Advances in Research
7(5): 1-10, 2016, Article no.AIR.26991
ISSN: 2348-0394, NLM ID: 101666096

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Fabrication and Mechanical Property Evaluation of Ethiopia Banana Fiber Reinforced Polymer Composites

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Authors' contributions

This work was carried out in collaboration between all authors. Author IM designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors JR and CZ managed the literature searches and analyses of the study performed the spectroscopy analysis. Authors IM and CZ prepared the sample and managed the experimental process. Author TG identified the species of plant. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AIR/2016/26991
Editor(s):
(1) Pradip K. Bhowmik, Department of Chemistry, University of Nevada Las Vegas, Las Vegas, USA.
Reviewers:
(1) R. Agung Efriyo Hadi, Universitas Malahayati, Lampung, Indonesia.
(2) André Leandro da Silva, Federal University of Campina Grande, Brazil.
Complete Peer review History: http://sciencedomain.org/review-history/15264

Original Research Article

Received 13th May 2016
Accepted 24th June 2016
Published 2nd July 2016

ABSTRACT

Banana and false banana fiber is important by-product of Ethiopian country farmers. The current work explains the characterization of different weight of a composite, natural fiber epoxy composites, by using hand lay-up technique and mechanical testing machine. Depending on the percentage of composite in resin, from 80%-95% by weight, which increasing the mechanical properties. SEM using to evaluate fiber, surface structure and fractured internal structure. The Experiment outcome illustrate that the impact strength, tensile strength and flexural strength are increased with the similar proportion as amount of epoxy (resin) increased. Scanning electron microscopy used to evaluate and analyze the experiment work. As well as form experimental result conclude that higher tensile, Impact and flexural strength exist at proportion of 80% epoxy resin with 20% banana fiber.

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Keywords: Banana; epoxy; tensile; flexure; impact strength; scanning electron microscopy.

1. INTRODUCTION

Last few decades have seen composite materials being used predominantly in various applications. It may seem surprising, but first natural fiber composites were used more than 100 years ago [1]. In 1896, for example, airplane seats and fuel-tanks were made of natural fibers with a small content of polymeric binders. Nowadays there a lot of composite of natural fiber in order to improve some of their properties particularly composite of one type of natural fiber to other types, and sometimes reinforced with some additive chemicals.

So the composition may take place natural fiber of the same categories or with different categories, the main categories are from plant (banana, abaca, bamboo, cotton, coir, flex, jute etc.) from, animal (Alpaca, angora, bisdown, camelhair, chasmere, etc.), cellulose (acetate, triacetate, art silk, bamboo) from minerals (Asbestos).

Maha M. Ibrahim, Alain Dufresne, Waleed K. El-Zawawy, Foster A. Agblevor" in their research work on "Banana fibers and microfibrils as lignocellulosic reinforcements in polymer Composites" [2]. This paper present about the Banana plant waste, as lignocellulosic fiber, was treated with alkaline pulping and steam explosion to produce banana fibers and banana microfibrils. The chemical composition of the ensuing fibers and microfibrils was determined. The chemical modification, with malleic anhydride, of the produced particles was further carried out. The FT-IR analysis and scanning electron microscopy observations of the resulting modified and unmodified banana fibers were investigated composite materials were processed from these natural unmodified and maleated lignocellulosic fibers using polyethylene as the polymeric matrix. The thermal and mechanical properties were studied by differential scanning calorimetry (DSC) and tensile tests, respectively. The morphology of processed composites was studied by scanning electronic microscopy (SEM). Better compatibility and enhanced mechanical properties were obtained when using banana microfibrils. The chemical composition of fibers, in terms of lignin and cellulose, as well as their degree of crystallinity, were found to have a strong influence on the mechanical properties of the composites.

S. U. Lokubalasooriya, S. M. Egodage, B. A. J. K. Premachandra studied about the "Banana fiber filled natural rubber compounds: the effect of filler loading and the coupling agent" [3]. The objective of the present study is to investigate the effect of fiber loading on rheological properties and the physico-mechanical properties of a dry rubber compounds. In this study, banana fibers were extracted using a mechanical retting method, and were ground using a domestic grinder to prepare fibers in the size range 0.01 – 1.2 mm.

Joseph and Thomas studied" The Effect of chemical treatment on the tensile and dynamic mechanical properties of short sisal fiber reinforced low density polyethylene composites" [4]. It was observed that the CTDIC (cardanol derivative of toluene diisocyanate) treatment reduced the hydrophilic nature of the sisal fiber and enhanced the tensile properties of the sisal-LDPE composites. They found that peroxide and permanganate treated fiber-reinforced composites showed an enhancement in tensile properties. They concluded that with a suitable fiber surface treatment, the mechanical properties and dimensional stability of sisal-LDPE composites could be improved.

N. Venkateshwaran, A. Elaya Perumal, D. Arunsundaranayagam. in his research "Fiber surface treatment and its effect on mechanical and visco-elastic behaviour of banana/epoxy composite" [5]. An experimental investigation is carried out to find the 1% NaoH treated fiber reinforced composites behaves superiorly than other treated and untreated fiber composites. SEM image analysis also shows the effect of alkali concentration over the fiber surfaces which leads to improving the mechanical properties of the composites

Venkateshwaran A. ElayaPerumal, A. Alavudeen, M. Thiruchitrambalam in his research. "Mechanical and water absorption behaviour of banana/sisal reinforced hybrid composites" [6]. The tensile, flexural, impact and water absorption tests were carried out using banana /epoxy composite material. The study showed that addition of sisal fiber in banana /epoxy composites of up to 50% by eight results in increasing the mechanical properties and decreasing the moisture absorption property. Morphological analysis as carried out to observe fracture behaviour and fiber pull-out of the samples using scanning electron microscope.

Emanuel M. Fernandes, João F. Mano, Rui L. Reis in their work on. "Hybrid cork–polymer composites containing sisal fiber: Morphology, effect of the fiber treatment on the mechanical properties and tensile failure prediction" [7]. In this study investigated the use of short sisal fiber with and without polyethylene-graft-maleic anhydride (PE-g-MA) as a strategy to reinforce cork–polymer composite (CPC) materials. The use of alkali treatment of sisal to improve fiber–matrix adhesion was evaluated. High density polyethylene (HDPE) was used as matrix and the composites were produced in a two-step process using twin-screw extruder followed by compression moulding. FTIR, TGA and XRD were used to confirm the sisal fiber modification. Additionally, morphology, density, diameter and tensile properties of the fibers were evaluated before processing. The hybrid composites containing cork powder (40% wt.) and randomly distributed sisal fibers were evaluated in terms of morphology and mechanical properties. The use of a 10 wt. % sisal fiber in the presence of a 2 wt. % coupling agent based on maleic anhydride has shown to improve the tensile and flexural properties of the composites. The higher mechanical properties were achieved by using alkali treated sisal fibers and PE-g-MA. In the presence of the coupling agent the composite morphology revealed good interfacial adhesion between the natural components and the polypropylene matrix, being in accordance with the mechanical results. Weibull cumulative distribution was successfully used to accurately predict the tensile strength failure of the hybrid.

S. Mukhopadhyay, R. Srikanta in their research works on "Effect of ageing of sisal fibers on properties of sisal – Polypropylene composites" [8]. A composite laminate based on natural sisal fiber and polypropylene was prepared by compression moulding. The mechanical properties of the composite were assessed under tensile, flexural and impact loading. Changes in the stress–strain characteristics, yield stress, tensile strength, and tensile Young's modulus, due to ageing have been analyzed. Important findings with the fresh and aged fibers and their behaviour in composites have been reported and analysed.

A lot of research has been done on natural fiber reinforced polymer composites but research on banana and sisal based polymer composites on uni- directionally & bi-directionally with epoxy resin composites is very rare. Against this background, the present research work has been undertaken, with an objective to study the mechanical characterization of different fiber ratio composites.

2. EXPERIMENT

2.1 Materials

As initial work before experiment investigation; banana fiber in form single ribbon component is extracted in four cycle form two site, Emdiber and Wolkite in southern part of Ethiopia. The method we used to extract fiber is traditional one, just by using metal and human hand to rub the bananas root in order to remove the gel component from fiber parts. The physical properties of the banana fibers are presented in Table 1.

Table 1. Physical properties of banana fiber [9]

Properties	Range
Cellulose (%)	63-64
Hemicellulose (%)	19
Lumen size (%)	5
Moisture content	10-11
Density(g/cm3)	1-1.5
Elongation at a break (%)	4.5-6.5
Young's modulus (GPa)	20
Microfibrillar angle (deg.)	11
Lignin (%)	5

2.2 Preparation of Composite Specimen

The short banana which is taken as reinforcement in this study is collected from local sources from Emdibir. The epoxy resin (LY5560) and the hardener methyl ethyl ketone peroxide (MEKPO) are supplied by SClab and Ranchem Company, Addis Ababa Ethiopia. Prepare moulds having dimensions of 50 x 50 cm were first manufactured for composite fabrication. The chemical (Acetone) treated short banana fiber are mixed with epoxy resin by simple mechanical stirring and the mixture was poured into the prepared moulds, keeping in view the requirements of various testing conditions and characterization standards.

Four sets of samples are prepared, 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 + 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. A releasing agent is used on the mould to release mallex sheets to facilitate easy removal of the composite from the mould after curing. Then place mallex sheet over the resin and fiber .The entrapped air bubbles (if any) 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 50 kg.

After curing, the specimens of suitable dimension are cut using a diamond cutter for mechanical tests as per the ASTM standards. The composition and designation of the composites prepared for this study are analyzed for various mechanical and physical properties and SEM images to indentify which fiber are stronger and efficiently treated reinforced epoxy composites. Extraction of composite from mould plates, repeat the same process by placing the fibers by varying their percentage in 0/90 degree orientation for (Banana) natural fibers. The raw bananas used for fabrication of composite pieces are presented in Fig. 1. The fabricated composite pieces are given Fig. 2.

2.3 Mechanical Properties of Composites

2.3.1 Tensile test

The mechanical behavior of the composites prepared with the fabricated samples was tested in the Universal Tensile testing machine with testing load range of maximum 5 Ton with gear rotation speed of 1.25, 1.5, 2.5 mm/min. The experiments were conducted at normal room temperature. The test specimens were cut as per ASTM standards using water jet machining. The tensile strength was determined as per ASTM D638 with standard gauge length of 50 mm, with a cross head seed of 1.25 mm/min.

2.3.2 Impact specimen test

Impact strength of the composite specimens was carried out in Izod impact testing machine according to ASTM A370 standard. The specimen size was 65.5*12.7*3 mm with depth under notch of 2.5 mm. The Charpy impact test, is a standardized high strain rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's toughness and acts as a tool to study temperature-dependent, ductile-brittle transition [10].

Fig. 1. Raw banana fiber

Fig. 2. Fabricated composite laminate

2.3.3 Flexural test

The flexural test measures the force required to bend a beam under three point loading situations. The three point bending test was performed in accordance with ASTM D790 standards. The samples were cut into 50.8*12.7*3 mm respectively. The data is often used to select elements for parts that will support loads without inflection. Flexural modulus is used as an indication of a material's stiffness when inflection. Since the physical properties of many elements can vary depending on ambient temperature, it is appropriate to test materials at temperatures that simulate the intended end user environment [11].

2.3.4 Microstructure

For Scanning, the electron microscope images were taken samples to observe the microstructure by the scanning electron microscope JSM-840 [12]. The images were taken for banana fiber and epoxy resin composites and the images were to indentify which fiber are stronger and professionally treated reinforced epoxy composites.

3. RESULTS AND DISCUSSION

The use of banana fiber in nowadays become popular specially in Asian country like India, Indonesia, Malaysia, to replace metal, alloys materials, glass fiber; as well as due to its advance benefit like recycling, biodegradable and eco-friendly [13]. So many researcher are tested the different properties of banana fiber and its composite, But Ethiopian banana which is very similar to False banana stem but different in some case is not considered since it's not popular in most country, by nature noticed that banana has strong and flexible root than false banana's root without test result manually. So since this banana is more popular in Ethiopia this research present the evaluation mechanical properties of this plant in form of epoxy composite. Specimen tested for tensile, impact and flexural strength with corresponding testing method. The table below shows the result of experiment for each mechanical property evaluated from different specimen investigated according to experiment procedure listed above. The result indicates banana fiber has very good mechanical property which is increased in related to epoxy content. Experiment results of the banana composite samples are given in Table 2.

3.1 Tensile Properties

The banana fiber composites prepared with the fabricated samples was tested in the Universal Tensile testing machine under room temprature with all volume fraction. The graph below shows the relation of loading capacity or tensile strength to ratio of composite. At early stage with smaller percentage of epxoy, tensile strength increase linearly up to the ratio increased to 15%, and then increased rapidly. This show the properties of banana fiber maximized based on composite component. The tensile strength test specimen before and after fracture of banana fiber reinforced composite are presented in Fig. 3 and Fig. 4.

3.2 Flexural Properties

The line graph below shows the relation of flexural propeties with weight fraction based on result tested by three point loading situations. The capacity of composite to resist breaking under load is high. Similarly at early stage with smaller percentage of epxoy, flexural strength increase linearly up to the ration increased to 10%, and then imidiatlty started increasing rapidly. The impact strength test specimen before and after fracture of banana fiber reinforced composites are presented in Fig. 6 and Fig. 7 and the result are shown in the Fig. 8.

Fig. 3. Tensile strength test specimen before fracture

Fig. 4. Tensile strength test specimen after fracture

Table 2. Tensile, Flexural and Impact properties of different composites samples

Fraction by weight %	Tensile strength (MPa)	flexural strength (MPa)	Impact strength (Joules)
95% resin + 5% Banana	37.8	211.338	1.5
90% resin + 10% Banana	42.6	226.675	1.8
85% resin + 15% Banana	47.4	286.375	2.3
80% resin + 20% Banana	56.5	340.625	2.8

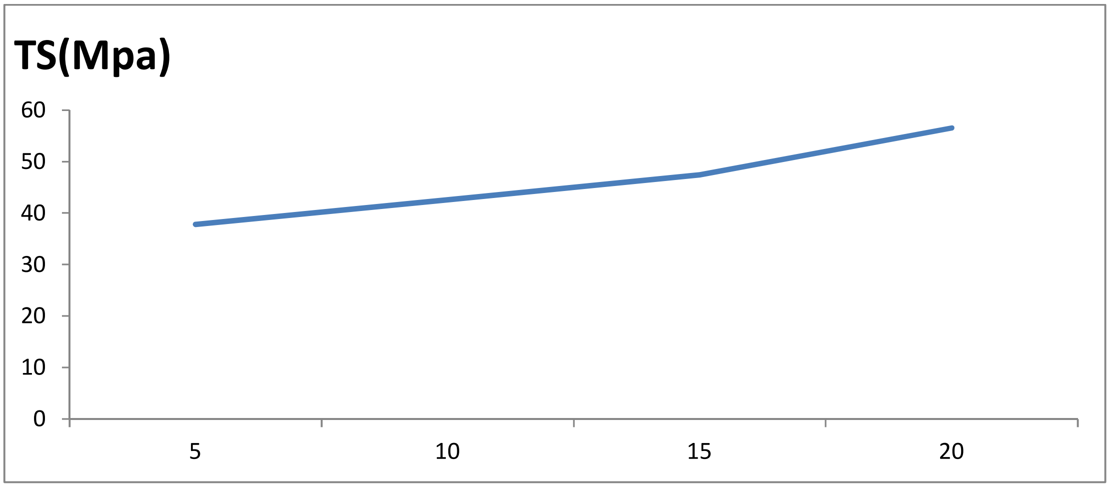

Fig. 5. Tensile strenght versus fiber weight ratio

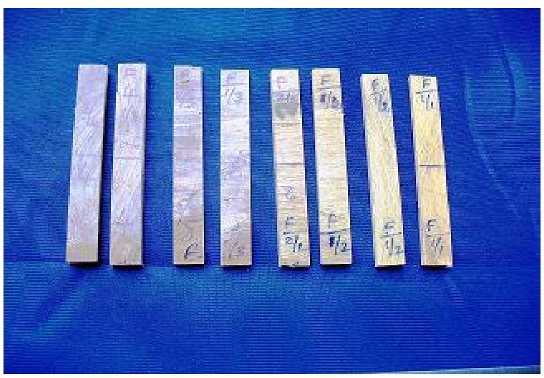

Fig. 6. Flexural test specimen before fracture

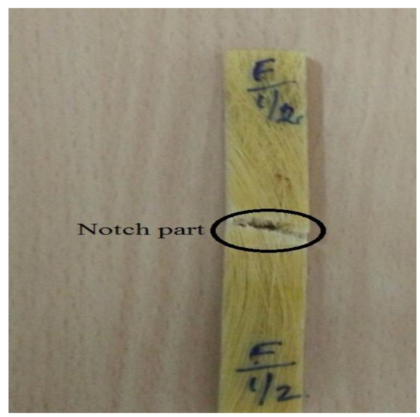

Fig. 7. Flexural test specimen after fracture

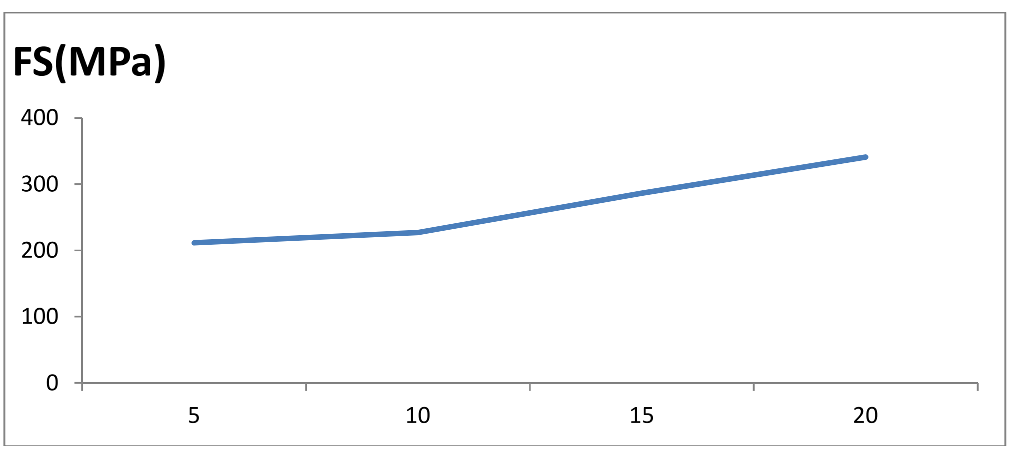

Fig. 8. Flexural strength versus weight ratio

3.3 Impact Properties

To Identify the sudden load carrrying capacity which depend on energy loss or absorbation of materials the impact test investigated. The impact strength test specimen before and after fracture of banana fiber reinforced composites are presented in Fig. 9 and Fig. 10. Similarly at early stage with smaller percentage of epxoy, flexural strength increase linearly up to the ration increased to 10%, and then imidiatlty started increasing rapidly the Fig. 11. present result shows banana fiber compiste has higher impact strength when compared most of natural fiber.

3.4 Scanning Electron Mcrocope (SEM) Analysis

The structure of the fractured surfaces due to the mechanical loading will be observed through SEM analysis. The SEM micrographs are to be used to observe the internal cracks, fractured surfaces and internal structure of the tested samples of the composite materials. In most of fiber composite the micro object has fiber, matrix, air voids and fiber agglomeration [14,15]. The SEM micrograph of the sample subjected to tensile loading, flexural loading and Impact loading. The figures below presented the result.

The fiber dispersion is clearly visible in the SEM images provided. In the figures of magnification of composite before load applied and fracture not happened, from percentage of 5-15% that clearly visible in which all parts are matrix without fiber is also visible clearly with little air voids (air gaps) These air gaps reduce the strength of the composite the fiber distribution and orientation are also visible is in the Figs. 13(a), 13(b), and 14(a). Similarly for 20% of banana fiber image shows more fiber agglomeration. The extensive fiber pullout of under load side which means fractured part of fracture is visible in the Figs. 14(b)-15(b) from which it can be deduced that there is no trace of matrix resin sticking to the fiber which indicates a poor fiber- matrix adhesion as a result of which the composite strength gets reduced by a considerable amount. Also indicates fiber agglomerations as well as fiber pull out.

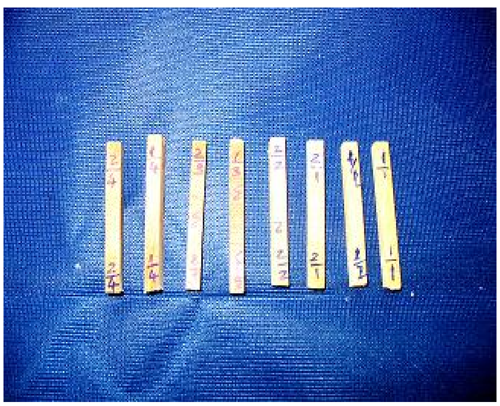

Fig. 9. Impact test specimen before fracture

Fig. 10. Impact test specimen before fracture

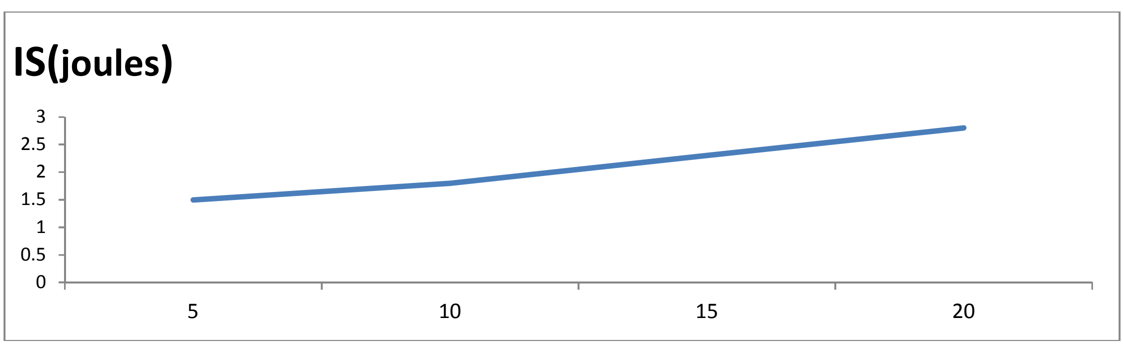

Fig. 11. Impact strenght versus weight ratio

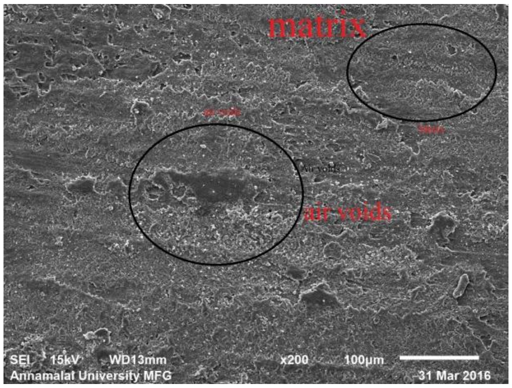

Fig. 12. (a) 5% Banana 90/0 before fracture.

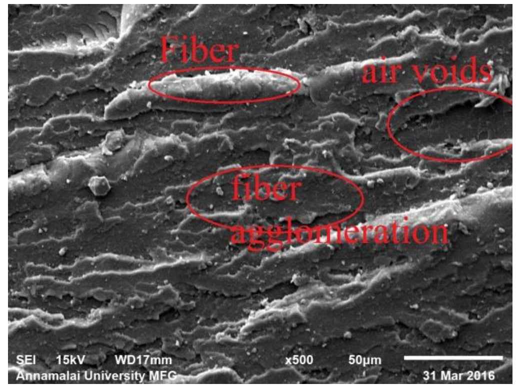

Fig. 12. (b) 5% Banana 90/0 after fracture

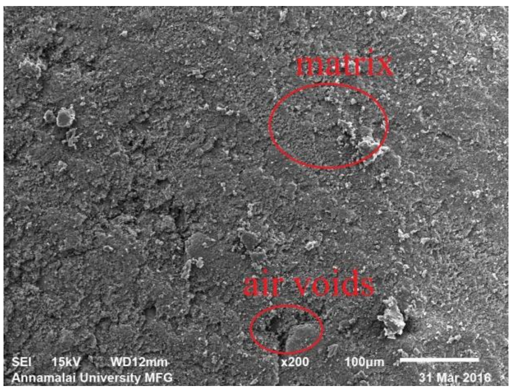

Fig. 13. (a) 10% Banana 90/0 before fracture

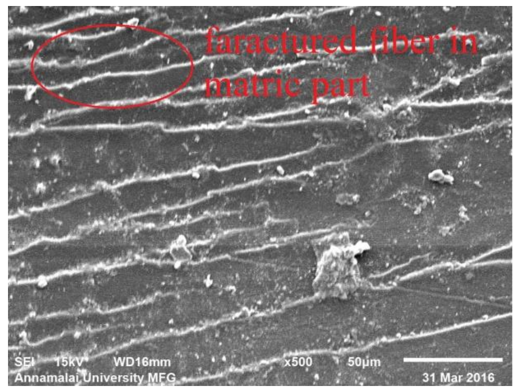

Fig. 13. (b) 10% Banana 90/0 after fracture

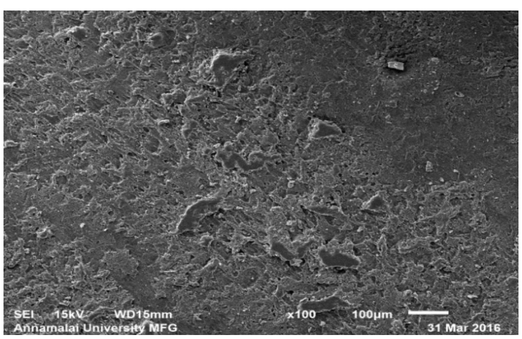

Fig. 14. (a) 15% Banana 90/0 before fracture

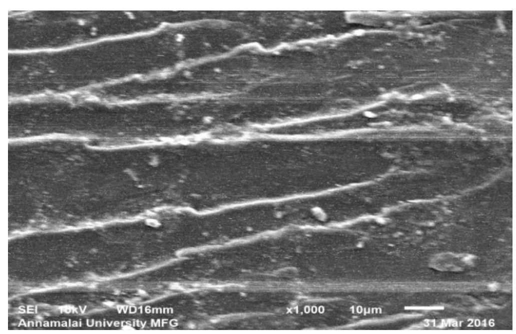

Fig. 14. (b) 15% Banana 90/0 after fracture

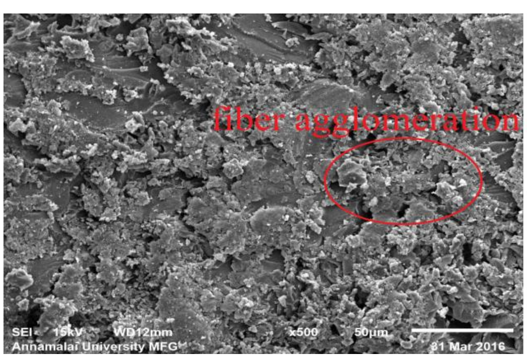

Fig. 15. (a) 20% Banana 90/0 before fracture

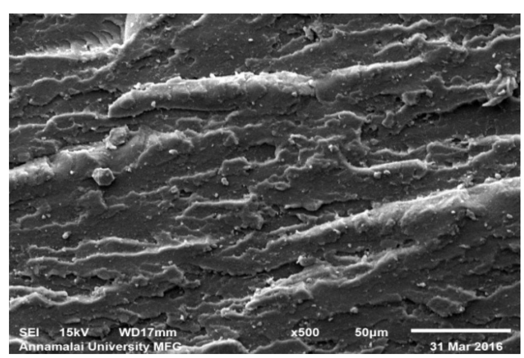

Fig. 15. (b) 20% Banana 90/0 after fracture

4. CONCLUSION

- Generally from Ethiopian banana fiber highly machineble, flexible and with better surface of materials (plate of composite) created and can easily produce for other purpose by reinforcing with epoxy resin. Also with higher percentage of banana fiber, the composites have better mechanical properties (Tensile, flexural, and impact strength) in this research optimum result of experiment exist at 20% banana fiber and 80% epoxy resin.
- Epoxy based banana fiber composites were fabricated by hand lay-up process. After testing and characterization the following observations are made from this study follows:
- The comparison of tensile strength reveals that 20% banana fiber and 80% epoxy on 90^0 orientation fiber/ epoxy composite has 56.5 MPa exhibit higher tensile strength than 15% banana unidirectional fiber 47.4 MPa. Whereas 10% banana unidirectional fiber/epoxy composite has exhibit better tensile strength of 42.6 MPa than 5% banana unidirectional fiber which has only 37.8 MPa. When fiber concentration increases the tensile strength also increases.
- Impact tests reveal that 20% banana fiber / epoxy unidirectional and 15% banana unidirectional posses higher impact strength than other fiber samples.
- The flexural strength of 20% banana fiber/ epoxy unidirectional exhibits better flexural strength of 340.625 MPa than other banana fiber percentage.
- The morphological study reveals that fibers pull out are occurred on various percentages of unidirectional fibers. From the figures epoxy resin are well bonded than unit directional fibers which results in weak interfacial bonding on fiber percentage and 5% banana 90° orientation fibers.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
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