كلية الدراسات العليا

Sudan University of Science and Technology
College of Graduate Studies
College of Engineering and Technology of Industries

Mechanical Properties of Banana Fibers Reinforced Polyester Composite

الخواص الميكانيكية لألياف الموز المقوية للبوليستر المركب

Thesis submitted in fulfillment of the requirements for the Degree of M.Sc. in fiber and polymer engineering

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May 2019

الايـة

بسم الله الرحمن الرحيم

(وَاتَّقُوا يَوْماً تُرْجَعُونَ فِيهِ إِلَى اللَّهِ ثُمَّ تُوَفَّى كُلُّ نَفْسٍ مَا كَسَبَتْ وَهُمْ لا يُظْلَمُونَ) [البقرة:281]

ACKNOWLEDGEMENTS

First and foremost I offer my sincerest gratitude to my supervisor **Prof. Ahmed Ibrahim Seedahmed For** provide guidance, advice and valuable assistance during my studies.

Thanks from the depths for **Dr. Ramadan Mohammed Ahmed** and **Dr. Magdi Elamin Gibril** for valuable help.

Especially thanks for **nada** and **Anfal** to help me in the manufacturing and preparing of the composite specimens.

I would like to express my special thanks to Material Research Center for helping me to carry out mechanical testing.

ABSTRACT

Natural fibers has been used extensively in various engineering fields, the mechanical properties of banana fibers play a broad role in determining their applicability in various industrial and engineering fields such as household, furniture, paper and automotive.

This study presents use of Banana fibers to reinforcing Polyester composite using hand layup technique. Unidirectional and quasi isotropic [0^0,90^0,45^0] samples were fabricated, Tensile strength, flexural and compression tests are performed to determine the load-displacement.

The result showed that the unidirectional [0^o] sample has high tensile and flexural strength comparison with unidirectional [90^o] and quasi isotropic [0^0,90^0,45^0] samples. But for Compression and water absorption test the quasi isotropic [0^0,90^0,45^0] sample was outperformed from the unidirectional [0^o] sample.

From the previous findings it was estimated that the Banana fibers reinforced polyester composite has high mechanical properties, low cost and easy in fabrication. Because of that the use of Banana fibers in polymer matrix composites is recommended.

المستخلص

استخدمت الالياف الطبيعية علي نطاق واسع في مختلف المجالات الهندسية ، والخواص الميكانيكية لالياف الموز تلعب دورا واسعا في تحديد قابليتها للتطبيق في مختلف المجالات الصناعية والهندسية مثل المستلزمات المنزلية والأثاث والورق والسيارات.

وتقدم هذه الدراسة استخدام ألياف الموز لتعزيز مركب البوليستر باستخدام تقنيه الفرد اليدوية، وتم تصنيع عينة احادية الاتجاه وعينه متقاطعة، وتم تنفيذ قوه الشد والمرونة واختبارات الضغط لتحديد الحمولة و الازاحة.

واظهرت النتيجة ان العينة احادية الاتجاه في اتجاه الطول لها قوة شد وثني عاليتين مقارنة بي العينة احادية الاتجاه في اتجاه العرض والعينة المتقاطعة، ولكن بالنسبة لاختبار الضغط وامتصاص الماء فإن العينة المتقاطعة كان اداؤها افضل من العينة احادية الاتجاه.

من النتائج السابقة وجد أن ألياف الموز المعززة لمركب البوليستر لها خصائص ميكانيكية عالية وهي أيضا منخفضه التكلفة وسهله التصنيع. بسبب ذلك ينصح باستخدام ألياف الموز في المواد المركبة.

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CHAPTER ONE

INTRODUCTION

1.1 Background:

Natural fiber-reinforced polymer composite materials are rapidly growing both in terms of their industrial applications and fundamental research as they are renewable, low, completely or partially recyclable and biodegradable. In order to produce cost effective polymer reinforced composites and to reduce the destruction of ecosystem, researchers have come up with new manufacturing trends for composite using natural fibers which are partially biodegradable, for which fibers such as flax, cotton, hemp, jute, sisal, kenaf, pineapple, banana, wood., used from time immemorial as a rich source of lignocellulosec fibers are more often applied as the reinforcement of composites. (Rohit and Dixit, 2016)

Some types of natural plants shown Fig (1.1)(Sanjay et al., 2016).

Fig (1.1) types of natural plants.

In the recent years, the natural fiber reinforced composites created a great interest among researchers towards technological developments. Among different fibers available, the banana fiber (a waste product obtained from the dry stalks of banana trees) offers a wide possibility for engineering applications. In general, the banana fiber reinforced polyester composites are used for structural applications, as they possess a good mechanical property, eco-friendly and are renewable(Prabu et al., 2017).

Polymeric based composites materials are being used in many application such as automotive, sporting goods, marine, electrical, industrial, construction, household appliances, etc. Polymeric composites have high strength and stiffness, light weight, and high corrosion resistance (Sapuan and Maleque, 2005).

Using agricultural wastes for industrial purposes is much more environmentally friendly practice than many residues available currently in use. Until recently, many farmers disposed of agricultural wastes by burning or land filling them (Hayes, 1998).

1.2 Composites material:

A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components.

Typical engineered composite materials include:

- Composite building materials, such as cements, concrete
- Reinforced plastics, such as fiber-reinforced polymer
- Metal composites
- Ceramic composites (composite ceramic and metal matrices).

1.2.1 Applications of Composites:

Composite materials are generally used for buildings, bridges, and structures such as boat hulls, swimming pool panels, race car bodies shower stalls, bathtubs, storage tanks, imitation granite and cultured marble sinks and countertops. The most advanced examples perform routinely on spacecraft and aircraft in demanding environments.

1.2.2 Classification of Composites:

Classification of Composites materials are shown in Fig (1.2).

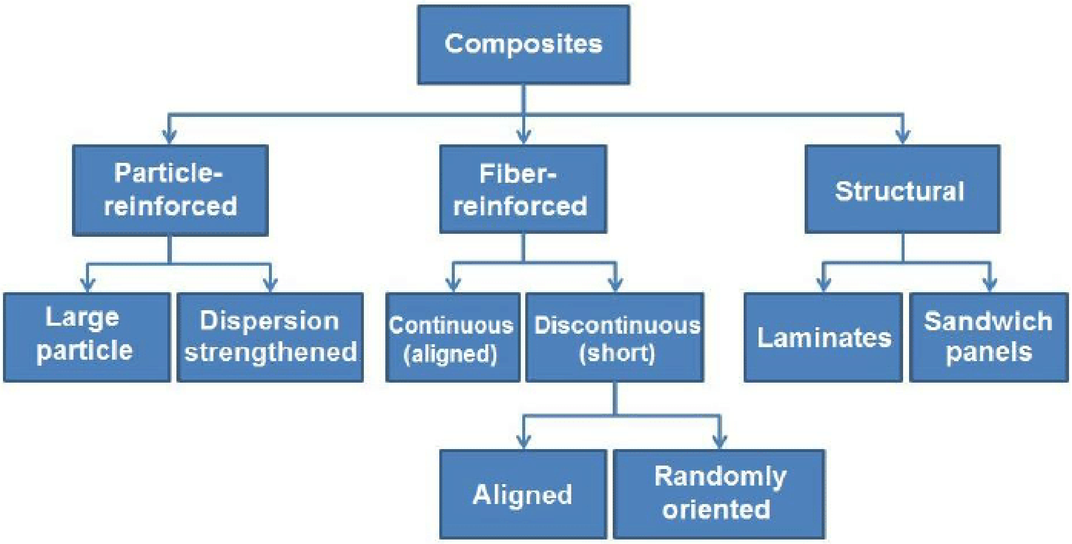

Fig (1.2): Classification of composite materials (Daniel et al., 1994).

1.2.3 Structure of Composites:

Structure of a composite material determines its properties to a significant extent.

Structure factors affecting properties of composites are as follows:

- Bonding strength on the interface between the dispersed phase and matrix.
- Shape of the dispersed phase inclusions (particles, flakes, fibers, laminates).
- Orientation of the dispersed phase inclusions (random or preferred).

1.2.4 Laminate structure:

Laminate is a stack of plies of composites. A composite laminate is an assembly of layers of fibrous composite materials which can be joined to provide required engineering properties, including in-plane stiffness, bending stiffness, strength, and coefficient of thermal expansion.

The individual layers consist of high-modulus, high-strength fibers in a polymeric, metallic, or ceramic matrix material.

Layers of different materials may be used, resulting in a hybrid laminate.

The individual layers generally are orthotropic (that is, with principal properties in orthogonal directions) or transversely isotropic (with isotropic properties in the transverse plane) with the laminate then exhibiting anisotropic (with variable direction of principal properties) (Talreja and Singh, 2012).

1.2.5 Composite Manufacturing Processes:

For making a composite part, a manufacturer can combine or alternate several processes, depending on the requirements for quality and cost, as follows:

- Hand lay-up.
- Prepregs forming.
- Pressure molding.
- Vacuum bagging.
- Filament winding.
- Pultrusion.
- Spray method.
- Resin transfer molding.

1.2.6 Hand lay-up technique:

For the Hand lay-up technique as shown in Fig (1.3), Resins are impregnated by hand into fibers which are in the form of woven, knitted, stitched or bonded fabrics. This is usually accomplished by rollers or brushes, with an increasing use of nip-roller type impregnators for forcing resin into the fabrics by means of rotating rollers and a bath of resin. Laminates are left to cure under standard atmospheric conditions.

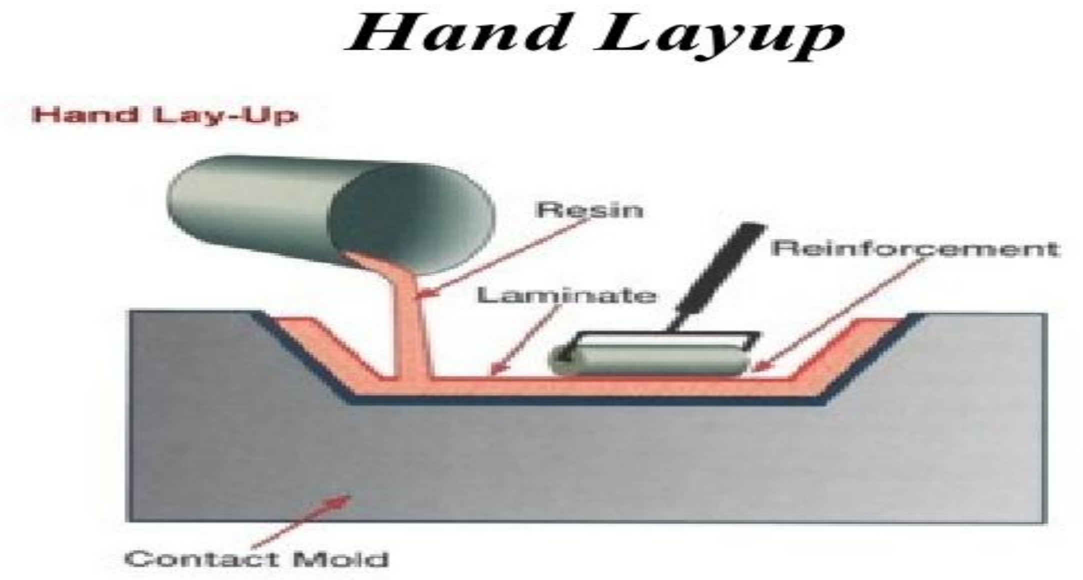

Fig (1.3): Hand Lay-Up technique.

1.3 Objectives:

The aims of this study are:

1. To Use of Banana fibers to fabricate Banana fibers reinforced Polyester composite.
2. To investigate the mechanical properties of Banana fiber reinforced Polyester composite at different fiber orientation.
3. To Study the behavior of the load-displacement curves which obtained from tensile, flexural and compression tests.
4. To predict the deformation behavior of the Banana fibers reinforced Polyester composite.

1.4 Scope of study:

The fabrication process involved hand layup technique to produce the composite. Then the mechanical test and physical test are carried out on this composite. The tests that involved are tensile test, flexural test, and comparison test.

CHAPTER TWO

LITERATURE REVIEW

2.1 Historical Background:

Composite material is a structural material prepared from two or more component materials with considerably different mechanical, physical, and/or chemical properties that, when combined, can produce a material with completely different characteristics from the individual components. This new composite contains new properties coming from the individual materials, and they may be favored for many reasons because they are stronger, lighter, and/or less expensive when compared to conventional materials. These new materials family can meet the challenges of the high technologies in aeronautic, aerospace, automotive, building, etc (Bayraktar, 2017).

2.2 Polymer Matrix Composites (PMCs):

The most common advanced composites are polymer matrix composites. These composites consist of a polymer thermoplastic or thermosetting reinforced by fibers, which can be used in automotive, transport, construction and packaging industries (Samivel and Babu, 2013),(Begum and Islam, 2013).

2.3 Natural Fiber Reinforced Polymer:

Common fiber reinforced composites are composed of fibers and a matrix. Fibers are the reinforcement and the main source of strength while matrix glues all the fibers together in shape and transfers stresses between the reinforcing fibers.

Natural fiber composites include coir, jute, baggase, cotton, bamboo, Banana, hemp. Natural fibers come from plants. These fibers contain lingo cellulose in nature.

Natural fibers are eco-friendly; lightweight, strong, renewable, cheap, and biodegradable. The natural fibers can be used to reinforce both thermosetting and thermoplastic matrices.(Drzal et al., 2001)

They provide sufficient mechanical properties in particular stiffness and strength at acceptably low price levels.

Natural fiber composites are very cost effective material especially in building and construction, packaging, automobile and railway coach interiors and storage devices (Rajesh and Prasad, 2012).

Recently the use of natural fiber reinforced Polyester composite in the various sectors has increased tremendously(Samivel and Babu, 2013).

2.3.1 Classification of natural fibers:

Natural fibers include those made from plant, animal and mineral sources, and Natural fibers shown in Fig (2.1).

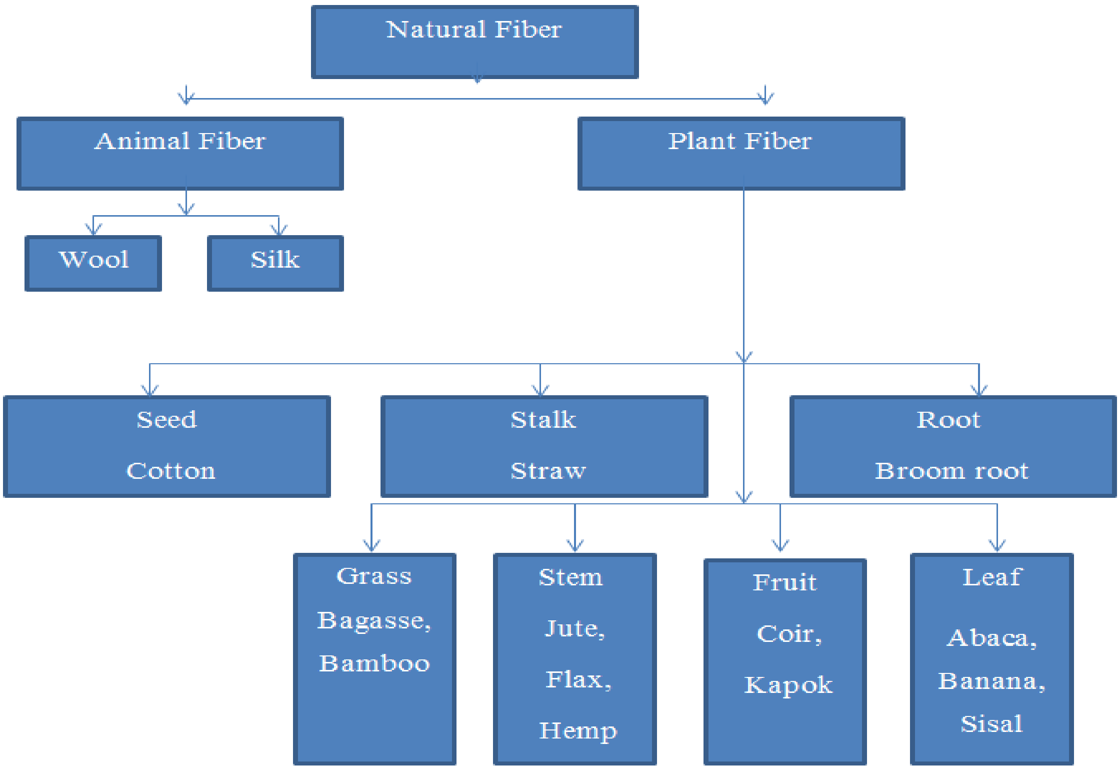

Fig (2.1): Classification of natural fibers.

2.3.2 Structure of Plant Fibres:

Structure of Plant Fibers shown Fig (2.2) (Rohit and Dixit, 2016).

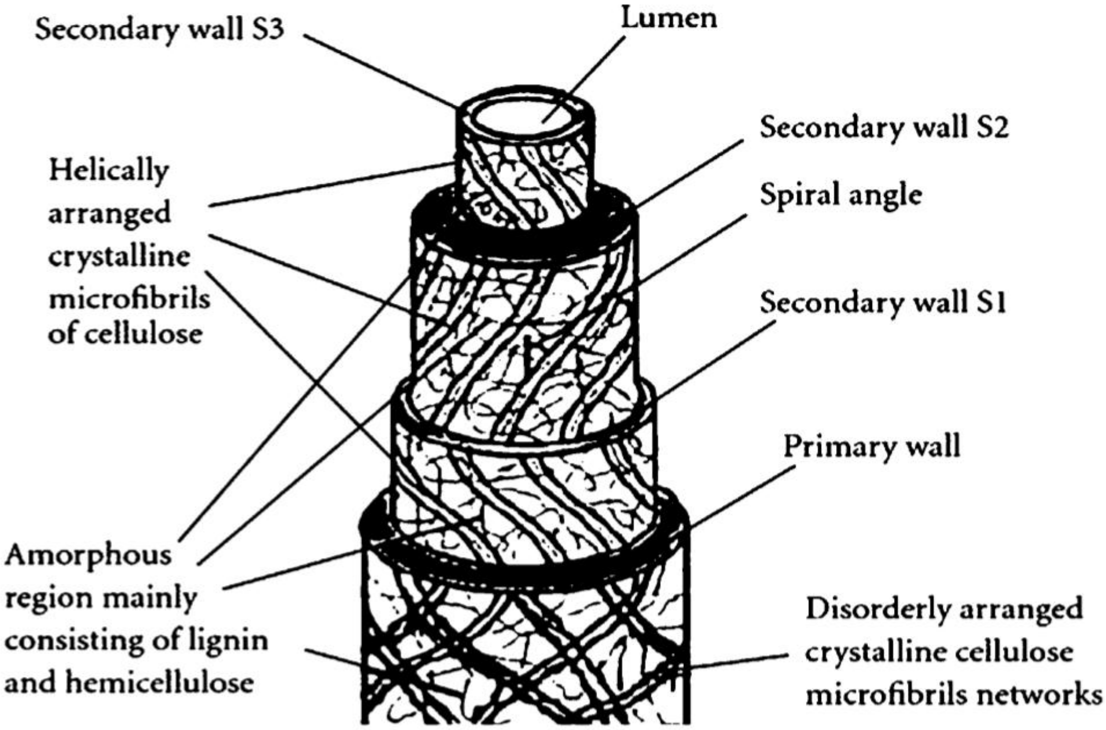

Fig (2.2): Structure of Plant Fibers.

2.4 Banana fibers:

Banana production was reported in Sudan since more than hundred years ago.

Fibers obtained from banana stem i.e., from the pseudo-stem of banana plant, which is a bast fiber has complex structure and relatively good mechanical properties (CHITRA, 2015).

Banana fiber is making products like filter paper, paper bags, greeting cards, lamp stands, pen stands, decorative papers, rope, mats and composite material etc (Bhatnagar et al., 2015a).

Properties of banana fibers are superior as compare to other natural fibers. The utilization and application of the cheaper goods in high performance appliance is possible with the help of this composite technology. Combining the useful properties of two different materials, cheaper manufacturing cost, versatility etc., makes them useful in various fields of engineering, high performance applications such as leisure and sporting goods, shipping industries, Aerospace etc (Bhatnagar et al., 2015b).

General properties of banana fiber:

Properties of banana fiber were shown in Tables (2.1),(2.2) and (2.3) (Bhatnagar et al., 2015b).

Table (2.1): Physical properties of banana fibers.

Property	Grade
Dia (μm)	80-250
Length(mm)	1000-5000
Aspect Ratio(l/d)	150
Moisture content (%)	60

Table (2.2): Chemical composition of banana fibers.

Property	Grade
Cellulose (%)	60-65
Hemi cellulose (%)	6-19
Lignin (%)	5-10
Pectin (%)	3-5
Ash (%)	1-3
Extractives (%)	3-6

Table (2.3): Mechanical properties of banana fibers.

Property	Grade
Tensile Strength (Mpa)	529-914
Specific Tensile Strength(Mpa)	392-677
Young's Modulus(Gpa)	27-32
Specific Young's Modulus (Gpa)	20-24
Failure Strain (%)	1-3
Density (Kg/m3)	750-950

2.5 Matrix (resin):

The primary functions of the resin are to transfer stress between the reinforcing fibers, act as a glue to hold the fibers together, and protect the fibers from mechanical and environmental damage. Resins used in reinforced polymer composites are both thermoplastic like polyethylene, polypropylene, polystyrene, and nylons. Or thermoset like epoxies, polyesters, and phenolics (Jawaid and Khalil, 2011).

Properties of different polymers will determine the application to which it is appropriate. The chief advantages of polymers as matrix are low cost, easy processability, good chemical resistance, and low specific gravity.

On the other hand, low strength, low modulus, and low operating temperatures limit their use (Adam, 1997).

Polyester resin:

Polyester resins are being increasingly used in industry. It is unsaturated thermo-setting resins which can be molded in almost any shape and size.

Alone they are usually not strong enough for commercial purposes but when combined with a reinforcing material, such as glass fiber, or fillers, such as glass dust or sand, they offer considerable possibilities(Bourne and Milner, 1963).

2.6 Previous studies:

Jannah, M., et al., Investigate the effects of fiber-loading and fiber surface treatments on flexural, impact and water absorption properties of the composites. Resulted that the acrylic acid treatment improved the mechanical and water absorption properties of the composites compared to the alkali treatment and untreated fiber composites (Jannah et al., 2009).

Mwaikambo, L.Y. and E.T. Bisanda, were manufactured a new class of materials from Cotton–kapok fabric–polyester composites that have demonstrated industrial potential. Increase in flexural strength and modulus as the fibre volume fraction is increased is an indication of a promising composite material in commercial use as design applications frequently involve a bending rather than tensile mode (Mwaikambo and Bisanda, 1999).

Sakthivel, M. and S. Ramesh, fabricated polymer matrix composites with natural fibers like coir, banana and sisal, using Hand Laminating Molding method, and found that polymer banana reinforced natural composites is the best natural composites among the various combination. It can be used for manufacturing of automotive seat shells among the other natural fiber combinations (Sakthivel and Ramesh, 2013).

Yıldız, A.B. and K. Çetinkaya, used recycled PET bottles broken in to pieces and mixed with polycarbonate polymer fibers which were produced by extrusion. Polymer fibers, glass fibers and banana fiber were used to produce polymer composite materials with the pulling operation and the polymer fiber production. From the obtained results, agricultural wastes offer a potential alternative raw material for the forest industry (Yıldız and Çetinkaya, 2012).

Saurab Dhakala, Keerthi Gowda B Sb, produced composite material from randomly oriented banana fiber with volume fraction varying as 5 %, 10 %, 15 %, 17.5 % and 20 %were fabricated by using hot compression molding method. The maximum value of tensile, flexural and impact strength obtained at 20 % fiber volume fraction for both 3 mm and 5 mm thick sample (Dhakal and Keerthi Gowda, 2017).

Mathew, J., et al., used bio-extracted banana fiber reinforced polypropylene in commingled composite systems. An entirely new method was adopted for the extraction of banana fiber, which is through an anaerobic process. The thermal properties of the commingled composite (both treated and untreated) were analyzed using thermo gravimetric analysis (TGA) and differential scanning calorimetry (DSC). The results showed an improved thermal stability for the treated composites. A noticeable increase in the hardness , tensile properties and decrease for the impact properties of the treated samples compared to the untreated ones (Mathew et al., 2016).

CONINCK, C., et al. developed new bio-composite by adding banana fibers to polypropylene matrix in to extruder then mixture were transferred to mould. this bio-composite showed an improvement in impact properties ,specific weight , thermal conductivity, Chemical and thermal stability (CONINCK et al., 2015).

VENKATASUBRAMANIAN, H. & RAGHURAMAN, S. fabricated Hybrid Composites using Abaca-banana-glass reinforcing Ortho-phthalic resin, Tensile, flexural and impact strength were investigated in the process of mechanical characterization. concluded that the hybrid composites possess good mechanical properties resulting (Venkatasubramanian and Raghuraman, 2015).

Mishra, S. and J. Naik*, used banana, hemp, and sisal fibers as fillers for the formation of natural fiber: polystyrene composites in the ratios of 55:45, 50:50, 45:55, and 40:60 (wt=wt) with compression molding method. Maleic anhydride treatment for fiber improves all the mechanical properties, such as Young's modulus, flexural modulus, tensile stress, flexural stress, Izod impact strength, and shore-D hardness in comparison with untreated fiber composites. It is due to the phenomenon of etherification of fibers (Mishra and Naik*, 2005).

Haneefa, A., et al., used longitudinally oriented banana/glass hybrid composites in polystyrene matrix, found that the tensile strength and Young's modulus of the composite increase with increase in volume fraction of glass fiber (Haneefa et al., 2008).

Pothan, L.A., Z. Oommen, and S. Thomas, conclude that the Dynamic mechanical properties of short banana fiber reinforced polyester composites are greatly dependent on the volume fraction of the fiber. The dynamic modulus shows a decrease with incorporation of fiber below the glass transition temperature and has a positive effect on the modulus at temperatures above Tg. The maximum improvement in properties is observed for composites with 40% fiber loading, which is chosen as the critical fiber loading. Increase of frequency shifts the Tg to higher temperatures supporting the good fiber/matrix interaction, which is clear from the SEM (Pothan et al., 2003).

Maleque, M., F. Belal, and S. Sapuan, obtain The tensile strength on the pseudo-stem banana woven fabric reinforced epoxy composite is increased by 90% compared to virgin epoxy, flexural strength increased when banana woven fabric was used with epoxy material, the pseudo-stem banana fiber improved the impact strength properties of the virgin epoxy material by approximately 40%, The banana fiber composite (Maleque et al., 2007).

Idicula, M., K. Joseph and S. Thomas, studied the Mechanical performance of short randomly oriented banana/polyester, sisal/polyester, and hybrid/polyester composites from the prepared Composites at 0.20, 0.30, 0.40, and 0.50 Vf by varying the relative volume fraction of the two fibers. And all composites mechanical properties increases with fibers loading. Composites having 0.40 Vf showed better performance. Finally it is revealed that banana/sisal hybrid fiber reinforced polyester composites results in a positive hybrid effect in tensile and flexural properties Impact strength was found to be maximum in sisal/polyester composites at all fiber loading (Idicula et al., 2010)

Pothan, L.A., et al., Investigate the affect of hybridization of banana fiber with glass on dynamic mechanical response of the composites. Found A layering pattern where glass fibers are incorporated between two banana layers lower the properties (Pothan et al., 2010).

Udaya Kiran, C., et al., Used short sun hemp, banana, and sisal fiber to reinforced polyester composites with different fiber Length and weight, observed that the tensile strength is increasing with increase in fiber weight ratio up to a certain point and further increment in fiber weight ratio has resulted in decreased tensile strength for three types of fiber reinforced composites. Random orientation of the fiber gives isotropic properties to the specimen (Udaya Kiran et al., 2007).

Jannah, M., et al., applied Chemical surface modifications (1% NaOH and 1% AA) to woven banana fabric and used as reinforcement in an unsaturated polyester matrix with four different volume percentages of fibers (5, 10, 15, and 20%).and investigated The effects of fiber-loading and fiber surface treatments on the flexural, impact and water absorption properties of the composites. And concluded that the impact strength, flexural strength and modulus of woven banana fiber composites increased with the increase in fiber content, and reduced the water absorption for Treated fiber composites compared to untreated composite system(Jannah et al., 2009).

Samivel, P. and A.R. Babu, Using kenaf and banana fiber to Reinforced Polyester composite, and that
the tensile and flexural properties of hybrid composites are markedly improved as compare to unhybrid composites. And indicated that the hybrid composites offer better resistance to water absorption(Samivel and Babu, 2013).

Zhu,W. B. Tobias, and R Coutts , when the fiber length is continuous and at sufficiently high content, the fibers act as reinforcement in polyester matrix to becomes an effective fibrous composite. Furthermore, a composite with a long fiber strand, and at a content of 30 wt %, has flexural strength 97 Map and flexural elastic modulus 6.5 GPa. There is also a 1.6 times increase in fracture toughness over the value of the neat resin (Zhu et al., 1995).

Prabu, V.A., et al., Fabricated Composites with sisal/USP, banana/USP and each of them was filled with red mud also through compression molding process. And concluded that the addition of red mud promotes a marginal increase in the mechanical strength(Prabu et al., 2012).

Pothan, L.A., et al., Used of chemically modified Banana fiber in preparation of composites with polyester matrix, found The electrical properties as well as mechanical properties of banana fiber reinforced polyester composites dependent on the fiber content as well as the fiber surface modification (Pothan et al., 2007).

Wong, K., U. Nirmal, and B. Lim, Studied the impact strengths of E-glass, coir, oil palm as well as E-glass/coir and E-glass/oil palm hybrid polyester composites, All types of composites reinforced with fiber volume fractions of 30%, 40%, and 50% and fiber lengths 3, 7, and 10mm, found that the longitudinal fiber mats always exhibit better impact toughness compared to transverse fiber mats, Impact strength is improved with the number of fiber layers but worsened by the fiber spacing (Wong et al., 2010).

CHAPTER THREE

MATERIAL AND METHOD

3.1 Materials:

In this present work Banana fiber is used for fabricating the composite specimen. The Banana fibers Fig (3.1), is obtained from Khartoum, Polyesters resin is obtained from industrial chemicals resins CO.LTD, Saudi Arabia.

Some properties of Banana fibers are illustrated in Table (3.1).

Table (3.1) Mechanical and Physical properties of the banana fibers.

Property	**range**
Tensile Strength (N)	17.2
Strain (%)	37.4%
Young's Modulus (N)	4.7
Average Length (mm)	1500
Diameter (mm)	0.6

Fig (3.1): Banana fibers.

Table (3.2): Some properties of Polyester resin.

Property	Range
Tensile Strength	60 Mpa
Tensile Modulus	7700 Mpa
Flex Strength	170 Mpa
Flex Modulus	7700 Mpa
Shrinkage	-0.14 %
Specific Gravity	1.96
% Moisture Absorption	0.5

3.2 Composites Manufacture Process:

Hand Lay-Up Molding:

The composite material used for present work is fabricated by hand layup process. Continues long Banana fiber was used to prepare the specimen. The composite specimen consists of total six layers.

The layers of fibers are fabricating by adding the required amount of polyester resin. The first layer of Banana fiber is mounted on the mold and then complete filled with Polyester resin. Before the resin gets dried, the second layer of Banana fiber is mounted over the first layer.

The process is repeated for the rest layers also. The Polyester resin applied is distributed to the entire surface by means of brush. The air gaps formed between the layers during the processing are gently squeezed out. The processed composite is pressed hard and the excess resin is removed and dried.

The two samples of Banana/Polyester composite unidirectional and quasi isotropic [0^0,90^0,45^0] were manufactured. Ceramic mold was used to fabricating the composite. The dimensions of the mold are 400 mm x 400 mm. for fabricating the laminated composite a release agent was applied on the mold.

For Quasi isotropic [0^0,90^0,45^0] sample the layers were laid in [0^o, 90^o, $+45^o$, -45^o, 90^o, 0^o].

The sample let to cure under small pressure in sun light for almost two hours.

Fabrication and final sample shows in Fig (3.2), (3.3) and Fig (3.4), (3.5) for unidirectional and quasi isotropic [0^0,90^0,45^0] sample respectively.

The materials used by weight were illustrated in table (3.3).

Table (3.3): weight of materials used.

Samples	Unidirectional sample	quasi isotropic [0^0,90^0,45^0]
Polyester (g)	400	600
Banana fiber (g)	20	65

Fig (3.2): preparation of unidirectional sample.

Fig (3.3): Unidirectional sample.

Fig (3.4): preparation of quasi isotropic [0^0,90^0,45^0] sample.

Fig (3.5): Quasi isotropic [0^0,90^0,45^0] sample.

3.3 Mechanical Testing:

In this research some tests were used to study some mechanical properties for Banana fiber reinforced polyester composite. The composite material fabricated is cut in to required dimension using a saw cutter for mechanical testing.

3.3.1 Tensile Test:

For tensile testing, the ZWICK/ROELL (ZWICK Z010) machine was used as shown in figure (3.6). Tensile test applied according to ASTM D 638 standards, the applied velocity is 5 mm/min, and the initial load is 0.1 Mpa. The samples have been prepared in the form of the dog bone shape. For tensile test, specimen was prepared according to the ASTM D638 standard. The dimensions table (3.4), gauge length and cross-head speeds are chosen according to the ASTM D638 standard.

Tensile test involves mounting the specimen in a machine and subjecting it to the tension. The testing process involves placing the test specimen in the testing machine and Appling tension to it until it fractures.

The tensile force is recorded as function of the increase in gauge length. During the application of tension, the elongation of the gauge section is recorded against the applied force.

There are three different kind of specimen are prepared according to the fiber orientation. The first specimen was unidirectional [0^o]. The second specimen was unidirectional [90^o] and the third specimen was quasi isotropic [0^0,90^0,45^0]. The preparation of specimen for tensile test is presented in Fig (3.7). The experiments are repeated for three times and the averages were used for discussion.

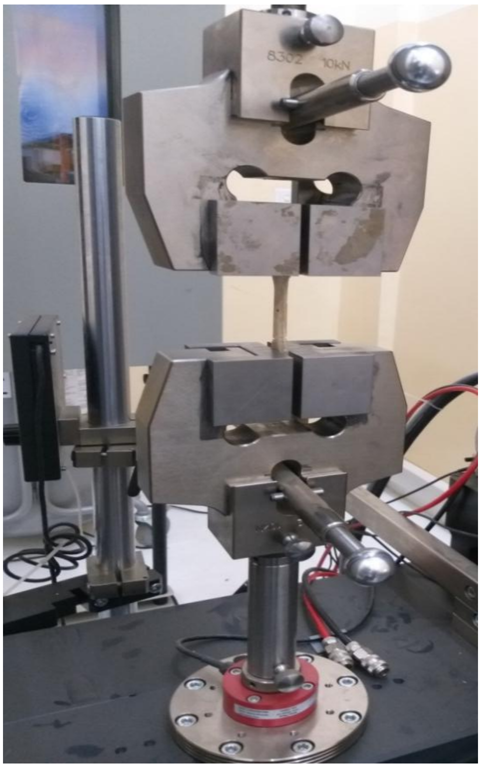

Fig (3.6): Tensile test machine.

Fig (3.7): Tensile test specimen.

3.3.2 Flexural Test (Three-Point Flexural Testing):

The 3-point Flexural test is the most common Flexural test for composite materials. For Flexural testing, the ZWICK/ROELL (ZWICK Z010) machine was used as shown in figure (3.8).Flexural test applied according to ASTM D 790 standards, the applied velocity is 1 mm/min, and the initial load is 0.1 Mpa. The samples have been prepared in the form of the rectangle shape.

The Flexural specimens were prepared according to the ASTM D 790 standard. The dimensions of these test specimens are listed in Table (3.4).Specimen deflection is measured by the cross head position.

Test result includes flexural strength and displacement. The specimen used for conducting the flexural test is presented in Fig (3.9).and Appling force to it until it fractures and breaks. Test results include flexural strength and displacement.

Fig (3.8): Flexural test machine.

Fig (3.9): Flexural test specimen.

3.3.3 Compression Test:

For Compression testing, the ZWICK/ROELL (ZWICK Z010) machine was used as shown in figure (3.10).Compression test applied according to ASTM D 695 standards, the applied velocity is 10 mm/min, and the initial load is 0.1 Mpa. The samples have been prepared in the form of the cube shape.

The Compression test specimens are prepared according to the ASTM D 695 standard. The dimensions of these test specimens are listed in Table (3.4),

The specimen was placed between compressive plates parallel to the surface. The specimen was then compressed at a uniform rate. The maximum load is recorded along with stress-strain curve. The specimen used for conducting the Compression test is presented in Fig (3.11).

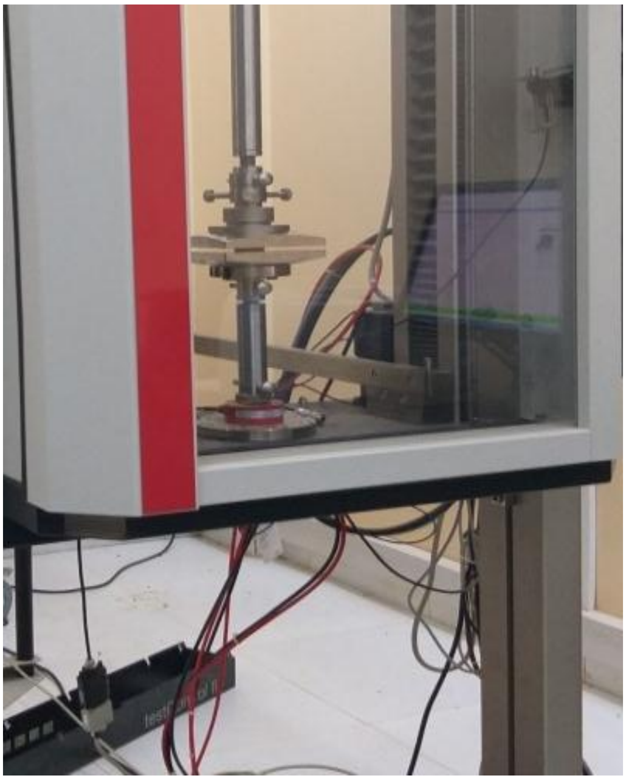

Fig (3.10): Compression test machine.

Fig (3.11): Compression test specimen.

3.3.4 Water Absorption Test:

The water absorption test is the most significant test for the natural fibers. The procedure of this test involves weighting the specimen firstly and after that immersing it in normal water.

The specimen is weighting daily for four days after immersion, and after two weeks from fourth day.

The water absorption specimens are shown in Fig (3.12). The water absorption of the composite was determined using the relationship below:

Water absorption = W1–W0/ W0 * 100%

Where:

W0 = Weight of laminate before immersion.

W1 = Weight of laminate after immersion.

Fig (3.12): water absorption test specimen.

3.3.5 Preparation of Composite Specimen:

Table (3.4): Dimensions of tests specimens.

Specimen Types and Specifications								
Unit	**Tensile Test**		**Flexural Test**		**Comparison test**		**Water absorption test**	
	a	**b**	**a**	**b**	**a**	**B**	**a**	**b**
Length (mm)	115	115	95	115	25	25	25	25
Width(mm)	19	19	13	13	25	25	25	25
Thickness (mm)	5	6	5	6	5	6	5	6

a: unidirectional sample.

b: Quasi isotropic [0^0,90^0,45^0] sample.

CHAPTER FOUR
RESULTS AND DISCUSSION

The test results for the tensile, flexural and compression testing for the three varieties of the composite samples are presented in table (4.1).

Table (4.1): results of tensile, flexural and compression test.

Type of tests / Type of specimen	Tensile strength (N)	displacement (mm)	flexural load (N)	displacement (mm)	Compression load(N)	displacement (mm)
Unidirectional $[0^0]$	2500	3	270	10	9200	o.7
Unidirectional $[90^0]$	270	0.9	145	3.75	-	-
Quasi isotropic$[0^0,90^0,45^0]$	1000	2	135	9.5	9500	0.4

4.1 Tensile Test:

4.1.1Load displacement behavior:

The different composite specimen samples were tested in the ZWICK/ROELL (ZWICK Z010) testing machine and the samples were left to break till the ultimate tensile strength occurs. Stress-strain curve is plotted for the determination of ultimate tensile strength and elastic modulus. The sample graph generated directly from the machine for tensile test with respect to load and displacement for unidirectional $[0^o]$ is presented in Fig (4.1), for unidirectional $[90^o]$ is presented in Fig (4.2), and for quasi isotropic $[0^0,90^0,45^0]$ is presented in Fig (4.3). The curves in this graphs shown a linear behavior at the first stage followed by a complete failure of the composite in unidirectional $[0^0]$ unidirectional $[90^0]$ samples, but vibration occurs in the quasi isotropic $[0^0,90^0,45^0]$ sample after failure due to the structure of the composite. Fibers and matrix behave linearly at low displacement.

The comparative results of the different composites specimens tested are presented in Fig (4.7) the results indicate that unidirectional [0^o] gives better tensile strength than the other two types of composites considered.
The tensile strength of the unidirectional [0^o], unidirectional [90^o] and quasi isotropic [0^0,90^0,45^0] are in the range 0f 2500N, 270N and 1000N respectively. The results indicate that the unidirectional [0^o] composite outperformed the other types of composites tested.
Stress-strain curve obtained from the ZWICK/ROELL (ZWICK Z010) testing machine for the unidirectional [0^o], unidirectional [90^o] and quasi isotropic [0^0,90^0,45^0] are shown in Fig (4.4), Fig (4.5) and Fig (4.6) respectively. The results indicated that same trend as that of the load vs displacement curve.
For the results, it can be asserted that the unidirectional (0^o) composite are performing well compared to the other types of composites due to fibers orientation.

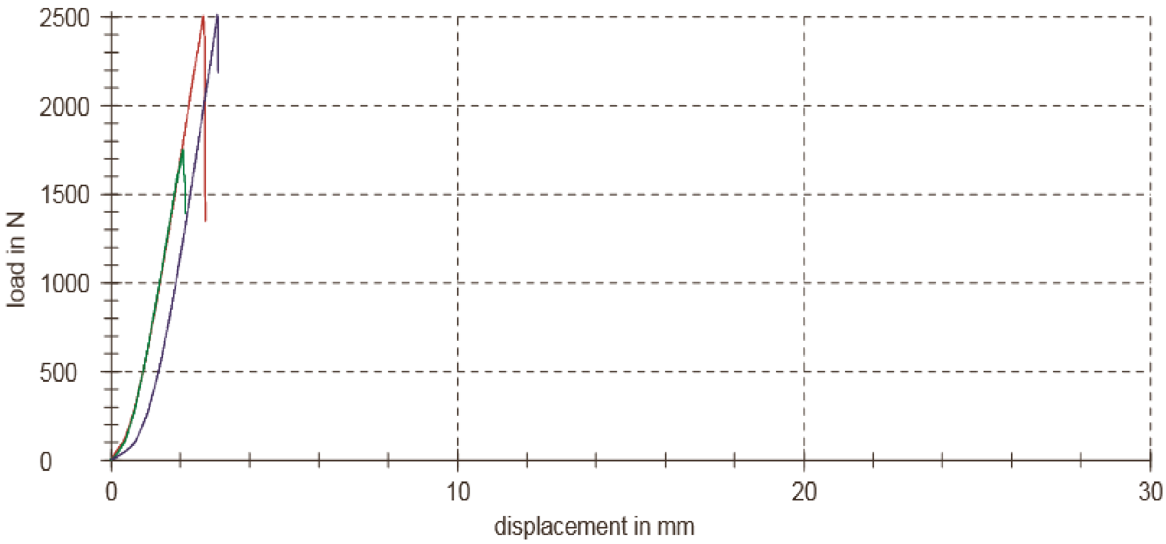

Fig (4.1): Load-displacement curve for tensile strength test of the unidirectional [0^0] specimen.

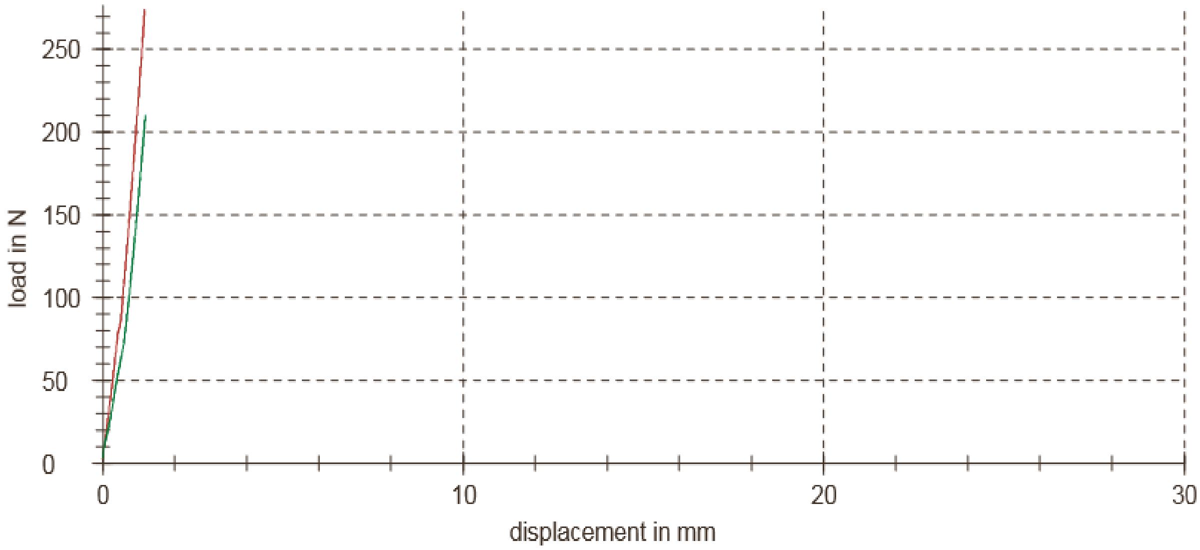

Fig (4.2): Load-displacement curve for tensile strength test of the unidirectional [90^0] specimen.

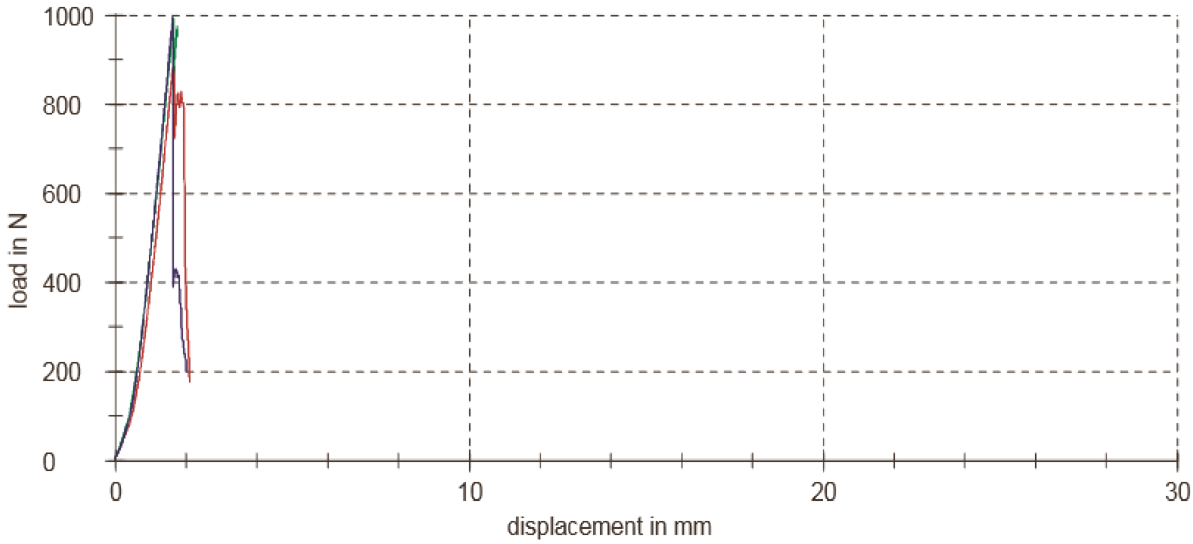

Fig (4.3): Load-displacement curve for tensile strength test of the quasi isotropic [0^0,90^0,45^0] specimen.

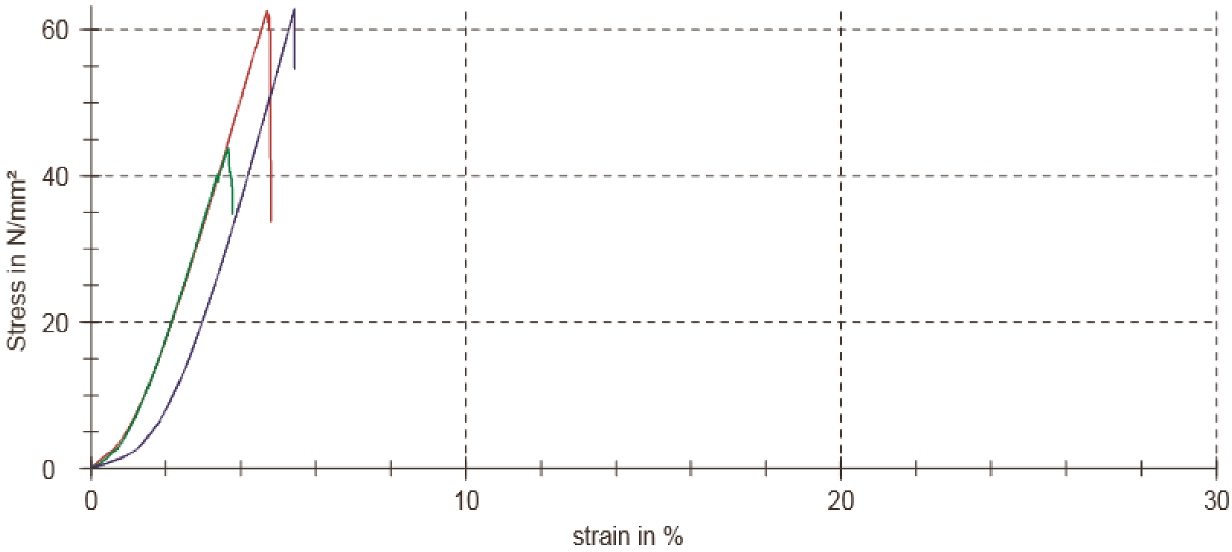

Fig (4.4): Stress-strain curve for tensile strength test of the unidirectional [0^0] specimen.

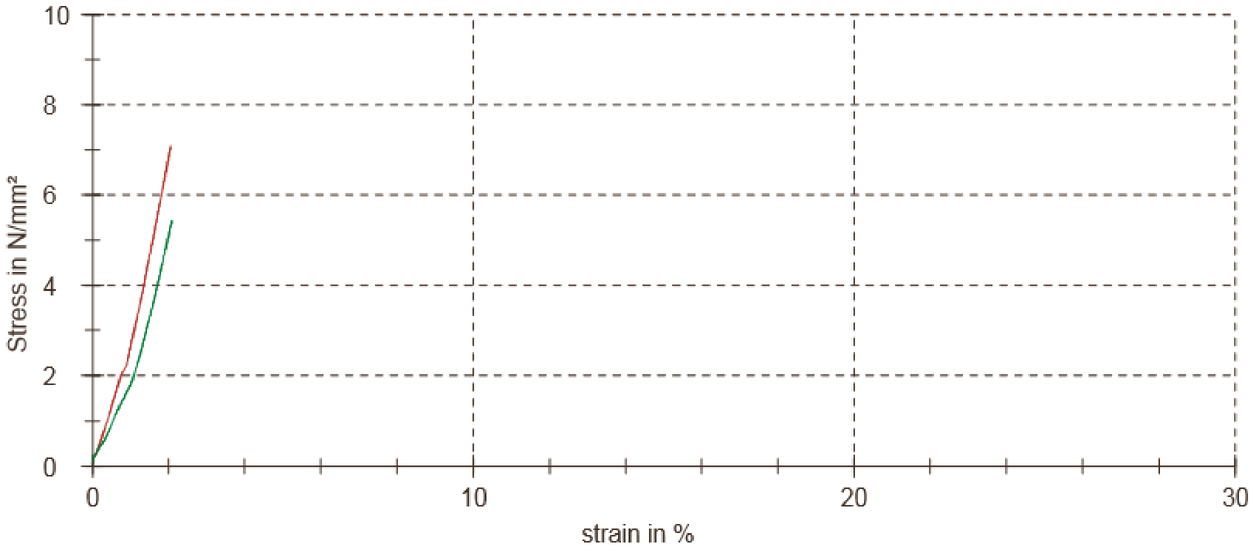

Fig (4.5): Stress-strain curve for tensile strength test of the unidirectional [90^0] specimen.

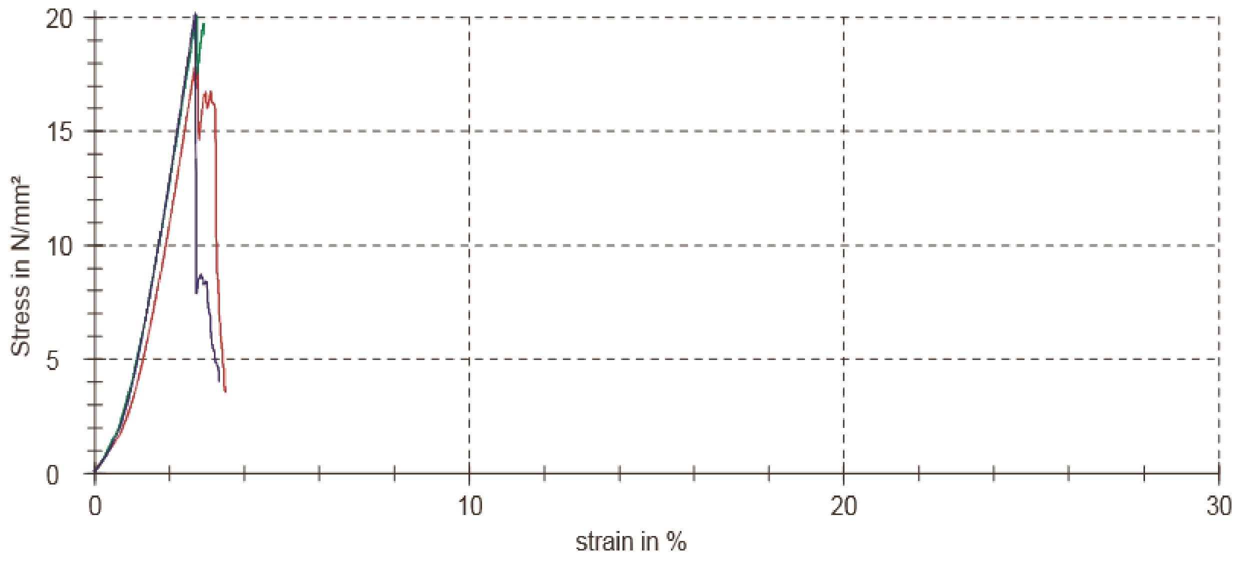

Fig (4.6): Stress-strain curve for tensile strength test of the quasi isotropic [0^0,90^0,45^0] specimen.

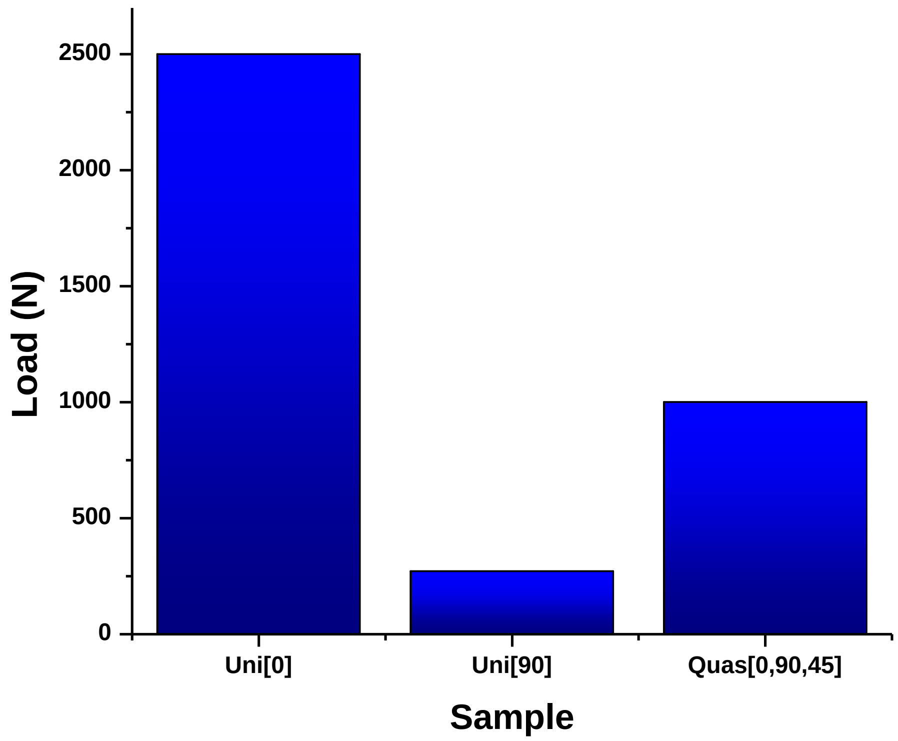

Fig (4.7): Tensile load comparison of different samples.

4.1.2 Failure Mode:

The failure observed in Fig (4.8) for the unidirectional [0^o], unidirectional [90^o] and quasi isotropic [0^0,90^0,45^0] specimens. The behavior was almost similar in the failure mode for the unidirectional [0^o] quasi isotropic [0^0,90^0,45^0], but for unidirectional [90^o] was different.

Specimen of the unidirectional [0^o] and quasi isotropic [0^0,90^0,45^0] shows crake matrix and exhibit small fiber pull-out and breakage but no complete breakage for the composite. Unidirectional [0^o] Specimen has high tensile strength and shows sudden break for the composite. Due to the composite brittleness.

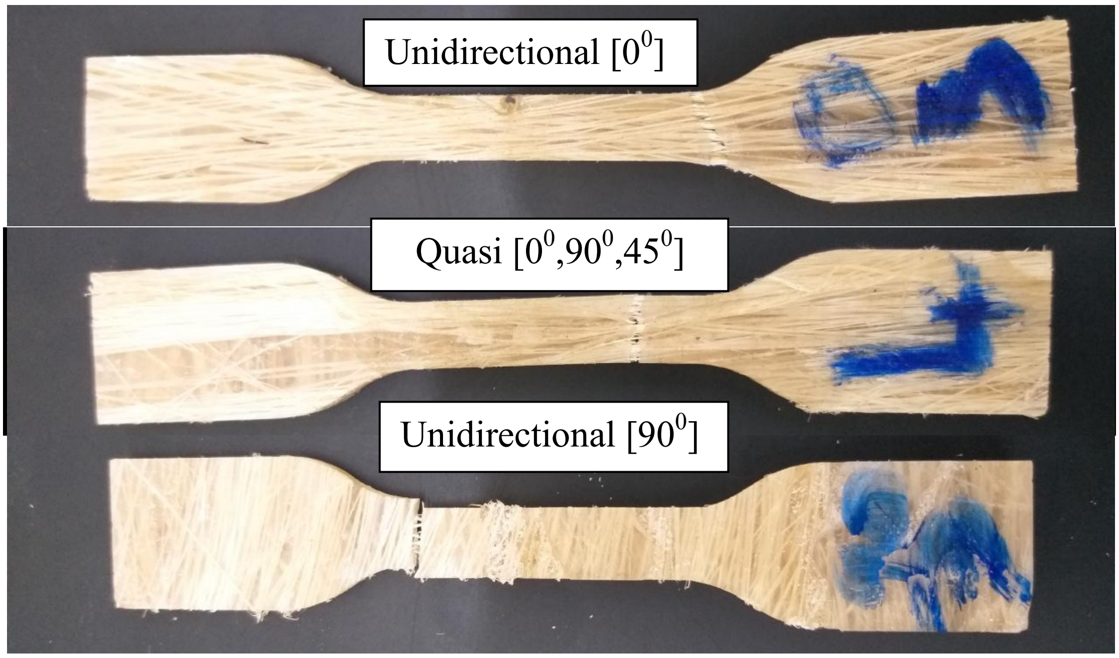

Fig (4.8): Tensile specimens after failure.

4.2 Flexural Test:

4.2.1 Load Displacement Behavior:

The three point Flexural tests were being performed in order to obtain the load-displacement curves for all specimens as shown in Fig (4.9), Fig (4.10) and Fig (4.11), for the unidirectional [0^o], unidirectional [90^o] and quasi isotropic [0^0,90^0,45^0] respectively. These curves were used to determine the behavior of the failure modes of banana Fiber Reinforced Composite.

Results of the three specimens from unidirectional [0^o] and quasi isotropic [0^0,90^0,45^0] have similar behavior, and that behavior indicated that displacement increases with the load increasing, after that, it is tends to decrease, breaking takes place. The results indicate that the unidirectional [0^o] shows better results than the other type of composites tested.

The curves can be divided into three regions, the first region, linear in appearance can explain the elastic deformation of the banana/polyester composite due to the composite sample carrying the load exerted, and the bonding was proper between the fiber and the matrix. The second region observes the oscillation form can explain the plastic deformation, due to the fibers only carry the load, In Third region the specimen failed.

Stress-strain curve obtained from the ZWICK/ROELL (ZWICK Z010) testing machine for the unidirectional [0^o], unidirectional [90^o] and quasi isotropic [0^0,90^0,45^0] are shown in Fig (4.12), Fig (4.13) and Fig (4.14) respectively. The results indicated that same trend as that of the load vs displacement curve, the results indicate that the unidirectional [0^o] composite are performing well compared to the other types of composites due to fibers orientation.

The average values observed for different composites specimen is presented in Fig (4.15).for the unidirectional [0^o], unidirectional [90^o] and quasi isotropic [0^0,90^0,45^0] are in the range 0f 270N, 145N and 135N respectively. The results indicate that the unidirectional [0^o] composite outperformed the other types of composites tested.

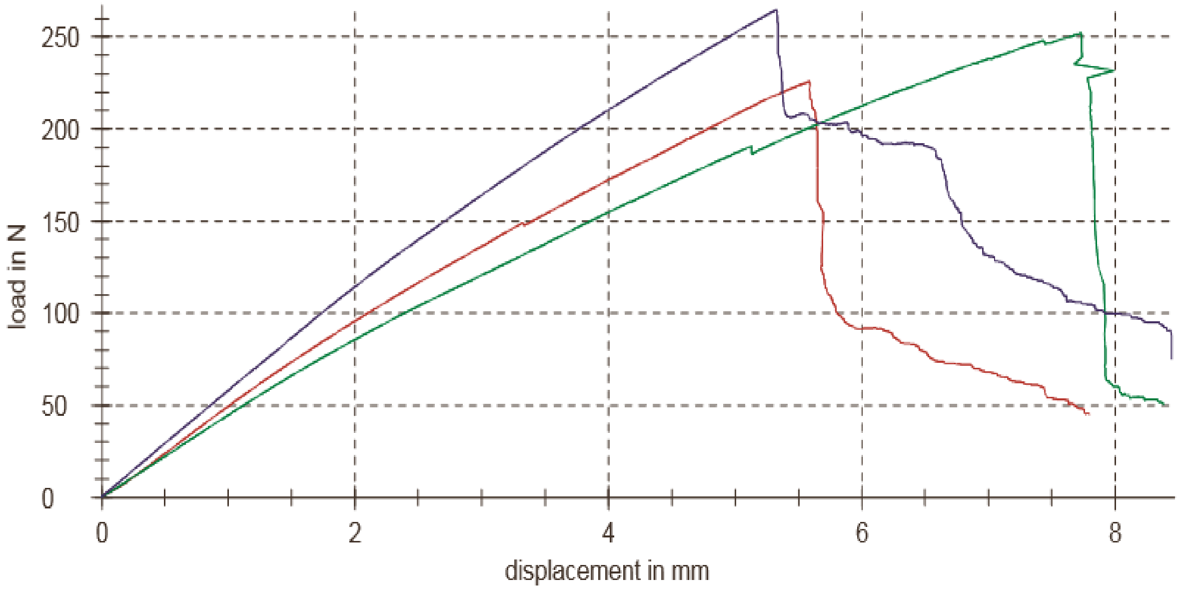

Fig (4.9): Load-displacement curve for flexural test of the unidirectional [0^0] specimen.

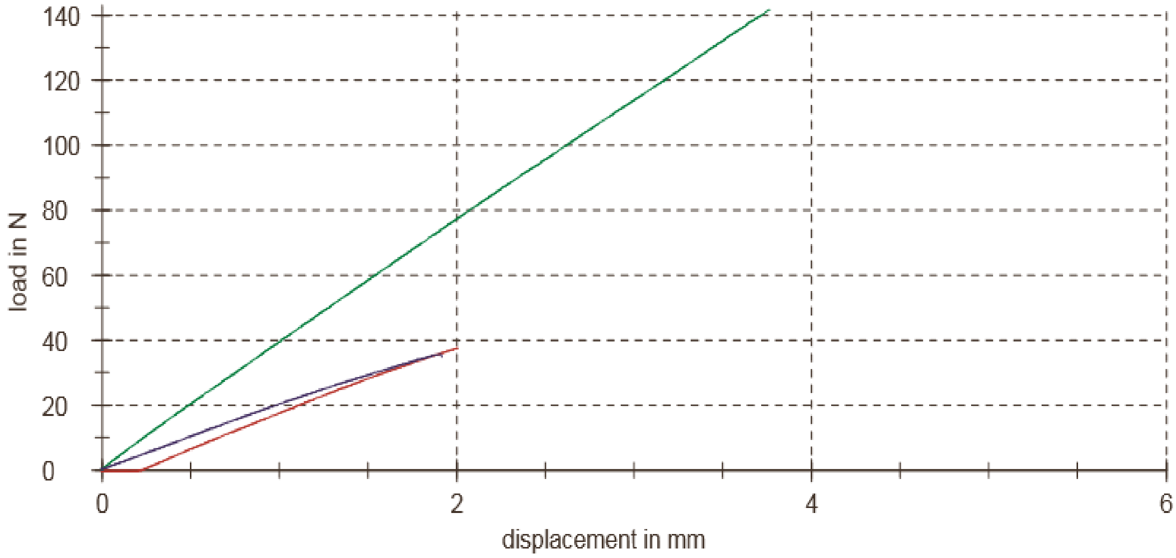

Fig (4.10): Load-displacement curve for flexural test of the unidirectional [90^0] specimen.

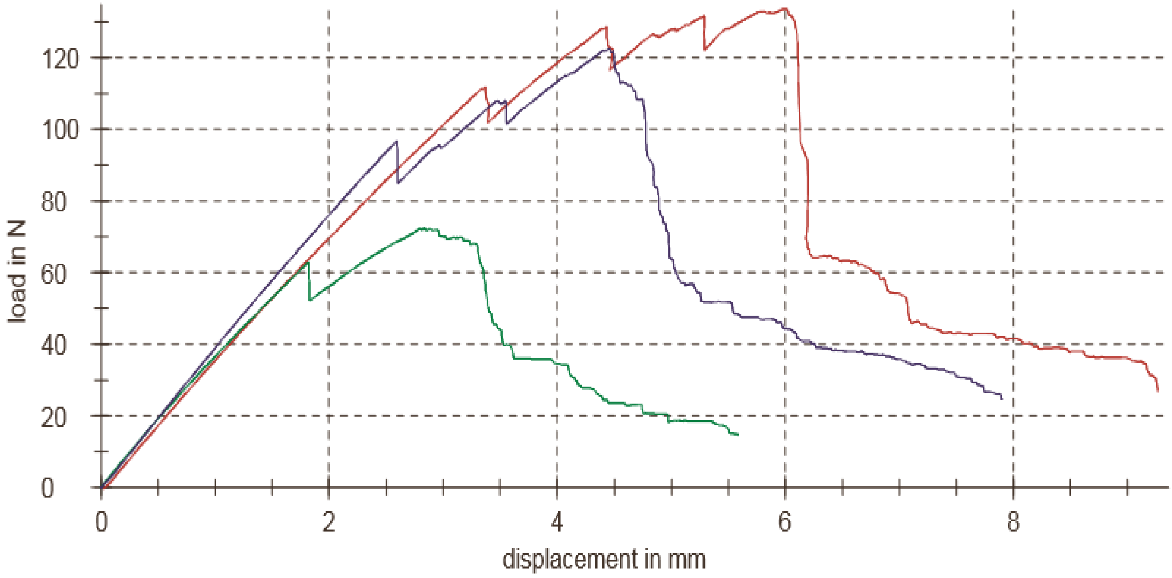

Fig (4.11): Load-displacement curve for flexural test of the quasi isotropic [0^0,90^0,45^0] specimen.

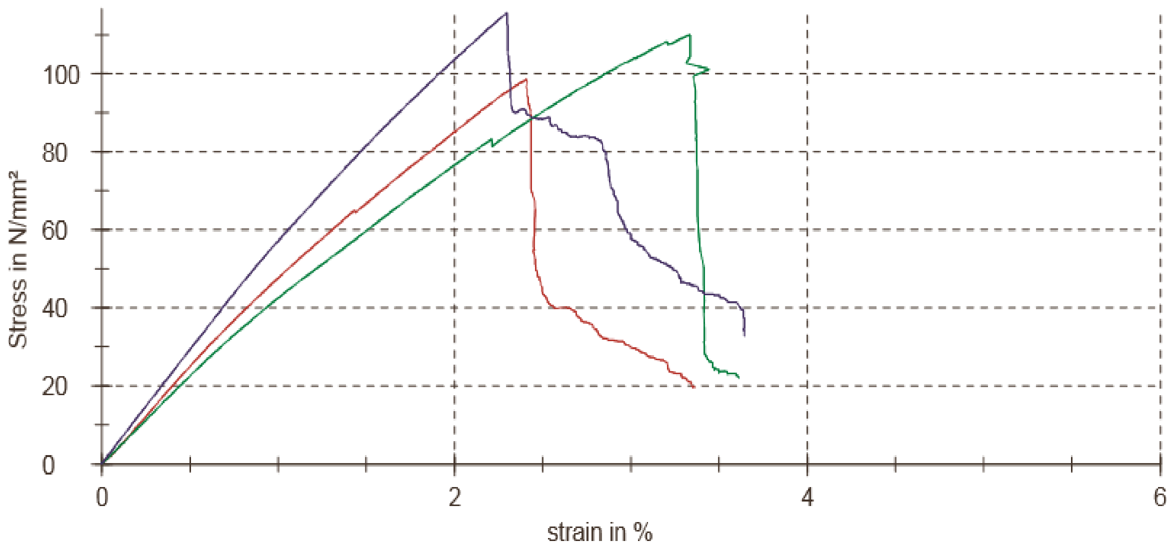

Fig (4.12): stress-strain curve for flexural test of the unidirectional [0^0] specimen.

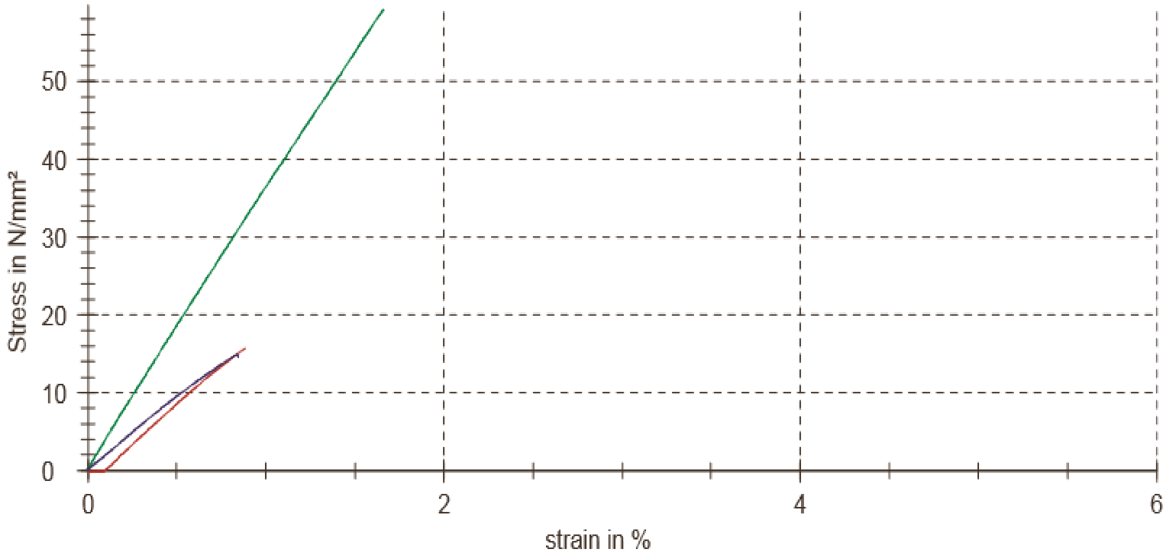

Fig (4.13): stress-strain curve for flexural test of the unidirectional [90^0] specimen.

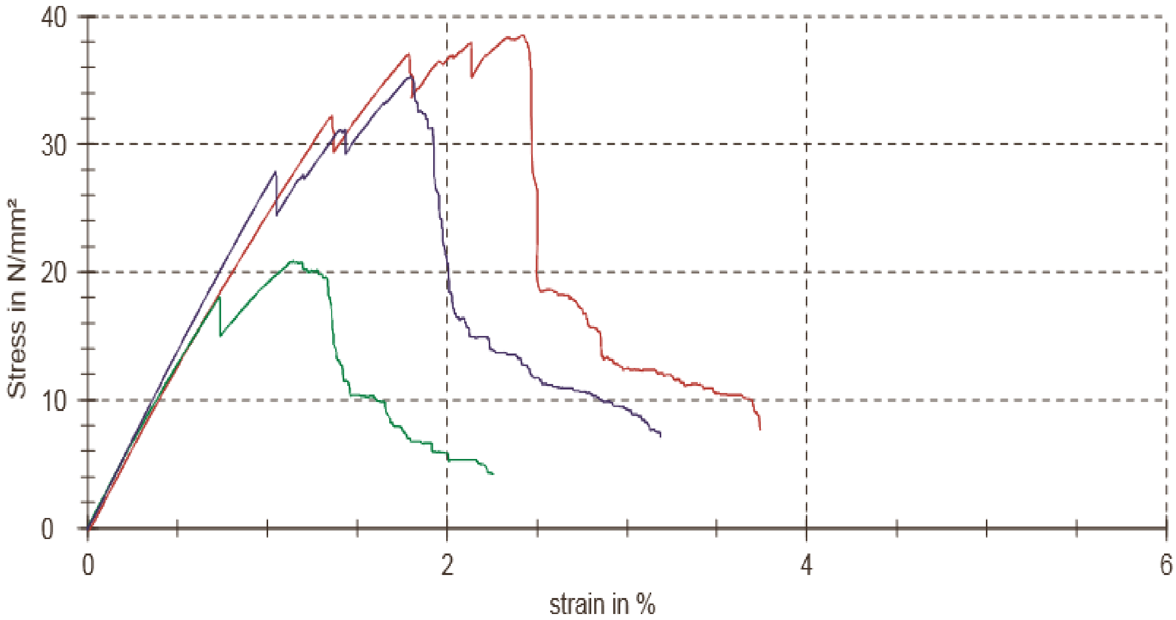

Fig (4.14): stress-strain curve for flexural test of the quasi isotropic [0^0,90^0,45^0] specimen.

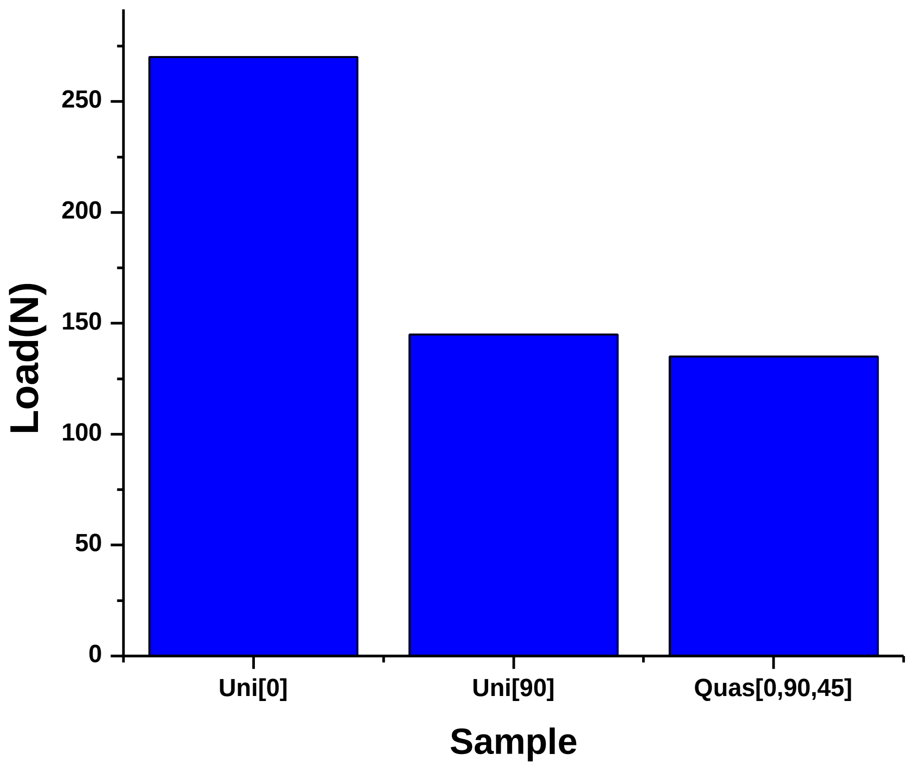

Fig (4.15): flexural load comparison of different samples.

4.2.2 Failure mode:

The Failure mode of banana/polyester composite illustrated in Fig (4.16).The damage in specimens after flexural event was evaluated by visual inspection. The failure modes involved in flexural damage of the composite were characterized as combinations of matrix cracking, fiber fracture, buckling, delamination.

Fig (4.16): flexural specimens after failure.

4.3 Compression Test:

4.3.1 Load Displacement Behavior:

The Compression tests were being performed in order to obtain the load-displacement curves for all specimens as shown in Fig (4.17) and Fig (4.18), for the unidirectional $[0^o]$ and quasi isotropic $[0^0,90^0,45^0]$ respectively for banana Fiber Reinforced Composite.

Results of the three specimens from unidirectional $[0^o]$ and quasi isotropic $[0^0,90^0,45^0]$ have similar behavior, and that behavior indicated that displacement increases with the load increasing; the results indicate that the quasi isotropic $[0^0,90^0,45^0]$ specimen shows better results than the unidirectional $[0^o]$ specimen.

The deformation started from 1000N load, 0.15mm displacement for unidirectional $[0^o]$ specimen Fig (4.17), and 1000N load, 0.06 mm displacement for quasi isotropic $[0^0,90^0,45^0]$ specimen Fig (4.18).

Stress-strain curve obtained from the ZWICK/ROELL (ZWICK Z010) testing machine for the unidirectional $[0^o]$ and quasi isotropic $[0^0,90^0,45^0]$ are shown in Fig (4.19) and Fig (4.20) respectively. The results indicated that same trend as that of the load vs displacement curve, the results indicate that the quasi isotropic $[0^0,90^0,45^0]$ composite are performing well compared to the unidirectional [0^{o}] composites due to fibers orientation.

The average values in displacement observed for different composites specimens of unidirectional [0^{o}] and quasi isotropic [0^{0},90^{0},45^{0}] are in the range 0f 0.7mm and 0.4mm respectively. The results indicate that the quasi isotropic [0^{0},90^{0},45^{0}] composite outperformed from the unidirectional [0^{o}] of composites tested.

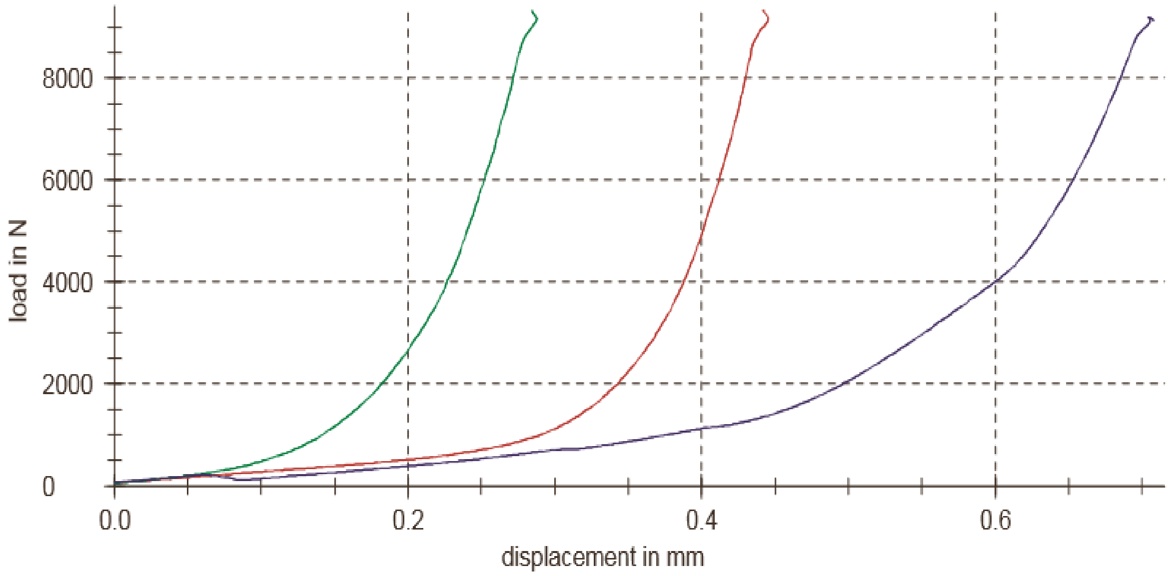

Fig (4.17): Load-displacement curve for Compression test of the unidirectional [0^{0}] specimen.

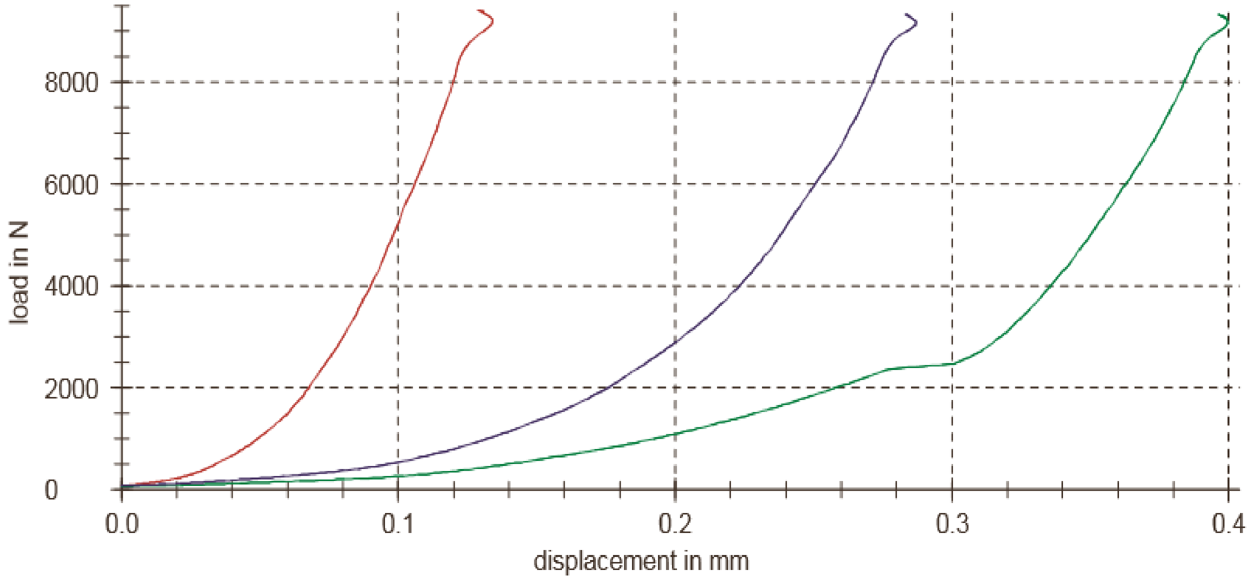

Fig (4.18): Load-displacement curve for Compression test of the quasi isotropic [0^0,90^0,45^0] specimen.

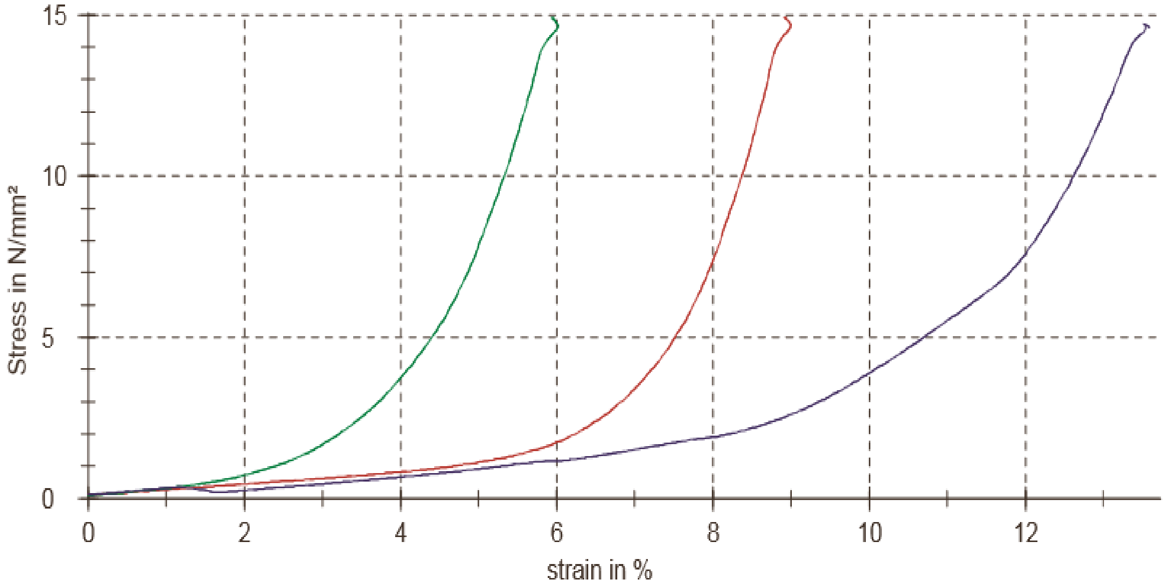

Fig (4.19): stress-strain curve for flexural test of the unidirectional [0^0] specimen.

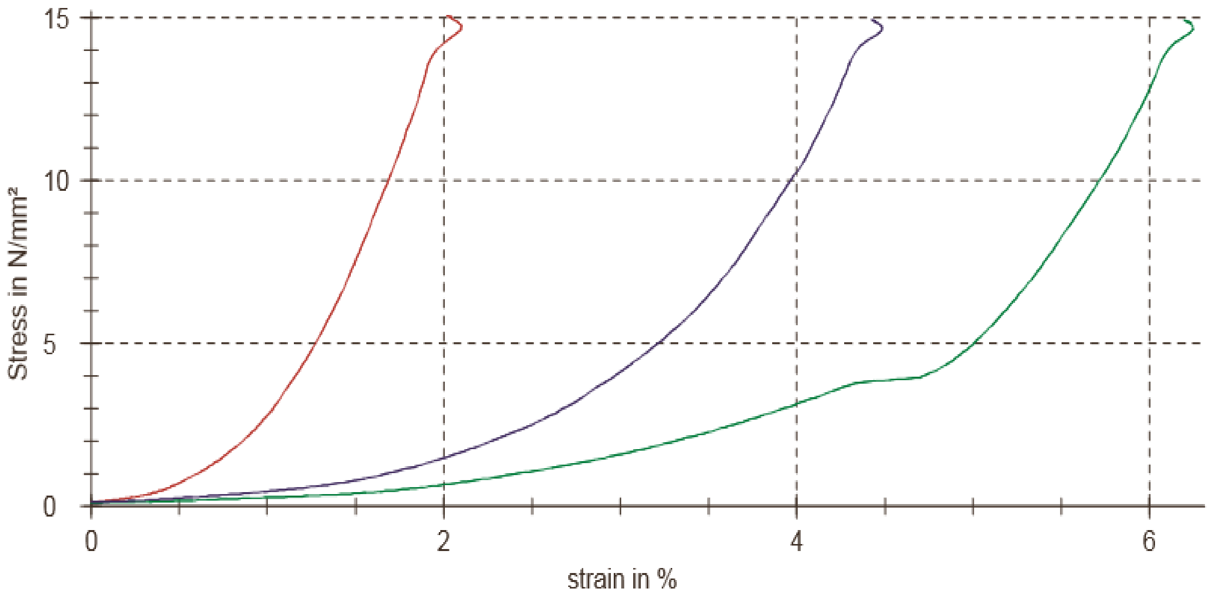

Fig (4.20): stress-strain curve for flexural test of the quasi isotropic [0^0,90^0,45^0] specimen.

4.4 Water Absorption Test:

The laminates gain weight by absorption of water, the percentage increase of these weights for the interval of one day for normal water is tabulated in the Table (4.2). The test was done for a period of 20 days. From the test, it was found that the maximum water absorption is observed in unidirectional sample while it is minimum in quasi isotropic [00,900,450] sample due to fibers orientation and contact angel between fibers and water.

Table (4.2): Water Absorption test results for normal water

Sample	Initial weight in grams	Percentage increase in weights (%)				
		Day 1	Day 2	Day 3	Day 4	Day 20
unidirectional	3.3	3.03	5.515	6.848	6.878	9.727
quasi isotropic [0^0,90^0,45^0]	4.419	2.69	4.186	4.435	4.865	6.359

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5-1 Conclusion:

The banana fiber reinforced polyester composite unidirectional and quasi isotropic [0^0,90^0,45^0] samples were fabricated by hand layup process. The composites samples were subjected to mechanical testing such as tensile, flexural and compression tests. Based on the results, the following conclusions are drawn:

- The tensile strength of the unidirectional [0^o], unidirectional [90^o] and quasi isotropic [0^0,90^0,45^0] specimens results indicate that the unidirectional [0^o] composite outperformed the other types of composites tested.
- The flexural strength results for different composites specimens indicate that the unidirectional [0^o] composite better than the other types of composites tested.
- The Compression results for different composites specimen of unidirectional [0^o] and quasi isotropic [0^0,90^0,45^0], indicate that the quasi isotropic [0^0,90^0,45^0] composite outperformed from the unidirectional [0^o] of composites tested.
- The water absorption results found that the maximum water absorption is observed in unidirectional sample while it is minimum in quasi isotropic [0^0,90^0,45^0] sample.

5-2 Recommendations:

Banana plants have grown in a wide range in Sudan so we recommend to:

- Optimize the use of Banana plants waste and make the most of it in all areas, especially in composite materials.
- Manufacture Banana fiber extraction machine and create specialized factories for it.
- Treatment of Banana fibers chemically to enhance their characteristics according to the application required.
- Concern for the manufacture of Banana fiber reinforced with polymer composite for their good properties, easy to manufacture and low cost.
- Manufacturing a banana fiber reinforced polymer composite, due to its good mechanical properties to use it in partitions, floors and household applications.

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