Applicability of Using Natural Fibers for Reinforcing Concrete

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Abstract. The demand for applying sustainability in the construction industry increases the necessity of using natural materials in concrete production. Plant-based natural fibers are cost effective renewable materials which considered a potential way to support sustainable development in both urban and rural regions. This paper investigates the potential of using sugarcane bagasse, palm trunk and banana fibers as concrete reinforcement by determining the effect of different volume percentages of these fiber on the mechanical properties of concrete. The percentage of fiber used was 0.5%, 1.0% and 1.5% for sugarcane, 1%, 2%, and 3% for Palm Trunk, and 0.3%, 0.5%, 0.7%, and 1% for banana. Results showed that the optimum value of sugarcane, and banana is 0.5%, 4% respectively. In addition, the addition of 1%, 2%, and 3% of palm trunk fiber improved the mechanical properties of concrete.

1. Introduction
Concrete has low tensile strength, accordingly, much attention has been given to enhance the mechanical properties of concrete [1]. One of the methods of improving the properties of the concrete is adding fibers [2]. Initial applications incorporate addition of straw to mud bricks, and horse hair to reinforce plaster [3]. The expansion of fiber reinforced concrete began in the early sixties. Currently, growing demand of concrete leads to originating alternate fibers that are sustainable and improve agricultural waste management [4].

Natural fibers like jute, coir, bamboo and sisal have been used as reinforcement materials in concrete mixtures for many years, especially in developing countries [1] [5]. The main benefits of reinforcing concrete with natural fibers are related to low cost of obtaining it and to the compatibility of its properties to fragile materials affirms [5]. Furthermore, natural fibers are renewable natural resources, and thus, do not damage the environment.

The quality of natural fiber reinforced concrete depends mainly on their strength which, in turn, is affected by many factors. The volume percentage of fibers and aspect ratio are considered the most significant factors [6-7]. Lee [8] stated that the addition of fibers to concrete is considered an effective method to improve tensile strength, fatigue resistance, toughness and ductility. Although the incorporation of natural fibers did not eliminate crack formation, they lessen the crack propagation. Lee, Cho and Choi [9] demonstrated that reinforcing composites with fibers delayed the fracture. This is attributed to the formation of transfer bridges by the fiber which absorb part of the stress and result in a more distributed cracking, the rupture becomes a progressive process [10].
The usage of natural fibers for reinforcing the concrete has evidenced valuable improvement in many aspects, nevertheless, it is required to strengthen this study. The aim of this research is to assess the effect of the addition of banana, palm trunk and sugarcane fibers on the mechanical properties of concrete through detecting the compression strength, tensile strength.

2. Experimental Work

2.1 Materials

2.1.1 Binders and Aggregates. The used constituents are ordinary Portland cement, fine aggregate, coarse aggregate and fibers. Ordinary Portland cement (ASTM Type I) is used. Physical properties, chemical analysis, and calculated compound compositions of the used cement are presented in Table 1. The coarse aggregate used in this study is a 19 mm crushed limestone, while the fine aggregate used is siliceous natural sand. The physical characteristics of both aggregates are outlined in Table 2. Both fine and coarse aggregate satisfy the sieved analysis grading in accordance with ASTM C136/C136M-14. The ratio of cement: coarse aggregate: sand is 1:3:1.5. Water-cement ratio was kept constant at 0.5. The mix design of concrete for 1 m$^3$ is shown in table 3. Table 4 presents the composition of banana, palm trunk, and sugarcane bagasse.

| Description                      | Amount       |
|----------------------------------|--------------|
| Setting Time                     |              |
| Initial:                         | 200 min.     |
| Final:                           | 270 min.     |
| Fineness of cement               | 3320 (cm$^2$/gm) |
| Chemical analysis                |              |
| Silicon Dioxide(SiO$_2$)         | 20.9         |
| Aluminum Oxide(Al$_2$O$_3$)      | 5.4          |
| Ferric Oxide (Fe$_2$O$_3$)       | 3.4          |
| Calcium Oxide (CaO)              | 61.28        |
| Magnesium Oxide (MgO)            | 2.6          |
| Sulfur Trioxide (SO$_3$)         | 1.8          |
| Insoluble residue                | 0.62         |
| Loss on ignition                 | 1.8          |
| Calculated Compound Composition  | 55.9         |
| Tricalcium Silicate (C$_3$S)     | 19           |
| Dicalcium Silicate (C$_2$S)      | 7.5          |
| Tricalcium Aluminate (C$_3$A)    | 9.8          |
| Tetracalcium aluminoterrite (C$_4$AF) |          |

Table 1: The chemical analysis and compound composition of cement

| Property                        | Sand | Coarse Aggregate |
|---------------------------------|------|------------------|
| Unit Weight/(t/m$^3$)           | 1.77 | 1.5              |
| Specific weight                 | 2.62 | 2.6              |
| Fineness Modulus                | 2.65 | .....            |
| Nominal Maximum Aggregate Size  | ……..| 19 mm            |

Table 2: The physical characteristics both aggregate
2.1.2 Fibers. The fibers used in this work are banana, palm trunk and sugarcane bagasse. Before being incorporated into the concrete the fibers are treated. As for Banana and sugarcane bagasse fibers, they are subjected to chemical treatment in order to increase the pH value of the fibers. Alkali treatment of cellulosic fibers is the usual method to produce high quality fibers. The sugarcane bagasse will dry under the sun until completely dry for 7 days. Then the bagasse will cut into small relatively uniform strips with estimation 5cm until 10cm. Both banana and sugarcane bagasse fibers are cleaned and submerged sodium hydroxide solution for two hours at room temperature as shown in Figure. 1. The concentration of sodium hydroxide solution is 6% and 50% for banana and sugarcane respectively. The fibers are then immersed in water to be washed thoroughly to remove the unreacted alkali and then dried in an oven at 80 °C for 24 h. Concerning the palm trunk fibers, they are taken directly from the plantation when the trees are recently fallen. The fibers with length vary from 25-300 mm are processed manually. The tested percentages for sugarcane are; 0.5%, 1%, and 1.5%, while for palm trunk are; 1%, 2%, and 3%, finally percentages for banana are; 0.3%, 0.5%, 0.7%, and 1%.

3. Specimens Preparation
Mixing concrete is performed by using a free-fall mixer, the natural fibers are the final material to be added in the mixture. Subsequently, 50 specimens are produced in the dimensions of 15 cm x 15 cm x 15
cm, as well as 15 prismatic specimens with a section of 4 cm x 4 cm and a length of 16 cm, as shown in Figure 2. The specimens are demolded after 24 hours and then cured in water for 28 days. The mechanical properties evaluations of the reinforced concrete with natural fibers are obtained through compressive strength, and tensile strength tests.

4. Test Procedures

4.1 Compressive strength
The axial compression test consists of determining the maximum load of rupture supported by the specimen. For the accomplishment of this mechanical test, 3 test specimens of each type of concrete used in this study are tested.

4.2 Tensile strength
In order to perform this test, a prismatic section specimen is submitted to bending, with loading in two symmetrical sections, until rupture. A total of 3 specimens of each concrete type are tested.

5. Results

5.1 Compressive strength
The control sample containing 0% fiber records a reading of 30 MPa. For concrete with sugarcane bagasse, samples containing 0.5%, 1.0%, and 1.5% fiber have compressive strength of 30.30, 31, 32 MPa respectively. For concrete with palm trunk, samples containing 1%, 2%, and 3% fiber have compressive strength of 40, 26, 21 MPa respectively. For concrete with banana fibers, samples containing 0.3%, 0.5%, 0.7%, and 1%, the compressive strengths are; 30.8, 38.7, 35, and 33 respectively. The effect of sugarcane bagasse, Palm trunk, and banana fibers are illustrated in Figure 3.

It can be seen that the addition of sugarcane bagasse has a minor effect on concrete compressive strength. However, the increase in compressive strength is directly proportional to the percentage of fiber added. This is in contrast to the results for concrete with banana fibers and palm trunk fiber. In both cases, the concrete compressive strength is enhanced till optimum percentage of fibers and then dimensioned. This may be attributed to the weak interfacial bond between fiber and concrete due to the formation of voids. From the previously mentioned discussion, it is obvious that the optimum percentages of banana fibers and palm trunk fiber are; 0.5% and 1% respectively. While more experiments should be done to assess the effect of higher percentages of sugarcane fibers on compressive strength.

| Fiber | Palm Trunk | Sugarcane bagasse | Banana |
|-------|------------|------------------|--------|
| Component | Percentage | Percentage | percentage |
| Cellulose | 50%       | 66              | 60     |
| Lignin    | 25%       | 21              | 15     |
| Extractives | 12%     | 6               | 9      |
| Moisture  | 8%        | ----            | 10     |
| Ashes     | 5%        | 7               | 6      |

Table 4: The composition of Palm trunk, sugarcane bagasse, and banana fiber.
5.2 Tensile strength

The control sample of normal concrete containing 0% fiber records a reading of 2.10 MPa tensile strength. For concrete with sugarcane bagasse, samples containing 0.5%, 1.0%, and 1.5% fiber has tensile strength of 2.15, 2.25, 2.3 MPa respectively. For concrete with palm trunk, samples containing 1%, 2%, and 3% fiber has tensile strength of 2.5, 2.08, 2.02 MPa respectively. For concrete with banana fibers, samples containing 0.3%, 0.5%, 0.7%, and 1%, record tensile strength of 2.4, 2.54, 2.72, and 2.9 respectively. As it can be seen from Figure 4, the tensile strength is directly proportional to the increase in percentages of fiber added either for banana fibers or for sugarcane bagasse. The addition of banana fibers has the highest effect on tensile strength. As for concrete reinforced with palm trunk fibers, the optimum percentage for fiber is 1%. This may be attributed to difficulty in compacting concrete containing a high percentage of palm trunk, accordingly, more voids and less bond between fiber and concrete is achieved. However, all concrete samples reinforced with the three types of fibers do not face complete rupture even under the ultimate load the maximum load was applied, the fibers diminish the crack mouth opening.

Figure 3. Effect of fiber on compressive strength (a) sugarcane bagasse, (b) Palm trunk, (c) banana fibers
Figure 4 Effect of fiber on tensile strength (a) sugarcane bagasse, (b) Palm trunk, (c) banana fibers

6. Conclusion
The addition of natural fibers improves the mechanical properties of concrete.
Addition of Banana fiber with 0.5% increase the compressive strength and tensile strength by 30% and 14% respectively compared to the control mixture. While the addition of 1% increases the tensile strength by 38% compared to control mixtures.
Addition of sugarcane bagasse increases both compressive and tensile strength but to lower limit compared to the other two types of fibers. The maximum increase in compressive and tensile strength is 7%, 9.5%.
Compressive strength of the concrete decreases when the amount of palm trunk fiber increased. The optimum percentage that gives the higher compressive strength is 1%. The same trend is observed in
testing the tensile strength. The addition of this percentage increases the compressive strength by 33% and the tensile strength by 19% compared to the control mixture.

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7. References
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