Investigation note

Biocomposite tepexil cement reinforced with fibers of *Agave angustifolia* Haw. as a light mortar

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Abstract

The agave bagasse is a residual material obtained in the mezcal process. The accumulation of this material is considered an environmental problem in the communities that produce this spirit drink in an artisanal way. This waste contains optimal fibers for use as reinforcement material, obtaining an added value and reducing environmental pollution. In the development of a new material, you need to know its mechanical properties. To know if the new material is feasible, one of the most important properties is the resistance to compression. For this work, the objective was to determine the compressive strength of a biocomposite cement/tepexil matrix material, reinforced with agave bagasse fibers. To obtain the material, the fibers were washed with water with a pressure washer, dried in the open for 7 hours and ground in a knife mill to 1 mm in length. Subsequently, they were treated with an aqueous solution of 10% calcium hydroxide, for 34 h. five different formulations were made with different proportions of fiber/tepexil. The compressive strength was measured on a Geotest universal machine at 7, 14 and 28 days. It was observed that in the increase of the proportion of fibers there is a decrease in the compressive strength and density of the biocomposite material. The optimum fiber ratio was 1:0:1 (Portland cement:tepexil:fiber), with a compressive strength of 6.19 MPa and a density of 1 366.73 kg/m^3 at 28 days.

Keywords: agave bagasse fibers, biocomposite material, compressive strength.

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Introduction

In the mezcal production process waste is generated, mainly agave bagasse. In the state of Oaxaca, approximately 4 807 275 tonnes of bagazo from *Agave angustifolia* Haw are produced (Gutiérrez, Altamirano and Urrestazaru, 2012). This waste contains lignocellulosic fibers that are not used and are dumped in fields or streams (Cortes, 2009) which contribute to the greenhouse effect (Gómez, 2014). In recent years, it has been preferred to use plant fibers to develop building materials due to its technical advantages: low density, low commercial value, tensile strength and excellent thermal comfort (Aguilar *et al*., 2005). At present, there are no studies that find industrial use to bagasse. For every ton of bagasse of *Agave angustifolia* Haw 3.1% fiber is obtained. The fibers are mainly composed of cellulose (43%), hemicellulose (19%), lignin (15%), sugars (10%), among others (Zárate, 2006).

Composite materials are of great importance in the science and technology of materials, since their combinations provide physical and mechanical properties different from those of their components. Abdullah *et al*. (2011) made a composite material of Portland cement reinforced with coconut fiber and sand, the size of the sand was less than 2 mm, with a water cement ratio of 0.55. The sand was replaced by coconut fiber at 3, 6, 9, 12 and 15%. The results to the modulus of rupture and resistance to compression with 9% fiber were the highest with 43.8 MPa at 28 days. On the other hand, Darsana *et al*. (2016) developed with a composite material of cement, sand and 25mm coconut fibers. They replaced the sand with fibers at 10 and 15%, with a water/cement ratio of 0.6, obtaining results at compressive strength of 40.10 MPa with 10% fiber substitution. Roma *et al*. (2008) carried out a mechanical, physical and thermal evaluation of tiles with various formulations of pozzolanic portland cement and silica fume, reinforced with 0.66 mm eucalyptus fibers and/or 1.66 mm sisal. It was found that materials reinforced with 28- day sisal fibers had the best results in tenacity and maximum load of 1152 J/m^2 and 1111 N respectively. They also observed that the type of fibers influence water absorption, bulk density and permeability. Finally, the thermal performance of the sisal reinforced material showed that they are acceptable as substitutes for fiber cement sheets.

The objective of the present study was to determine the compressive strength of a biocomposite cement/tepexil matrix material, reinforced with agave bagasse fibers for later applications in the construction.

Materials and methods

Conditioning of fibers

The bagazo of *Agave angustifolia* Haw was collected in a palenque of Santiago Matatlan, Oaxaca, 16º 51’ 55.4” north latitude 96º 22’ 41.1” west longitude (Figure 1). The bagasse was immersed in drinking water until it was completely covered for 24 h in order to separate and soften the pulp of the fibers. The bagasse was washed with a Karcher Model K4 Premium Car washer, in order to remove the pulp and sugars from the fibers and not alter the final results of the mortar mixtures. The washed fibers were exposed to the sun for 7 h to be dried. Once dry, the fibers were cut in a Fritsch Pulverisette 19 blade mill with a 1 mm sieve

(Figure 2). Finally, the fibers were immersed for 34 h in an aqueous solution of calcium hydroxide at 10%, this treatment was carried out with the objective of eliminating the lignin from the fibers and improving the interface of the fibers with cement.

Figure 1. Collection of agave *angustifolia* Haw bagasse.

Figure 2. Fiber grinding.

Matrix

Compound portland cement (CPC) Impercem 30R was used, which meets the specifications of the Mexican standard NMX-C-414-ONNCCE. In Table 1 its chemical composition of the Impercem is shown.

Table 1. Standard composition of composite Portland cement IMPERCEM 30R.

Component	Mass (%)
Calcium oxide	≈ 57.62
Silicon oxide	≈ 22.03
Aluminum oxide	≈ 4.74
Iron oxide	≈ 2.79
Magnesium oxide	≈ 1.30
Sulfates	----
Other materials	< 11

The tepexil was obtained from the banks of Perote, Veracruz. It was sieved in meshes #4, #8 and #16 with a Rotap model RX-29, which performs two movements, a circular horizontal movement and a vertical nailing movement. Tepexil retained in mesh #16 was selected since it is sought to manufacture a material with low density. In the Table 2 shows the chemical composition of tepexil.

Table 2. Chemical composition of tepexil.

Component	(%) mass
Calcium oxide	≈ 1.7
Silicon oxide	≈ 67.5
Aluminum oxide	≈ 14.52
Iron oxide	≈ 2.41
Magnesium oxide	≈ 0.44
Sulfates	----
Other materials	< 13

Source: Méndez (2008).

In Table 3 the experimental design is shown to evaluate the effect of the fibers in the matrix on the mechanical properties.

Table 3. Experimental design.

Length of fibers (mm)	Size of tepexil (mm)	Cement/water ratio 1:0.5 and 1:0.4 / Fiber proportions CPC: tepexil: fibers
1	1.18	1:1:0 1:0.6:0.4 1:0.5:0.5 1:0.4:0.6 1:0.2:0.8 1:0:1

Three repetitions per age were performed for the compression resistance test.

Preparation of biocomposite material

For the preparation of the biocomposites, cubes of 50 mm were made based on the ASTM C 109/C 109M - 05 standard with 1:1 CPC: tepexil (control) and 5 more mixtures, replacing a part of tepexil with fibers of agave in the following concentrations: 40, 50, 60, 80 and 100% by weight. Previously, the cement, tepexil and fibers were mixed dry in a Hamilton Beach brand blender for 4 min to homogenize the materials. Subsequently, water was added to the blender with a water/cement ratio of 0.5 for concentrations 40 to 80% and 0.4 for the concentration of 100% fibers and mixed again for 4 min (Figure 3).

Figure 3. Hydrated mixture in the blender.

Once the mixture was ready, 50 x 50 x 50 mm metal cubes were filled according to the method of ASTM C 109/C 109M-05. After 24 h, the cubes were immersed in an aqueous solution with 3% calcium hydroxide based on the weight of the water, as shown in Figure 4, for its cure.

Figure 4. Curing of cubes.

Compressive strength

The specimens were tested at the ages of 7, 14 and 28 days as established in the standard. The machines used for these tests, due to the load capacity, were a Geotest press, model S5830 Multiloader, applying load at a speed of 1 mm/min (Figure 5) and a 120 ton manual press Helicoio brand. To obtain the value of the compressive strength the following equation was used:

$$fm=P/A \quad (1)$$

Where: fm - resistance to compression in MPa; P - total maximum load in N; A - area of the surface charged in mm^2.

Figure 5. Resistance to compression in the GEOTEST press.

Results and discussion

In Figure 6 it can be seen that the increase in fiber content produces a low density in the samples. This is due to the difficult packing of the fibers, introducing holes in the biocomposite. Because of the low density, the compressive strength decreases when the proportion of fibers increases (Paramasivam *et al.*, 1984; Khedari *et al*., 2001). In Table 4, it is possible to observe that the increase in fibers reduces the compressive strength and density of the material, but this value increases with increasing age. For samples of specimens with 100% fiber substitution had values of 80%, due to the water:cement ratio of 0.4 that was added and that caused an increase in compressive strength. The 1:0:1 ratio (CPC: tepexil: fibers) halved its resistance to the control ratio 1:1:0 at 28 days. All proportions at 14 days have a compressive strength greater than 5.2 MPa, which is higher than that required by ASTM C 270-07. In Figure 7 the increase in compressive strength can be seen as days go by. One of the advantages of lignocellulosic fibers is their low density, which translates into lighter materials. In the proportions of 1:0.2:0.8 and 1:0:1, there is a compressive strength greater than 5.2 MPa at 14 days.

Table 4. Resistance to compression.

Proportion of CPC fibers: tepexil: fibers	7 days		14 days		28 days	
	f'c [A] (MPa)	Density (kg/m^3)	f'c (MPa)	Density (kg/m^3)	f'c (MPa)	Density (kg/m^3)
1:1:0	10.76 ± 2.03	1451.46 ± 13.58	10.71± 4.73	1502.95 ± 5.83	12.4 ± 0.99	1566.77 ± 85.43
1:0.6:0.4	6.61 ± 2.12	1478.30 ± 34.87	9.13 ± 0.06	1499.51 ± 20.34	10.08 ± 0.35	1512.32 ± 19.50
1:0.5:0.5	5.6 ± 0.64	1383.11 ± 1.43	5.89 ± 1.05	1383.79 ± 22.09	7.06 ± 0.60	1401.06 ± 14.04
1:0.4:0.6	5.23 ± 0.67	1442.32 ± 11.49	5.81 ± 0.30	1428.92 ± 18.26	6.24 ± 0.76	1452.94 ± 8.56
1:0.2:0.8	4.67 ± 0.29	1376 ± 13.56	5.47 ± 0.33	1386.8 ± 16.98	6.38 ± 0.49	1453.29 ± 7.70
1:0:1	4.94 ± 0.31	1364.73 ± 17.56	5.55 ± 0.30	1355.27 ± 1.38	6.19 ± 0.30	1366.73 ± 12.67

[A] f'c= compression resistance.

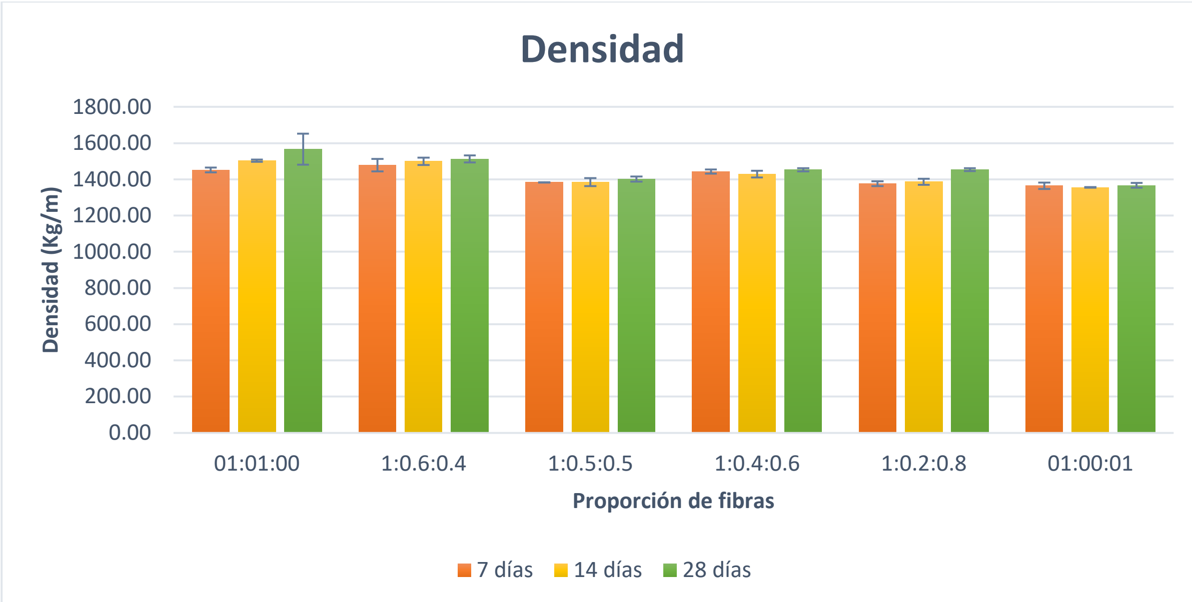

Figure 6. Graphical comparison of the densities obtained.

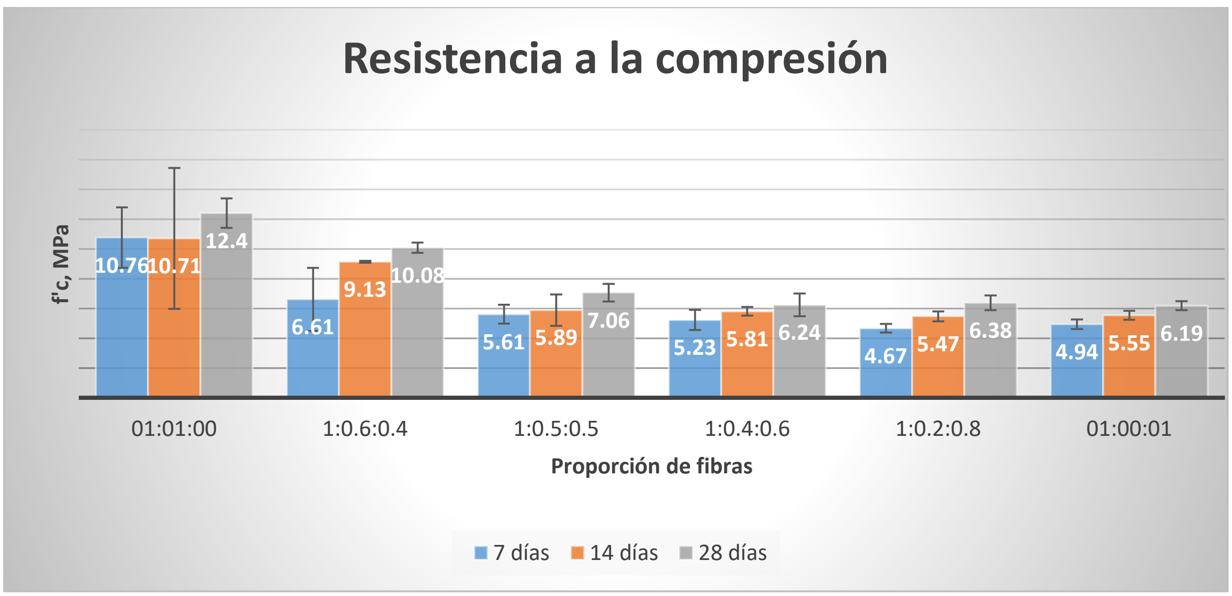

Figure 7. Graphical comparison of compression strengths obtained.

The 1:0:1 ratio (CPC:tepexil:fibers) has the lowest density with acceptable compressive strength per ASTM C 270-07. The density and compressive strength of an ordinary mortar is 2 000 kg/m^3 and 22 MPa respectively (Khedari *et al*., 2001). In this study a light mortar with a density of 1 366.73 kg m^3 was achieved, but the compressive strength was not exceeded.

Khedari *et al*. (2001) made two composite materials made of cement, sand and coconut fibers and cement, sand and durian fibers, resulting in the compressive strength of 2.46 and 3.29 MPa, with densities of 959 and 1 456 kg m^3 respectively. It is observed that the sample of proportion 1:0:1 exceeds the compressive strength of the samples with coconut fibers and durian fibers and has lower density of the sample of cement, sand and durian fibers.

Abdullah *et al*. (2011) developed a composite material with cement, sand and coconut fibers having a compressive strength of 43.8 MPa and density of 1 955 kg m^3, when compared to ordinary mortar, it does not have a light material because the density it has a similar value. However, the ratio 1:0:1, although it does not exceed the compressive strength, if it was possible to decrease its density, making a light mortar.

The 1:0:1 ratio also exceeds the compressive strength and is lighter than the composite material of Khedari *et al*. (2005) made with cement, earth, sand and coconut fibers obtaining values of compressive strength of 3.88 MPa and density of 1 586.77 kg m^3.

Conclusions

The presence of vegetable fibers on cement/tepexil matrix allows obtaining lighter materials than those traditionally used in the construction industry. However, the presence of the fibers reduces the compressive strength of these materials. According to the ASTM C 270-07 standard, it establishes that the minimum compressive strength of this type of materials must be greater than 2.4 MPa, while the materials studied in this work have values 250% greater than the minimum value. The optimum proportion of fibers is 1:0:1 (CPC:tepexil:fibers) with a compressive strength of 6.19 MPa at 28 days. With this proportion you can make different products for construction, such as: blocks, tiles, partitions, among others, with the advantage of being a lightweight mortar of low density.

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