Study of the mechanical performance and durability of mortars reinforced with treated and untreated cabuya fiber

Viviana M. Guerrero[1], **Mauricio H. Cornejo**[2]
[1] Faculty of Engineering in Earth Sciences, ESPOL, Km 30.5 via Perimetral, Campus Gustavo Galindo,Guayaquil, Ecuador
Email:
vigusern@espol.edu.ec; mcornejo@espol.edu.ec

Received xxxxxx
Accepted for publication xxxxxx
Published xxxxxx

Abstract

Currently, the cement industry causes great damage to the environment, generating immeasurable amounts of carbon dioxide (CO_2). According to statistics, at least 8% of global CO2 emissions are caused by humans in the cement industry alone. Faced with this problem, there is a need to reduce contamination by incorporating natural fibers into the cement mixture, in order to obtain a more sustainable mortar, since this reduces the amount of cement. One of the intrinsic properties of mortar is its low tensile and flexural strength, which leads to limitations in structural applications. In order to improve the mechanical properties of the mortar and its durability, experimental designs will be established using different volume percentages of treated and untreated cabuya fibers, cement and zeolite. The tensile strength and flexural strength increased when using a percentage of 7.5% chemically treated cabuya fiber, 50% zeolite and 42.50%.

Keywords: fiber, mortar, reinforced, lignin, treatment

1. Introduction

Concern for the environment and overexploitation of fossil fuels such as oil, drive a paradigm shift focused on the use of renewable, sustainable and more ecological materials (AL-Oqla & Salit, 2017),. taking advantage of the local productive matrix to achieve a great regional sustainable economic development. In this context, (BCE) 2021 specified that the agriculture, livestock, hunting and forestry sector represented 8.61% of Ecuador's GDP, approximately 8,507.6 million dollars during 2020.

Natural fibers are a renewable raw material and are available in almost unlimited ways, in addition, their abrasive nature is much less compared to other fibers, which implies advantages in the context of recycling materials or composite materials in general. (Bledzki & Gassan, 1999; Joshi et al., 2004). On the other hand, natural fibres are composed mainly of cellulose, hemicellulose, and lignin (Kunanopparat et al., 2008).

When natural fibers are incorporated without any treatment into a cementitious matrix, that is, without removing the lignin, there is competition between the fiber and the matrix for the absorption of water, and depending on the absorption properties of the fiber, it can occur drying of the cementitious mixture (Muensri et al., 2011), therefore, it is necessary to carry out some chemical treatment to the fibres in order not to reduce the workability of the mortar.

Ordoñez Viñan et al. (2019) showed that when adding 0.50% of natural fibre of cabuya in a mortar, with respect to the weight of the cement, for a water-cement ratio of 0.65, there was an increase in compressive strength between 9 and 11%.

Further, Ulloa et al. (2018) showed an increase in compressive strength, with large proportions of the activator / zeolite ratio, in polymer mortars.

The addition of small percentages of natural fibers in mortar reinforced with palm fibers, coir, sisal and jute produced an increase in durability, especially in the attack on sulfates. (Ozerkan et al., 2013; Ramakrishna & Sundararajan, 2005).

In this article, the mechanical behavior of a mortar reinforced with cabuya fibers will be evaluated, replacing a part of the sand mixture with zeolite.

2. Background

The fiber of the cabuya is extracted from the leaf of the cabuya, likewise, this rice plant grows wild in the Ecuadorian highlands and can reach up to 1.50 m in height in the vegetative part (Guerrero et al., 2011).

Masaco (2018) pointed out that for 2% fibre percentage there was a notable increase in the flexural strength of a mortar reinforced with cabuya fibres. In the same way, Briseño, (2016) analysed the flexural strength of beams reinforced with cabuya and showed that when adding cabuya fibres with random arrangement, the flexural strength increased between 7.8 and 24.9% with respect to concrete without fibre. In this frame, Coudert (2019) evaluated the influence of the surface treatment of the cabuya fibers on the mechanical properties of a cementitious mixture, denoting that in the case that only the cementitious matrix is the one that contributes to the flexural strength, the fiber treatment will affect the resistance to bending of the mortar.

Ulloa et al. (2018) made mortars with zeolite incorporating a steel corrosion inhibitor considered as activator, additionally added alkaline activators (NaOH and Na_2SiO_3) in different proportions, they concluded that the best mixture was obtained with an activator / zeolite ratio of 0.5, Na_2SiO_3 / NaOH of 3 and the ideal curing temperature was 60 °C.

Also, Lynch et al. (2018) examined the effects of two foaming agents, aluminium powder and hydrogen peroxide in zeolite-based geopolymers, while NaOH, $Ca(OH)_2$ and $Na_4Si_5O_{12}$ were used as alkaline activator, demonstrating that geopolymer preparation methodology complied with Ecuadorian regulations. in terms of compressive strength.

In another context, Almeida et al. (2013) evaluated the incidence of natural fibres in the accelerated carbonation process in cementitious composites reinforced with eucalyptus fibres, concluding that accelerated carbonation, after 2 days of curing, is viable for cementitious composites reinforced with eucalyptus fibres.

Today, the cement industry causes great damage to the environment, generating immeasurable amounts of carbon dioxide (CO_2). According to statistics at least 8% of global CO_2 emissions are caused by humans only in the cement industry. Faced with this problem, there is a need to reduce contamination by incorporating natural fibers in the cementitious mix, in order to obtain a more sustainable mortar, since this reduces the amount of cement. One of the intrinsic properties of mortar is its low tensile and flexural strength, which leads to limitations in structural applications. In order to improve the mechanical properties of the mortar and durability, experimental designs will be established using different percentages by volume of treated and untreated cabuya fibers, cement and zeolite.

3. Materials and methods

Materials and equipment needed to make the fiber-reinforced mortar:

3.1. Materials

- Cement
- Cabuya fiber
- Water
- Sand
- Zeolite

3.2. Equipment

- 1000 ml beaker
- Glass rod
- 500 ml volumetric flask
- Analytical balance
- 1% sodium hydroxide (NaOH)
- Distilled water
- Tensile strength test machine
- Flexural strength Test Machineral

3.3. Study development

For the present study, a set of mix design was established to prepare reinforced mortars with treated and untreated cabuya fibers with sodium hydroxide to the 1%. In addition, a percentage of sand was replaced by zeolite in the samples. The incidence of the volume percentage of natural fiber, sand and zeolite in terms of resistance will be studied, additionally the effects caused by the treatment of natural fibers in the compression and tensile strength of the mortar will be analyzed.

The cabuya fibers used to carry out the experimental project were acquired through the Hilos Artesanales company, located in the city of Quito. The fibers were obtained in 50 cm filaments, therefore, to avoid the loss of workability of the cementitious sample, the cabuya fibers were cut into approximately 1 cm lengths, likewise portland cement type GU and zeolite supplied by the Zeolite company were used. SA located in the city of Guayaquil.

For the experimental design, treated and untreated cabuya fiber was taken into account, obtaining the mix design for 14 samples, in which the resistance to bending and traction will be estimated, among them 7 untreated cabuya samples and 7 cabuya samples treated with volume percentages of fiber, zeolite, and sand. In total, 28 specimens were made, 14 for the tensile tests and 14 for the bending tests.

The water-cement ratio was (W/C) 0.44, while the ratio between cement and sand was 1:2.75 (ASTM C109, 2021). Furthermore, two samples with 0% fiber were made, one with sand, water, and cement (SP), while in the other test tube the sand was replaced by zeolite (ZP). The following table shows each of the specimens with the respective proportions of the materials in terms of percentage with respect to 1 m^3 of mortar, additionally it specifies in which samples the chemical treatment of the cabuya fibers was carried out.

Table 1 Mix design of mortar reinforced with cabuya fibers

Specimen	Cabuya fiber (%V)	Zeolite (%V)	Sand (% V)	Fiber treatment
1	5.00	20.00	75.00	No
2	5.00	80.00	15.00	
3	10.00	20.00	70.00	
4	7.50	80.00	12.50	
5	7.50	50.00	42.50	
6	7.50	50.00	42.50	
7	7.50	50.00	42.50	
8	7.50	50.00	42.50	Yes
9	7.50	50.00	42.50	
10	7.50	50.00	42.50	
11	11.04	50.00	38.97	
12	3.97	50.00	46.04	
13	7.50	92.42	0.08	
14	7.50	7.58	84.92	
SP	0.00	0.00	100.00	-
ZP	0.00	100.0	0.00	

3.4. Treatment of cabuya fibers

Figure 1 cabuya fiber before and after treatment

Lewandowski (2015) argued that natural fibers from cold climates are less resistant and finer than those from hot climates. In addition, the well washed rope has more resistance, in contrast the dirty rope has a great elongation power. Subsequently, the treatment of the cabuya began where they were immersed in an aqueous solution of sodium hydroxide (NaOH), in a concentration of 1% by mass, diluted in 1 liter of distilled water for 24 hours (Ipa & Di, 2017). In the case of the cabuya fiber, a lower percentage of solution was used because we wanted to observe the incidence of the solution on the cabuya fiber, since no previous work had been carried out in this context. The objective of this treatment in the cabuya fiber is to reduce the amount of lignin, waxes and impurities that the fibers contain, to improve the fiber-cementitious matrix adhesion and thus increase the mechanical properties of the composite materials subjected to the bending and bending tests. traction.

3.5. Tensile strength

To estimate the tensile strength, specimens called dog bones were made, considering the guidelines established by Zhang et al. (2015). The tensile force and the elongation of the specimen were measured as a function of time, from this the traction stress was estimated.

Figure 2 Tensile test

3.6. Flexural strength

Figure 3 Flexure test

The applied force and the deflection in the centre of the beam were measured, taking into consideration the recommendations described in ASTM C348 (2021). The flexural strength was calculated with:

$$\sigma_f = 0.0028P$$

Where:

σ_f = Flexural strength (MPa)

P = Total maximum load (N)

4. Results and discussion

4.1. Tensile strength

According to the tensile tests, the following results were obtained based on the percentage of fiber, zeolite and sand:

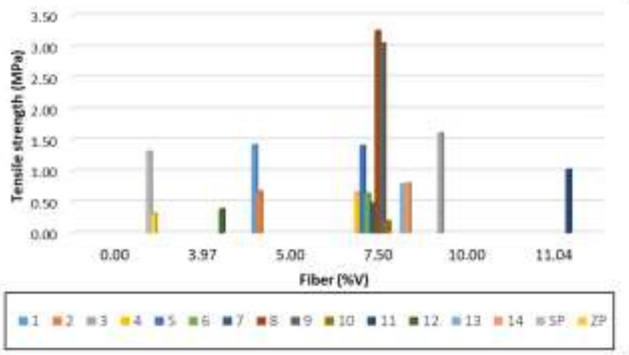

Figure 4 Tensile strength as a function of fibre percentage

The maximum tensile strength was obtained for specimens 8 and 9, with a percentage of treated fiber of 7.50%, 3.26 MPa and 3.06 MPa, respectively.

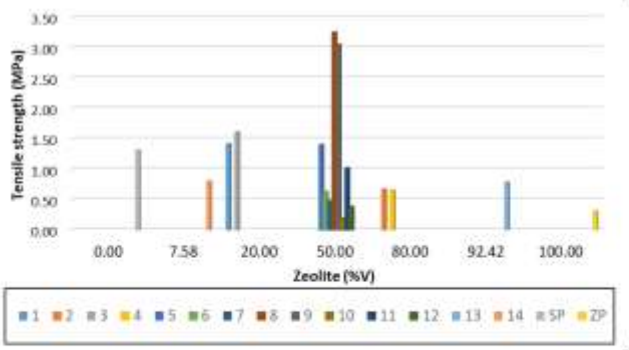

Figure 5 Tensile strength as a function of zeolite percentage

The maximum tensile strength was also obtained for specimens 8 and 9 with 50% zeolite.

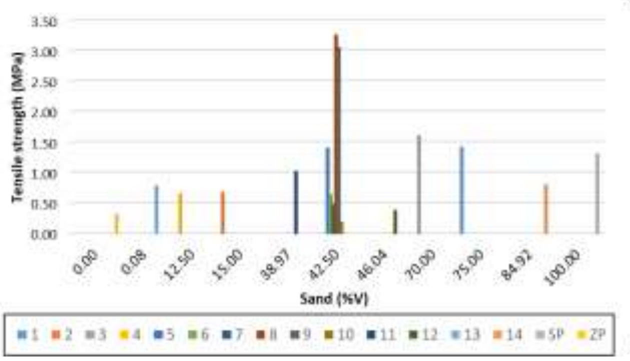

Figure 6 Tensile strength as a function of sand percentage

The maximum tensile strength was also obtained for specimens 8 and 9 with 42.5% sand.

Estrella (2016) analyzed the addition of cabuya fibers to concrete, determining that there was an increase in tensile strength for 3% of treated cabuya fibres with respect to the weight of the cement

On the other hand, Coudert (2019) studied the influence of the fiber treatment on the mechanical properties of a cementitious matrix fiber composite, and concluded that when the fibers are not adequately washed after immersing them in a NaOH solution, the tensile strength decreases compared to when the cabuya fibers are not treated. Therefore, it is important to carry out a correct washing of the fibers after the chemical treatment.

4.2. Flexural strength

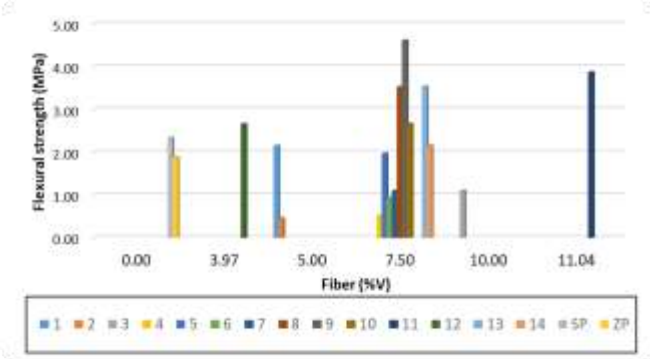

Figure 7 Flexural strength as a function of fibre percentage

The maximum flexural strength was obtained for specimens 8 and 9, with a percentage of treated fiber of 7.50%, 3.52 MPa and 4.61 MPa, respectively.

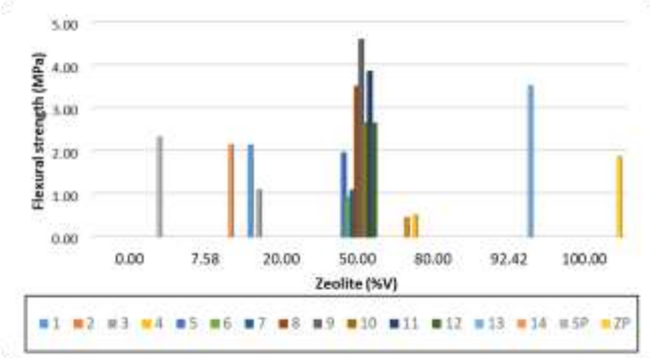

Figure 8 flexural strength as a function of zeolite percentage

The maximum flexural strengths were also obtained for specimens 8 and 9 with 50% zeolite.

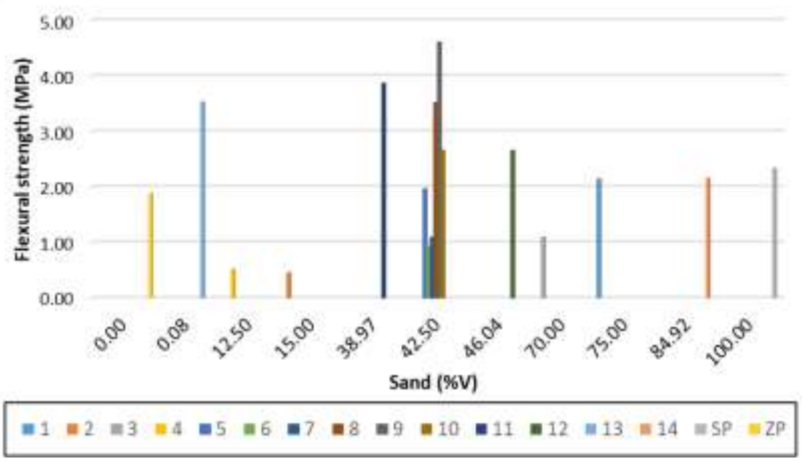

Figure 9 flexure strength as a function of sand percentage

The maximum tensile strength was also obtained for specimens 8 and 9 with 42.5% sand.

Ordoñez Viñan et al. (2019) studied the addition of small percentages of cabuya fibre in the flexural strength of cementitious mortars, concluding that the optimum percentage of fibre was 0.50% with respect to the weight of the cement, since the flexural strength was increased by 11%.

Suárez et al. (2021) analyzed the incidence of adding 1% percentage of fiber with respect to the weight of cement in cementitious mortars, resulting in an 8% increase in flexural strength.

5. Conclusions

The design of mixtures between fiber, sand and zeolite has as its main objective to obtain the optimal percentage of each of these compounds to obtain the maximum resistance to bending and traction of the mortar.

When using cabuya fibers, the tensile behavior of the reinforced mortar shows an increase in ductility.

According to the appropriate treatment, that is, when using 1% NaoH in the Cabuya fibers, the tensile and flexural strength of the mortar improved.

The increase in resistance to traction and bending is evident in the specimen 8, that is, when using a percentage of 7.5 % of treated fiber, 50% of zeolite and 42.50%.

The natural polymer called lignin produces a notable decrease in flexural strength, that is, when the fiber is not treated with sodium hydroxide (NaOH), it is shown that there are no improvements in flexural strength.

6. References

[1] AL-Oqla, F. M., & Salit, M. S. (2017). *2 - Natural fiber composites* (F. M. AL-Oqla & M. S. B. T.-M. S. for N. F. C. Salit (eds.); pp. 23–48). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100958-1.00002-5

[2] Almeida, A. E. F. S., Tonoli, G. H. D., Santos, S. F., & Savastano, H. (2013). Improved durability of vegetable fiber reinforced cement composite subject to accelerated carbonation at early age. *Cement and Concrete Composites*, *42*, 49–58. https://doi.org/10.1016/j.cemconcomp.2013.05.001

[3] American Society for Testing and Materials, A. (2021). ASTM C348 - Standard Test Method for Flexural Strength of Hydraulic-Cement Mortars. *Annual Book of ASTM Standards*, *03*.

[4] ASTM International. (2021). ASTM C109 / C109M - 2021. Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50 mm] Cube Specimens). In *Annual Book of ASTM Standards*.

[5] Banco Central del Ecuador (BCE). (2021). *Información Estadística Mensual No. 2036 - Octubre 2021*. https://contenido.bce.fin.ec/home1/estadisticas/bolmensual/IEMensual.jsp

[6] Bledzki, A. K., & Gassan, J. (1999). Composites reinforced with cellulose based fibres. *Progress in Polymer Science*, *24*(2), 221–274. https://doi.org/10.1016/S0079-6700(98)00018-5

[7] Briseño Sánchez, D. Y. (2016). *Análisis del comportamiento a flexión de vigas reforzadas con fibra de cabuya* [Universidad Técnica de Ambato]. https://repositorio.uta.edu.ec/bitstream/123456789/24183/1/Tesis 1062 - Briseño Sánchez Daniela Yajaira.pdf

[8] Coudert, L. (2019). *Influencia del tratamiento superficial de las fibras de fique en las propiedades mecánicas del compuesto fibra-matriz cementante* [Universidad Nacional de Colombia]. https://repositorio.unal.edu.co/bitstream/handle/unal/78742/Tesis Loic Coudert Final.pdf?sequence=1&isAllowed=y

[9] Estrella, S. (2016). *Estudio de un material compuesto a base de fibras naturales de cabuya para mejorar las propiedades mecánicas de elemento de concreto reforzado* [Universidad Nacional de Chimborazo]. http://dspace.unach.edu.ec/bitstream/51000/3072/1/UNACH-ING-CIVIL-2016-0038.pdf

[10] Guerrero, V., Dávila, J., Galeas, S., Pontón, P., Rosas Laverde, N., Sotomayor, V., & C.Valdivieso. (2011). *Nuevos Materiales: Aplicaciones Estructurales e Industriales*.

[11] Ipa, P., & Di, S. (2017). *No 主観的健康感を中心とした在宅高齢者における 健康関連指標に関する共分散構造分析 Title*.

[12] Joshi, S. V, Drzal, L. T., Mohanty, A. K., & Arora, S. (2004). Are natural fiber composites environmentally superior to glass fiber reinforced composites? *Composites Part A: Applied Science and Manufacturing*, *35*(3), 371–376.

https://doi.org/https://doi.org/10.1016/j.compositesa.2003.09.016

[13] Kunanopparat, T., Menut, P., Morel, M. H., & Guilbert, S. (2008). Plasticized wheat gluten reinforcement with natural fibers: Effect of thermal treatment on the fiber/matrix adhesion. *Composites Part A: Applied Science and Manufacturing*, *39*(12), 1787–1792. https://doi.org/10.1016/j.compositesa.2008.08.006

[14] Lynch, J. L. V., Baykara, H., Cornejo, M., Soriano, G., & Ulloa, N. A. (2018). Preparation, characterization, and determination of mechanical and thermal stability of natural zeolite-based foamed geopolymers. *Construction and Building Materials*, *172*, 448–456. https://doi.org/10.1016/j.conbuildmat.2018.03.253

[15] Masaco Pinta, J. I. (2018). *Mortero de cemento y refuerzo de fibra vegetal de cabuya* [Universidad Técnica Particular de Loja]. http://dspace.utpl.edu.ec/handle/20.500.11962/22616

[16] Muensri, P., Kunanopparat, T., Menut, P., & Siriwattanayotin, S. (2011). Effect of lignin removal on the properties of coconut coir fiber/wheat gluten biocomposite. *Composites Part A: Applied Science and Manufacturing*, *42*(2), 173–179. https://doi.org/10.1016/j.compositesa.2010.11.002

[17] Ordoñez Viñan, M. A., Arcos Logroño, J., Ibañez Moreno, W., & Cazar Rivera, S. (2019). Caracterización del Mortero Compuesto con Fibras de Cabuya Obtenidas en la Ciudad de Riobamba. *Ciencia Digital*, *3*(3), 33–48. https://doi.org/10.33262/cienciadigital.v3i2.6.564

[18] Ozerkan, N. G., Ahsan, B., Mansour, S., & Iyengar, S. R. (2013). Mechanical performance and durability of treated palm fiber reinforced mortars. *International Journal of Sustainable Built Environment*, *2*(2), 131–142. https://doi.org/10.1016/j.ijsbe.2014.04.002

[19] Ramakrishna, G., & Sundararajan, T. (2005). Studies on the durability of natural fibres and the effect of corroded fibres on the strength of mortar. *Cement and Concrete Composites*, *27*(5), 575–582. https://doi.org/10.1016/j.cemconcomp.2004.09.008

[20] Suárez, C. M., Carrillo, C. H., Junco, O. G., & Vera-López. (2021). Mechanical performance of mortar mixes reinforced with hemp and fique fibers treated with sodium silicate. *Journal of Physics: Conference Series*, *2046*(1), 12059. https://doi.org/10.1088/1742-6596/2046/1/012059

[21] Ulloa, N. A., Baykara, H., Cornejo, M. H., Rigail, A., Paredes, C., & Villalba, J. L. (2018). Application-oriented mix design optimization and characterization of zeolite-based geopolymer mortars. Construction and Building Materials, 174, 138–149. https://doi.org/10.1016/j.conbuildmat.2018.04.101

[22] Zhang, Z., Zhang, Q., Qian, S., & Li, V. C. (2015). Low E Modulus Early Strength Engineered Cementitious Composites Material: Development for Ultrathin Whitetopping Overlay. *Transportation Research Record*, *2481*(1), 41–47. https://doi.org/10.3141/2481-06