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Evaluation of Rice Husk Ash Pozzolan on the Mechanical and Physical Properties of Cement Matrix Composites

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present study aims to reduce the use of cement and encourage the utilization of plant biomass. The rice husk ash (loading: 2, 6, 10, 15, 25, 30, 35, 40, 45 and 50%) was used as a cement substitute. The effects of rice husk ash on the physical and mechanical properties of cement matrix composite was investigated. The results of this study show a drop in compressive strength of 19.75 to 5.10 between M0 and MR50 with a remarkable value of 17.02MPa at 10% (MR10). Likewise, we have a variation of the flexural strength from 2.96 to 0.47 between M0 and MR50 with a remarkable value of 1.87 at 10% (MR10). The material MR10 is light and can be used as a filling element.

Keywords: Rice husk; mechanical and physical properties; cement matrix composites; pozzolan.

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1. INTRODUCTION

Recently, several types of research have recommended the use of various pozzolanic materials to be incorporated into the composition of the cement to reduce its cost and environmental impact. The issue of combating global warming is guiding research into materials that meet environmental, ecological, and economic criteria. Buildings and other constructions account for more than 35% of global final energy and almost 40% of CO_2 emissions related to energy used in 2016 [1]. Moreover, Beck-Broichsitter and al [2] have shown that construction, through the production of cement, occupies the second place in the production of CO_2 behind industries that occupies the first place. This information clearly shows us that cement, the most widely used binder in construction, is a great source of threat to the existence of long-term life. We must therefore immediately find a way to reduce its use. This study aims to reduce the use of cement and increase the utilization of plant biomass. This is the reason why several authors have worked on different aspects of composite materials with a cementitious matrix where the cement is replaced by rice husk ash. For example, WILSON [3] worked on durable concrete based on rice bark ash. In his study, he illustrated the potential of Rice Husk Ash (RHAs) on the one hand in industrialized countries to improve the durability of high performance concretes and to improve the properties in the fresh state of self-compacting concretes; and on the other hand, in developing countries to democratize sustainable concrete produced with technologies adapted to local realities. From his work it emerges that the optimal dosage of RHAI (Rice bark ash produced by the industries of India) is 10 or 15% to replace the cement, to have a significant improvement in durability, then the mechanical strengths are little affected by the RHAI dosage, and that 20% (or more) of RHAI causes handling problems associated with a rheo-thickening consistency. Also, Nehdi and Damatty [4] had already succeeded with their special controlled combustion process in showing us that the right calcination temperature of the rice husk is between 750 and 830°C.

In this paper, we will study the effect of rice husk ash pozzolan on physical and mechanical properties of a cement matrix composite.

2. MATERIALS AND METHODS

The compression and flexural test were characterized using an INSTRON 5585H instrument. Speed during test: 0.1 to 117 mm / min; load during the test: from 0.05 KN / sec, loading: brushless motor controlled by a 12-bit digital variator, maximum capacity: 250 KN in compression, 150 KN in traction, control and data acquisition by through a PC.

2.1 Sand

The sand used is locally available natural sand from the Dèkoungbé sand extraction quarry in Benin. A particle size analysis performed, shows a spread particle size distribution, for Cu = 4.02 between 2 and 5 and graduated, according to standard NF EN 933-1, the sand equivalent (ES) of 81.38 <71 gives a sand clean with low percentage of fine clay, good for high-quality mortar and concrete. The fineness modulus Mf = 2.25, 2.2 <Mf <2.8, shows suitable sand for good workability and good resistance, the apparent density is 2.64 Kg / m3.

2.2 Cement

The cement used for the study is a Portland cement of BUFFALO CEMII / B-LL 42.5R Standard NF EN 197-1 produced in Benin.

2.2.1 Physical characteristics of cement

The physical characteristics of the cement are listed in Table 1.

Table 1. Physical characteristics of cement

Apparent density	Volumic mass	Beginning of setting	End of setting	Specific surface	Expansion	Refusal on sieve 0.08	Refusal on sieve 0.16
1.073	3.01	3h and 5min	4h and 9min	3155	1.50	10.92	0.80

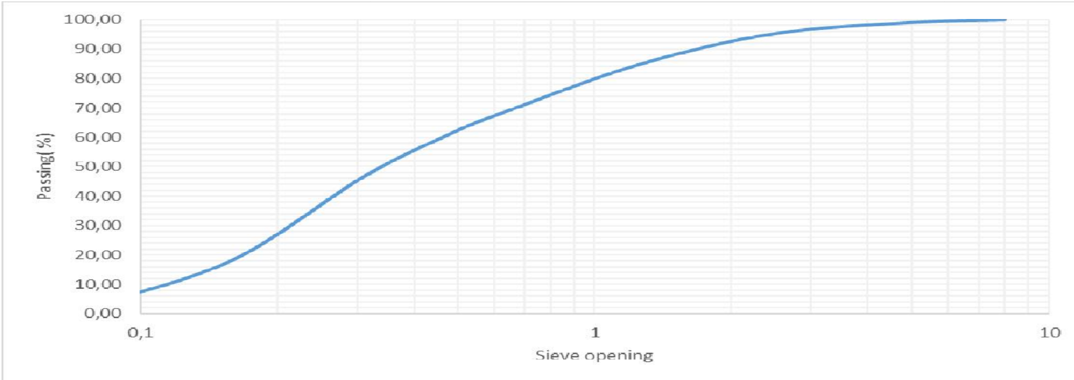

Fig. 1. Granulometric analysis curve of the sand

2.2.2 Mechanical characteristics of cement

The mechanical characteristics of the cement are summarized in Table 2.

Table 2. Mechanical characteristics of cement

Number of days	Compressive strength (MPa)
2 days	13.20
7 days	24.20
28 days	33.00

2.2.3 Rice husk

The rice husks of the present study are wastes from husked rice from industries located in Zangnalando in central Benin. The rice husk is crushed to obtain the pass through an 80-micron sieve, with the aim of achieving complete calcination of the material at all points at the same calcination temperature (600°C).

2.2.4 Preparation of cement matrix samples

The cement test specimens are substituted with a different loading of rice husk ash pozzolan. The materials code M0, MR2, MR6, MR10, MR15, MR25, MR30, MR35, MR40, MR45 and MR50 are designated for the rice husk ash loading, i.e., 0, 2, 6, 10, 15, 25, 30, 35, 40, 45 and 50%, respectively. Prismatic specimens of dimensions 160 mm x 40 mm x 40 mm according to standard NF EN 196-1 are prepared for each type of composite. The cement is mixed with sand and water for 5 min for the M0 control specimen. For each of the above formulations, 0.7 water/cement (W/C) ratio were used. The test pieces are stored in the laboratory at a temperature of 20 ± 5°C.

3. METHODS

A reactive artificial pozzolan from the rice husk was obtained by its calcination, at different temperatures from 400°C to 850°C. The optimum calcination temperature was obtained from the stabilization temperature of the ash mass. The heating rate of the oven was set at 5 °C/min to obtain a calcined and homogeneous ash, according to the protocol, for 5 h of time. The temperature was kept constant for 2 h the loss on ignition was constant from 600 ° C as show in Fig. 4. Mango-Itulamya and Arsène [5]

Fig. 2. Rice husk(a) and rice husk ash obtained after calcination(b)

Fig. 3. Labeled test pieces

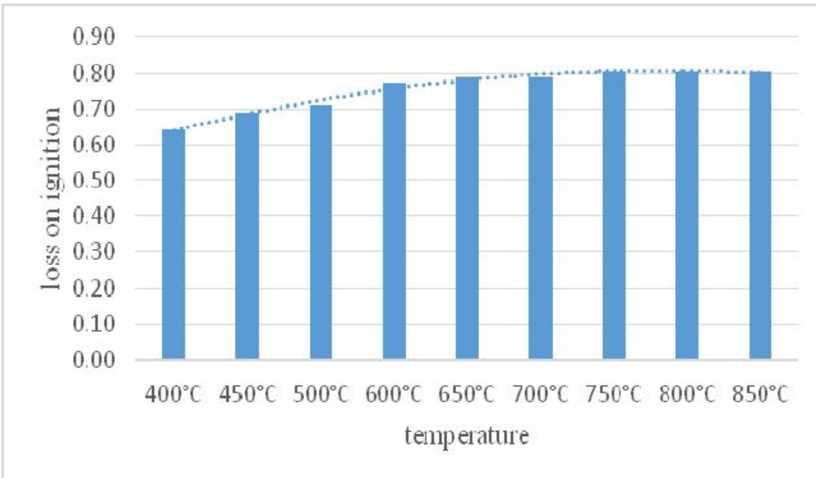

Fig. 4. Evolution of loss on ignition as a function of temperature

used the same method and retained the calcination temperature from that where the loss on ignition became constant and concluded that the ash of the rice husk was not crystalline but amorphous.

The mineralogical characterization of the ash of the rice husk, given in Table 3, is obtained by X-Rays Diffraction (XRD) and X-Ray Fluorescence (XRF). XRD and XRF proceeded following the method of Khaled. Boughzala, and al [6], are based on linear correspondences between the intensities diffracted by each crystalline phase and their proportion in the powder of rice husk ash. The results are presented in Fig. 6 and the constituent's mineralogical content of the rice husk ash in Table 3.

According to ASTM Standard, C618-08a, a material is characterized as pozzolanic if:

- Its chemical composition checks: Al_2O_3 + SiO_2 + Fe_2O_3> 70% (1)
- Its activity index for a substitution rate of 25% at 28 days is greater than 67%.
- Its glass content given by the difference between the raw silica and lime (Silica - Lime) contents is greater than 34%.

The pozzolanic material must have a minimum of 67% as an activity index at 28 days with a substitution percentage of p = 25%, according to the equation (2):

$$i_a = \frac{R_{C28j}(M)}{R_{C28j}(25C)} \quad (2)$$

4. RESULTS AND DISCUSSION

4.1 Assessment of the Activity Index

A reactive artificial pozzolan of the rice husk was obtained by calcination of the husks of rice husk, according to the varied temperatures of 400°C and 850°C. The optimum calcination temperature was obtained from that of the constant mass of the ash at 600°C. Fig. 4 gave the loss on ignition as a function of the temperature variation.

The mineralogical components of this rice husk ash are presented in Table 3

Fig. 5 shows the diffractogram of the rice husk ash. It shows the presence of minerals of silica, magnesium oxide, calcium oxide dominant. Thus, rice husk ash has a mineralogical composition similar to that of a pozzolan and contains an amorphous phase that can react when used in cement.

Fig. 6 shows the TGA curve of the rice husk ash.

This test result shows that the calcination temperature of at 600°C is better than that of 700°C. In fact, from this temperature there is no more variation in loss on ignition.

The reactivity of this elaborate rice husk ash pozzolan of 0.71 given by equation (2), close to the nominal value of 0.67, expresses a slow reactivity in the cement matrix and causes a decrease in the compressive strength of the mortar at 28 days.

4.2 Effect of Rice Husk Ash in the Porous Cement Matrix

Table 4 gives the evolution of the spreading as a function of the rate of substitution of the cement by the pozzolana of the rice husk at different loading.

Fig. 7 shows a decreasing of the mortar's flow value with the increase in the substitution for rice husk ash pozzolan. The workability decreases with the increase in substitution of cement by pozzolan. This rice husk ash pozzolan, when incorporated, absorbs water from the pores of the mixture [7]. The consequence is the reduction of free water between the grains of sand, the mortar becomes more consistent [8], hence a reduction in the workability of the mortar.

4.3 Effect of Pozzolana from Rice Husk Ash on the Properties of Fresh Cement Material

The aim is to study the effect of adding pozzolana to the ash of the rice husk on the consistency of the paste of the mortar, also its effect on the density of the fresh mortar. The data on the density of the fresh cement mortar, in which the composition of cement are substituted by the rice husk ash, are given in the following Table 5.

Fig. 8 shows the decreasing evolution of the density of the fresh mortar as a function of the increase in the rice husk ash loading. We observe an almost linear drop in the density of fresh mortar with the increase in the rate of rice husk ash. From a value of 2437.50 kg/m^3 for the reference mortar, we obtain 1414.62 kg/m^3 for the mortar with 50% substitution of cement by rice husk ash. The rice husk pozzolan increases the pores' size in the fresh mortar for the same occupied total volume [9], making the fresh mortar lighter.

Table 3. Chemical constituents of rice husk ash

	Chemical constituents (%mass)							
	SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**$S0_3$**	**K_2O**	**Na_2O**
Proportion %	98.78	0.10	0.24	0.41	2.64	0.05	1.93	0.00

Table 4. Evolution of the flow as a function of rice husk ash loading

	M0	**MR2**	**MR6**	**MR10**	**MR15**	**MR25**	**MR30**	**MR35**	**MR40**	**MR45**	**MR50**
d1	25.5	23.3	21.8	21.4	16.8	15.5	14.8	14.1	12.9	11.6	10.1
d2	25.5	23.7	22.4	20.6	16.6	15.9	15	13.9	12.9	11.4	10.4
dr	25.5	23.5	22.1	21	16.7	15.7	14.9	14	12.9	11.5	10.3
E%	155	135	121	110	67	57	49	40	29	15	3

Remark : d1 is spread diameter in first direction; d2 is spread diameter in second direction ; dr is the average of d1 and d2 ; E% is the flow value

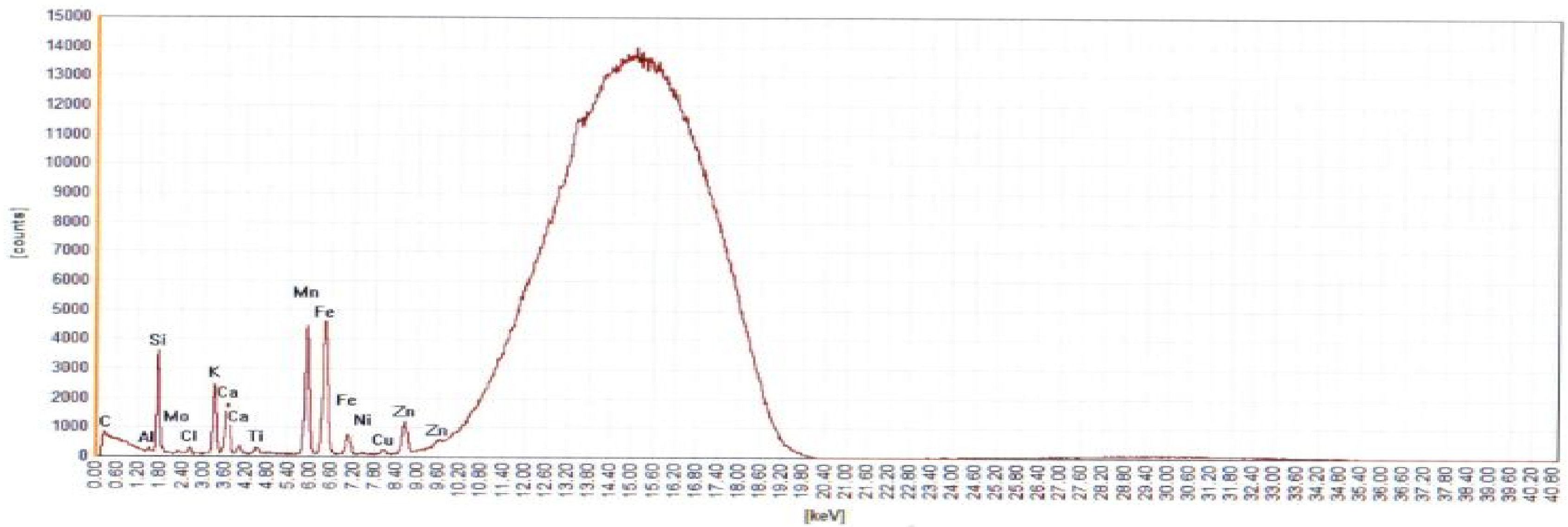

Fig. 5. XRD diffractogram of rice husk ash

Table 5. Evolution of the density as a function of rice husk ash loading

	M0	MR2	MR6	MR10	MR15	MR25	MR30	MR35	MR40	MR45	MR50
Density (Kg/m^3)	2437.50	2356.77	2214.84	2189.56	2094.14	1987.18	1858.53	1737.54	1641.59	1554.25	1414.62

Table 6. Evolution of the hardened samples' density as a function of rice husk ash loading

	M0	MR2	MR6	MR10	MR15	MR25	MR30	MR35	MR40	MR45	MR50
Density (Kg/m^3)	2123.70	2048.18	2067.71	1818.15	1746.17	1660.16	1454.18	1276.06	1106.82	988.66	898.26

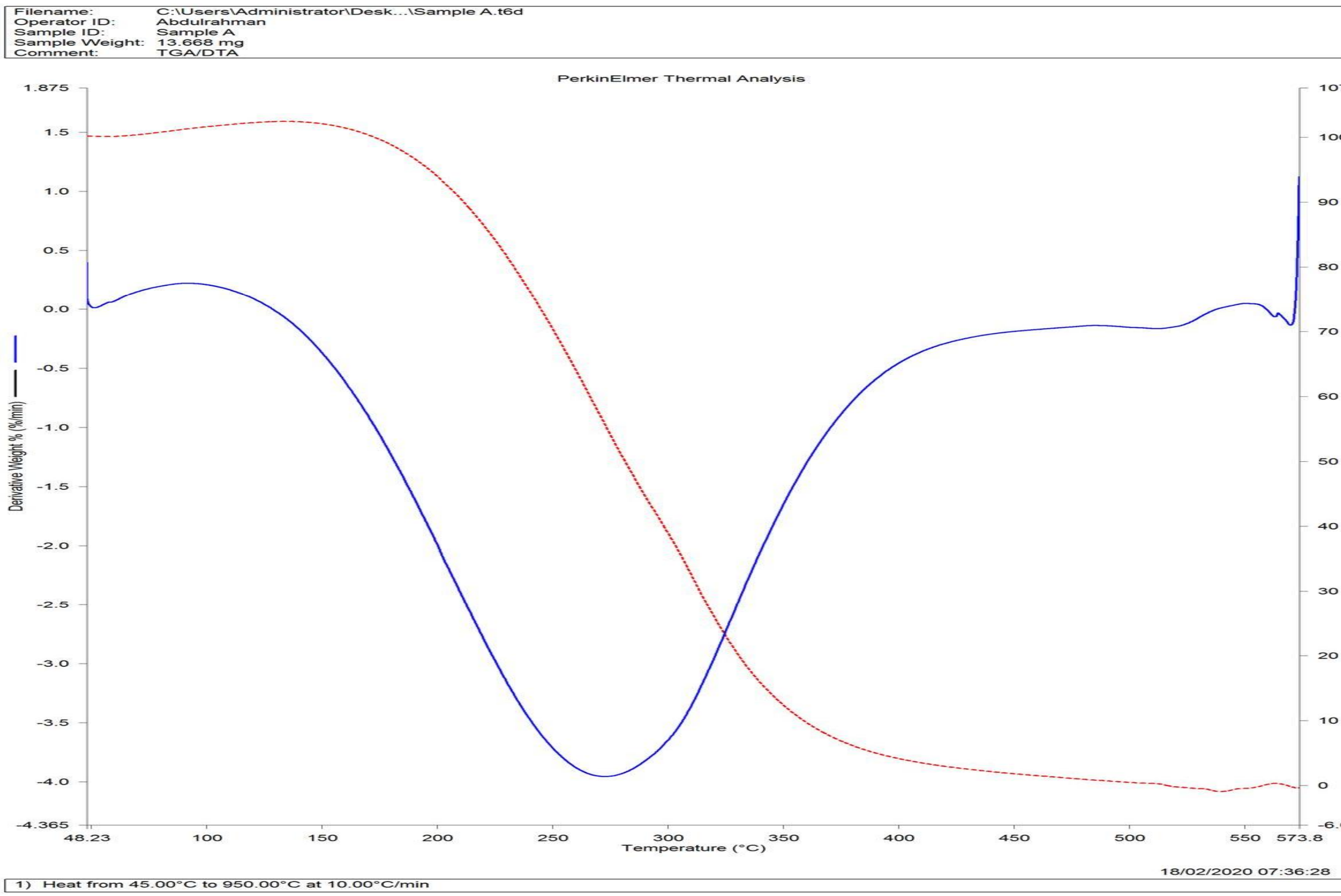

Fig. 6. TGA curve of the rice husk ash

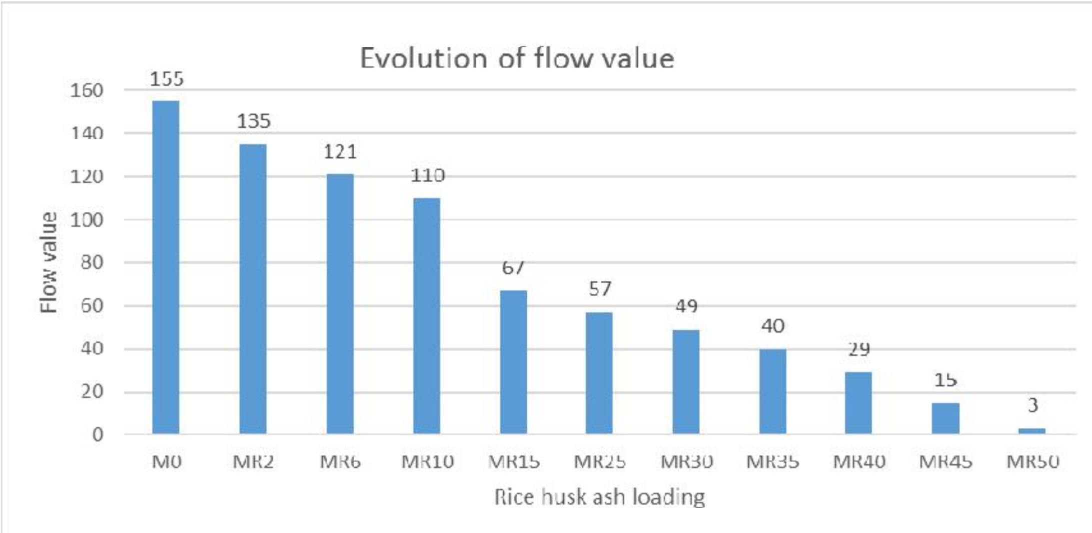

Fig. 7. Evolution of the Flow value as a function of the ash loading

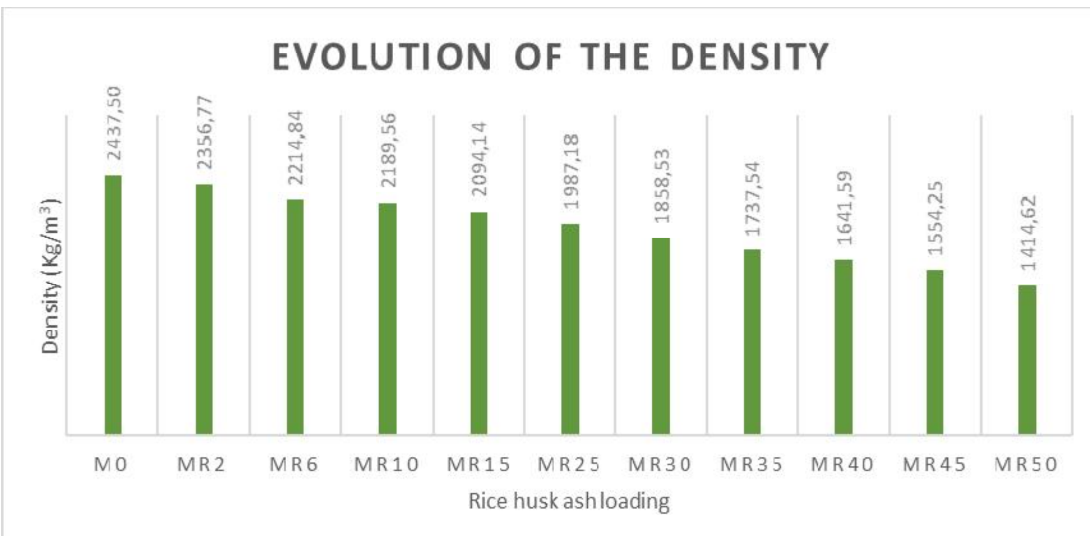

Fig. 8. Density of fresh mortar as a function of the rice husk ash loading

4.4 Effect of Rice Husk Pozzolana on the Properties of Hardened Cementitious Material

Fig. 9 shows a loss of mass of the cured material. We observe an almost linear drop in the density of fresh mortar with the increase in the loading of rice husk ash. From a value of 2123.70 kg/m^3 for the reference mortar we obtain 898.26 kg/m^3 for the mortar with 50% substitution of cement by rice husk ash. We observe an evolution similar to that of fresh mortar except that here we have lower densities; this is attributed to the water evaporation during the setting of the cement.

4.5 Effect of Rice Husk Ash on the Compressive and Flexural Strength of the Material Produced

MR refers to all cement matrix composites in which cement is replaced by loading of rice husk ash.

The 28 days' compressive strength of the tubes is shown by the Fig. 10.

We observe an overall decrease in compressive strength with the increase of rice husk ash loading. However, we have a more noticeable drop at 10% substitution of cement by rice husk ash; with a resistance of 17.2Mpa at 10%. This large drop after 10% would be linked to the fact that the water is no longer sufficient for the hydration of the cement at high loading. This is because the rice husk ash absorbs almost all of the free water between the grains [7]. This could be beneficial in the long term since this water absorbed by the rice husk ash will facilitate chemical reactions in the long term [10,11]; and therefore it will probably help to have greater mechanical resistance in the long term (after 28 days).

MR refers to all cement matrix composites in which cement is replaced by loading of rice husk ash.

The 28 days' flexural strength of the MR test tubes is shown in Fig. 11.

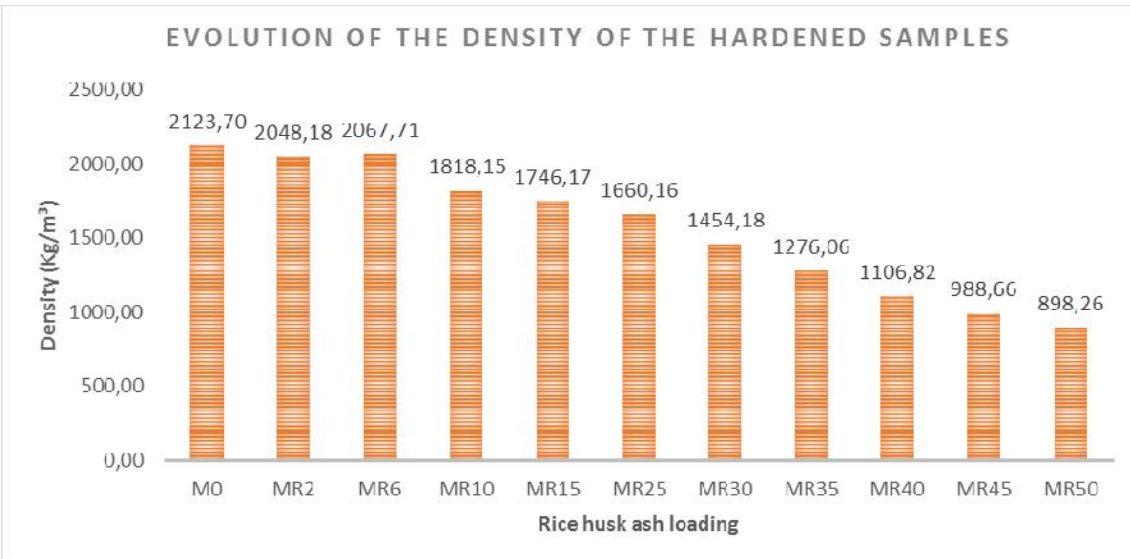

Fig. 9. Density of hardened samples as a function of the rice husk ash loading

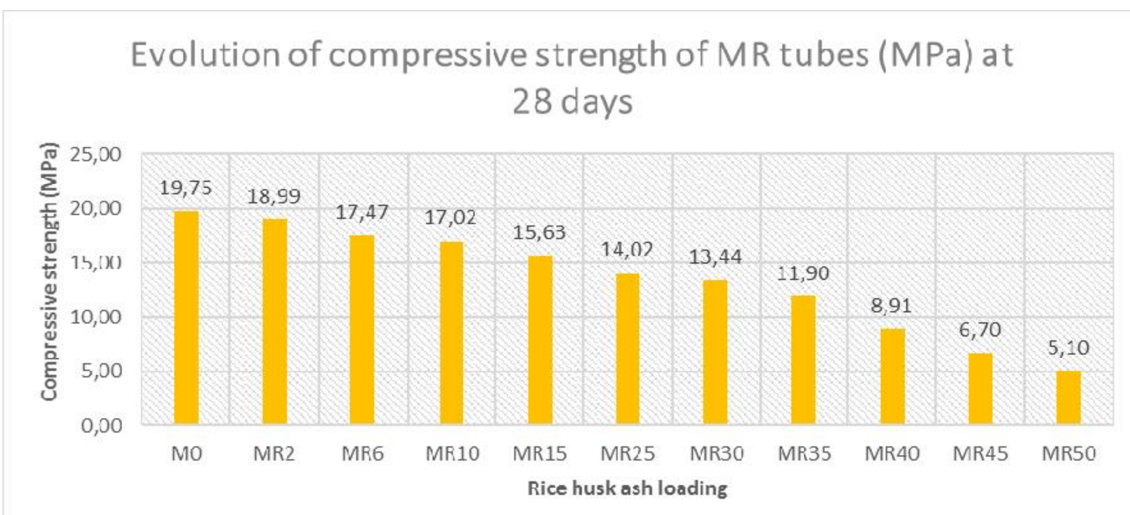

Fig. 10. Compressive strength of MR pieces as a function of rice husk ash loading

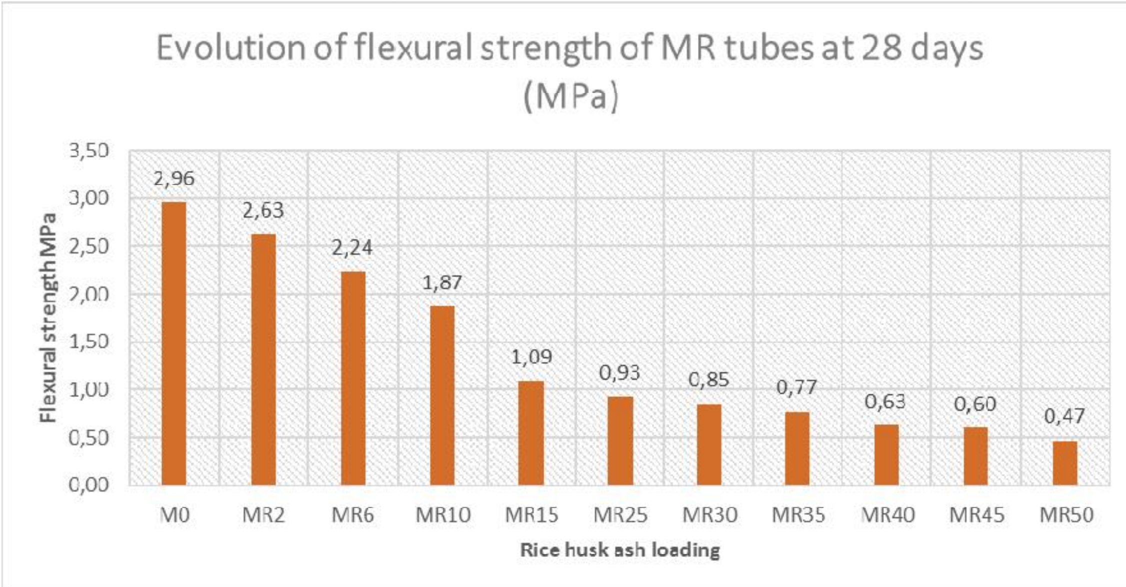

Fig. 11. Flexural strength of MR tubes as a function of rice husk ash loading

We observe an overall decrease in flexural strength with the increasing loading of rice husk ash. However, we have a more noticeable drop at 10% substitution of cement by a loading of rice husk ash; with a flexural strength of 1.87MPa at 10%. This large drop after 10% would be linked to the fact that the water is no longer sufficient for the hydration of the cement at high loading. This is because the rice husk ash absorbs almost all of the free water between the grains [7]. As mention above the rice husk pozzolan increases the pores' size in the fresh mortar for the same occupied total volume [9]. This state of things means that there are of zones of weakness in the test pieces. However, we are sure that this substitution of cement by rice husk ash pozzolan is better than a simple removal of the same percentage of cement; because the presence of pozzolan facilitates the development of chemical reactions producing additional silicates [12,13].

5. CONCLUSION

This study aims to determine the effect of rice husk ash pozzolan on the physical and mechanical characteristics of a cement matrix composite. During our work it was determined that the workability, the density of the fresh mortar decrease with the increasing of loading of rice husk ash. Also, we note a drop in the density of the hardened pieces with the increase in the loading of rice husk ash. As for the mechanical characteristics, we note a significant decrease in flexural strength with the RHA loading. However, the MR10 material has been remarkable with a flexural strength of 1.87Mpa and a compressive strength of 17.02MPa. The low density of this material (MR10) makes it to be appropriate to serve as filler.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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