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Evaluation of the dynamic modulus of elasticity of a pozzolanic mortar of rice husk ash reinforced with sugarcane bagasse

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Abstract

In the last decades, many works are going in the direction of valorization of vegetable biomass.

The aim of the present work is to determine the dynamic modulus of elasticity of a cementitious matrix composite with rice husk ash pozzolan reinforced with sugarcane bagasse. To do this, we formulated mortars in which we varied the volume fraction of sugarcane bagasse and kept 10% of rice husk ash as a cement replacement. The sugarcane bagasse fractions of 0%, 3%, 6% and 10% yielded the mortars denoted RHA10, R10SB3, R10SB6, R10SB10, respectively. We have experimentally determined the density, the porosity of the different mortars obtained. Then, we determined by ultrasound test the speed of propagation of sound waves in the different mortars before calculating their dynamic moduli of elasticity. The results of the study show that the porosity, density, and dynamic modulus of elasticity of RHA10 mortars decreases with the increase of the volume fraction of sugarcane bagasse. The dynamic moduli of RHA10, R10SB3, R10SB6 and R10SB10 are 3.25GPa, 3.14GPa, 2.56GPa, 1.71GPa respectively with a porosity-dynamic modulus correlation R^2 of 0.94.

Keywords: Matrix; Rice husk ash; Sugar cane bagasse; Porosity; Dynamic modulus of elasticity

1. Introduction

The global warming [1] and the depletion of raw materials have awakened the consciousness of humanity on the need to find an alternative [2,3] to the usual materials.

It is therefore necessary to find materials that emit less environmental pollutants [4] including greenhouse gases [1]. Also, it is necessary to resort to renewable materials [5] to cope with the depletion of raw materials [6]. In this sense, natural fibers are very interesting [7], without forgetting the fact that they allow to have lower construction costs [8].

The works of have shown that the use of sugarcane bagasse ash in cement matrix materials allows reducing the amount of cement [9] used in construction and in fact allows mitigating the environmental impact of cement production [2,10]. In addition, the ash of sugar cane bagasse allows the transformation of portlandite, weakness of the cementitious leg [9], in silicates that are elements of resistance [11,12] of materials.

On the other hand, the incorporation of sugarcane bagasse, like any other lignocellulosic fiber, reduces the density [13-15], workability [16] of the materials while improving the tensile strength [17].

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Like sugarcane bagasse ash, rice husk ash is used as a partial replacement for cement by several authors in their research. From this work it is understood that incorporation of rice husk ash in mortar improves compressive strength [18-20], compactness [21] due to the reduction of porosity of the mortars when the rice husk ash is ground. Giogetti [11] and Bezerra [21] link these improvements in physical and mechanical properties to the development of silicates as a result of pozzolanic reactions.

Also, we understand that incorporating rice husk ash into mortar reduces the thermal conductivity [22], sodium sulfide attacks [23] of the hardened mortar, and reduces the workability [12,24] of the fresh mortar. Olubajo [18] and Nassar [25] find that 10% replacement of cement with rice husk ash provides the optimal physicomechanical performance.

All these works give us a lot of information about the use of rice husk ash and sugarcane bagasse in construction materials. The information on the mechanical characteristics is given to us by destructive tests; what is interesting when it is question of characterization. There is a problem of accuracy of information when it comes to verify the quality of the material already implemented. In this work we will determine the dynamic modulus of elasticity, by non-destructive test, of a composite with rice husk cement matrix reinforced by sugarcane bagasse.

2. Material and methods

2.1. Sand

The sand used is purchased from the market in Istanbul, Turkey.

The particle size distribution of the sand is determined by sieve size analysis according to the standard (NF EN 12620 - 2013).

2.2. Cement

The cement used is ordinary portland cement CEM I 42.5R.

2.3. Sugar cane bagasse

The sugar cane bagasse is supplied by the Benin Sugar Company (SUCOBE).

This sugarcane bagasse was thermally treated as follows:

- Pour the SB fibers into a ceramic bowl and add water,
- Place the ceramic bowl in the oven and heat up to 200 °C for the first hour,
- Maintain the oven temperature for another hour,
- Turn off the oven and let it cool down,
- Remove SB fibers from oven and rinse with tap water to remove sugar dissolved during heating.

2.4. Rice husk ash

Rice husk ash is produced by calcining rice husk at a temperature of 600 °C.

The chemical composition of rice husk ash, determined by X-ray diffraction, is given in the following table1.

Table 1 Chemical composition of rice husk ash

Elements	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K2O	Cr_2O_3	Mn_2O_3	F	P_2O_5	Cl	LOI
Proportions	86.46	1.27	0.59	2.64	0.47	0.25	0.06	1.37	0.01	0.11	0.04	0.36	0.01	6.35

2.5. Preparation of rice husk ash mortar

Rice husk ash mortars are made by replacing cement with rice husk ash in mass fraction. With substitution rates of 0%, 2.5%, 5%, 7.25%, 10%, 12.5%, we obtain composites coded as follows: RHA0, RHA2.5, RHA5, RHA7.5, RHA10, RHA12.5 respectively.

2.6. Preparation of rice husk ash mortar with sugarcane bagasse reinforcement

The sugarcane bagasse reinforced rice husk ash mortars are made by substituting the volume fraction of RHA10 mortar with sugarcane bagasse heat treated at 200°C. With substitution rates of 0%, 3%, 6%, 10% we obtain composites coded as follows: RHA10, R10SB3, R10SB6, R10SB10.

2.7. Determination of compressive strength

The compressive strength was determined on 50*50*50mm3 specimens at 28 days of maturity.

2.8. Determination of porosity and density

Prior to the determination of the compressive strength, we determined the porosity and density of the specimens according to ASTM C948-81.

2.9. Ultrasonic wave pulse test

This test is conducted in accordance with ASTM C597-02

This test allows to control the homogeneity of the mortar, the presence of cracks and voids, and possibly the evolution of the mechanical and physical properties of a material with time.

The principle of the test consists in sending an ultrasonic wave through a rigid material. This wave takes a certain time to cross a given distance of the material. The speed of propagation of the waves through the material reveals the properties of the latter.

The equipment used to perform this test is displayed in Figure 1

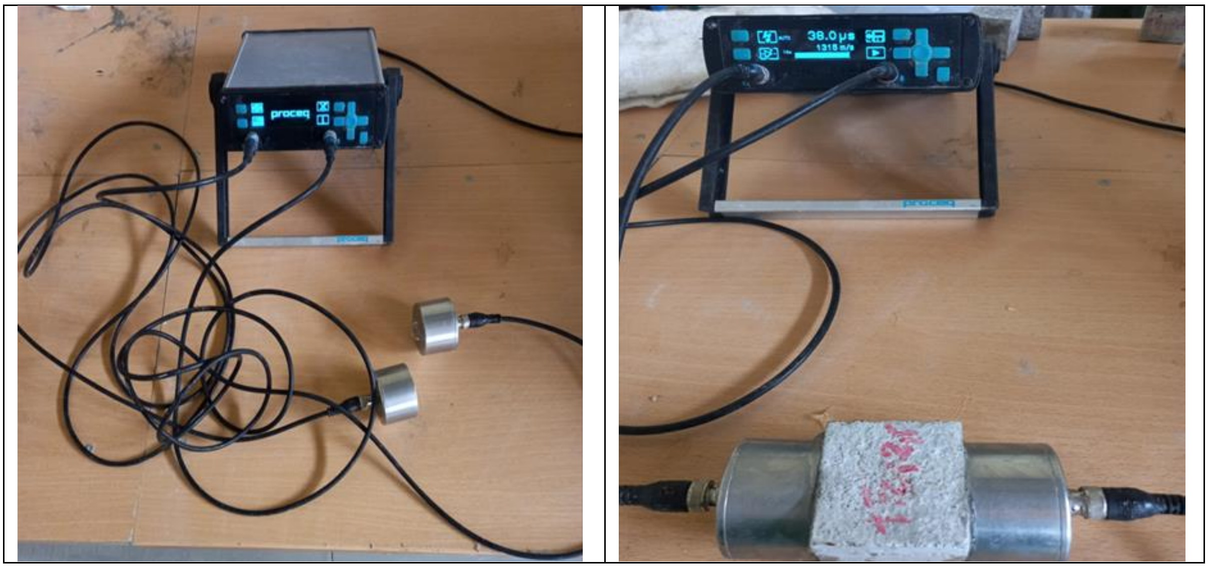

Figure 1 Ultrasonic testing machine

2.10. Determination of the dynamic modulus of elasticity

The determination of the dynamic modulus of elasticity is based on the propagation velocity of the ultrasonic waves in the material and the density of the material.

We calculate the dynamic modulus of elasticity using the following formula taking from Latroch [26]:

$$\boldsymbol{E_d} = \frac{\boldsymbol{V^2 \rho}}{\boldsymbol{g}} \times \mathbf{10^{-2}} \;\; \dots \dots (\boldsymbol{Eq1})$$

Where $\boldsymbol{E_d}$ is the dynamic modulus of elasticity (GPa), **V** is the propagation velocity of ultrasonic waves (Km/s), **ρ** is the density of the material (Kg/m3), and **g** is the acceleration of gravity (9.81m/s2).

3. Results and discussion

3.1. Sand grain size

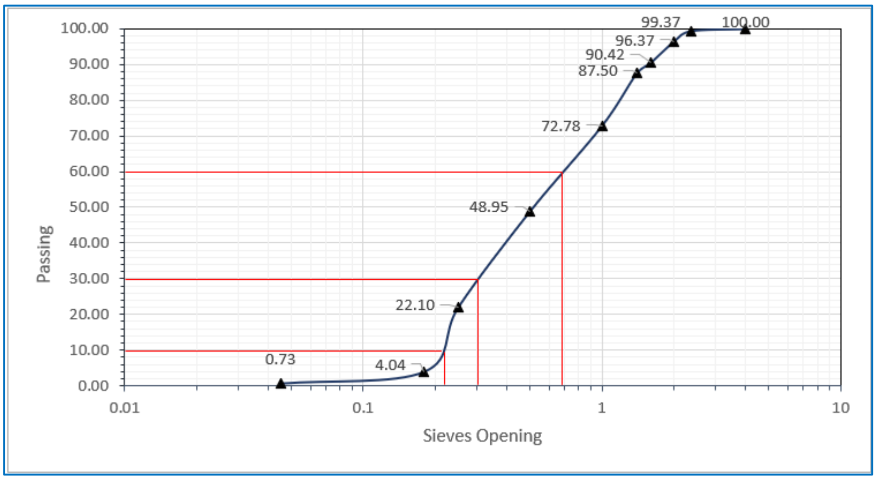

Figure 2 Grain size curve of the sand used

Figure 2 shows the particle size distribution of the sand used in this study.

Mf=1.83: fine sand (EN 12620 -2013)

Cu=3.18: The grain size of the sand is uniform

Cc=0.58: Absence of certain diameters between D10 and D60. So poorly graded sand [27].

3.2. Porosity of mortars

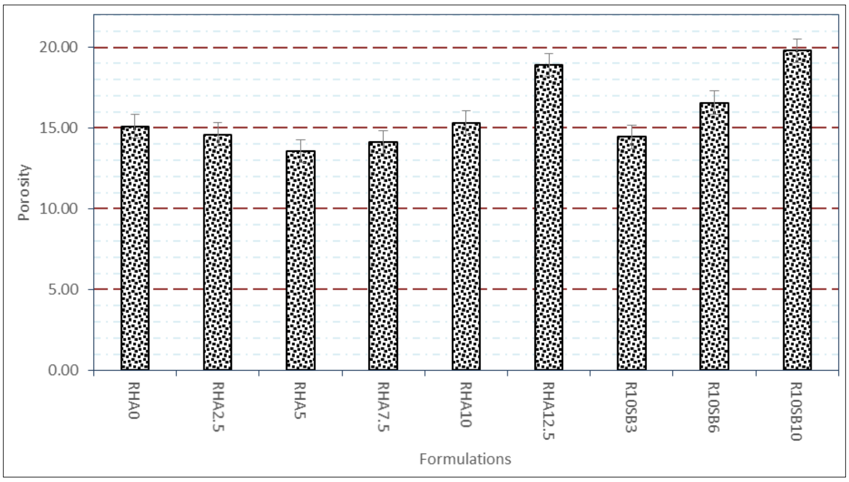

Figure 3 Porosity of mortars

Figure 3 shows the evolution of porosity at 28 days for rice husk ash mortars and rice husk ash mortars reinforced with sugarcane bagasse.

It can be seen that the porosity decreases with increasing rate of replacement of cement by rice husk ash up to 7.5%. This could be related to the fact that rice husk ash fills the voids in the mortar due to its fineness and the pozzolanic reaction [11] that it develops with lime to form silicates [12].

With the 10% and 12.5% replacement rates of cement with rice husk ash, the porosity exceeds that of the reference mortar. This is due to the dilution effect because not all of the rice husk ash is converted to silicate and thus forms porous areas.

It is also noted that mortars with 10% rice husk ash reinforced with sugarcane bagasse (R10SB) present a higher porosity than RHA10. This is related to the internal porosity of sugarcane bagasse which accentuates the resulting porosity in R10SB [28].

3.3. Mortars Density

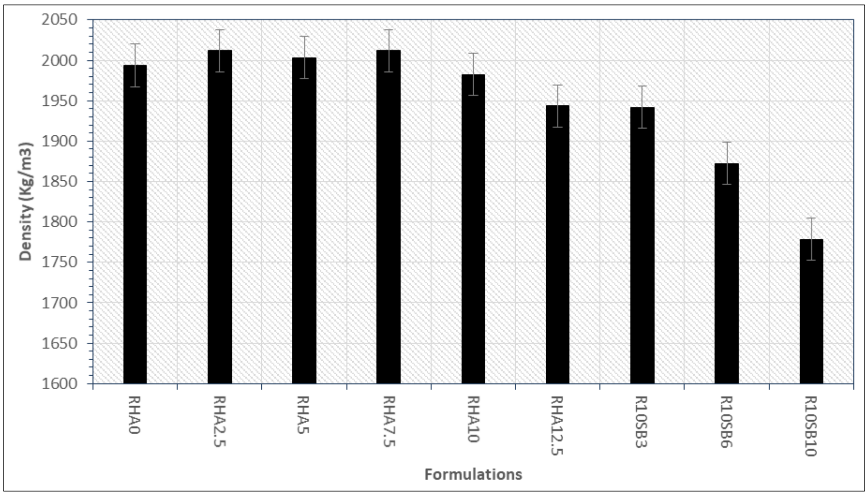

Figure 4 Density of mortars

Figure 4 shows the evolution of the density, at 28 days of the rice husk ash mortars and the rice husk ash mortars reinforced with sugarcane bagasse.

It can be seen that only the RHA2.5, RHA5, RHA7.5 mortars have a higher density than the reference mortar. This is due to the fact that only these mortars have their porosity reduced comparing to the reference mortar [29] as observed in Figure 3.

For the other mortars it is noticed that the density decreases both with the increase of rice husk ash rate [30,31] and with the increase of sugarcane bagasse rate [13-15]. This is related to the introduction of pores in the reference mortar both when using high rates of rice husk ash [32,33], and when using sugarcane bagasse [28] in RHA10.

3.4. Dynamic modulus of elasticity

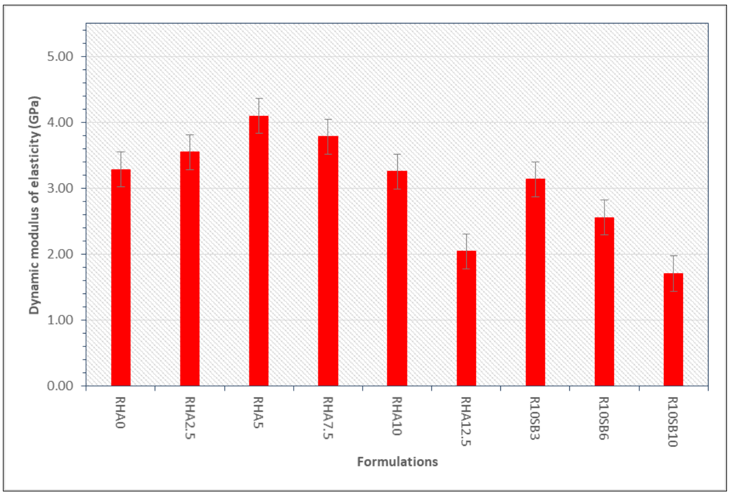

Figure 5 Dynamic modulus of elasticity of mortars

Figure 5 displays the evolution of the dynamic modulus of elasticity, at 28 days of the rice husk ash mortars and the rice husk ash mortars reinforced with sugar cane bagasse.

The analysis of this figure allows us to notice a variation of the dynamic modulus of elasticity from 3.29GPa for the reference mortar to 4.10GPa for the RHA5 mortar, which corresponds to an improvement of the material compactness. This result is related to the filling of voids in the material, thus promoting faster propagation of sound waves [26,34].

After a 5% replacement of cement with rice husk ash, there is a decrease in the dynamic modulus of elasticity, with a value of 3.79GPa for RHA7.5 that remains higher than that of the reference mortar. This is related to the fact that the lime is no longer sufficient to convert all the rice husk ash into silicate [35].

For rice husk ash mortars reinforced with sugarcane bagasse, a drop in dynamic modulus of elasticity is observed with increasing sugarcane bagasse in the mortar. This is related to the increase of pores with the increase of sugarcane bagasse in the mortar [28]; which decreases the propagation velocity of sound waves in the mortar [26,34]. The decrease in sound wave propagation velocity directly translates into the decrease in dynamic modulus of elasticity as shown in equation (eq1).

3.5. Porosity-dynamic modulus of elasticity correlation

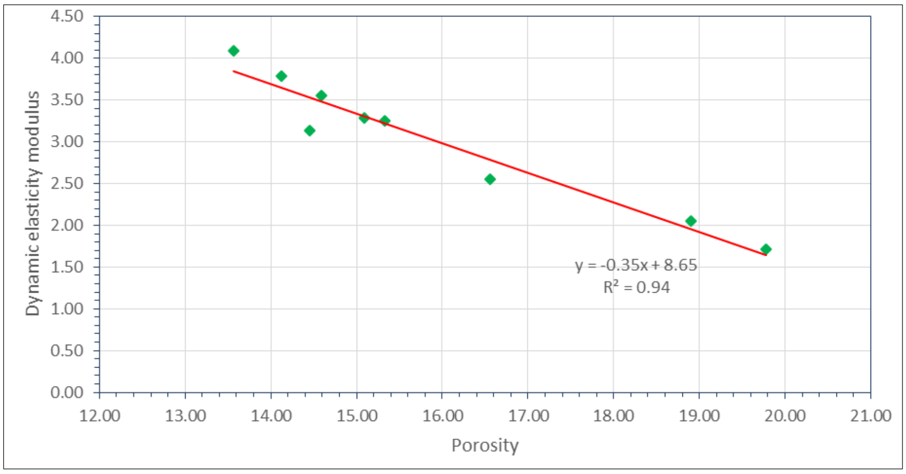

Figure 6 Correlation between porosity and dynamic elasticity modulus

Figure 6 displays the correlation between porosity and dynamic modulus of elasticity. From this trend curve we can see that an increase in porosity leads to a decrease in the dynamic modulus of elasticity with a high correlation coefficient R^2 of about 0.94.

Moreover, the histograms in Figure 3 and Figure 5 confirm this trend. This strong correlation, porosity-dynamic modulus of elasticity, could explain the use of the ultrasound characterization method to express the porosity of a material.

4. Conclusion

The present work has determined the dynamic modulus of elasticity of a rice husk ash pozzolan cementitious material reinforced with sugarcane bagasse.

The results of the study allow us to draw the following conclusions:

- The increase in porosity leads to the decrease in dynamic modulus of elasticity,
- The addition of rice husk ash increases the dynamic modulus of elasticity at low rate and decreases it at high rate,
- The dynamic modulus of elasticity decreases with the increase of the rate of sugarcane bagasse,
- The simultaneous addition of rice husk ash and sugarcane bagasse increases the decrease of the dynamic modulus of elasticity.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare that they have no potential conflict of interest in this manuscript.

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