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CARACTERIZACIÓN MECÁNICA DE MICROCONCRETO FIBRO-REFORZADO CON FIBRAS DE GUADUA Y FIBRAS DE FIQUE

MECHANICAL CHARACTERIZATION OF FIBER-REINFORCED MICROCONCRETE WITH GUADUA FIBERS AND FIQUE FIBERS

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Resumen: Las fibras son un material para reforzamiento de concreto que ha sido utilizado desde la antigüedad. El objetivo es desarrollar mezclas de microconcreto fibro-reforzados con fibras naturales. Se realizó un tratamiento químico con hidróxido de sodio para eliminar la lignina de las fibras disminuyendo la reacción alcalina entre el cemento y las fibras. Se realizaron dos mezclas de microconcreto: con fibras de guadua y fique. Para cada una de las mezclas se varió la cantidad de fibras entre 1 y 3% con el fin de determinar la proporción con mejores resultados. 12 réplicas se realizaron para cada una de las muestras. Se obtuvo que las fibras de fique con adición del 1% presenta resultados similares a microconcretos fibro-reforzado con fibras de vidrio. Mientras que las muestras reforzadas con fibras de guadua no presentan un comportamiento característico y por lo tanto no se puede identificar una adición de fibras óptima.

Palabras clave: Agregado, comportamiento mecánico, compuesto, concreto, fibras, fique, guadua, material orgánico, microconcreto, zona intersticial.

Abstract: Fibers are a concrete reinforcement material that has been used since ancient times. The aim is to develop fiber-reinforced microconcrete mixtures with natural fibers. A chemical treatment with sodium hydroxide was carried out to remove the lignin from the fibers, decreasing the alkaline reaction between the cement and the fibers. Two microconcrete mixtures were made: with guadua and fique fibers. For each of the mixtures, the number of fibers was varied between 1 and 3% in order to determine the proportion with the best results. 12 replicates were made for each of the samples. It was obtained that the fique fibers with the addition of 1% present similar results to micro-concrete fiber-reinforced with glass fibers. While the samples reinforced with guadua fibers do not present a characteristic behavior and therefore an optimal addition of fibers cannot be identified.

Keywords: Aggregate, composite, concrete, fibers, fique, guadua, interstitial zone, mechanical behavior, microconcrete, organic material.

1. INTRODUCTION

Fiber-reinforced concrete is a building material that has been used since ancient times, when it was made from animal hair. However, after the development of modern Portland cement concrete, it has been determined that there are concrete durability problems due to the alkaline reaction generated between the natural fibers and the cement. Among the alternatives for fiber reinforcement in concrete, the use of synthetic fibers has been studied: steel, glass, carbon, plastic, etc. Several studies have been developed on the use of synthetic fibers, such as the one by Campoy-Bencomo et al. (2021) who studied the inclusion of steel fibers in concrete mixtures, varying the number of fibers between 0.25 and 1.5%. Carrillo et al. (2013) developed concrete with steel fibers and tested its resistance to compression, indirect tensile or diametral tensile and flexural strength. On the other hand, Peñaranda-Haro and Rincón-Urrego (2016) studied the approach of an alternative to the pollution caused by polyethylene terephthalate (PET) plastic bottles that take 500 years to degrade. Quintero-Blandón and Mahecha Rico (2016) used recycled PET to create a composite material [4]. Tami and Landinez (2019) analyzed the effects produced on the mechanical behavior and open porosity of a concrete matrix by the addition of recycled PET macrofibers. Blazy and Blazy (2021) investigated the impact of polypropylene fibers on the physical and mechanical properties of concrete, as well as on the ecological and economic properties.

On the other hand, the most commonly used synthetic fibers are glass fibers (GRC). GRC are mainly used for the manufacture of plates. Several studies have emerged around the use of glass fibers, such as those studied by Beltrán-Díaz et al. (2013), who developed a fiber-reinforced concrete using glass fiber textiles with the objective of analyzing the flexural behavior. Enfedaque et al. (2015) analyzed the failure fracture of glass fiber reinforced concrete (GRC). Kumar et al. (2020) studied the effect of glass fiber within concrete mixtures, with amounts varying between 0 and 1% of the concrete mass. However, the use of synthetic fibers tends to be costly and generates negative externalities in the manufacturing itself. This is why the study of fiber-reinforced concrete has transcended the environmental and circular economy needs, for which the use of other types of fiber reinforcements that contribute to waste mitigation has been used. Agro-industrial waste, which has no particular use, has generated the need for its use in the construction industry. Such as the use of fibers from banana stalk residues, sugar cane bagasse, corn husks, coconut husks, coffee husks, among others. These fibers also provide significant properties when it comes to increasing the strength of concrete.

Several studies have been developed around the use of natural origin fibers. Taborda-Rios (2017) conducted a study of fiber-reinforced concrete in which he used bamboo angustifolia. Sika (2017). Bejarano-Vigoya (2019) investigated the mechanical strength in concrete cylinders reinforced with Guadua angustifolia Kunth fibers, starting from a fiber-free mixture and performing a comparative analysis. Martinez and Poveda (2018) determined the mechanical properties of concrete reinforced with guadua fibers. Guadua belongs to the bamboo family, and its use in construction is due to its high compressive, flexural and tensile strength. Saavedra-Joaqui and Ortega-Montes (2020) studied the mechanical behavior of concrete reinforced with natural fique fiber, using the finite element analysis software 'Abaqus' to establish the mechanical behavior of beams and cylinders.

Therefore, the objective of this research work is to identify the mechanical characteristics of microconcrete mixtures fibroreinforced with guadua and fique fibers, in order to compare them with microconcretes that have not been fibroreinforced and with microconcretes fibroreinforced with Alkali-Resistant (AR) glass fibers.

2. MATERIALS AND METHODS

The mechanical properties of the microconcrete developed with natural origin fibers were determined: guadua and fique fibers. The study of the mechanical properties led to the fabrication of 12 replicas of one of the samples. The microconcrete developed had two parts: one part is the mortar matrix composed of sand, cement, water and additives; the second part is the fibro-reinforcements. The mortar matrix was manufactured with the following proportions: sand/cement ratio is 0.84; water/cement is 0.33; plasticizer represents 2% of the cement quantity; and Forton VF-774 admixture represents 8% of the cement quantity. For a standard cement lump of 42.5 kg, the material quantities are: 37.5 kg of quartz sand, 14.025 Lt of water, 0.85 kg of SikaPlast® MO Superplasticizer and 3.188 kg of Forton® VF-774. The fiber reinforcements were varied in proportions between 1 and 3% by volume of the total amount of microconcrete. Therefore, the samples of microconcrete made with guadua fibers were 1, 2 and 3%; the samples of microconcrete with fique fibers were 1, 2 and 3%. These samples were compared with a microconcrete sample without reinforcement and with a microconcrete with 3% AR glass fibers.

2.1. Methodology for the determination of the mechanical properties of fibrereinforced microconcrete.

The compressive strength (Rc) of the microconcrete was studied. Cubes of 4 cm on each side (Figure 1a) were fabricated and tested in a hydraulic compression press. The maximum load supported was measured and the pressure was determined by dividing the load by the contact area. The flexural modulus of rupture (MOR) and modulus of elasticity (Ec) were determined. Prisms of 4x4x16cm (Figure 1b) and plates of 2x15x40cm (Figure 1c) were fabricated and tested in flexure, in order to plot a two-way diagram of force vs. deformation. Finally, the density of the samples was measured by dividing the weight by the volume of the specimens tested.

2.2. Methodology for the determination of the theoretical mechanical behavior of masonry type slabs with fiber reinforced microconcrete.

A statistical analysis of the results presented for each of the mixtures developed was carried out, comparing the 12 replicates with each other, in order to eliminate sampling errors. Then, an average trend of the results was identified. Solid plates 98 cm long, 50 cm high and 12 cm thick were studied. The plates were analyzed for axial load by compression, bending and shear in a finite element software, in addition to identifying the stiffness of the plates in order to identify the functionality of the material to be used in the construction. The ability to withstand axial compression loads requires knowledge of the strength of the masonry. According to Title D of NSR-10 [16], the masonry strength (f_m^') can be determined theoretically if the mechanical behavior of the material is known, for which equation (1) is required to be applied.

$$f'_m = 0.75\left[\left(\frac{2h}{75+3h}\right) f'_{cu} + \left(\frac{50k_p}{75+3h}\right) f'_{cp}\right] \quad (1)$$

From equation (1) we have that h is the height of the masonry plate in mm. The other factors are calculated as $f'_{cu} = 0.70R_c$, $k_P = 1.4$, $f'_{cp} = 14MPa$

(a)

(b)

(c)

Fig. 1. Figure 1. (a) Compression test on 4x4x4cm cubes. (b) Flexural test on 4x4x16cm blanks. (c) Flexural test on 2x15x40cm plates.

The maximum theoretical stresses that can be supported by 12x50x98cm solid plates were calculated. The stresses calculated were: axial load (Pu) with equation (2); cracking moment (Mcr) with equation (3); shear (Vu) with equation (4); and stiffness (K) with equation (5).

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$$Pu = 0.60 * 0.80\left\{0.85f'_m A_e\left[1-\left(\frac{H}{40e}\right)^3\right]\right\} \quad (2)$$

$$Mcr = e * {l_w}^2 * MOR \quad (3)$$

$$Vu = 0.60 * 100 * \sqrt{f'_m} * A_e \quad (4)$$

$$K = \frac{1}{\frac{H^3}{12E_c I} + \frac{1.2H}{GA_e}} \quad (5)$$

From equation (2), equation (3), equation (4), equation (5), $A_e = 0.0654m^2$, $H = 2.50m$, I is the moment of inertia of the plate section and G=0.4E_c.

3. RESULTS AND DISCUSSION

Average trend curves were made for each of the microconcrete samples reinforced with fique and guadua fibers, varying the proportion between 1 and 3%. The curves were contrasted with the graphs for unreinforced and glass fiber reinforced microconcrete. Figure 2a shows the curves of the microconcrete with fique fibers (FRC-1), in which it can be seen that all the mixtures have very similar behaviors to the samples with glass fibers and also shows an improved behavior at the exit of the sample without fiber reinforcement. In addition, it can be observed that the mixture with 1% of fique fibers has a very similar slope of the graph in the elastic zone, so that a similar modulus of elasticity can be deduced. On the other hand, the mixture with 3% of fibers reaches a much higher breaking strain, higher than 1.5 mm, similar to the GRC, so this mixture can be defined as the one with the highest ductility.

Figure 2b shows the load vs. deformation curves of the microconcrete samples with guadua fibers (FRC-2) contrasted with the unreinforced and glass fiber reinforced microconcrete samples. It is evident in the graphs that there is a notable difference between all the mixtures developed. The samples with 1 and 2% of guadua fibers are very elastic and of low rupture, similar to the mix without fiber reinforcement. This indicates that these mixtures would not be giving a significant contribution to the microconcrete. On the other hand, the mix with 3% is far from the expected results, since it does not reach the stiffness and elastic modulus of rupture for which it was designed. Therefore, it can be concluded that the mixtures with guadua fibers require a different treatment to be included in the microconcrete mixtures.

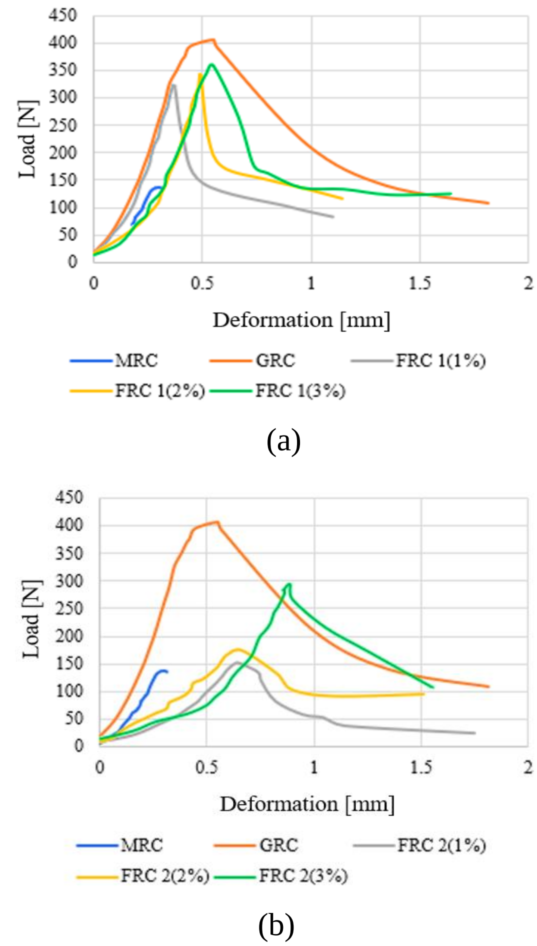


Fig. 2. (a) Load vs. strain curves of FRC-1 specimen (fique fibers). (b) Load vs. strain curves of FRC-2 specimen (guadua fibers). Compared with curves of MRC (without fibers) and GRC (AR glass fibers).

Table 1 shows the mechanical properties obtained in the compression and flexural tests performed. As mentioned in previous paragraphs, the FRC-1 mix shows similar results to the GRC mix, being the sample with 1% fique fibers the one with the best performance. The FRC-1 (1%) reaches 77% of the flexural modulus of rupture of the GRC and exceeds the modulus of rupture of the MRC by 1.4 times, exceeds the compressive strength of the GRC by 6%, reaching 83% of the compressive strength of the MRC. The stiffness of FRC-1 (1%) expressed in modulus of elasticity reaches 95% of that obtained with GRC. In other words, adding 1% of fique fibers to the microconcrete mixes contributes to achieve 90% of the results that would be obtained with GRC.

Therefore, fique fibers are a viable alternative to AR glass fibers (leaving as a first step the study of the long-term durability of microconcrete with fique fibers).

Table 1. Mechanical properties of the developed microconcrete.

Muestra	MOR [MPa]	Rc [MPa]	Ec [GPa]	Densidad [g/cm^3]
MRC	4.52	43.40	20.46	1.98
GRC	13.79	34.05	26.58	2.07
FRC-1 (1%)	10.66	36.12	25.38	2.06
FRC-1 (2%)	11.21	32.73	21.57	2.08
FRC-1 (3%)	11.88	24.74	21.45	2.14
FRC-2 (1%)	4.99	38.92	14.06	2.06
FRC-2 (2%)	5.74	29.05	14.58	2.12
FRC-2 (3%)	9.70	18.21	18.23	2.15

Where: MOR is the flexural modulus of rupture; Rc is the compressive strength; Ec is the modulus of elasticity; MRC is microconcrete without reinforcement; GRC is microconcrete reinforced with fiberglass; and FRC is microconcrete reinforced with natural fibers (FRC-1 with fique fibers and FRC-2 with guadua fibers).

As Table 1 shows, there is evidence of dispersion in the results of the FRC-2 samples. Although it is observed that by adding more guadua fibers, better results in modulus of rupture can be obtained, the compressive strength decreases and, in turn, the modulus of elasticity is much lower than expected. If only the modulus of rupture is analyzed, it is evident that the best FRC-2 mix is with 3% of guadua fibers, since the mix is 70% of that obtained for the GRC sample and 2 times greater than that obtained for the GRC sample. sample. GRC sample. Now, if the compressive strength is contrasted, it is observed that the best mix is that of FRC-2 with 1% of guadua fibers, since the strength reaches 14% more than that of GRC and 90% of the strength of MRC. While the FRC-2 sample is with 3% guadua fibers, it only reaches 53% of the strength of GRC and 42% of the strength of MRC and the modulus of elasticity of FRC-2 is between 53% and 69% of the stiffness achieved with GRC. In other words, it is not possible to identify a fiber-reinforced microconcrete mix with guadua fibers that has a similar behavior to GRC.

Table 2.1 and Table 2.2 present the theoretical mechanical characteristics of the 12x50x98cm solid plates, according to equation (1), equation (2), equation (3), equation (4) and equation (5). It is observed that the MRC plate supports the highest axial compressive load, however, it resists the lowest cracking moment compared to the other mixes. Now, if the FRC mixes are compared with the GRC mixes, it is evident that the mixes with 1% of fibers, both guadua and fique, support higher axial and shear loads than the GRC mixes, which indicates that these mixes are edifying for their use in masonry type walls. However, theoretically, mixtures with 3% fibers, both guadua and fique, have better functionality if used in bending.

Table 2.1. Theoretical mechanical characteristics of 12x50x98cm solid plates. Strength and stiffness.

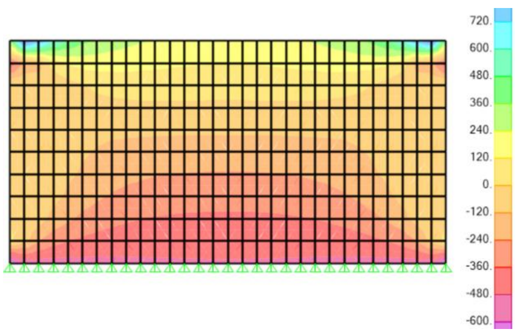
Muestra	f'm [MPa]	K [kN/m]
MRC	15	80862.22
GRC	12	105049.75
FRC-1 (1%)	13	100307.1
FRC-1 (2%)	11	85249.18
FRC-1 (3%)	9	84774.91
FRC-2 (1%)	13	55568.08
FRC-2 (2%)	10	57623.23
FRC-2 (3%)	7	72048.79

Table 2.2. Theoretical mechanical characteristics of 12x50x98cm solid plates. Axial load, cracking moment and shear.

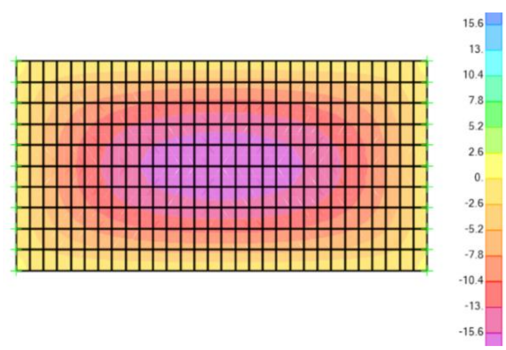
Muestra	Pu [kN]	Mcr [kN-m]	Vn [kN]
MRC	342	10	15
GRC	271	32	13
FRC-1 (1%)	287	25	14
FRC-1 (2%)	261	26	13
FRC-1 (3%)	200	27	12
FRC-2 (1%)	308	12	14
FRC-2 (2%)	233	13	13
FRC-2 (3%)	150	22	10

Microconcrete mixtures with fique fibers have better functionality in terms of the ductility of the material, since they have greater stiffness and greater cracking moment than mixtures with guadua fibers. In other words, these concrete mixes can support a greater load with less deformation and, at the same time, the moment at which they begin to crack is much greater, which indicates that they are concretes that do not require reinforcing steel to function correctly.

Figure 3a shows the mathematical modeling in finite element software of 12x50x98cm solid slabs when working with flexural compression. The loads used for the modeling result from a load transfer analysis of a structural masonry system for single-story dwellings. It is evident that the compression forces are concentrated in the upper corners and in the lower central part. This behavior is due to the internal reactions generated by the system to control the deformations of the plates. The maximum load values are around 200kN, so it can be deduced that all the developed specimens have the capacity to support compression loads, except the microconcrete with 3% fiber addition. However, for moment control, the use of reinforcing steel is required in the case of MRC and FRC-2: while the GRC and FRC-1 mixes have the capacity to support moments without the need for reinforcing steel reinforcement.



(a)



(b)

Fig. 3. (a) Comportamiento a flexo-compresión de placas macizas de 12x50x98cm. (b) Comportamiento a flexión y cortante de placas macizas de 12x50x98cm.

Figure 3b shows the mathematical modeling in finite element software of 12x50x98cm solid plates when working in bending and shear. The concentration of moments is observed in the center of the span while in the supports the moments are minimal. The highest moment is 15.6kN-m. Therefore, the concrete slabs capable of supporting such moments in the entire slab are the GRC and FRC-1 mixes, whose Mcr values are between 24.57 and 31.79 kN-m. While the MRC and FRC-2 mixtures resist moments between 10.42 and 13.23kN-m, which means that reinforcing steel is required to support the load orders. Although the mix with the addition of 3% guadua fibers was able to resist the moments requested.

4. CONCLUSIONS

Two mixtures of fiber-reinforced microconcrete with natural fibers were developed; one with fique fibers and the other with guadua fibers. An analysis of the mechanical behavior of these mixtures was carried out and the results were contrasted with unreinforced microconcrete mixtures and with microconcrete reinforced with alkali-resistant glass fiber. It was obtained that the blends with 1% of fique fibers have similar characteristics to those reinforced with glass fiber. This indicates that fique fibers can be replacement precursors for glass fibers. On the other hand, an analysis of microconcrete mixtures to be used as masonry type slabs for use in walls and slabs was carried out. As in the behavior of the material, the slabs perform better with microconcrete with fique fibers and glass fibers. Since slabs with guadua fibers and without fiber reinforcement require steel reinforcement to guarantee their correct performance.

RECOGNITION

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