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Bond Behaviour of Banana Fiber Bars Under Three Point Bending Load Test.

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ABSTRACT

Abstract: As a result of tyranny and exceeding the limit with the environment, it may lead to many mistakes and have a response of 1900, a counter-reaction to us from disasters, and this is considered a universal law. If mankind is overwhelmed by this universe, it will be affected by this tyranny. To protect the environment and make it a pure environment, free from impurities and damages. This research is considered a point in the sea in order to reach environmentally friendly materials and re-use natural materials in many industries without the need for industrial materials.

The interest in using natural, renewable materials reflects a very positive effect when used in many industrial purposes, including these plant fibers, including banana fiber, as it is one of the renewable elements and is produced from banana tree waste and thus works to reduce the cost of the materials used by it and also contributes to preserving the environment in a way It is essential that some statistics have been included that by the year the use of raw materials used in construction will diminish and the emission of carbon dioxide will double from 1900 million tons to 2700 million tons (146), which leads to a severe impact on the environment and leads to global warming.

The bond strength reflected by the experimental program observed the relation between banana fiber bars and concrete using 27 bar of banana fibers that were installed in an attempt to study the scope of its contribution for reinforcing concrete and compare the results with non-reinforced concrete. The results showed that there was a good performance in the bond strength and cohesion between the concrete and banana fiber bars. The bond strength between fiber and concrete increases the over load by 25% compared with the plain concrete.

Keywords: Banana Fiber; cohesion; Flexure; Cracking.

1 Introduction

In this chapter experimental tests were carried out to investigate the behavior of reinforced concrete beams reinforced with banana fiber bars and to provide the wide of adequacy of the banana fiber in the structural purpose and its uses as material building. Detailed description of the specimens, material properties, testing equipment, specimen's fabrication and test procedures are discussed in this chapter.

The main objective of this investigation is to conduct an experimental study on strength, behavior of the simply supported beams with different parameters. All specimens were simply supported and reinforced by banana fiber bars, glass fiber bars and hybrid fiber bars this composite fiber contain the both of banana and glass fiber with the same percent to study its influence in the flexure strength. Each beam was tested under one-point top loading at the surface.

As a result of tyranny and exceeding the limit with the environment, it may lead to many mistakes and have a response of 1900, a counter-reaction to us from disasters, and this is considered a universal law. If mankind is overwhelmed by this universe, it will be affected by this tyranny. To protect the environment and make it pure free from impurities and damages, this research is considered as a point in the sea in order to reach environmentally friendly materials and re-use natural materials in many industries without the need for industrial materials.

The interest in using natural, renewable materials reflects a very positive effect when used in many industrial purposes, including these plant fibers, including banana fiber, as it is one of the renewable elements and is produced from banana tree waste and thus works to reduce the cost of the materials used by it and also contributes to preserving the environment in a way it is essential that some statistics have been that by the year the use of raw materials used in construction will diminish and the emission of carbon dioxide will double from 1900 million tons to 2700 million tons [22], which leads to a severe impact on the environment and leads to global warming.

Recently, a widespread increase in banana agriculture has been recognized at the equatorial regions, reaching 26 million acres in 2012 and still increasing day by day. Africa has the largest percentage of increased banana production around the world, accounting for 54% of the world's banana crop which amounts to 14 million acres with a production capacity of 6 ton/acre. The Americas is the second with 23% of the total cultivation of the banana in the world utilizing 6 million acres with a production capacity of 22 ton/acre. Asia is third with 21% using about 5.5 million acres with a production capacity of 16 ton/acre. (See Figure 14) [24 and 23].

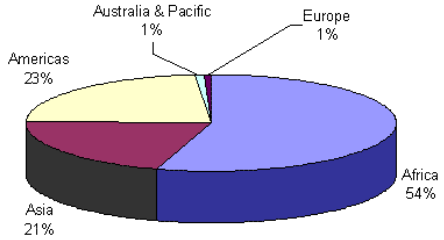

Figure 14: Relative distribution of banana-growing worldwide [24]

The total volume of worldwide banana production in 2012 is over 138 million tons. The highest production came from Asia with a total of 62 million tons, followed byAfrica at about 40 million tons and then Americas with about 36 million tons. Figure 15 represents the distribution and relative quantification of banana production globally [25].

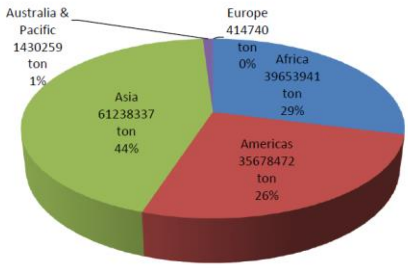

Figure 15 : Percentage distribution and volume of banana production [25]

This research highlights the use of composite materials that have become common use in building materials, and these materials consist of two parts, the first part is a matrix, and the second part is fiber. There are two phases of fiber the synthetic fibers such as Carbon, Glass, Aluminum, Aluminum Oxide, Boron, etc., and natural fibers such as banana, Jute, Coir, Silk, Bamboo, Coconuts, etc. Synthetic fibers are the most common and used despite their high cost, so, it has been directed in this research to natural fibers that are generally extracted from plant wastes and therefore are considered without cost. This research is based on the identification of natural fibers and their impact on the mechanical properties of concrete. The experimental studies are conducted depend on a group of nine models of concrete beams with various parameters to determine the performance of banana fibers in the flexure behavior of RC beams, study the influence of the hybrid fiber that contains banana and glass fiber, study the mix design ratio of the banana fibers in RC, study the influence of banana fibers on concrete behavior and study the influence of banana fiber with different concrete grades. Results obtain that using banana fibers has a significant effect in increasing the ability to resist cracking and spalling in concrete beams. From this research, it became clear that natural fibers increase flexure strength that contributes to reduce the depth of a section and design a reinforced concrete member with high load-bearing capacity.

2 Banana Fiber as Main Bars.

FRP is generally categorized by a linear behavior up to failure and all fibers fail without any yield or flow in a brittle manner. The banana fiber reinforced polymer was invented using banana fibers and thermosetting polyester resin. The BFRP reinforcements used in this program with different diameters that ranges from 12 to 18 mm as shown in Figure (1) .

Figure 1: BFRP fiber and bars of Some Tested Beams

3 Preparation of the models

The test program included nine specimens B1 to B9. All specimens had the same length of 1050 mm loading span of 1000 mm, and concrete effective depth of 230 mm (total depth of 250 mm and concrete cover of 20 mm). Table 1 and Table 2 shows the dimensions and properties of the tested specimens such as section dimensions, longitudinal reinforcement, and transverse reinforcement of the beams.

Table 1: Studied Parameters

Group	**Reference Model**	**Group (A)**				**Group (B)**		**Group (C)**	
Specimen Symbol	B1	B2	B3	B4	B5	B6	B7	B8	B9
Studied Parameter		Banana Fiber Bars Ratio				Concrete Strength		Hybrid Material Composite	

Table 2 : Details of the Tested Specimens

Specimen	**Bottom RFT**	**Top RFT**	**Vl. Web RFT**	**Type of RFT**	***f_{cu} (MPa)***
B-1	----	----	-----	Plain concrete	*25*
B-2	3Φ 12	2ϕ 6	ϕ 6 @ 125 mm	Banana fibers	*25*
B-3	3Φ14	2ϕ 6	ϕ 6 @ 125 mm	Banana fibers	*25*
B-4	3Φ16	2ϕ 6	ϕ 6 @ 125 mm	Banana fibers	*25*
B-5	3Φ18	2ϕ6	ϕ 6 @ 125 mm	Banana fibers	*25*
B-6	3Φ16	2ϕ 6	ϕ 6 @ 125 mm	Banana fibers	*35*
B-7	3Φ16	2ϕ 6	ϕ 6 @ 125 mm	Banana fibers	*45*
B-8	3Φ16	2ϕ 6	ϕ 6 @ 125 mm	Banana fibers	*Glass Fiber*
B-9	**3Φ16**	**2ϕ 6**	**ϕ 6 @ 125 mm**	**Banana fibers**	***Hybrid Fiber***

- Details of all specimens.

Table 3:Details for the Tested Beams

Specimen	Longitudinal Main RFT	Type of RFT	Top RFT	Type of RFT	Stirrups	*Concrete Strength (MPa)*
B-1 (Plain concrete)	----		----		-----	*25*
B-2	3Φ 12	Banana fibers	2ϕ 6	Steel	ϕ 6 @ 125 mm	*25*
B-3	3Φ14	Banana fibers	2ϕ 6	Steel	ϕ 6 @ 125 mm	*25*
B-4	3Φ16	Banana fibers	2ϕ 6	Steel	ϕ 6 @ 125 mm	*25*
B-5	3Φ18	Banana fibers	2ϕ6	Steel	ϕ 6 @ 125 mm	*25*
B-6	3Φ16	Banana fibers	2ϕ 6	Steel	ϕ 6 @ 125 mm	*35*
B-7	3Φ16	Banana fibers	2ϕ 6	Steel	ϕ 6 @ 125 mm	*45*

4 Material Properties

4.1 Reinforced Concrete Materials

All tested beams expect Beam 6 and Beam 7 were casted using normal strength concrete with local materials. The concrete mixture was designed for characteristic compressive strength of 25 MPa after 28 days. The compression test for concrete cubes were done to ensure the required concrete compressive strength where six test cubes 150*150*150 mm were prepared during the pouring of the beam samples and tested after 28 days using compression test machine as shown in Figure 2. The results showed that the specimens achieved the required average compressive concrete strength of 25 MPa.

Figure 2: Compression Test of Concrete Cube

Table (4) Concrete Mix Properties by Weight

Specimen	Cement Kg	Water Liter	Coarse aggregate Kg	Fine aggregate Kg
From B1 to B5 , B8 and B9	**350**	**180**	**1240**	**620**
B6	**400**	**200**	**1100**	**720**
B7	**480**	**150**	**1150**	**650**

4.2 Reinforcing Banana Fibers

tensile strength of the single banana fiber was (265 MPa) according to the lab tests. Mild steel bars (24/35) of 6 mm diameter were used for secondary steel and for stirrups. Figure 3 shows the layout of banana fiber reinforcement of some tested beams during construction.

Figure 3: Fiber Reinforcement of Some Tested Beams

4.3 BFRP as Main Bars

FRP is generally characterized by a linear behavior up to failure and all fibers fail in a brittle manner without any yield or flow.

The BFRP (Banana Fiber Reinforced Polymer) were fabricated using banana fibers and thermosetting polyester resin. The BFRP reinforcements used in this program were various in diameter from 12 to 18 mm as shown in Figure 4.

Figure 4: BFRP fiber and bars of Some Tested Beams

4.4 GFRP as Main Bars

GFRP is a new kind of composite material, which is glass fiber as reinforcement material, combines with epoxy (resin) and curing agent, then through pultrusion Molding process. The GFRP reinforcements used as a bars with diameter 16 mm as shown in Figure 5.

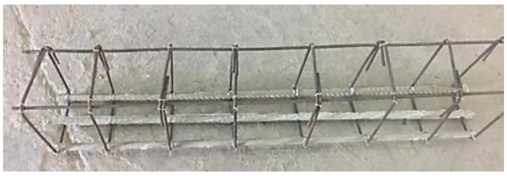

Figure 5: GFRP bars of Some Tested Beams

4.5 HFRP as Main Bars

In this study we try to fabricate a composite material that contain of natural fiber and synthetic fiber the natural fiber was banana fiber that came from the waste of cultivation and the synthetic was glass fiber as shown in Figure 6.

Figure 6: HFRP (Hybrid Fiber Reinforced Polymer) Bars of Some Tested Beams

4.6 Casting and Curing

The dry materials were mixed firstly then water was added gradually with continuous mixing to achieve the required workability. Then, pouring concrete carefully in the formwork to avoid damage in the formwork. After filling the formwork nearly about half depth of the beam, continuous compaction using electrical vibrator took place. After casting, the top surface was smoothed by trawling.

The specimens were removed from the form 24 hours after casting and covered by the wet canvas that was sprinkled with water once a day. The water-curing period lasted 4 weeks in order to obtain the specified concrete strength. The specimens were left in the laboratory`s ambient temperature until testing. During casting 3 cubes were taken and cured in the same manner as the specimens. Figure 7 shows the curing process for the casted cubes and Figure 8 shows curing of tested beams[26].

Figure 7: Curing of Concrete Cubes

Figure 8: Curing of Tested Beams

4.7 Test Set-Up, Instrumentation and Loading

The test set-up was constructed to apply one-point vertical monotonic load at the mid span of the tested specimens at top surface; where all the tested specimens were simply supported as shown in Figures (3.2) to (3.8). During the test operation, the specimens were subjected to vertical load by a hydraulic jack of 1500 kN-capacity attached to a rigid steel frame. A sensitive load cell was used to measure the vertical load. Three Linear Variable Displacements Transducers (LVDTs) were attached to the specimens at its thirds and at the middle to measure the vertical displacement at various locations and loading stages.

The test was carried out subjected to one point of loading at the mid span using a hydraulic jack of 1500 kN, tied with steel frames, through which we control the applied load to the specimens (load cell). For determined the vertical displacement that happened in the specimens we used Three Linear Variable Displacements Transducers (LVDTs) at the bottom of each specimen at quarter, half and three quarters. Concrete strains were measured using 2 -inch gauge length" Demec gauges". The "Demec gauges" were in a rosette configuration and were placed at the surface of the beam. The purpose of the "Demec gauges" was to measure concrete strain in 2 different directions.

Loads and reactions were applied through rollers and bearing steel plates to allow free rotation and horizontal movement of end supports. At every stage of loading, the readings of the Demec mechanical dial gauges were observed, and crack patterns were mounted on the surface of the tested beam. The applied load was with different increments until reach to the peak load After which a failure occurs. Readings of the vertical displacement and the vertical load were recorded after each increment. The cracks patterns and the elongation of the concrete were recorded in all directions using Demec points arranged in different position to evaluate flexure cracking load as shown in Figure 9.

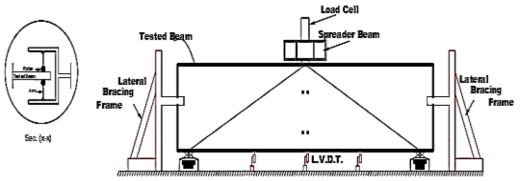

Figure 9: Schematic Test Set-ups, Instrumentation, and Loading

4.8 Test Procedure

The specimens were tested as described in the following steps:

1- At the beginning of each test, the specimen was installed and adjusted under the test rig.

2- The beam ends were clamped by the system of steel plates and rollers.

3- All the sensors were adjusted in their position, and connected to the data acquisition interface system.

4- The electrical instrumentation readings were initialized to zero using the testing software of the data acquisition system.

5- The load is applied gradually by the machine head over the specimen's state rate of loading.

6- The data acquisition system recorded continuous reading of the electrical load cell, the LVDT's, and the strain gauges.

7- The cracks were monitored and marked during the test, and high-resolution photographs and videos were taken for the two faces of the specimens.

8- The test was continued until the specimen experienced strength degradation equal to 25% of the ultimate load of the specimen.

For specimen, Figure 10 shows the crack pattern. At an early loading level of about 11 kN, fine flexural cracks formed at the mid-span. Upon increasing the load, flexure cracks appeared at the middle of the beam. At higher levels of loading, the flexure cracks propagated and the width of the main cracks increased. Finally, the beam failed in flexure at a load of 26 kN at the line of the point of loading and the middle of the bottom of the beam.

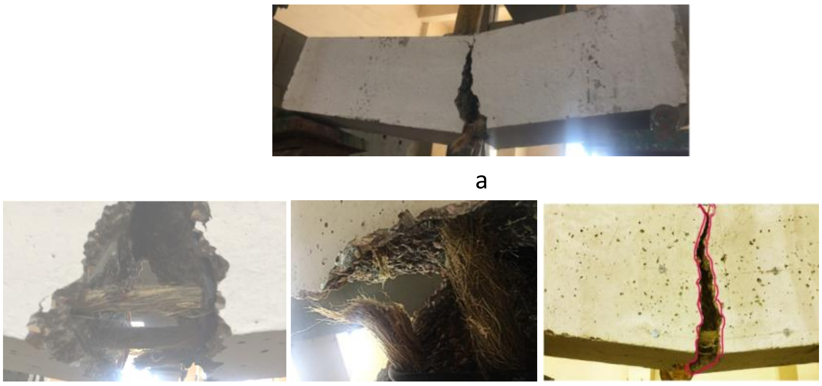

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Figure 10: Rapture of the banana fiber bars

The ultimate bearing load for each specimens show that rang of homogenous between the concrete and banana fiber bars and this contribute to increase the bond strength each of them as shown in Table 6.

Table 6 Test results

model	Main RFT	Φ	Ultimate load (kN)	Type of failure	Bars mode
Model-1	Plain concrete	----	20	Brittle	----
Model-2	BFB	12	26	Flexure	Bars rapture
Model-3	BFB	14	26.8	Flexure	Bars rapture
Model-4	BFB	16	27.3	Flexure	Bars rapture
Model-5	BFB	16	28	Flexure	Bars rapture
Model-6	BFB	16	27	Flexure	Bars rapture
Model-7	BFB	16	27	Flexure	Bars rapture

Where BFB : Banana fibers bars

4.9 The flexure strength

The stress - strain curve for the tested beams is shown in Figure 11, it can be illustrated that the banana fibers bars has a big influence in ultimate load and flexural strength with improved by about 26 % compared to plain concrete beam that illustrate the good cohesion between the surrounding concrete and the used bars In reference to the increase in bond strength [27].

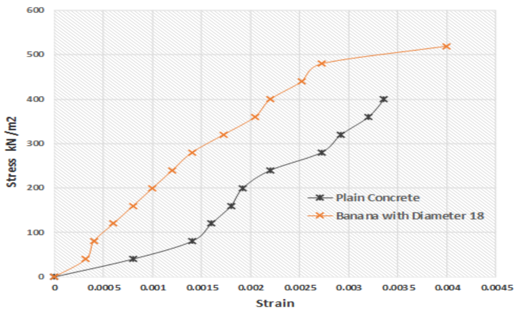

Figure 11 : Stress-Strain curves for banana fibers bars compared with plain concrete

Study the effect of the ratio of banana fibers reinforcement, the specimens from (B-1 to B-5) were utilized as shown in Figure 12 . The results shown that the breadth of crack and vertical displacement at mid-span are significantly decreased by increase the ratio of reinforcement. the maximum load improved by by 2 % to 6 % as the reinforcement ratio improved from 0.73 to 1.66 25 [28].

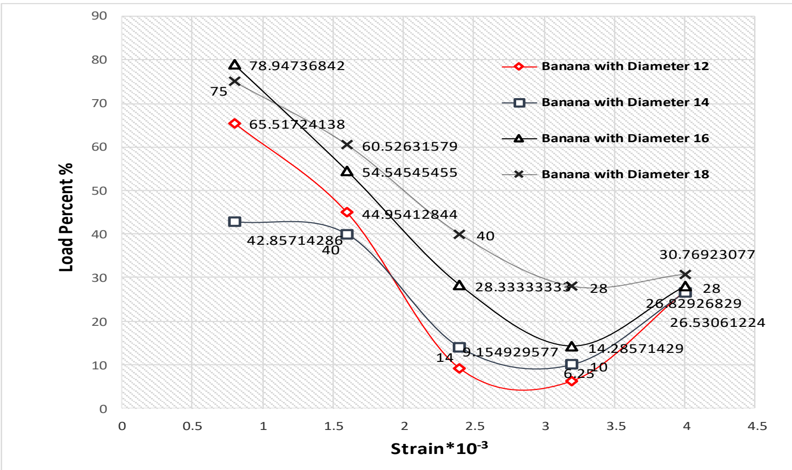

Figure 12: Increment of load as to plain concrete

4.10 The concrete strength

Three models from ((B-4), (B-6) and (B-7)) reinforced with the same ratio of the banana fibers bars Φ16 with different grade of concrete (25, 35 and 45 MPa) were used to know its impact factor and its influence on the behavior of reinforced concrete beams and its influence in the bond aspect of the concrete reinforced with banana fibers. Based on this research, the results indicated that there is no effect of the grade of concrete to the ultimate load as shown in Figure 13 and the rapture was the same for all models.

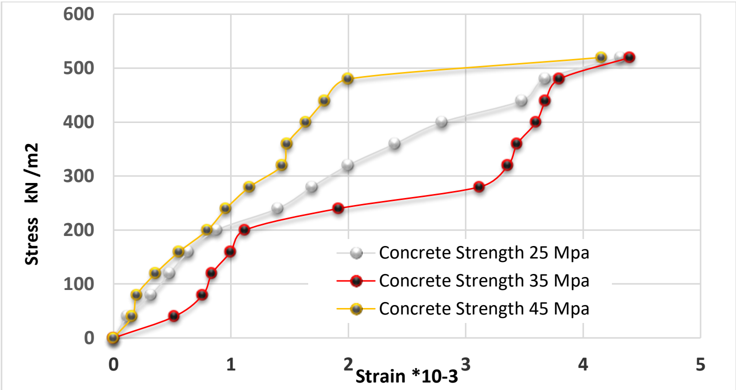

Figure 13: Stress-Strain curves for specimens has different concrete strength

5 The Practical Applications of BFRP in Construction

Nowadays Banana fiber polymers become one of the most important fiber composites materials because of its high strength, non-corrosiveness and many other properties. The application of banana fiber is not limited in the industrial purpose but also it reaches to using in construction material. Banana fiber can be used in the construction (compressed earth block, plain concrete, hybrid material and reinforced structures) and in the green buildings

The green buildings have to be designed to decrease the impact of the residential environment on the natural environment and human health by [90]:

1) Implementing the efficient use of energy, water and other related resources;
2) Reducing the waste and pollution emissions which are harmful to the environment; and
3) Improving employee productivity and occupant health.

It is also an approach that utilizes:

1) "Environmental" or "Natural" materials that use very low energy in their production, transportation and consumption

2) Sustainable and durable materials: recyclable, reusable, and renewable resources in its building construction, reducing pollutants and creating a healthy interior environment. ; and

3) "Intelligent" equipment: "Low energy" house appliances and efficient heating system.

5.1 Cost Variations

Even without taking sustainable design into account, there is a wide variation in cost per square foot between buildings on a regular basis. This certainly contributes to the cost variations from country to country as well as from one area to another in the same country. Unit production costs will differ based on local conditions [150]. Causes for cost variations include:

1) Cost of raw material of banana fiber per ton;

2) The rental cost per ton;

3) Labor cost per ton;

4) Additional material cost per ton;

5) Manufacturing cost for Banana bars per ton;

6) Administrative costs.

The cost of using banana fiber bars in concrete is very low comparing to the cost of using normal steel reinforcement or even less due to its reduced density affecting transport and handling cost. This gives banana fiber bars the opportunity to compete with steel bars as reinforcement in concrete elements. The price of banana fiber bars ranges from 4500 to 5000 LE per one ton and the price of the steel bars ranges from 10500 to 10700 LE per one ton. Here, it is important to note that the difference of density of the bars makes the comparison between the price of the volume of the bars more realistic. The price of one meter cube of steel bars ranges between (42120 L.E. to 56160 L.E. and the price of one meter cube of banana bars ranges between (10725 L.E. to 11700 L.E.). This demonstrates that the price of banana fiber bars is about one quarter of the price of the same volume of steel bars.

5.2 Effect of Banana Fiber Bars on Prices

As a conclusion of the experimental and numerical programs which were performed on banana fiber bars, the use of banana fiber bars as reinforcement in different concrete elements shows some advantages and disadvantages. The use of banana fiber bars as reinforcements in beams provide lower weight in comparison with steel bars. There are three cases controlling the economy of choosing the use of banana fiber bars or steel bars.

5.3 Case of Same Area of Bars

The first case is the assumption that the same area of the two types of reinforcement bars are used in the cross section. Table 7 shows the comparison between the cost of using banana fiber bars as main reinforcement in a beam to that of using steel bars. The main assumption in the comparison is taking the same number of bars and the same diameter.

Table 7: Comparison between the cost of using banana fiber bars as main reinforcement in beam and using of steel bars when providing the same area of bars.

RFT type	Beam section (mm)	Beam length (mm)	No. of bars in the beam	Weight of bars (kg/m)	Weight of bars in beam (kg)	Price of bars (LE/kg)	Total price of bars in beam (LE)
Steel 12mm	250*700	5000	5	0.88	22	10.3	226.6
Banana fiber bars 12mm	250*700	5000	5	0.22	5.5	4.8	26.4

The reduction in the cost of reinforcements is about 88.3 %.

5.4 Case of the Same strength

The second case is the assumption that the same strength of the two types of reinforcements bars are used in the cross section. Therefore, the equation used to get the area of BFRP bars equivalent to the area of steel bars is as follows.

$$f_{us} A_s = f_{ub} A_b \qquad \text{Eq. [3.1]}$$

where

f_{us} = Maximum ultimate tensile strength of steel bars =360 MPa.

f_{ub}= Maximum ultimate tensile strength of banana fiber bars = 265 MPa.

A_s= Area of steel bars in mm^2;and

A_b= Area of banana bars in mm^2.

Table 8 shows the comparison between the cost of using banana fiber bars as main reinforcement in the previously used beam to that of using steel bars.

Table 8: The comparison between the cost of using banana fiber bars as main reinforcement in a beam and using of steel bars when providing the same strength of bars.

RFT type	Beam section (mm)	Beam length (mm)	No. of bars in beam	Weight of bars (kg/m)	Weight of bars in beam (kg)	Price of bars (LE/Kg)	Total price of bars in beam (LE)
Steel 12mm	250*700	5000	5	0.88	22	10.3	125.4
Banana fiber bars 12mm	250*700	5000	7	0.22	7.7	4.8	36.96

The reduction in the cost of reinforcements is about 70.5%.

5.5 Case of the Same stiffness

The third case is the assumption that the two types of reinforcement bars has the same stiffness. The equation used to get the area of BFRP bars equivalent to the area of steel bars when has the same stiffness as follows.

$$E_{us} A_s = E_{ub} A_b \qquad \text{Eq. [5.1]}$$

Where E_{us} = Modulus of elasticity of steel bars =200 GPa;

E_{ub}= Modulus of elasticity of banana bars = 30 GPa;

A_s= Area of steel bars in mm^2;and

A_b= Area of banana fiber bars in mm^2.

Table 9 shows the comparison between the cost of using banana fiber bars as main reinforcement in the previously used beam to that of using steel bars.

Table 9: The comparison between the cost of using banana fiber bars as main reinforcement in a beam and using of steel bars when providing the same stiffness of bars.

RFT type	Beam section (mm)	Beam length (mm)	No. of bars in beam	Weight of bars (kg/m)	Weight of bars in beam (kg)	Price of bars (LE/Kg)	Total price of bars in beam (LE)
Steel 12mm	250*700	5000	2	0.88	8.8	10.5	92.4
Banana fiber bar 12mm	250*700	5000	13	0.22	14.3	4.8	68.64

The reduction in the cost of reinforcements is about 26 %.

The above given comparisons show that the cost of banana fiber bars is less than the cost of steel reinforcement depending on whether the same, area or stiffness or strength of the bars, respectively as shown in Figure 16.

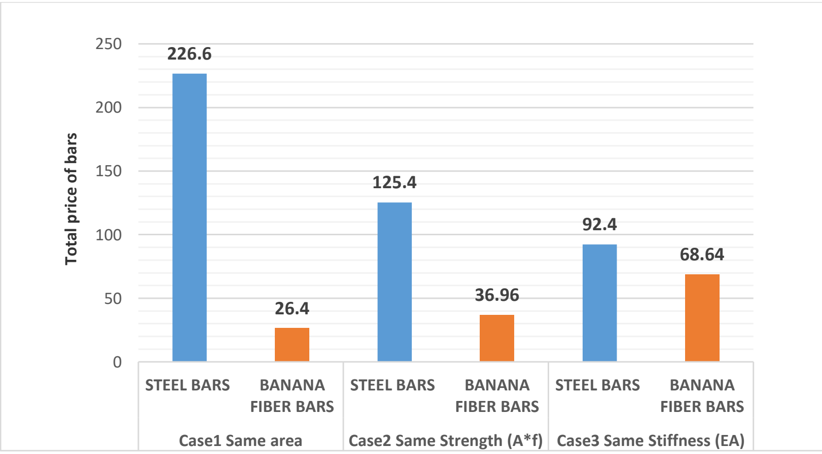

Figure16: Comparison between the cost of using banana fiber bars as main reinforcement in a beam and that of steel bars.

In most cases of design, the strength is the critical factor and therefore considerable savings can be achieved, while the design of slender flexural elements only is controlled by stiffness of reinforcements. In beams, this can be overcome by increasing the depth. However, for slabs, it is not economical to increases its thickness while, the application of the banana fiber bars as reinforcement in slabs or beams provides the building with lower weight which will result in slabs of lower cost than the steel reinforced ones, where the equal stiffness criterion is applied. The slabs in any building represent more than 50% of the total amount of reinforced concrete used in the building and the beams represent 10-20% of the total amount of R.C. Therefore, the use of banana fiber bars as reinforcement in slabs and beams will provide lower cost.

6 Conclusions

Based on the experimental program and the numerical study that were conducted in this study on reinforced concrete beams reinforced with BFRP as bars , the following conclusions may be drawn:

1. Convert the waste materials that came from banana fiber to a new source that can be used in construction element.

2. This banana fiber recycling participate in reducing the global warming that came .f rom pruned of this waste and also reduce the percent of Co2.

3. This good environmental friendly feature makes the materials very popular in engineering markets such as the automotive and construction industry.

4. The banana fibers are waste product of banana cultivation, therefore without any additional cost and have economic impact factor when used in construction purpose.

5. These banana fibers consider one of the renewable resource so can be obtained for industrial purpose

6. Banana fibers as a reinforcement for concrete beams give more flexural strength compared to plain concrete by about 25%.

7. The concrete strength has no effect on the ultimate load and the failure of the concrete beams reinforced using banana fibers.

8. This experimental indicates that the hybrid fiber banana fibers contributes to reducing the cost as a result of the participation of banana fibers resulting from the agricultural waste. As banana fibers work mainly in resisting loads and increasing elongation, increasing the bearing capacity over time.

9. It is suggested that these banana- -glass fibers reinforced hybrid epoxy composites can be used as an alternate material for synthetic fiber reinforced composite materials.

10. ~~The predicted numerical results from ANSYS program for loading and deflection at ultimate and first cracking levels result, show a good agreement with the experimental results. Also, the simulated cracking patterns and failure modes are nearly similar to the testing results for all beams. The average ratio between measured load and predicted load is 0.989 at ultimate level. Finally, the average ratio between numerical and experimental ultimate deflection values is 0.866 this is due to the assumption of full bond between reinforcing steel and concrete and also the numerical analysis hasn't descending~~ branch.

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