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Strengthening the Design Mix of Concrete Using Abaca Fiber for Reinforced Concrete Design

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ABSTRACT: The research study on strengthening the design mix of concrete using abaca fiber for reinforced concrete design demonstrate a load-deflection relationship that drew the ideas that the addition of abaca fiber for concrete application particularly for members under flexure reinforced the toughness and ductility of concrete even in higher fiber content. Likewise, it indicates that the conventional uses of abaca fibers in various households and industrial applications particularly in the form of rope would be extended to something with structural concerns. The abaca fiber was utilized as reinforced to concrete and was evaluate through various ASTM standards to acquire information, which concerns to its effect to engineering structures. The addition of fibers significantly affected the physical properties the fiber reinforced concrete. As the fiber increases, the slump decreases, and the mixture became more laborious to mix for all of the three specified lengths. The use of abaca fiber for FRC contributed positive and negative effect in terms of the compressive strength. The modulus of rupture proved to be as one of the most enhanced property of the abaca fiber reinforced concrete compared to other mechanical properties. The flexural test gave significant results to this particular engineering property. Thus, the addition of fibers

KEYWORDS: design mix, concrete, abaca fiber, concrete design

1 INTRODUCTION

Plain concrete is a brittle material with low tensile strength and strain capacities. However, an increase in both tensile strength and ductility is possible with the addition of fibers. The use of randomly oriented and short fibers to improve the physical properties of the matrix is an old age concept. These fibers were from various materials, such as from organics to inorganics, from metallic to polymeric, and from synthetic to natural. The basic role of this randomly oriented, discrete and discontinuous fiber when added is to produce a fiber reinforced concrete (FRC) which bridges across the cracks that develop in concrete either as it is loaded or as it is subjected to environmental change. In this study, abaca fibers, known products of the abaca plant (musa textiles nee) are use as alternative to the common FRC using inorganic, metallic and polymeric fibers. They fall under the classification of naturally occurring fibers including sisal, coconut, jute, and bamboo.

2. EXPERIMANTAL PROGRAM

2.1 Material & Fiber Selection, Preparation and Testing

[A] Selection

The cement used was classified as Type 1 Portland cement. The fine aggregate was white sand lahar type while the coarse aggregate was crushed gravel type with particles sizes ranging from 4.76 mm to 19.1 mm.

Table 1. Properties of Materials

Material	Specific Gravity	Dry Rodded Density (kg/m^3)	Absorption (%)	Remarks
Cement	3.15			Portland Cement Type 1

Fine Aggregate	2.40	1,300	4.67	White Sand
Coarse Aggregate	2.60	1,620	1.03	Crushed Gravel
Admixture	1.00			HRWR/RA Type Super plasticizer

Table 2 presents the summary of various physical property tests applied to abaca fibers.

Table 2. Properties of Abaca Fiber

Properties	Character
Specific Gravity	1.48
Density (kg/m^3)	1480
Absorption	131
Average Diameter (mm)	0.14
Tensile Strength (MPa)	857
Tensile Strength, CV (%)	12.6
Fineness	258.92
Fineness, CV (%)	17.2

2.2 Mix Design and Proportions

The design mix was based on the established physical properties of the ingredients as per standards and specifications of ACI 211 [18] using the weight basis method of design.

Table 3. Mix Proportions

ID	W/C (%)	S/A (%)	Weight (kg)							
			W	C	FA	CA Particle Size (mm)			Fiber	SP
						4.76-9.52	9.52-15.9	15.9-19.1		
C-000-00	50	42.6	184	368	752	152.3	507.5	355.2	0	1.84
C-025-10	50	42.6	184	368	752	152.3	507.5	355.2	5.8	3.68
C-	50	42.6	1	3	7	152.3	507.5	355.2	5.8	3.

025-15			84	68	52					68
C- 025-20	50	42.6	1 84	3 68	7 52	152.3	507.5	355.2	5.8	3. 68
C- 050-10	50	42.6	1 84	3 68	7 52	152.3	507.5	355.2	11. 6	3. 68
C- 050-15	50	42.6	1 84	3 68	7 52	152.3	507.5	355.2	11. 6	3. 68
C- 050-20	50	42.6	1 84	3 68	7 52	152.3	507.5	355.2	11. 6	3. 68
C- 075-10	50	42.6	1 84	3 68	7 52	152.3	507.5	355.2	17. 4	3. 68
C- 075-15	50	42.6	1 84	3 68	7 52	152.3	507.5	355.2	17. 4	3. 68
C- 075-20	50	42.6	1 84	3 68	7 52	152.3	507.5	355.2	17. 4	3. 68
C- 100-10	50	42.6	1 84	3 68	7 52	152.3	507.5	355.2	23. 2	3. 68
C- 100-15	50	42.6	1 84	3 68	7 52	152.3	507.5	355.2	23. 2	3. 68
C- 100-20	50	42.6	1 84	3 68	7 52	152.3	507.5	355.2	23. 2	3. 68

Table 3 summarizes the different mix proportions for all of the materials used in various FRC mixes. ID number “C-025-20” indicates the type of matrix, the fiber content, and the length of fiber used. “C” means that the matrix is concrete containing cement, fine and coarse aggregates. The next term”025” indicates the amount of fiber content equal to 0.25% by the weight of concrete. Finally, the last number “20” signifies the fiber length of 2.0 inches.

2.3 Concrete Mix

There were a total of 13 different mixes done with different amount of fibers ranging from 0, 0.25%, 0.50%, 0.75% and 1.00% by the total weight of concrete and variables lengths of 1.0, 1.5, and 2.0 inches. The mixing was done through a concrete mixer.

The fresh concrete was then subjected to slump test immediately after mixing (ASTM C 143).

2.4 Casting of Specimens

[A] Cylindrical Specimens

Three (3) – 100 mm x 400 mm cylinders for compressive strength test.

Three (3) – 100 mm x 200 mm cylinders for split tensile strength test.

[b] Prismatic Specimens

Three (3) – 100 mm x 100 mm x 400 mm beams for flexural strength test or rupture strength test.

2.5 Curing

Upon removal from molds, the specimens were submerged in the water until they reached the 28-day curing age before they were subjected to mechanical tests.

2.6 Testing

After reaching the 28-day curing age of the specimens, the cylindrical samples were subjected to testing under ASTM C 39 and ASTM C 496. For the prismatic samples, they had undergone flexural toughness determination using ASTM C 293.

[A] Compressive Strength Test

When the specimens were removed from the curing pond, the specimens were positioned onto the universal testing machine for the measurement of the compressive strength.

[B] Split Tensile Strength Test

In carrying out the split tensile test, the cylindrical specimens were subjected to the same machine for testing but of different position. During the positioning stage, plywood strips about 1/8" thick, 2" wide and 8" long were placed on top and bottom sections of the cylinder intersecting the diametral markings. The load was then applied until the specimen was at failure.

The split tensile strength was computed using the formula,

$$T = \frac{2P}{\pi/d}$$

T denotes the splitting tensile strength measured in mega Pascal (MPa), ***P*** is the maximum load at the time of failure of the specimen indicated by the testing machine in Newton (N), while ***I*** and ***d*** is the length and diameter of the specimen expressed in millimeters (mm).

[C] Flexural Strength Test

The prismatic specimens were subjected to flexural test using the compression machine with regards to rupture strength. The proving ring where the applied load was being monitored, and another dial gauge where the progress of deflection was being read, were simultaneously recorded. Upon reaching the maximum load the specimen exhibited failure by cracking into two segments, the readings in both dials were recorded.

The value of the modulus of rupture was computed using the following formula:

$$R = \frac{3PL}{2bd^2}$$

Where ***R*** is the modulus of rupture in mega Pascal (MPa), ***P*** is the maximum load at the time of failure of the specimen indicated by the testing machine in Newton (N), ***L***, is the unsupported length of the specimen in millimeters (mm) while ***b,*** and ***d*** is the width and depth respectively of the specimen expressed in mm.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

Upon reaching the desired curing age (28 days) of the different concrete specimens with various length and proportions of fiber, they were removed from the curing pond and underwent the proposed series of tests (ASTM C 39, ASTM C 496, and ASTM C 293) were carried out.

Table 4 shows the testing results in terms of slump, density of the hardened concrete, compressive strength, split tensile strength, rupture strength, and fracture energy.

Table 4. Results of Various Test Programs

ID	Slump	Density	Comp. Strength f'c	Split Tensile Strength T	Modulus of Rupture R	Fracture Energy
	(mm)	(kg/m^3)	(MPa)	(MPa)	(MPa)	(N/mm)
C-000-00	70	2337.13	31.66	3.46	4.97	1180.15
C-025-10	95	2327.53	32.61	3.39	5.4	1635.75
C-025-15	90	2281.66	31.29	3.38	5.74	1620.64
C-025-20	81	2292.92	34.14	3.39	5.73	1658.28
C-050-10	90	2176.35	33.66	3.25	5.36	1580.15
C-050-	82	2234.9	33.52	3.14	5.49	1483.9

15		2				
C-050-20	90	2206.13	32.37	3.34	5.43	1527.35
C-075-10	35	2102.98	28.4	3.26	5.37	1192.9
C-075-15	31	2110.07	25.21	3.47	4.84	1116.42
C-075-20	40	2149.75	24.1	3.49	4.89	1119.75
C-100-10	30	2050.78	21.32	3.05	4.35	1178.63
C-100-15	26	2035.04	22.52	3.36	4.75	1139.09
C-100-20	22	2094.68	21.08	3.01	4.26	1116.74

3.1 Effect of Fiber Content to Slump

It was observed that the inclusion of abaca fibers in fresh concrete significantly altered the stability, workability, and compactibility of concrete. The abaca fiber concrete resulted in a more cohesive mixture, which was an indicator of good stability and stiffness. The intertwining of the fibers caused the concrete enclosed in a matrix, which made it extra cohesive in character.

In terms of workability, the addition of increasing amount of fiber at constant water-cement ratio and constant amount of super plasticizer resulted to mixtures exhibiting a lower slump.

During casting, it was observed that the compactibility of concrete was affected by the amount of fiber in the mixture.

3.2 Effect of Fiber Content to Density of Concrete

The density of an abaca FRC was inversely proportional to the amount of fiber added in the concrete. This suggested that the greater the amount of abaca fiber introduced in the mixture, the lighter the concrete would become. This was because abaca fiber was less dense than the normal components such as gravel and cement.

3.3 Effect of Fiber to Compressive Strength

The results showed that at lower proportions 90.25% and 0.50%) of fiber in the mixture, there was a slight increase in the compressive strength compared to the control mix. However, at higher percentage of abaca fibers in the mixture (0.75% and 1.00%), the compressive strength was reduced to a value much lower than the control mix. The result showed that the lesser fiber contents (0.25% and 0.50%) gave the optimum contribution (especially 0.25% fiber) I terms of compressive strength.

The longest fiber length (2.0-inch) gave the optimum contribution in terms of compressive strength but only at considerable amount. The intertwining effect of longer fibers enhanced the matrix, which provided a more cohesive composite resisting compression.

3.4 Effect of Fiber to Tensile Strength

The result of the study showed no significant increase in the split tensile property of concrete in general. Although there were obvious changes in the compressive strength characteristics of the FRC, but in terms of split tensile strength, the result seemed insignificant.

3.5 Effect of Fiber to Modulus of Rupture

At 1.0-inch strands fiber, all the first three different fiber proportions gave a significant contribution in that particular strength of concrete: +9% of 0.25% fiber, +8% for 0.50% fiber, and +8% for 0.75% fiber. At 1.0%for the same kind, the stress was reduced by 12%. Similarly, for the 1.5-inch series, the 0.25% and 0.50% fiber content was quite good to enhance the modulus of rupture of normal concrete by giving an additional 15% and 10% stress. Finally, in the last series of concrete (2.0-inch), it showed that the same two lesser amounts of fiber in the mix gave positive effect to develop the modulus of rupture capability of concrete by supplying additional 15% and 9% for 0.25% and 0.50% fiber content.

From the same data acquired, it was obviously observed that the addition of abaca fiber contributed positively to enhance the flexural toughness of concrete. The ideal amount of fiber that would give an optimum contribution to modulus of rupture was at 0.25% fiber by weight of concrete.

The result of the study suggested that for a significant contribution of fiber to concrete, the following dosage were recommended for each fiber lengths: at 1.0-inch fiber length, the fiber content ranges from 0.25% to 0.75%. About 1.5-inch and 2.0-inch fiber strand, 0.25% to 0.50% fiber content would still result to a considerable increase in rupture strength of concrete.

3.6 Effects of Fiber to Fracture Energy Capacity

It was observed that the control mix suddenly failed and snapped as it reached its ultimate load thus separated the specimen into two parts at the midpoint or within the middle third of the span. In the case of concrete with abaca fiber, especially at greater proportions from 0.50% to 1.0%, the specimens exhibited a greater cohesion inside by keeping the concrete still intact at the time of failure. As observed, the fibers were still holding the concrete up to the complete crack. However, for the 0.25% abaca FRC series, the beam behaved similar to the control mix in terms of failure.

In terms of the values obtained in the test, the innate energy absorption capacity of the control mix was about 1180 N/mm. As observed, all the three different fiber lengths used in this study portrayed similar thread line in their fracture energy for the four variable proportions of fiber. The 1.0-inch sequence showed that at 0.25% and 0.50% fiber, the energy capacity was significantly increased by 39% and 34%. In the case of the 1.5-inch series, the same amount of fiber contributed to the increase in the fracture energy (37% and 26%). Also, for the 2.0-inch group, an increase of 40% and 29% was attributed to the addition of 0.25% and 0.50% fiber in the concrete. On the other hand, the 0.75% and 1.00% proportions for all the length in this study gave no considerable increase in the energy absorption capacity.

3.7 Effect of Fiber Evaluated in Terms of Load and Deflection

The attained load does not represent the actual rupture load at the time of failure of the specimen. In addition, the 0.25 mm limiting deflection observed for all of the 13 mixtures does not correspond to the maximum deflection achieved by the specimen. The rupture load and maximum deflection values were all greater than the values presented in this table.

Table 5. Summary of Load at a Specified Deflection

ID	Attained Load	Specified Deflection
	(N)	(mm)
C-000-00	6,361.03	0.25
C-025-10	6,150.40	0.25
C-025-15	6,908.66	0.25
C-025-20	6,445.28	0.25
C-050-10	7,709.06	0.25
C-050-15	7,638.85	0.25
C-050-20	7,666.93	0.25
C-075-10	7,803.34	0.25
C-075-15	7,835.44	0.25
C-075-20	6,940.76	0.25
C-100-10	6,992.92	0.25
C-100-15	7,175.46	0.25
C-100-20	6,253.37	0.25

The load-deflection relationship drew the ideas that the addition of abaca fiber for concrete application particularly for members under flexure reinforced the toughness and ductility of concrete even at in higher fiber content. Since the attained load of almost all FRC composites were greater than that of the control mix at the specified deflection, it signified the idea that the fibers helped in providing flexural resistance by increasing the resistance of the matrix on the load applied.

4. CONCLUSIONS

This study indicates that the conventional uses of abaca fibers in various households and industrial applications particularly in the form of rope would be extended to something with structural concerns. The abaca fiber was utilized as reinforced to concrete and was evaluate through various ASTM standards to acquire information, which concerns to its effect to engineering structures. After series of test, considerable interpretation and analyses of data, the following conclusions were drawn.

1. The concrete mixtures used in this study were designed using the weight basis method. The references and results of the design process were shown on Appendices A and B.

2. The addition of fibers significantly affected the physical properties the fiber reinforced concrete. The composite developed the following behaviors:

- As the fiber increases, the slump decreases, and the mixture became more laborious to mix for all of the three specified lengths. The amount of fiber added into the mixture contributed to the decrease in the compactibility of concrete.
- The density of an abaca FRC was inversely proportional to the amount of fiber added in the concrete. As the fiber content increases (1.00%), the hardened concrete became a much lighter composite (2060 kg/m3) as compared to the control mix (2340 kg/m3). There was a 12% reduction of the density at 1.00% fiber content.

3. The use of abaca fiber for FRC contributed positive and negative effect in terms of the compressive strength.

- Addition of fibers at contents ranging from 0.25% to 0.50% contributed to a slight increase in the strength of FRC from 2% to 8%.
- Addition of fibers at contents ranging from 0.75% to 1.00% resulted to a significant decrease in the strength of FRC from 10% to 33%.
- The fiber length of 2.0 inches was ideal to give a considerable increase (8%) in the compressive strength of FRC over the control mix. This addition strength could be achieved at a minimal amount (0.25%) of abaca fiber.

4. The presence of abaca fiber in various amounts and lengths to concrete as it affected the split tensile characters showed that:

- The amount of fiber (0.25% to 0.75%) added in concrete gave no significant contribution. However, at 1.00% fiber content, the FRC's tensile strength was reduced to as low as 13%.
- Similarly, the length of fiber showed no significant effect in the tensile strength of concrete.

5. The modulus of rupture proved to be as one of the most enhanced property of the abaca fiber reinforced concrete compared to other mechanical properties. The flexural test gave significant results about this particular engineering property.

- The amount of fiber that gave optimum contribution (5.74 MPa) to the modulus of rupture was at 0.25% by weight of concrete. At this limited amount of fiber, sufficient fiber distribution and compactibility was attained.
- At greater fiber content (1.00%), the composite behaved entirely different. Higher amount of fiber contributed in the aggravation of microcracks, which resulted to complete pullout of the matrix, which consequently reduced the modulus of rupture.

6. The addition of fibers significantly altered the energy absorption capacity of composite.

- In terms of fiber content, the 0.25% fiber proportion still gave the ideal dosage, which contributed to a 39% increase of fracture energy compared to the control mix.
- At 0.50% fiber content, an average increase of 30% was observed for the given fiber lengths.
- There is no significant effect on fracture energy at higher fiber contents (0.75% and 1.00%).
- In terms of fiber length, the 2.0-inch fiber strands registered the maximum value of fracture energy (1658.28 N/mm) at lesser amount of fiber (0.25%).

7. The effect of fiber evaluated in terms of the load and deflection revealed the following behaviors of FRC:

- At 0.25% fiber content, there was no significant increase in the attained load for 1.0-inch and 2.0-inch fiber strands. However, a 9% increase was observed for the 1.5-inch fiber length.
- At 0.50% fiber content, a higher increase of load was attained for the three fiber lengths (21% average increase) compared to the mix.
- At 0.75% fiber content, the increase in the attained load at this specified deflection for the 2.0-inch fiber strand was 9%. Also in this series, the highest increase of load was observed for the 1.0-inch and 1.5-inch fiber lengths (23% increase))
- At 1.00% fiber content, no significant increase in the attained load for the 2.0-inch fiber strands but an average increase of 11% was observed for the two shorter fiber lengths.

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