Analysis of the mechanical characteristics in mortar mixtures with the incorporation of corn leaf fibers

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Abstract. This article presents the results of an experimental design research work, aimed at adding the fibers of the corn leaf to the cement mortar matrix 1:3, performing tension and compression, humidity and density tests to determine the degree of final resistance of the new reinforced mortar. Once described the way in which the fiber of the corn leaf is acquired, the quantities of the elements of the mixture are detailed, and the results of three samples and the average obtained are disclosed.

1. Introduction

The industrialization process in developing countries derived from an increase in the production of agricultural products, and the consequent non-usable waste reserves. Products such as rice, wheat and corn doubled their production between 1961 and 1991. From 1988 to 2010, cereal crops in developing countries would be increased by 1.4 percent, according to Food and Agriculture Organization of the United Nations (FAO) [1]. Cereals such as wheat between 1969 and 1971 had a growth of 67 million metric tons and for the years 1988 and 1990 an increase of 132 million metric tons and 2010, millions of tons arrived until 2015. For other cereals such as rice in 1969 and 1971 there were 177 tons and for 1988 and 1990 it increased to 301 tons and for 2010 their contribution reached 459 tons. For other cereal as in the same periods of 1969 and 1971 it had 70 tons and for the years 1988 and 1990 it increased to 112 tons and for the year 2010 it reached up to 196 tons, which allows to determine that for the year 2010 it had a total of 995 tons including the sum of other cereals that were increased [1].

In Colombia, corn production for 2016 had 306.402 hectares with a production of 4.78 million tons where its production directly involves large-scale waste that is not reused but generally serves as food for other animals or their cycle ends as stubble.

The above constitutes an environmental problem, considering the large energy expenditure involved in the production processes of large industries. This situation has motivated efforts around sustainable construction and development, in which ecological practices are beginning to be implemented that also prove to be profitable [2].

And for this reason, it is notorious that the use of fibers for the reinforcement of materials is presented as a valid alternative for Latin American countries [1] given that plant fibers represent a cost reduction while maintaining adequate levels of yield [3].
The use of vegetable fibers as additives and supplements makes possible the innovation of traditional materials, repowering and diversifying their properties [4]. These can be an effective way to improve masonry performance [5,6].

In this way, the work of investigating and experimenting with the modification of mortars and the addition of vegetable fibers is undertaken, in this case, use will be made of fibers extracted from the leaves of the corn, of which we will present characteristics below.

2. Materials and methods

2.1. Characterization of the materials

2.1.1. Corn fiber. Corn Leaves were obtained from vendors in the market square of the municipality of Caldas, Antioquia, Colombia. And the characteristics were established from a study conducted by [7]. Similarly, morphological characterization of the leaf is also necessary. The leaves of the corn plant, are characterized by elongated, alternate and lanceolate, are born in each knot of the stem and consist of pod, ligule and leaf blade. The leaf blade (up to 150 cm), wide and flat, has parallel and central ribs and its surface is rough and pubescent, regular form of monocot leaves, as shown in Figure 1.

The preparation of vegetable fiber for external and commercial use is carried out through the synthesis of the following steps. “El Enriado”: In the open air or in water the leaves are left for 2 to 5 weeks until the soft tissues of the leaf are destroyed. The aggravated or scattered: In this phase the leaves are dried to the passage of a striated roller, and finally, stir or shake: Operation that causes the fibrous parts to fragment, defining the fiber as such, which are smoothed by means of stir or shake. Finally, they are classified and go through the final enlistment process such as cleaning, brushing and combing, together with the final drying [8].

In addition to the morphological study, the biometric properties of the corn leaf were established, as shown in Figure 2.

The results of this study coincide with what was explained by [9], who proposed classification and measures regarding the average length of the fibers of the cob leaves, placing them within the group of fibers moderately long. That length is even similar to that presented by some coniferous woods.

Runkel's relationship, as expressed [10], indicates that the lower this value, the more flexibility the fiber will have, and when this index is less than 0.25, the quality is considered to be excellent. If the value is between 0.25 and 0.50, the quality will be very good. Between 0.50 and 1.00 you will have good quality. Values between 1.00 and 2.00 indicate a regular quality and when the index is greater than 2.00, the quality is bad [11].

The lower the length/width ratio, the greater the flexibility of the fibers. The flexibility index indicates that the cob leaf fibers have the property of partially collapsing. Also, they have an elliptical...
cross-section, a union between fiber and good fiber, and the cell wall is thin. This coefficient is directly related to the resistance to bending, the greater the flexibility, the greater the ability to bend [10].

The coefficient of the stiffness of the cob leaf fibers is low, according to the classification presented by [11] and catalogs the fiber wall as thin, so the stiffness is low. This coefficient has a significant influence on tear resistance, it also has a negative relationship on the porosity of the sheet [12]. The corresponding formulas for the calculation of the parameters of wall thickness Equation (1), flexibility Equation (2) and Runkel ratio Equation (3), are as follows:

\[
\text{Wall thickness} = \frac{\text{Fiber} - \text{Lumen Width}}{\text{Lumen}} \quad (1)
\]

\[
\text{Flexibility} = \frac{\text{Lumen}}{\text{Fiber width}} \quad (2)
\]

\[
\text{Runkel relationship} = \frac{2 \times \text{Wall thickness}}{\text{Lumen}} \quad (3)
\]

2.1.2. Portland cement. The cement used to carry out the tests was commercially distributed by the company ARGOS, it is type 1 or general-purpose cement.

2.1.3. Sand. Propitious sand was used for this type of test, with a percentage of clays and delectable particles less than 1% of the total mass. Likewise, the material that passes the 75 µm sieve is less than 5%. The amount of particular lightweight is less than 0.5%, the sulfate content is less than 1.2% and there is no presence of organic material. In addition, the sand has a maximum water absorption capacity of 4% and a plasticity index equal to 0.

2.1.4. Mortars reinforced with vegetable fibers. Mortars are a dosed mixture of a binder (cement), in aggregate, to provide greater resistance to a mortar, combined with various materials that have proven in practice, to be convenient, to extend the use of mortars. These mortars with artificial fiber additives, natural (organic or mineral), are called reinforced mortars [13,14]. The parameters that define the properties and resistance of the reinforced mortars are: Type and quality of the cement and the granulometry of the aggregate; the design of the mixture or dosage; water / cement ratio; porosity of the compound; reinforcement characteristics (type, quality and quantity); hygroscopic reinforcement humidity conditions; reinforcement covering thickness; and the supervision and quality of the final product [14].

The American Society of Testing Materials Standard (ASTM) C1116-89, who determines the standard specification for concrete and cast concrete, reinforced with fibers, defines fibers as "Thin and elongated filaments in the form of a beam, mesh or braid, of some natural or manufactured material that can be distributed through a mixture of fresh concrete" [15].

2.2. Characterization of the materials
The work methodology was established based on experiences carried out in other investigations. Initially, the extraction and treatment of the fibers were carried out in the following manner: the longitudinal separation of the longitudinal fibers of the corn leaf was carried out in its natural moisture state, as shown in Figure 3. For purposes of standardization of qualities and properties of the fiber for the development of the tests; the fiber was arranged in units of average length approximately 2 cm long; in a dry state (dried in the open air) at room temperature. Before the drying process, the natural moisture content of the fiber was determined, indicated by 10.4%.

In the same way, the dosage and design of mixtures were carried out, as it was shown previously with materials such as: cement: sand: pigment of 1: 1.5: 0.125. With a water / cement ratio
of 0.5 and 1% by weight of fiber in relation to the amount of cement. Figure 4. Where quantities are available: cement 2260.0 g (Figure 4(a)), sand 3390 g (Figure 4(b)), fiber 22.6 g (Figure 4(c)), and pigment 282.5 g (Figure 4(d)), water 1130.0 g for a total of 7085.1 g.

Figure 3. Manual removal of the fibers.

Figure 4. Materials used to make the mortar: (a) Cement, (b) Sand, (c) Fiber and (d) Pigment.

The test tube was made as established by the Colombian Technical Standard (NTC) 112, in 2-inch cube type molds as shown in Figure 5. The mixing of the material was initially done by mixing the sand, cement and pigment, then the fiber is incorporated and finally the water. In total three series were manufactured, of three test tube each.

Figure 5. Emptying test tube.

It was possible to observe a phenomenon of setting delay in the mixture. Although the mechanism of action is not fully known, it is assumed that the additive that retards the setting is absorbed by the cement grains, producing a relatively impermeable layer that retards the normal process of hydration of the paste. Finally, this layer is penetrated by the water starting the setting, following the usual mechanism. In the case of fibers, the component that acts as a retarder of setting is glucose, which is part of the cellulose and hemicellulose present in the cell walls of the corn leaf fibers.

Finally, one day in the mold was determined at normal environmental conditions of humidity and temperature, then 7 days unmold and preserved in full immersion in water so that the test tube had sufficient consistency to continue failing the test tube through the compression test.

After the 7-day curing period, the dynamic elastic modulus and compression resistance were determined, using ultrasound and simple compression tests respectively, as can be seen in Figure 6.

Once the test tube was removed from the water tank, a high moisture content of the fibers that were exposed on the faces was observed, so a period of rapid drying in the oven was carried out at 110 °C as follows: For series 1, it failed in the humidity conditions once removed from the tank, for series 2 a time of 5 minutes in the oven and for series 3, a time of 10 minutes; having as such some data directly affected in the resistance by the moisture content of each specimen.
Performing an analysis of the failed sample, it is observed that the failure is mainly due to the lack of adhesion between the fiber and the matrix since in no case did the material fail due to fiber breakage, but due to lack of adhesion between them.

![Image](image1.jpg)

**Figure 6.** (a) Ultrasound and (b) Compression test.

### 3. Results

#### 3.1. Density analysis

The average density of three of the cubes made with the same dosages and under the same curing conditions is calculated. Table 1 shows the results obtained.

The values obtained are consistent and show the uniformity obtained from a good mixing and incorporation of the different materials, mainly the vegetable fiber of the corn leaves.

**Table 1.** Density of the test tube.

| Test tube | Volume (cm$^3$) | Mass (g)  | Density (g/cm$^3$) |
|-----------|----------------|-----------|--------------------|
| Sample 1  | 125            | 287.9     | 23.032             |
| Sample 2  | 125            | 285.3     | 22.824             |
| Sample 3  | 125            | 283.8     | 22.704             |
| Average   | 125            | 285.7     | 22.850             |

#### 3.2. Dynamic elasticity module

This parameter was calculated from the ultrasound test, which consists of a non-destructive inspection method, which is based on the phenomenon of reflection, that is, from acoustic waves in an object the different reflections that occur when these waves find discontinuities in their propagation are measured. Subsequently, with the use of correlations with other parameters such as density and the Poisson module, the dynamic elastic modulus is calculated, as expressed in Equation (4).

$$ E_{dem} = \frac{\rho C^2 \cdot (1 + \nu)(1 - 2\nu)}{(1 - \nu) \cdot 10^9} $$

Where, $\rho$: density in kg/m$^3$, C: speed in m/s, $\nu$: Poisson module, C: constant of 0.22, $E_{dem}$: dynamic elasticity module in GPa. The results obtained by the ultrasound test are shown in Table 2.

**Table 2.** Ultrasound results.

| Test tube | Speed (m/s) | Density (g/cm$^3$) | Edem (GPa) |
|-----------|-------------|--------------------|------------|
| Series 1  | 3311.3      | 2303.2             | 22.1       |
| Series 2  | 3225.8      | 2282.4             | 20.8       |
| Series 3  | 3225.8      | 2270.4             | 20.7       |
| Average   | 3254.3      | 2285.3             | 21.2       |

The average values of the three series give a value of 21.2 GPa. With a maximum deviation of 4.25%. These are consistent values for the tests performed, it was also determined that at higher density better module values are obtained. The material performance indices indicate that they could be implemented
as a mortar, showing significant improvements with respect to traditional mortars that are harder, denser and heavier, however it is not yet advisable to use this mortar with natural fibers for structural purposes, but these data allow to open a new field of investigation that improves certain characteristics of the mortar improved with fibers so that its use can be extended to different applications.

3.3. Compressive strength
The tests were carried out with a universal simple compression machine, and the results obtained for the three series of specimens are shown in Table 3.

From the analysis of the results, an increase in the values is observed, which is related to the drying time in the oven of the different series of specimens, that is to say that the resistance of the mortar with corn fibers is affected by the humidity conditions, so its use should be restricted to structures that are not exposed to high moisture content.

Table 3. Ultimate compression resistance tests.

| Test tube  | (kN) | (MPa) |
|------------|------|-------|
| Series 1   | 13.92| 5.54  |
| Series 2   | 17.83| 7.10  |
| Series 3   | 21.45| 8.55  |
| Average    | 17.73| 7.06  |

4. Conclusions
Carrying out an analysis of the failed sample, it is concluded that the composting failure is due to the lack of adhesion between the fiber and the matrix, since in none of the test specimens a fiber breakage was evidenced, but for lack of adhesion between them.

A natural moisture content of the fiber of 10.4% was determined. The mechanical and resistance behavior of composting depends largely on the state of humidity to which it is subjected. It is observed that the mixture with vegetable fibers acquires a lower resistance than with a stone aggregate or a traditional reinforcement. It is observed that the moisture content directly alters the results in the ultimate strength of the composting.

Corn particles have a high porosity that determines their low density, this characteristic is due to their plant nature. This high porosity of the particles gives the resulting composting absorbent properties that increase its thermal and acoustic insulation capacity.

The implementation or inclusion of natural fibers seeks to provide strategies for the use of agricultural waste. However, the improvements of its mechanical properties depend on the moisture content and treatment given to the fibers before including them within a matrix.

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