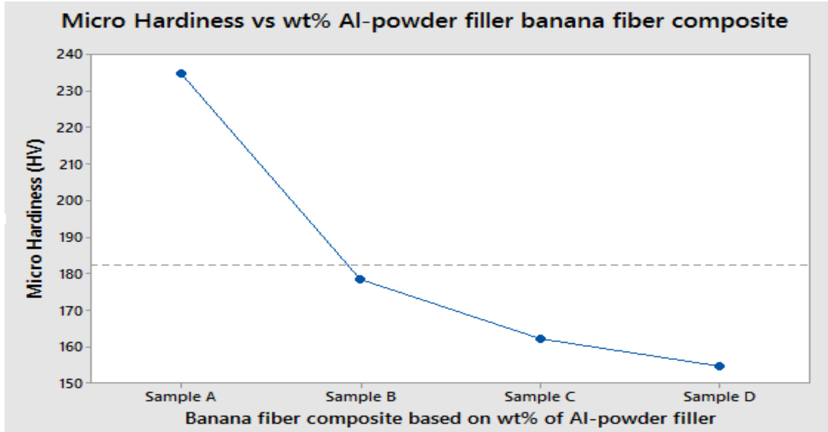


Figure 4.3: Micro-hardness vs wt% Al-powder filler Banana fiber composite

4.5. Water Absorption percentage

Weight measurement for each 24hrs difference and water absorption percentage was briefly indicated in the Table 4.3 and Figure 4.4.

Water absorption percentage analyzed for each days and averagely for 196 hours.

Table 4.3: Samples results of water absorption percentage for 8 days (196 hours)

Sample	Mass (grm)	Measuring duration of samples water absorption test								WA %
		24hrs	48hrs	72hrs	96hrs	120hrs	144hrs	168hrs	192hrs	
A	9.7119	9.9237	10.0121	10.0491	10.0498	10.0550	10.0473	10.0398	10.0465	3.25%
WA (%)		2.18%	3.09%	3.47%	3.48%	3.53%	3.45%	3.38%	3.45%	
B	8.1079	8.3267	8.3953	8.4904	8.5273	8.5489	8.5410	8.5316	8.5306	4.66%
WA%		2.69%	3.54%	4.72%	5.17%	5.44%	5.34%	5.22%	5.21%	
C	7.9688	8.0721	8.1764	8.1953	8.2480	8.2694	8.2650	8.2619	8.2590	3.13%
WA%		1.29%	2.6%	2.84%	3.50%	3.77%	3.72%	3.67%	3.64%	
D	8.2457	8.3572	8.4005	8.4702	8.5011	8.5258	8.5097	8.5212	8.5190	2.79%
WA%		1.35%	1.88%	2.72%	3.09%	3.39%	3.20%	3.34%	3.31%	

Water absorption percentage of all sample was tabulated and analyzed individually by 24 hours time interval for 8 days. The comparison is done on average value of each samples.

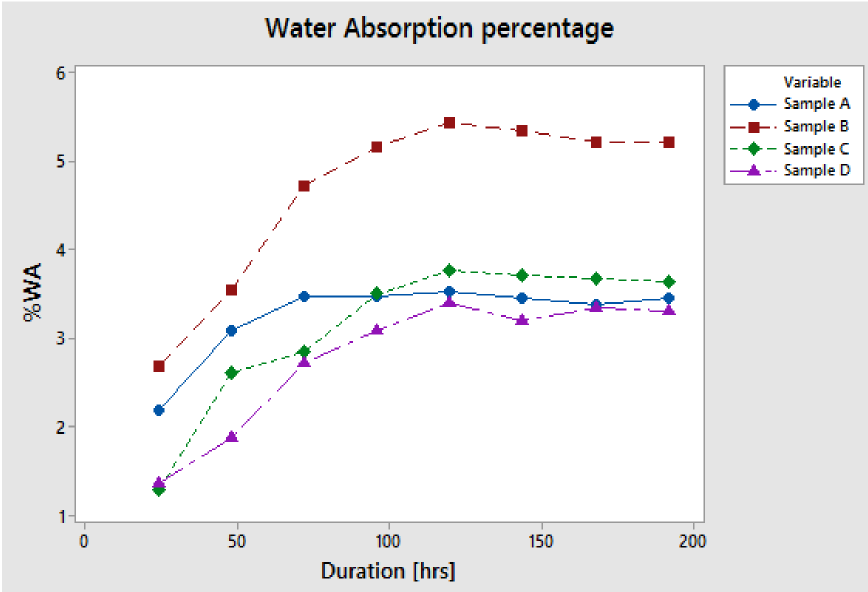


Figure 4.4: Water absorption percentage vs duration for 8 days

Sample A, sample C and Sample D have lower water absorption percentage than sample B. This shows that over 192 hours sample D shows lowest water absorption percentage than other samples. As Al-powder increase the water absorption percentage decreases. Lower water absorption are more recommended for automotive body.

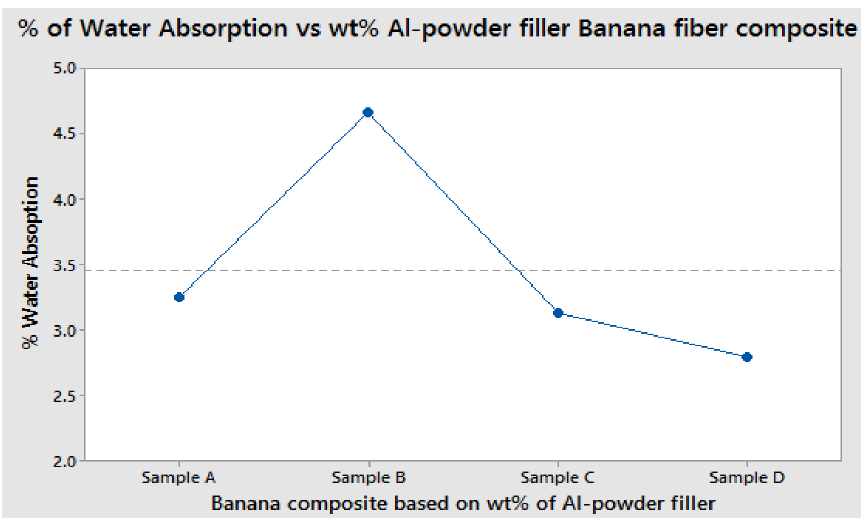


Figure 4.5: WA% vs wt% of Al-powder filler Banana fiber composite

From the result point of view, as wt% Al-powder filler increases the water absorption percentage of the samples decrease. Sample B has higher water absorption percentage which followed by sample A. Sample C and D have less water abrorption properties. Higher water absoption percentage is not recommended for automotive body and other industry applications. So, sample D and C are suitable for automotive body. As compared to unfilled banana fiber, those Al-powder filled have lower water absorption percentage.

4.6. Microstructure

The microstructure results for the all samples are described in Figure below based on their wt% of Al-powder.

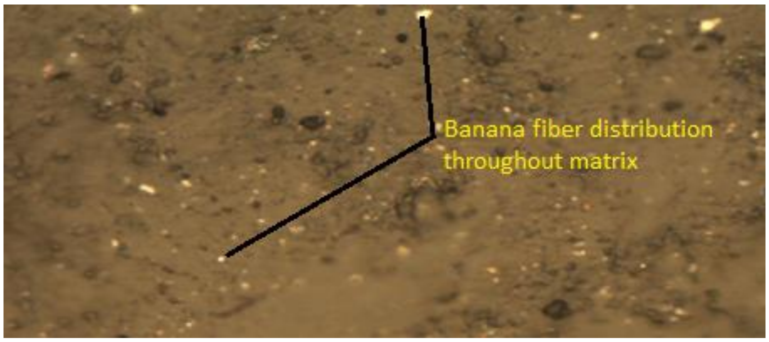


Figure 4.6: Microstructure of Sample A

Microstructure of sample A shows that banana fiber polymer matrix ditribution was to some extent uniform. To obtain excate uniformity consider other oreintation rather than non woven, decreasing fiber chopped length, and even fabricating at micro and nano level may be best option. But, under this study it is suitable for automotive body application based on the mechanical and physical properties results.

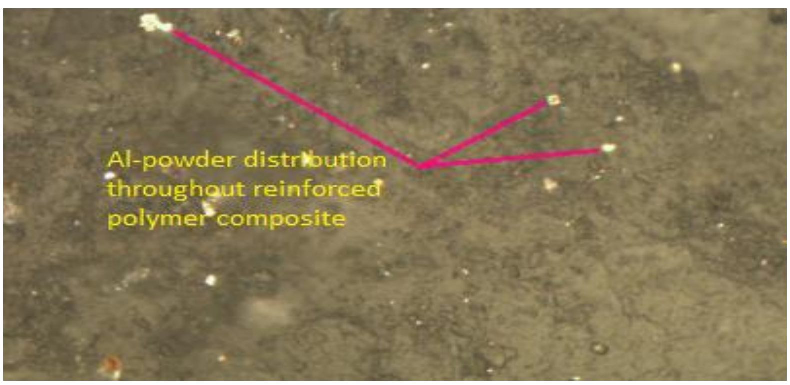


Figure 4.7: Microstructure of sample B

Al-powder filler was seen as it was distributed randomly through out laminated composite. At Microstructure Al-powder filler was seen by white point boundary from banana fiber mixed by resin-hardener mixture.

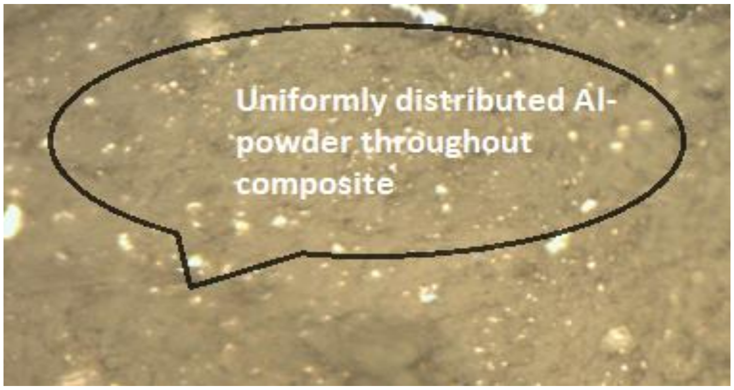


Figure 4.8: Microstructure of sample C

Al-powder distribution was seen at randomly mixed boundary to banana fiber polymeric matric composite. As Al-powder wt% increases the boundary of mixtures clearly shown. It have better Microstructure mixture.

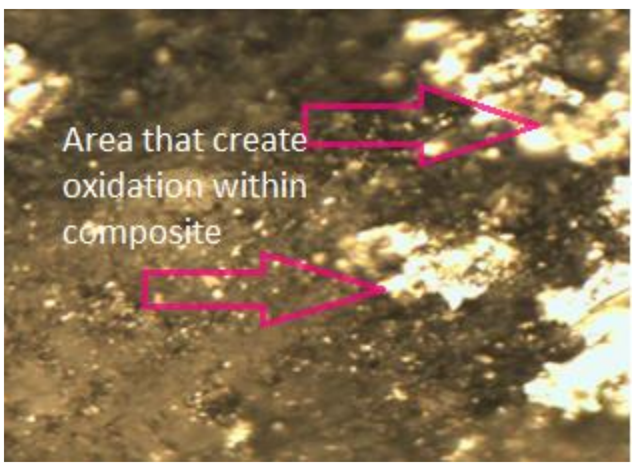


Figure 4.9: Microstructure of Sample D

From result seen in sample D the distribution of Al-powder was not evenly distributed. It was some what collected to some boundary zone. This is due to metalic property of Al-powder that create oxidation with resin-hardener mixture. So, as Al-powder wt% exceed some point it was form oxidation before creating best composite based of weight fraction of fiber, resin-hardner mixture and Al-powder filler.

When compared to other researcher results, mechanical and physical properties value obtained in this study has best tensile stress, water absorption and density. The Microstructure and micro hardness of this banana fiber reinforced polymer composite filled Al-powder filler is greater than some pure light weight material hardiness. For example the strength of sisal epoxy composite and sisal-epoxy-Aluminium powder composite studied by (Haldar et al., 2017) has 13.323MPa and 15.807MPa tensile strength respectively. (Boopalan *et al.*, 2013) studied on jute/banana hybrid composite and obtained tensile strength of 17.82MPa, 18.96MPa, 18.25MPa and 17.92MPa for 75/25, 50/50, 25/75 and 0/100 jute/banana fiber ratio respectively. (Bakri *et al*., 2017) obtained tensile strength of 22.5MPa for 5 wt% of banana composites. On other hand a few results of glass fiber, carbon fiber and wood fiber related are discussed as follow. (Vieira *et al*., 2009) conducted their study on development and evaluation of manufacturing to produce short fiber hybrid mats by aqueous and fluidized bed methods and obtained that as glass fiber increases for 0 to 100 vol% water absorption decreases from 4.4% to 0.4% under aqueous technique. They concluded as tensile strength increases from 25MPa to around 50.6MPa for 0 vol% and 100 vol% of glass fiber fabricated composite. (Tewari *et al.*, 2012) conducted their study on bagasse-glass fiber reinforced composite with 15 wt%, 20 wt%, 25 wt% and 30 wt% of bagasse fiber with 5 wt% of fixed glass fiber added in resin. They obtained that water absorption percentage increase as bagasse fiber amount increase from 15 wt% to 30 wt% which was recorded as 7.84% at 30 wt% of bagasse. Addition of bagasse fiber from 15 wt% to 30 wt% decreases ultimate tensile strength from 4.69MPa to 1.56MPa at 30 wt% bagasse and 5 wt% of glass fiber filled composite. Density of bagasse filled composite decreases from 1.04 g/cm^3 at 15 wt% of bagasse to 0.8 g/cm^3 at 30 wt% of bagasse. Compression strength of bagasse-glass fiber composite filled with epoxy resin decreases from 9.6MPa at 15 wt% bagasse fiber to 1.83PMa at 30 wt% of bagasse fiber. They have also concluded that micro hardness of fabricated composite decrease from 53 to 39.8 for 15 wt% and 30 wt% of bagasse fiber respectively. (Tamilarasan *et al*., 2015) conducted their study on Aluminium AA6061-T6 and 2x2 carbon fiber fabric property with epoxy resin LY556 and hardener HT 672 and found tensile strength which vary from 283MPa to 316MPa depending on the produced samples. (Yadav *et al*., 2015) conducted their study on wood-plastic composite and concluded that the maximum tensile strength of their sample was obtained on composite filled 2.5 wt% of Nano clay that have 32.04MPa while without nano clay they obtained tensile values is limited to 28.25MPa. They also concluded that water absorption percentage increases with increasing the amount of filler.

Shortly, beside on the light weight, low water absorption percentage, better tensile stress and good micro hardness the whole samples fabricated from banana fiber filled with Al-powder suitable for automotive body application when compared to other natural fibers those uses for the same purpose.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Banana fiber reinforced polymer composite filled with Al-powder exhibits excellent tensile strength with as Al-powder filler amount increases (by wt %). In this study, as wt% Al-powder filler by 10% shows maximum value of tensile strength. But beyond 10 wt% of Al-powder the tensile strength of the composite decreased. The maximum observed value of tensile strength was at sample C which has 33.07MPa. Generally, Al-powder filled composite have higher tensile strength than unfilled sample in this study.

Based on the result obtained from this study sample D has the highest density value, while sample A has the lowest density. The density of sample D, C, B and A is 1.192, 1.151, 1.096, and 1.069 g/cm^3 respectively. Generally, all samples of banana fiber reinforced polymer composite fabricated for this study have lower density than pure Aluminium that has 2.7 g/cm^3. So, all samples are light weight and low in density.

Experimental result shows that micro hardiness decreases with Al-powder filler wt% increasing. Sample A has the highest micro hardiness value of 234.83MPa while sample D has the lowest micro hardiness value of 154.57MPa.

Results show that as Al-powder filler wt% increase to 15% water absorption percentage also decreases. Sample D has the lowest water absorption percentage of 2.79% which followed by sample C with value of 3.13%. Sample B has highest absorption value of 4.66% when compared to other fabricated samples. So, sample D is the optimal sample which followed by sample C for best water absorption percentage as the least number is more preferable.

Microstructure of each sample is observed by metallurgical (optical) microscope. Banana fiber reinforced polymer composite distribution of sample A shows randomly distribution of fiber through matrix. Sample B Al-powder distribution Microstructure seen in non-uniform fashion. Sample C has best Al-powder filler distribution throughout banana fiber reinforced polymer composite. But, in sample D Al-powder filler creates oxidation and form Aluminium oxidized major zone. Due to metallic property of Aluminium reaction will be happens with resin-hardener mixture before uniformly distributed throughout banana fiber reinforced polymer composite samples those fabricated. Addition of Al –powder more than 10 wt% forms oxidation before uniformly distributed throughout produced composite.

For justification since light weight, water absorption and strength are the crucial and critical factor in automotive industry to reduce fuel consumption and environmental pollution, banana fiber reinforced polymer composite filled with Aluminium powder filler is compatible to use in different interior part of vehicles. The maximum density of fabricated composite from banana fiber is obtained at 15 wt% Al-powder filled with 1.192 g/cm^3. This density is better when compared to 2.7g/cm^3 of Al-powder and 1.1 g/cm^3 of polyester resin. Tensile strength of banana fiber reinforced polymer composite filled Al-powder filler fabricated under this study for sample A, B, C and D has an average tensile strength value of 23.87Mpa, 29.6MPa, 33.07MPa and 30.6MPa respectively. Micro-hardness and water absorption percentage of banana fiber reinforced polymer composite filled Al-powder is best when compared to synthetic fiber composite. When compared to other composite fabricated sample C has higher tensile strength, better Microstructure, moderate water absorption percentage and density. Overall optimal mechanical and physical properties obtained at sample C when compared to other samples fabricated in this study. Generally, based on mechanical and physical properties all samples are suitable for automotive body.

5.2. Recommendations

Based on the property analysis samples finding, the future scope of this study recommends in the following points.

- Banana stem of different aging, climatic condition and soil type those disposed throughout country as a waste should be utilized by conducting further researcher on their mechanical, chemical, thermal and physical properties.
- By changing wt% of banana fibers, fiber orientation, filler material, treatment medium and other parameters/causes for output composite properties; researcher recommend higher institute, automotive company, manufacturing companies, construction sector and government to conduct on how to utilize this abundant waste banana stem resource.

- The trends of replacing heavy metals with low density, biodegradable, renewable, environmental friendly and green composite should have to get attention in country dependent on agricultural sector like Ethiopia.

5.3. Scope of Future Work

- Banana fiber conducted at fiber level should have to be studied at micro and nano level as a filler to obtain best composite that exhibits superior mechanical, chemical, physical and thermal properties.
- Researcher should have to conduct their study on how to control many causes and parameters that affect the output laminated composite properties.
- Further study should have to done on banana fiber that disposed as a waste i.e., false ceiling, partition board, household utilities and etc.
- Additional investigation should have to be done on crash analysis of natural fiber used in automotive body.

References

Adhikari, R.K., and Gowda, K. (2017). Exploration of Mechanical properties of Banana/Jute hybrid Polyester Composite. *International Conference on Advancements in Aeromechanical Materials for Manufacturing (ICAAMM-2016)* (pp. 7171-7176). Materials Today: Proceedigs 4.

Akova, E. (2013). Development of natural fiber reinforced polymer composites. *Transfer inovacii*, *25*, 03-05.

Alves, C., Silva, A. J., Reis, L. G., Freitas, M., Rodrigues, L. B., and Alves, D. E. (2010). Ecodesign of automotive components making use of natural jute fiber composites. *Journal of Cleaner Production*, *18*(4), 313-327.

Amir, N., Abidin, K. A. Z., and Shiri, F. (2017). Effects of fibre configuration on mechanical properties of banana fibre/PP/MAPP natural fibre reinforced polymer composite. *Procedia engineering*, *184*, 573-580.

Arpitha, G. R., and Yogesha, B. (2017). An overview on mechanical property evaluation of natural fiber reinforced polymers. *Materials today: Proceedings*, *4*(2), 2755-2760.

Ashik, K. P., and Sharma, R. S. (2015). A review on mechanical properties of natural fiber reinforced hybrid polymer composites. *Journal of Minerals and Materials Characterization and Engineering*, *3*(05), 420-426.

Badrinath, R., and Senthilvelan, T. (2014). Comparative Investigation on Mechanical properties of Banana and Sisal Reinforced Polymer based Composite. *International Conference on Advances in Manufacturing and Materials Engineering, AMME 2014* (pp. 2263-2272). Procedia Materials 5.

Baharin, A., Fattah, N.A., Bakar, A. A., and Ariff, Z. M. (2016). Production of laminated natural fibre board from banana tree wastes. *5th International Conference on Recent Advances in Materials, Minerals and Environment (RAMM) and 2nd International Postgraduate Conference on Materials, Mineral and Polymer (MAMIP)*, 4-6 August 2015 *Procedia Chemistry*, *19*, 999-1006.

Bakri, M. K. B., Jayamani, E., and Hamdan, S. (2017). Processing and Characterization of Banana Fiber/Epoxy Composites: Effect of Alkaline Treatment. *Materials Today: Proceedings*, *4*(2), 2871-2878.

Begum, K., and Islam, M. (2013). Natural fiber as a substitute to synthetic fiber in polymer composites: a review, *Research Journal of Engineering Sciences, Vol. 2*(3), 46-53.

Benitez, A. N., Monzon, M. D., Angulo, I., Ortega, Z., Hernandez, P. M., and Marrero, M. D. (2013). Treatment of banana fiber for use in the reinforcement of polymeric matrices. *Measurement*, *46*(3), 1065-1073.

Bhatnagar , R., Gupta, G., and Yadav, S. (2015, May). A Review on Composition and Properties of Banana Fibers. *International Journal of Scientific and Engineering Research, Volume 6*(Issue 5), 49-52.

Bogoeva-Gaceva, G., Avella, M., Malinconico, M., Buzarovska, A., Grozdanov, A., Gentile, G., and Errico, M. E. (2007). Natural fiber eco-composites. *Polymer composites*, *28*(1), 98-107.

Boopalan, M., Niranjanaa, M., and Umapathy, M. J. (2013). Study on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites. *Composites Part B: Engineering*, *51*, 54-57.

Cicala, G., Cristaldi, G., Recca, G., Ziegmann, G., El-Sabbagh, A., and Dickert, M. (2009). Properties and performances of various hybrid glass/natural fibre composites for curved pipes. *Materials and Design*, *30*(7), 2538-2542.

Dasari B.L., Morshed, M., and Nouri, S.N. (2018). Mechanical properties of Graphere Oxide reinforced Aluminium matrix Composites. *Composites Part B 145*, 136-144.

De Paola, S., Minak, G., Fragass, C., and Pavlovic, A., (2013). Green Composites . *A Review of state of Art in Proceedings of 30th Dambai Adria Symposium on Advanced Mechanics Croation Society*, 25-28.

Dhakal, S., and Gowda, K. (2017). An experimental Study on Mechanical Properties of Banana Polyester Composite. *ICAAMM-2016* (pp. 7592-7598). Materials Today: Proceedings 4.

Dittenber, D. B., and GangaRao, H. V. (2012). Critical review of recent publications on use of natural composites in infrastructure. *Composites Part A: Applied Science and Manufacturing*, *43*(8), 1419-1429

Elanchezhian, C., Ramnath, B.V., Ramakrishnan, G., Rajendrakumar, M., Naveenkumar, V., and Saravanakumar, M.K. (2018). Review of Mechanical Propreties of Natural Fiber Composites. *International Conference on Processing of Materials and Energy* (pp. 1785-1790). Materials Today: Proceedings 5.

Edeerozey, A. M., Akil, H. M., Azhar, A. B., and Ariffin, M. Z. (2007). Chemical modification of kenaf fibers. *Materials Letters*, *61*(10), 2023-2025.

Faruk, O. (2015, March 10). Cars from Jute and Other Bio-Fibers. *ResearchGate*. *Available in: http://www.researchgate.net/publication/267389048*.

Fragassa, C. (2017). Marine Applications of Natural Fibre-Reinforced Composites: A Manufacturing Case Study. In *Advances in Applications of Industrial Biomaterials* Springer (pp. 21-47).

Geethamma, V. G., Mathew, K. T., Lakshminarayanan, R., and Thomas, S. (1998). Composite of short coir fibres and natural rubber: effect of chemical modification, loading and orientation of fibre. *Polymer*, *39*(6-7), 1483-1491.

Haldar, P., Modak, N., and Sutradhar, G. (2017). Comparative Evaluation of Mechanical Properties of Sisal-Epoxy Composites with and without Addition of Aluminium Powder. *Materials Today: Proceedings*, *4*(2), 3397-3406.

Herrera-Estrada, L., Pillay, S., and Vaidya, U. (2008). Banana fiber composites for automotive and transportation applications. In *8th Annual Automotive Composites Conference and Exhibition (ACCE)* (pp. 16-18).

John, K., and Naidu, S. V. (2004). Effect of fiber content and fiber treatment on flexural properties of sisal fiber/glass fiber hybrid composites. *Journal of reinforced Plastics and Composites*, *23*(15), 1601-1605.

Jordan, W. and Chester, P. (2017). Improving the Properties of Banana Fiber Reinforced Polymeric Composites by Treating the Fibers. *3rd International Conference on Natural Fibers: Advanced Materials for a Greener World, ICNF*, (pp. 283–289). Braga, Portugal.

Koli, D.K., Hotri, G. A. and Purohit, R. (2015). Advanced Aluminium Matrix Composites: The critical need of Automotive and Aerospace Engineering Fields. *4th International Conference on Materials Processing and Characterization* (pp. 3032-3041). Materials Today: Proceedings 2.

Kumar, K. S., Siva, I., Rajini, N., Jappes, J. W., and Amico, S. C. (2016). Layering pattern effects on vibrational behavior of coconut sheath/banana fiber hybrid composites. *Materials and Design*, *90*, 795-803.

Lau, K. T., Hung, P. Y., Zhu, M. H., and Hui, D. (2018). Properties of natural fibre composites for structural engineering applications. *Composites Part B: Engineering*, *136*, 222-233.

Mehamud, I., Raj, J., Zeleke, C., and Gebre, T. (2016). Fabrication and Mechanical Property Evaluation of Ethiopia Banana Fiber Reinforced Polymer Composites. *Sciencedomain international*, 1-10

Merlini, C., Soldi, V., and Barra, G. M. (2011). Influence of fiber surface treatment and length on physico-chemical properties of short random banana fiber-reinforced castor oil polyurethane composites. *Polymer Testing*, *30*(8), 833-840.

Metu, C., Aduloju, S. C., Agarana, D., Udeh, E., and Sheidu, S. O. (2015). Comparative Computational Modelling of CO_2 Gas Emissions for Three Wheel Vehicles. *International Journal of Research in Engineering and Science*, *3*(7), 48-55.

Mishra, S., Naik, J. B., and Patil, Y. P. (2000). The compatibilising effect of maleic anhydride on swelling and mechanical properties of plant-fiber-reinforced novolac composites. *Composites Science and Technology*, *60*(9), 1729-1735.

M.R. Sajay, M.R, Maduhu, P., Mohammed Jawaid, Senthamarai, P., Senthil, S., and Pradeep, S. (2018). Characterization of Natural fiber Polymer Composites. *Journal of Cleaner Production 172*, 566-581.

Nagendra, P. S., Prasad, V. V. S., and Ramji, K. (2017). A Study on Dynamic Mechanical Analysis of Natural Nano Banana Particle Filled Polymer Matrix Composites. *Materials Today: Proceedings*, *4*(8), 9081-9086.

Onyedum, O., Aduloju, S. C., Sheidu, S. O., Metu, C. S., and Owolabi, O. B. (2015). Comparative Mechanical Analysis of Okra Fiber and Banana Fiber Composite Used in Manufacturing Automotive Car Bumpers. *Am. J. Eng. Technol. Soc*, *2*(6), 193-199.

Osborne, J. (2013). Automotive composites–in touch with lighter and more flexible solutions. *Metal Finishing*, *111*(2), 26-30.

Patil, A., Patel, A., and Purohit, R. (2017). An overview of Polymeric Materials for Automotive Applications. *5th International Conference of Materials Processing and Characterization (ICMPC 2016) Materials Today: Proceedings*, *4*(2), 3807-3815.

Paul, S.A., Boudenne, A., Ibos, L., Candau, Y., Joseph, K., and Thomas, S. (2008). Effect of fiber loading and chemical treatments on thermophysical properties of banana fiber/polypropylene commingled composite materials., (pp. 1582-1588).

Pervaiz, M., Panthapulakkal, S., Birat, K. C., Sain, M., and Tjong, J. (2016). Emerging trends in automotive lightweighting through novel composite materials. *Materials Sciences and Applications*, *7*(01), 26-38

Pothan, L. A., George, J., and Thomas, S. (2002). Effect of fiber surface treatments on the fiber–matrix interaction in banana fiber reinforced polyester composites. *Composite Interfaces*, *9*(4), 335-353.

Pothan, L. A., Oommen, Z., and Thomas, S. (2003). Dynamic mechanical analysis of banana fiber reinforced polyester composites. *Composites Science and Technology*, *63*(2), 283-293.

Prabu V.A., Uthayakumar, M., Manikandan, V., Rajini, N., Jeyaraj, P. (2014). Influence of redmud on the mechanical, damping and chemical resistance properties of banana/polyester hybrid composites. *Materials and Design 64*, 270-279.

Prasad, V., Joy, A., Venkatachalam, G., Narayanan, S., and Rajakumar, S. (2014). Finite Element analysis of jute and banana fibre reinforced hybrid polymer matrix composite andoptimization of design parameters using ANOVA technique. *12^th^ global congress on manufacturing and management, GCMM 2014*, (pp. 1116 – 1125).

Pujari, S., Ramakrishna, A., and Balaram, K.T. (2017). Prediction of Swelling Behaviour of Jute and Banana Fiber Composites by using ANN and Regression Analysis. *ICAAMM-2016* (pp. 8548-8557). Materials Today: Proceedings 4.

Pujari, S., Ramakrishna, A., and Kumar, M.S. (2014, February). Comparison of Jute and Banana Fiber Composites: A Review. *International Journal of Current Engineering and Technology*(Special Issue-2), 121-126.

Rafiquzzaman, Rahman, H., Sayeed, A., and Ali, N. (2016, May 25). Evaluation of Mechanical Behavior of Jute Fibre-Aluminium Powder Reinforced hybrid Polymer Composites. *International Journal of Mechanical Engineering and Automation, 3*(5), 202-207.

Raj, J., Gebre, T., Mehamud, I., and Zeleke, C. (2016, May 514-521). Mechanical Property Evaluation Of Bi-Directional Ethiopian Banana Fiber Epoxy Composites. *International Journal of Advance Research in Science and Engineering, Vol.No: 5*(Issue. No: 05).

Ramesh, M., Atreya, T. S. A., Aswin, U. S., Eashwar, H., and Deepa, C. (2014). Processing and mechanical property evaluation of banana fiber reinforced polymer composites. *Procedia Engineering*, *97*, 563-572.

Ramnath, V., Manichayasagam, B., Elanchezhian, V.M., Krishna, C.V., and Karthi, C. (2014). Determination of Mechanical properties of intra-layer abaca-jute-glass fiber reinforced composite. *Mater. Des. 60*, 643-652.

Rathore, A., and Pradhan, M. K. (2017). Hybrid Cellulose Bionanocomposites from banana and jute fibre: A Review of Preparation, Properties and Applications. *Materials Today: Proceedings*, *4*(2), 3942-3951.

Saba, N., Paridah, M. T., Abdan, K., and Ibrahim, N. A. (2016). Effect of oil palm nano filler on mechanical and morphological properties of kenaf reinforced epoxy composites. *Construction and building materials*, *123*, 15-26.

Saliba, C. C., Orefice, R. L., Carneiro, J. R. G., Duarte, A. K., Schneider, W. T., and Fernandes, M. R. F. (2005). Effect of the incorporation of a novel natural inorganic short fiber on the properties of polyurethane composites. *Polymer Testing*, *24*(7), 819-824.

Sapaun S.M., Leenie, A., Harimi, M., and Beng, Y.K. (2006). Mechanical properties of woven banana fibre reinforced epoxy composite. *Materials and Design 27*, 689-693.

Santhosh, J., Balanarasimman, N., Chandrasekar, R., and Raja, S. (2014). Study of properties of banana fiber reinforced composites. *International Journal of Research in Engineering and Technology*, *3*(11), 144-150.

Sarkar, P., Modak, N., and Sahoo, P. (2017). Mechanical Characteristics of Aluminium Powder Filled Glass Epoxy Composites. *International Journal of Engineering and Technologies: ISSN:2297-623X*, *12*, 1-14.

Sarkar, P., Modak, N., and Sahoo, P. (2018). Mechanical and Tribological Characteristics of Aluminium Powder filled Glass Epoxy Composites. *Materials Today: Proceedings*, *5*(2), 5496-5505.

Satyanarayana, K. G., Guimarães, J. L., and Wypych, F. E. R. N. A. N. D. O. (2007). Studies on lignocellulosic fibers of Brazil. Part I: Source, production, morphology, properties and applications. *Composites Part A: Applied Science and Manufacturing*, *38*(7), 1694-1709.

Senthilkumar, K., Saba, N., Rajini, N., Chandrasekar, M., Jawaid, M., Siengchin, S., and Alotman, O. Y. (2018). Mechanical properties evaluation of sisal fibre reinforced polymer composites: A review. *Construction and Building Materials*, *174*, 713-729.

Singh, J. I. P., Dhawan, V., Singh, S., and Jangid, K. (2017). Study of Effect of Surface Treatment on Mechanical Properties of Natural Fiber Reinforced Composites. *Materials Today: Proceedings*, *4*(2), 2793-2799.

Spinks, P. (2017, July/August). Deploying cutting-edge surface treatment technology to develop light weight and affordable composites for use in future Automotive applications. *Reinforcedplastics*, *61*(4), 226-229.

Sood, M., and Dwivedi, G. (2017). Effect of fiber treatment on Flexural Properties of Natural reinforced Composites: A Review. *Egyptian Journal of Petroleum*, 1-9.

Srinivasan, V.S, Boopathy, S.R., Sageetha, D., and Ramnath B.V. (2014). Evaluation of mechanical and thermal properties of banana-flax based natural fibre composite. *Materials and Design 60*, (pp. 620-627).

Tamilarasan, U., Karumamoorthy, L., and Palanikumar, K. (2015). Mechanical properties Evaluation of the carbon fibre reinforced Aluminium sandwich composites. *Material Research 18(5),* 1029-1037.

Temesgen, A. G., and Sahu, O. (2014). Process ability enhancement of false banana fibre for rural development. *Journal of Agricultural Economics, Extension and Rural Development, Vol. 1(6)*, 064-073.

Tewari, T., Singh, V.K., Gope, P.C., and Chaudhary, A.K. (2012). Evaluation of mechanical properties of bagasse-glass fiber reinforced composite. *Jouranl of material Environmental Science 3(1),* 171-184.

Tudu, P. (2009). *Processing and characterization of natural fiber reinforced polymer composites.*

Venkateshwaran, N., ElayaPerumal, A., Alavudeen, A., and Thiruchitrambalam, M. (2011). Mechanical and water absorption behaviour of banana/sisal reinforced hybrid composites. *Materials and Design*, *32*(7), 4017-4021.

Venkateshwaran, N., Elayaperumal, A., and Sathiya, G. K. (2012). Prediction of tensile properties of hybrid-natural fiber composites. *Composites Part B: Engineering*, *43*(2), 793-796.

Vieira, C.A.B., Susin, S.B., Friere E., Amico, S.C., and Zattera, A.J. (2009). Characterization of hybrid composites produced with mats made using different methods. *Material Research*, Vol.12, No.4, 433-436

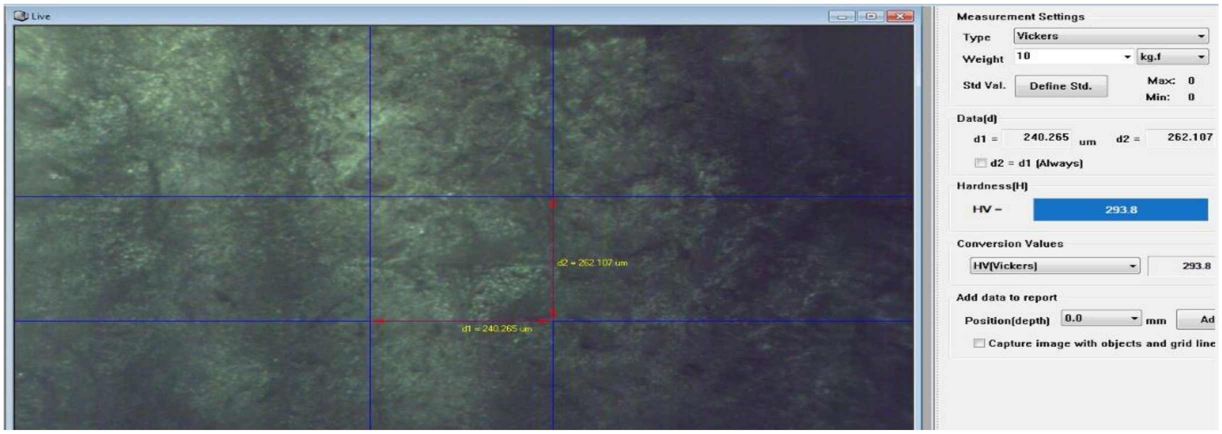
V.P.Arthanarieswaran, V.P., Kumaravel, A., and Selvam, M.K. (2014). Evaluation of Mechanical Properties of banana and sisal fiber reinforced epoxy composites: Influence of Glass fiber hybridization. *Materials and Design 64*, 194-202.

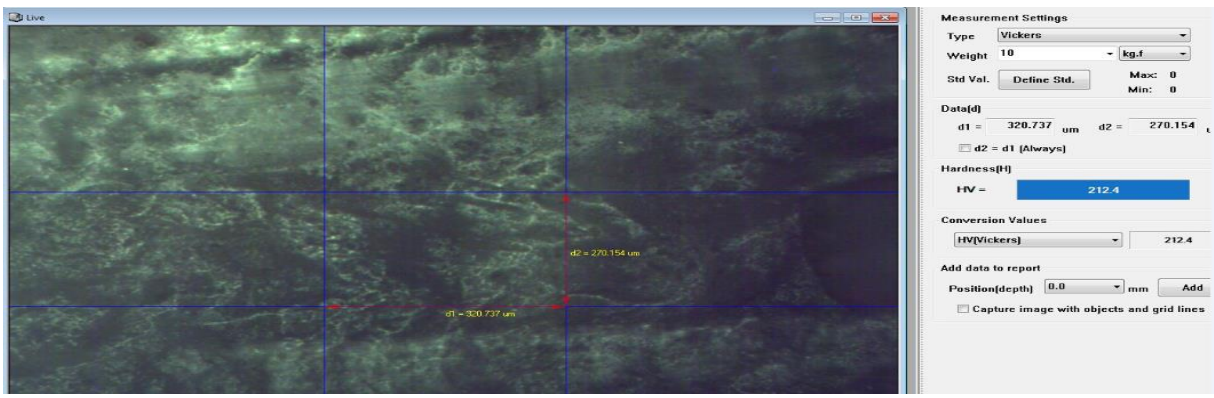
Yadav, S.M and Yusoh, K. (2015). Mechaical and physical properties of wood-plastic composites made of polypropylene, wood flour and nano clay. *Proceeding-kuala lumpur International Agricultural, Forestry and Plantation,1-10*

Appendix I

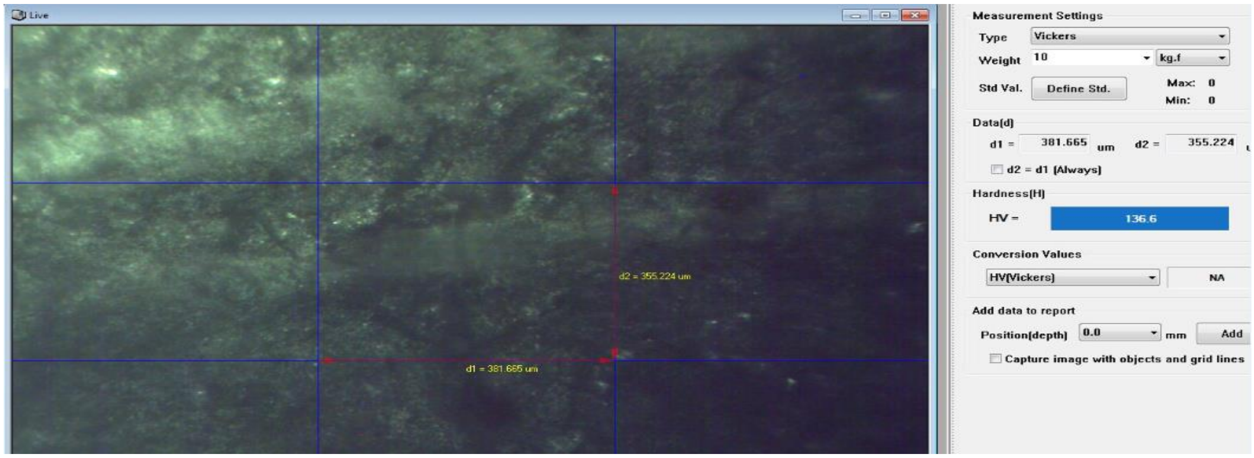
Micro hardiness results of all samples:

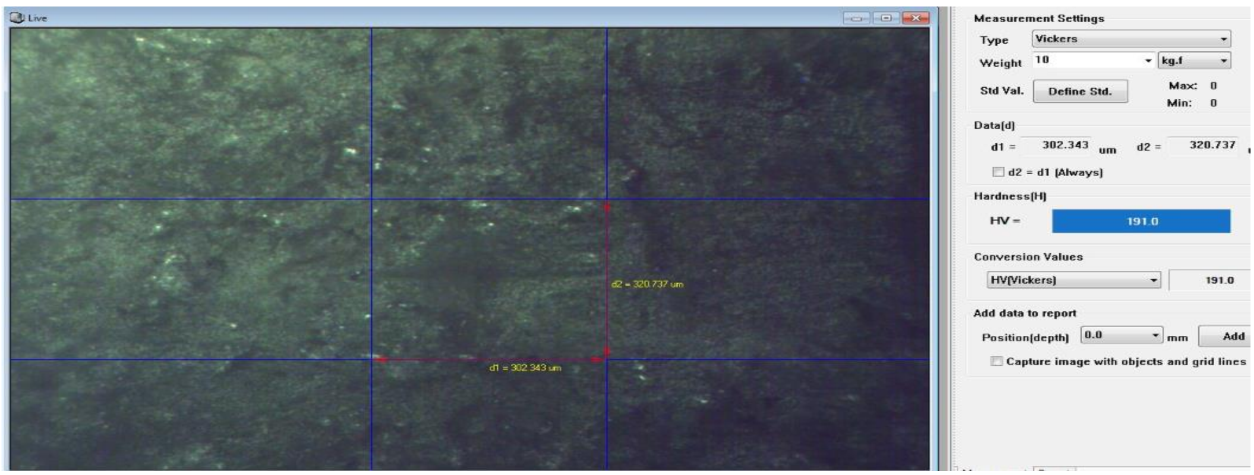
Sample A: Micro-hardness results:

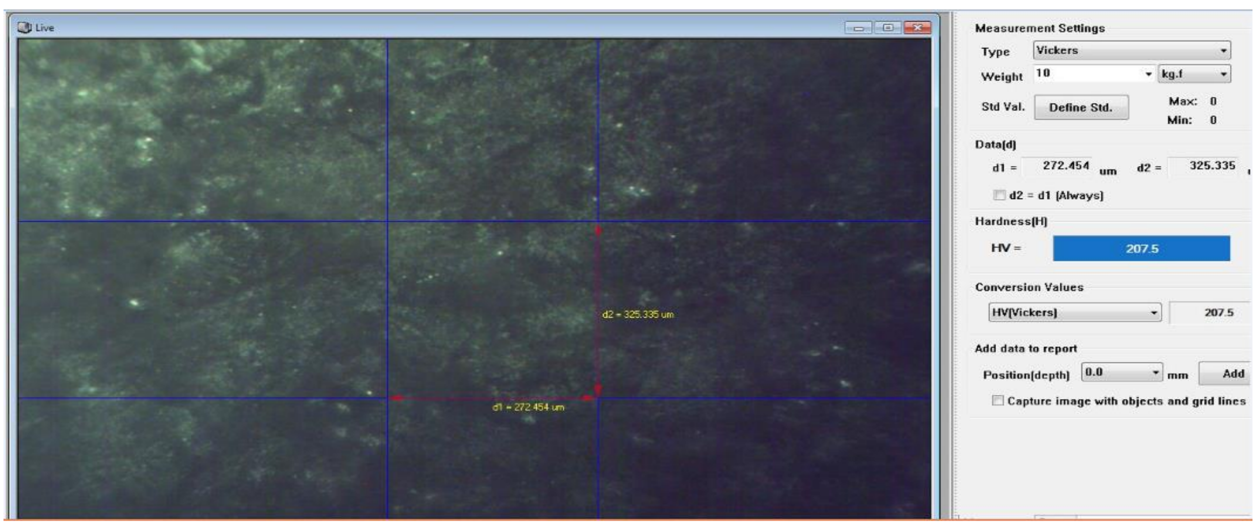




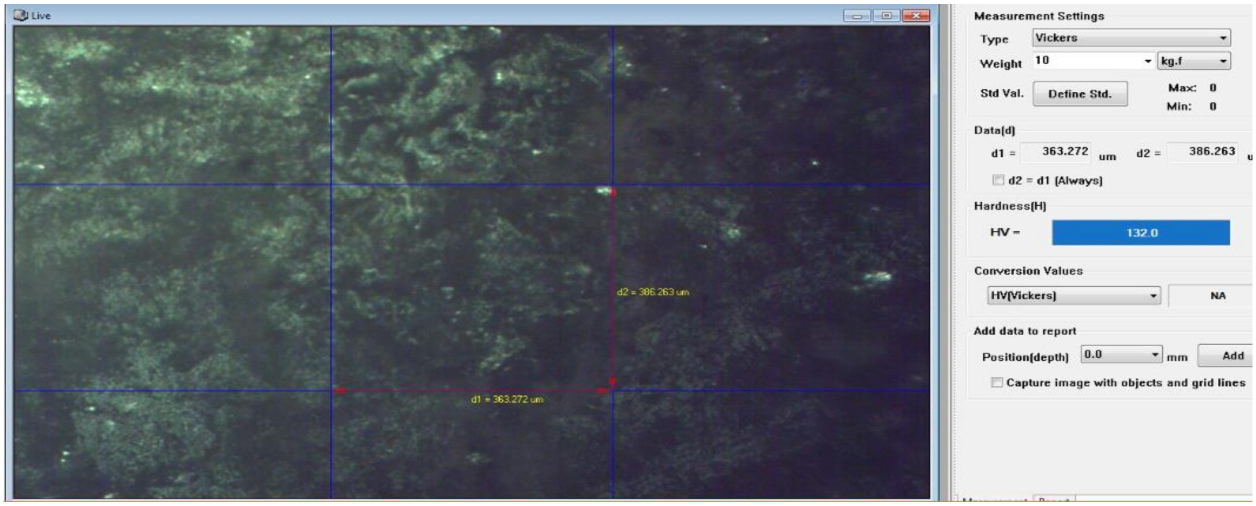
Sample B: Micro-hardness results:

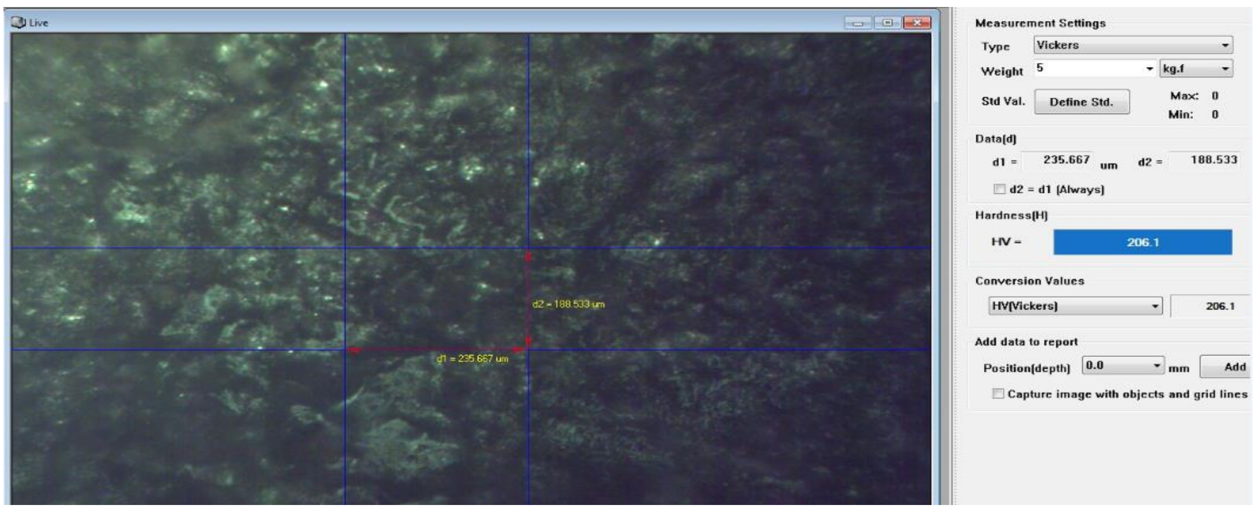


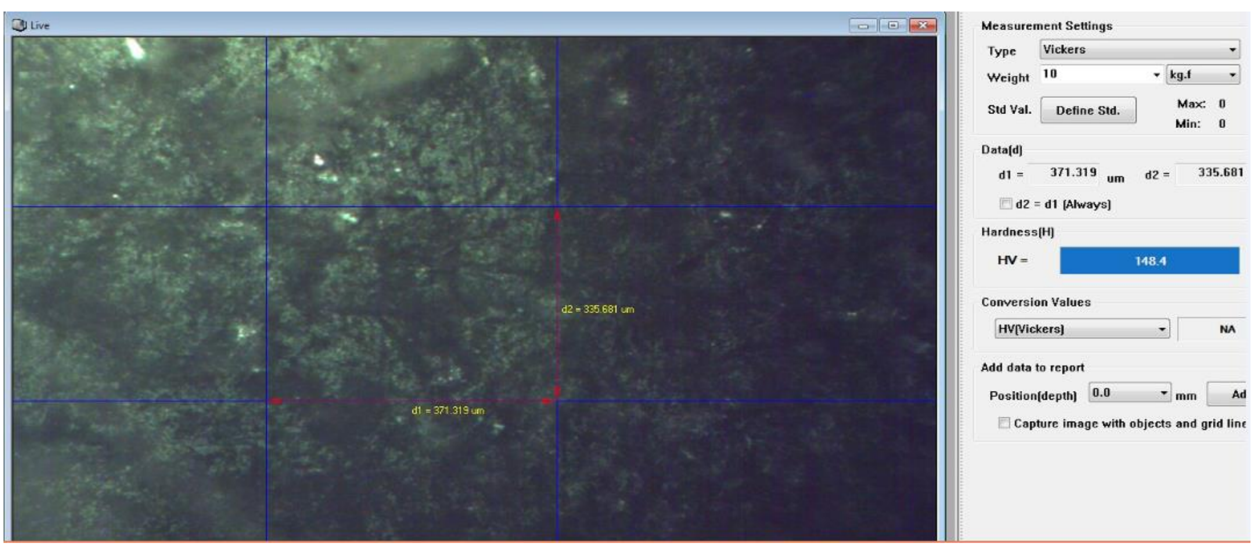




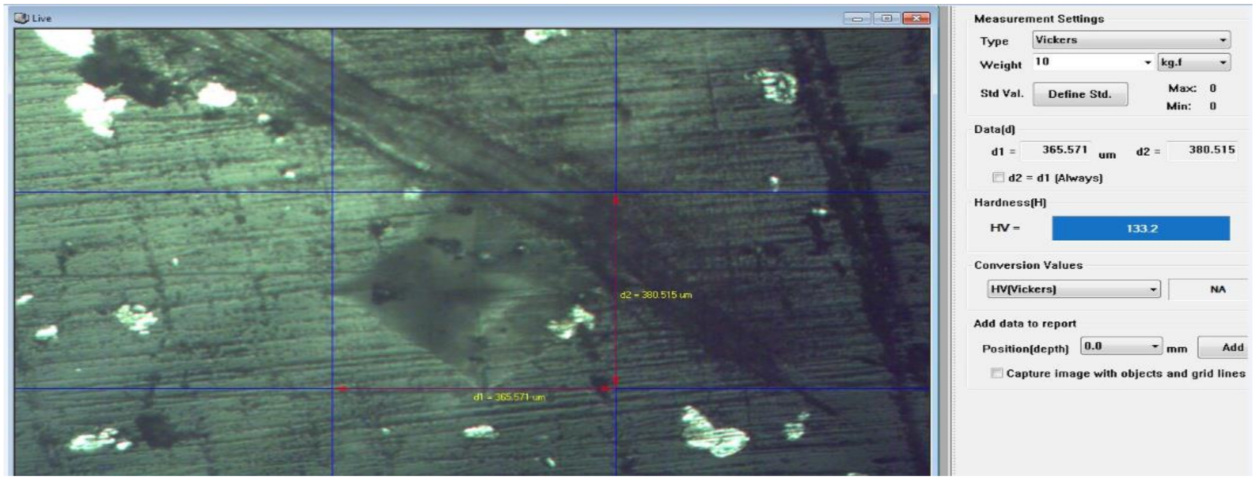
Sample C: Micro-hardness results:

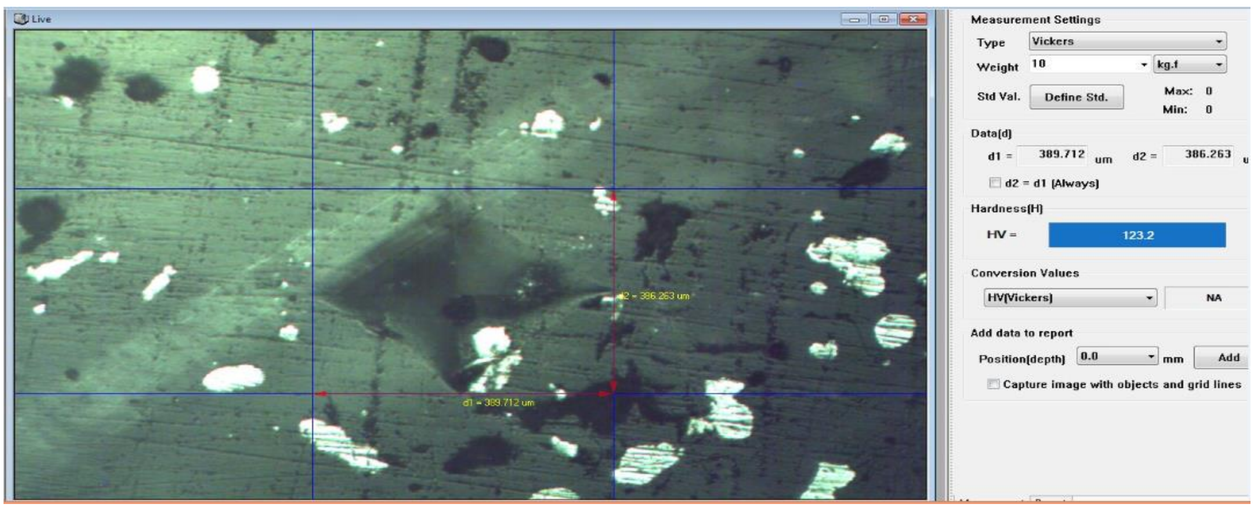


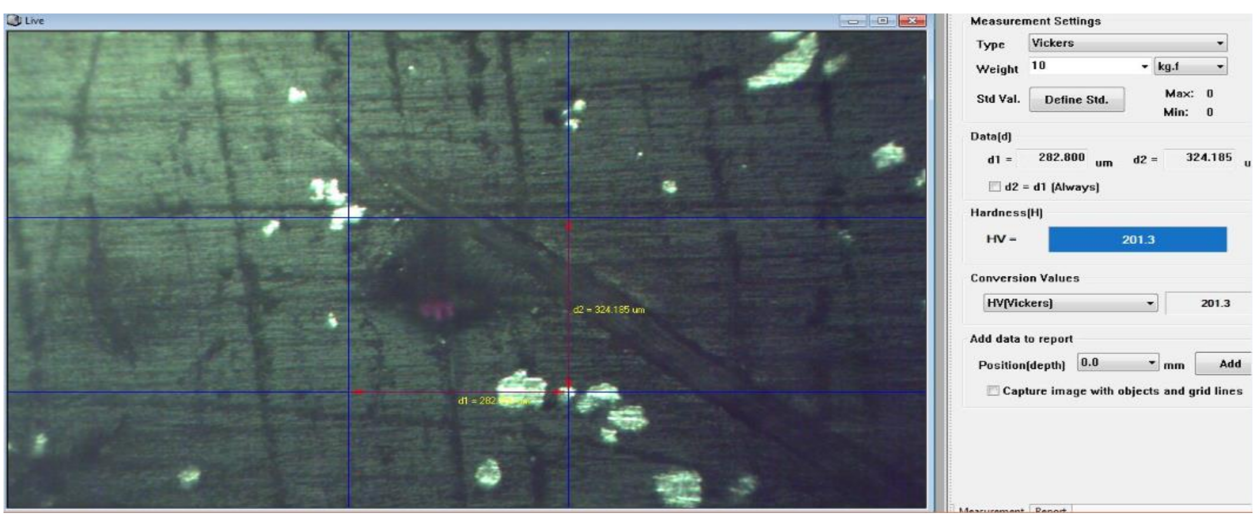




Sample D: Micro-hardness results:







Appendix II

Tensile results of Sample A, B, C and D for each specimen

የኢትዮጵያ የተስማሚነት ምዘና ድርጅት

Ethiopian Conformity Assessment Enterprise

ቁጥር (No.) 2/8/16-2/2957/10

ቀን (Date) 21 ግንቦት 2010

ለአዳማ ሳይንስና ቴክኖሎጂ ዩኒቨርሲቲ

አዳማ

ግንቦት 10 ቀን 2010 ዓ.ም በቁጥር MDME/0124/2018 በተፃፈ ደብዳቤ የBanana fiber reinforced polyment composite ናሙናዎች እንዲፈተሹላችሁ መጠየቃችሁ ይታወሳል፡፡

ስለሆነም በጥያቄው መሠረት ፍተሻው ተካሂዶ 4 ገጽ የፍተሻ ውጤት በዚህ ደብዳቤ ሸኘንት የላክን መሆኑን እንገልፃለን፡፡

ከሠላምታ ጋር

አባሪ፡ 4 ገጽ የፍተሻ ውጤት MTR/1723-1726/18

ግልባጭ፣

ለኢትዮጵያ የተስማሚነት ምዘና ድርጅት

- ለደንበኞች አገልግሎት

አዲስ አበባ

ወደ ላቀ ብቃት የሚያደርስ!

Moving you forward!

ECAE ኢተምድ	የኢትዮጵያ የተስማሚነት ምዘና ድርጅት Ethiopian Conformity Assessment Enterprise	Document No: TLD/F5.10-1	
		Copy No: -	Rev No: 1
Title:	TEST REPORT ይህ የናሙና ፍተሻ ሪፖርት እንጂ ሰርተፍኬት አይደለም	Page No: 1 of 1	Effective Date: 13Jan 13

Report No: MTR/1723/18
Test order No: ---

1	Name and address of client	ROBSON BALCHA Tel: +251-911-57-00-36, Adama
2	Date and place of sampling	21/05/18
3	Sampled and submitted by	Client
4	Date sample received	21/05/18
5	Client's sample code	Adama Science & Technology University
6	Laboratory designated sample No.	10254010
7	Type of sample	Banana fiber reinforced polymer composite
8	Test method	ES ISO 6892-1:2014
9	Test date(s)	24/05/18
10	Date of Submission of test report	24/05/18

Test result

L.D.S No.	Ser no.	Sample code	Tensile strength (Mpa)
10254010	A1	Al 0 %	28.1
	A2	Al 0 %	19.8
	A3	Al 0 %	23.7

1. This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name Liyew Wudie Position Analyst I Sign

✉ 11145 ☎ 011 6 46-05-69, Fax 011 6 45-97-80, E-mail info-ca@eca-e.com Web site: www.eca-e.com
BOLE SUBCITY, WOREDA 6
ADDISABABA, ETHIOPIA

ECAE

የኢትዮጵያ የተስማሚነት ምዘና ድርጅት

Ethiopian Conformity Assessment Enterprise

Title: TEST REPORT

ይህ የናሙና ፍተሻ ሪፖርት እንጂ ሰርተፍኬት አይደለም

Document No: TLD/F5.10-1 | Copy No: - | Rev No: 1 | Page No: 1 of 1 | Effective Date: 1Jan 13

Report No: MTR/1724/18
Test order No: ---

1	Name and address of client	ROBSON BALCHA Tel: +251-911-57-00-36, Adama
2	Date and place of sampling	21/05/18
3	Sampled and submitted by	Client
4	Date sample received	21/05/18
5	Client's sample code	Adama Science & Technology University
6	Laboratory designated sample No.	10254011
7	Type of sample	Banana fiber reinforced polymer composite
8	Test method	ES ISO 6892-1:2014
9	Test date(s)	24/05/18
10	Date of Submission of test report	24/05/18

Test result

L.D.S No.	Ser no.	Sample code	Tensile strength (Mpa)
10254011	B1	Al 5 %	32.8
	B2	Al 5 %	32.3
	B3	Al 5 %	23.7

1. This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name Liyew Wudie Position Analyst I Sign.

✉ 11146 ☎ 011 6 46-05-69, Fax. 011 6 46-97-20, E-mail info-cs@eca-e.com Web site: www.eca-e.com
BOLE SUBCITY, WOREDA 6
ADDISABABA, ETHIOPIA

ECAE	የኢትዮጵያ የተስማሚነት ምዘና ድርጅት Ethiopian Conformity Assessment Enterprise	Document No: TLD/F5.10-1	
		Copy No: -	Rev No: 1
Title:	TEST REPORT ይህ የናሙና ፍተሻ ሪፖርት እንጂ ሰርተፍኬት አይደለም	Page No: 1 of 1	Effective Date: 11an 13

Report No MTR/1725/18
Test order no. —

1	Name and address of client	ROBSON BALCHA Tel: +251-911-57-00-36, Adama
2	Date and place of sampling	21/05/18
3	Sampled and submitted by	Client
4	Date sample received	21/05/18
5	Client's sample code	Adama Science & Technology University
6	Laboratory designated sample No.	10254012
7	Type of sample	Banana fiber reinforced polymer composite
8	Test method	ES ISO 6892-1:2014
9	Test date(s)	24/05/18
10	Date of Submission of test report	24/05/18

Test result

L.D.S No.	Ser no.	Sample code	Tensile strength (Mpa)
10254012	C1	Al 10 %	42.1
	C2	Al 10 %	24.7
	C3	Al 10 %	32.4

1. This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name Liyew Wodaje Position Analyst I Sign.

✉ 11145 ☎ 011 6 46-05-69, Fax 011 6 46-07-20 E-mail info-cs@eca-e.com Web site: www.eca-e.com

ECAE ኢተምድ	የኢትዮጵያ የተስማሚነት ምዘና ድርጅት **Ethiopian Conformity Assessment Enterprise**	Document No: TLD/F5.10-1 Copy No: - Rev No: 1
Title:	TEST REPORT ይህ የናሙና ፍተሻ ሪፖርት እንጂ ሰርተፍኬት አይደለም	Page No: 1 of 1 Effective Date: Jan 13

Report No: MTR/1726/18
Test order No: —

1	Name and address of client	ROBSON BALCHA Tel: +251-911-57-00-36, Adama
2	Date and place of sampling	21/05/18
3	Sampled and submitted by	Client
4	Date sample received	21/05/18
5	Client's sample code	Adama Science & Technology University
6	Laboratory designated sample No.	10254013
7	Type of sample	Banana fiber reinforced polymer composite
8	Test method	ES ISO 6892-1:2014
9	Test date(s)	24/05/18
10	Date of Submission of test report	24/05/18

Test result

L.D.S No.	Ser no.	Sample code	Tensile strength (Mpa)
10254013	D1	Al 15 %	25.3
	D2	Al 15 %	35.6
	D3	Al 15 %	30.9

1. This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name Liyew Wubie Position Analyst I Sign

✉ 11145 ☎ 011 6 46-05-69, Fax 011 6 46-87-20, E-mail info-ca@eca-e.com Web site: www.eca-e.com
BOLE SUBCITY, WOREDA 6
ADDISABABA ETHIOPIA

WORLD FIBER GLASS

AND WATER

PROOFING

ENGINEERING

1.Technical Data

2. Application Method

3. Product Code

4. Safety Data Sheet

5. Iso Certificate

شركة كيماويات الراتنجات الصناعية المحدودة

Industrial Chemicals & Resins Co. Ltd.

Chamber of Commerce No. 3801/2 $475m^2$ رقم اشتراك الغرفة التجارية ٣٨٠١/٢

TOPAZ – 1110 TP, GENERAL PURPOSE RESIN

UNSATURATED POLYESTER RESIN

TECHNICAL DATA SHEET

INTRODUCTION

TOPAZ - 1110 TP is a medium reactive unsaturated Polyester Resin based on Phthalic Anhydride, with excellent laminating properties.

TOPAZ - 1110 TP is Thixotropic and has a built-in accelerator system giving long gel time and rapid curing for shorter demoulding time.

TOPAZ - 1110 TP impregnates the fiberglass quickly and the laminate gives a smooth tackfree surface due to the presence of wax.

TOPAZ - 1110 TP is designed for general purpose moulding for hand lay-up and spray up applications.

PHYSICAL PROPERTIES (at 25° C)

PROPERTIES	VALUES	UNIT	TEST METHODS
Appearance	pinkish Viscous liquid		
Viscosity	575-675	cps	ISO 2555-1974
Specific Gravity	1.13	g/cc	ISO 2811-1974
Acid Value	23-28	mg/koh/gm	ISO 2114-1974
Styrene Content	38±3	% Weight	ISO 2114-1974
Flash Point	34°	Centigrade	ASTM D 3278-73
Storage Stability	4	Months	
Gel Time (1.5% MEKP)	15-20	Minutes	
Peak Exotherm	150-165	Centigrade	

PACKING

Available in 220 kg. Metallic Drums and in 25kg. 10kg, and 4kg packing, to suit the bulk as well as small requirements.

STORAGE

Recommended to be stored bellow 25°C, Storage life decreases with increase in storage temperature. Avoid exposure to heat source, such as sunlight or hot pipes. Keep containers sealed to prevent moisture entering or monomer escaping out.

The product has a shelf life of three months, stored in accordance with the conditions mentioned above. On request, however, the Resin can be modified for prolonged shelf life.

ص.ب ٧٩٥٢ – الدمام ٣١٤٧٢ – المملكة العربية السعودية – تلفون [illegible]
[illegible]034096 - P. O. Box 7952 - Dammam 31472 - Saudi Arabia - Tel.: 8122050 (3 Lines) 8122086 Fax: 8121995
e-mail : icr@zajil.net Web : www.icr.com.sa e-mail : icr@icr.com.sa