Comparative study of the formulation and physical and mechanical features of cement matrix composite reinforced with plant biomass: the case of fibers *borassus aethopium mart* and rice husk

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ABSTRACT:

The present study is integrated in general problems of development of building materials innovating with reduced environmental impact. Within this framework we proposed to study two types of cementing composite reinforced by vegetable biomass with knowing fibers of borassus aethiopum mart and the rice husk. To this end, studies of formulation, compatibility of cement with the biomass and of mechanical and thermal behavior of the batches formulated were carried out for two granular compositions of fineness 2.17 and 3. The study of compatibility revealed that the vegetable biomass well not having undergone a preliminary treatment in study are compatible with cement CPJ35.The comparison of the characteristics physical and mechanical of the two composites enabled us to conclude that the fibers concrete of borassus aethopium mart are better in term of mechanical performances. The values of the mechanical resistances corresponding to the optimum reports/ratios water/cement and cement/fibers are included respectively between 5.5 and 8.37 Mpa for the composite fibers of borassus aethopium mart.-cement and 3.63 and 12.25 Mpa for the composite rice husk-cement in traction and 6.84 and 16.26 Mpa for the composite fibers of borassus aethopium mart-cement and 3.8 and 15.63 Mpa for the composite rice husk -cement in compression.

KeyWords: Cement, biomass vegetal, *borassus aethiopum mart*, rice husk, compatibility, composite, hydratation

1. Introduction

The palmyra also called *borassus aethopium mart* is a woody "monocotyledon" plant. It comes from sub-Saharan Africa and has been classified by FAO experts [1]. It is a renewable resource that produces wood and can't get deteriorated. The Palmyra is very resistant to wood-eating insects and has a low absorption rate of fibers. People in rural areas use it in the form of strips to make houses, and sometimes people in urban areas use it too for the same purpose. According to an experimental study of the mechanical behavior conducted in the context of using Palmyra as a vegetable framework in the concrete, the *borassus aethopium mart* has a tensile strength and a high modulus of elasticity similar to those of steel with a longitudinal withdrawal rate equal to zero [2]. In countries such as Senegal, Gambia, Niger, etc, the transformation of the trunk in strips produce some fibrous waste unused due to a lack of fiber upgrading process in the manufacture of cementitious composites. Rice is a well-known crop throughout the world. It is the second cereal crop (149 million ha) and the third output (380 million tons), consumed and exported in the world after wheat and corn. However, in Africa, rice comes after millet / sorghum and maize [3]. The rice husking generates a lot of garbage about 30 to 40% rice husks, which are hygroscopic and rot. Moreover, rice husks are rich in cellulose and ash in particular silica ($SiO2$ content estimated at 20%). These waste rice husks are a big environmental problem for African countries due to lack of ecological management. With the aim to contribute to the recovery of waste rice husk, S. Tamba [4] has studied physical and mechanical characteristics of the composite obtained by incorporating the waste in a cementitious matrix starting from a formulation based on an experimental method. Ajiwe et al showed that it was possible to create false ceilings with rice husk by mixing it with sawdust using synthetic glue known as «cascamite» [5]. Various fibers and particles of gas wood coming from the retraining of agricultural wastes were the object of several relative works to the cementitious composite. It is about residues of sisal, banana tree and eucalyptus J.H. SAVASTANO et al [6]; of date palm fibers A. KRIKER et al [7], of coconut fibers, of sugar cane and banana tree C. ASASUTJARIT et al [8]; of linen fibers E. AAMAR et al [9]; of diss fibers M. MERZOUD et al [10]; cuttings of wood S. TAMBA et al [11]; particles of hemp P. TRONET et al [12].

The objective of this work is the use of a method of formulating cementitious composites based on the principle of absolute volumes, staying within a reasonable range of cement content and deduces the physical and mechanical characteristics of composites.

2. Materials and methods

The fibers of *borassus aethopium mart* used in this study come from the waste of liability of the trunk's strips and mashing of blanks while the rice husk particles come from the factory husking rice of Mallanville, a city in the north of Benin Republic. Fibers and particles thus obtained are dried in an sterilizer at 105 ° C to a constant mass. After that, the fibers and particles are classified in series by sieving into four different small seeds portions (Table I) and mixed in granular compositions (Figure 1). They have not undergone any chemical treatment and are kept in a room maintained at a temperature of 20 ° C.

TABLE I - Proportions used in granular compositions

Granular classes	Fine Mixing (MF)	Rough Mixing (MG)
[2.5 ;5[	40%	16.67%
[1.25 ; 2.5[	30%	16.67%
[0.63 ; 1.25[	20%	30.33%
[0.315 ;0.63[	10%	30.33%

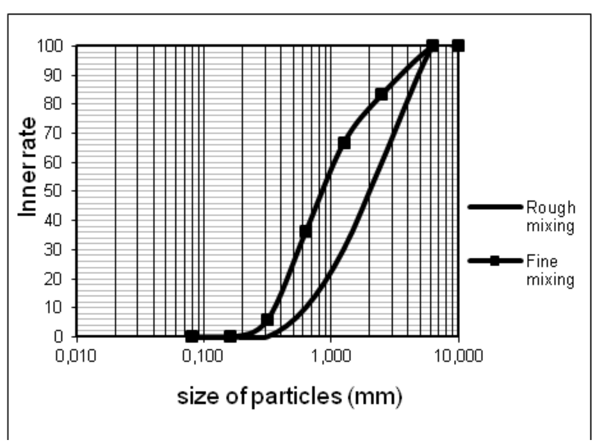


FIG.1 – Granulometric bends of the two granular compositions

Modules fine mixture of fine and rough mixture are respectively 2.17 and 3.0. Their densities are respectively 687 kg/m3 and 771 kg/m3 for fibers borassus aethiopum mart and of 749 kg/m3 and 648 kg/m3 for rice husks.

The cement used is a CPJ 35 produced in Benin Republic by Lafarge cement company (SCB) of Onigbolo.

The composites performed to study the compatibility between cement and plant biomass are composed of 200 g of cement and 80 ml of water for the control witnessed sample and 200 g of cement, 90 ml of water and 15 g of plant biomass. These are placed in a tempered adiabatic chamber (FIG. 3) in which there is a speed of hydration of the cement through the quantity of heat released during the reaction. Formulation of the composites consisted in fixing the dosage in cement, then choose the mixing water on reports cement content (E/C or k_e) adapted according to the fitness of the fresh mix by testing handling of composites and finally to determine the mass of vegetable granulars (R) to make use of 1 m3 of composites.

Three cases of dosages are used in the present work. It is 400 kg/m^3, 450 kg/m^3 and 500 kg/m^3 respectively noted D_1, D_2 and D_3.

The method used to determine the masses of the granules to implement based on the cement content and water is based on the expression of the absolute volume of fresh mixture and absolute densities of the components of the composite (ρ_{br}: specific weight of the granular composition in question; ρ_C: specific weight of the cement; ρ_e: density of water).

The absolute volume of the fresh mixture of the different constituents of the composite is given by the following expression:

$$V_{abs\,mix} = V_{abs\,cement} + V_{water} + V_{abs\,granules} \tag{1}$$

Where, $V_{abs\,mix}$, $V_{abs\,cement}$, V_{water} and $V_{abs\,granules}$ are respectively the absolute volumes of the fresh mixture of cement, water and granules used.

For the physical and mechanical characterization of composites, thirty-six composites were formulated due to eighteen by each composite. For each of the composites, cement was first mixed with the vegetable granules and then the mixing water has been added. The fresh mixture was placed in three molds 4 × 4 × 16 cm^3 packed with a stem. The specimens were demolded after twenty-four hours and left in the open air for twenty-eight days. The tests of mechanical resistances in traction by inflexion and compression were performed according to the norm EN-196-1.The measurement of absorption rate was performed according to the protocol described in the work of M. Merzoud and al [10].Once the mechanical characteristics are known, the eighteen composites have been crafted by composite were optimized in six composites.

3. Results and Discussion

3.1 Study of the compatibility

Figure 2 shows the evolution of the temperature during the hydratation reactions of cement alone and cement in the presence of fibers borassus aethiopum mart, on one hand and rice husks on the second hand. The table II summarizes the different characteristics of the cement hydration in all the three mixtures: the maximum temperature Tm, the time tm taken to reach this temperature, the energy hydratation A corresponding to the area under the curve and the coefficient of hydration C_A.

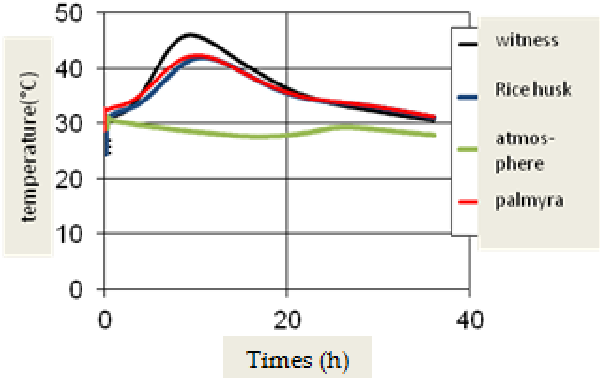


FIG.2- Curves of hydratation of cement in the witness and presence of fibers of vegetable biomass.

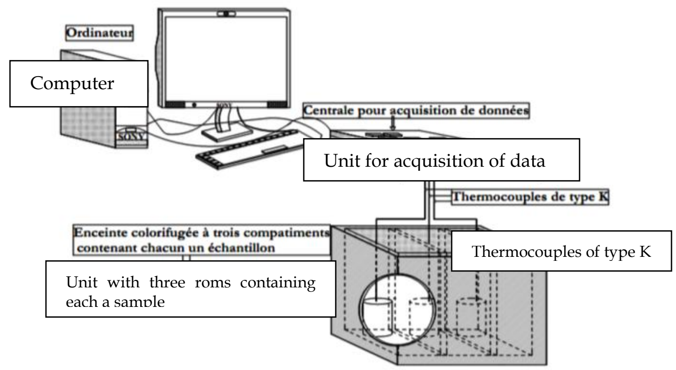


FIG.3- Device of measurement of heat hydratation of cement by the method of calorimetry isotherm.

TABLE II-Features of hydratation mixtures

Type of mixing	Tm(°C)	tm(hours)	A (kCal)	C_A(%)
witness (Ciment + water)	46.0	9.38	0.245	100
Ciment + water + palmyra fibers	42.4	9.80	0.218	89.11
Ciment + water + rice + rice husks	42.1	10.28	0.201	82.04

As a result, the presence of *borassus* fibers or rice husks have resulted in a decrease of the maximum temperature and the calorific energy released during the hydratation of cement. This is due to the presence of organic substances in the vegetable biomasses. Although these reduce the degree of hydratation of cement, they seem to have no significant effect about the required time to reach the maximum temperature. In view of the scale of comparison in the work M. Hachmi and al [13], it appears that the borassus fibers and rice hulks are compatible with cement (because their $C_A > 68\%$). That gives us the choice to introduce some treatments or not in the process of preparation of composites of vegetable biomasses.

3.2 Formulation and characteristics of composites

Let's express the different components of the formula (1) according to their absolute density in:

$$V_{\text{abs cement}} = \frac{c}{\rho_c}; V_{\text{abs water}} = \frac{k_e c}{\rho_e}; V_{\text{abs granules}} = \frac{R}{\rho_{br}} \quad (2)$$

Substituting the expressions (2) into (1) and considering $V_{\text{abs mix}} = 1\text{m}^3$, we deduce the general expression for the mass of the aggregates.

$$R = \rho_{br}.\left(1 - \frac{c}{\rho_c} - \frac{k_e.c}{\rho_e}\right) \quad (3)$$

Knowing the masses of granules, we can define the mass ratios (C/R) used in the formulation of composites (Tables III and IV).

TABLE III- Optimal formulation of composite cement-fibers of *borassus aethiopum mart* and the corresponding features

Formulations			**Physical charactristics**		**Mechanical characteristics**	
Relation C/R	**Relation E/C**	**Nomination of composites**	**Density (kg/m^3)**	**Rate of ab-sorption (%)**	**Resistance in traction (Mpa)**	**Resistance in compression (Mpa)**
2.15	0.60	MF-D1-E0.6	1080	42.48	5.50±0.43	6.84±0.34
1.92	0.50	MG-D1-E0.5	1190	39.46	5.75±0.43	9.16±0.61
3.64	0.40	MF-D2-E0.40	1420	15.06	7.75±0.57	10.01±0.39
3.25	0.40	MG-D2-E0.40	1380	25.76	6.75±0.38	11.97±0.28
4.45	0.35	MF-D3-E0.35	1420	21.86	7.63±0.22	15.52±0.72
3.96	0.30	MG-D3-E0.30	1470	20.36	8.38±0.43	14.43±0.61

TABLE IV- Optimal formulation of composite cement-rice husk and the corresponding features.

Formulations			**Physical charactristics**		**Mechanical characteristics**	
Relation C/R	**Relation E/C**	**Nomination of composites**	**Density (kg/m^3)**	**Rate of ab-sorption (%)**	**Resistance in traction (Mpa)**	**Résistance in compression (Mpa)**
1.97	0.30	MF-D1-E0.3	1080	42.00	4.886±0.38	5.68±0.16
2.24	0.40	MG-D1-E0.4	1270	43.00	3.63±0.22	3.83±0.14
3.34	0.30	MF-D2-E0.3	1310	30.00	8.00±0.22	10.11±0.77
3.80	0.40	MG-D2-E0.40	1290	42.00	7.50±0.65	8.11±0.53
4.08	0.20	MF-D3-E0.2	1580	22.00	10.25±0.94	15.00±1,16
4.64	0.25	MG-D3-E0.25	1450	32.00	12.25±0.57	15.63±1.02

In terms of densities of composites that are less than 2000 kg/m3, it appears that the composite fibers of *borassus aethiopum mart* cement and cement-rice husk can actually be classified as lightweight concretes.

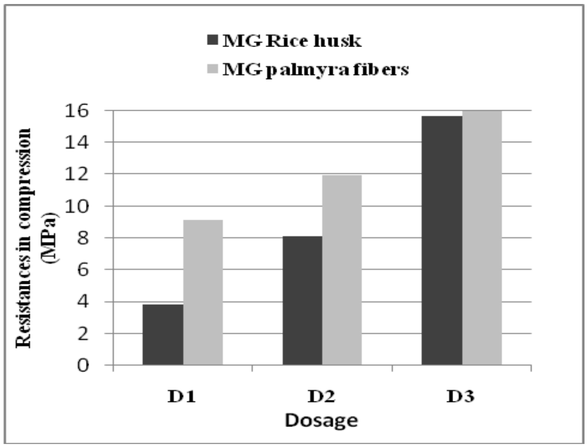
The absorption rate increases with E/C ratio used for making wet composites, which obviously lowers the density and consequently the mechanical resistance. However the increase of massive fraction C/R leads to lower absorption capacity, increase in the density and improved mechanical resistance.

Reports of resistance in compression on traction resistance are 1.27 for rice husk composite- cement and 1.72 for the composite fibers of *borassus aethiopum mart*-cement showing that these composites have some significant resistances in traction, which is opposite to the usual mortar whose report is about 10. The same observation was made by M. Merzoud and Al [6], but note that the mechanical resistance of our composites are much higher to mechanical resistances studied on composites of Diss-cement by M.Merzoud and Al [6], although the reports massiques Diss/cement = 5 are higher than those used in the case of our study.

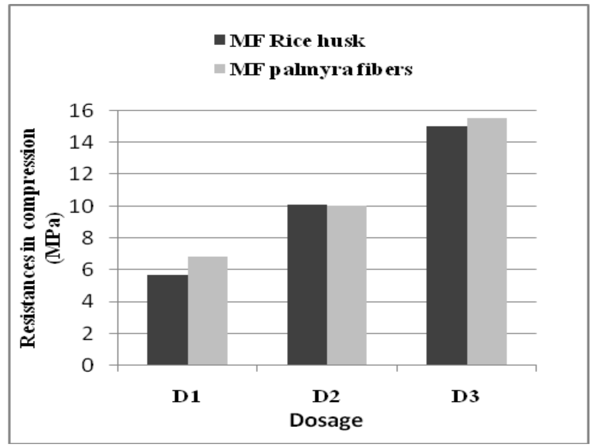
After analyzing both Figures 4-A and 4-B below, we note that the resistance in compression recorded on the composite *borassus aethiopum mart*- cement are always higher than those recorded on the composite of rice husk-cement, except the fine mixture dosage D2 for which the resistance obtained for the composite *borassus aethiopum mart*-cement is slightly less than the one obtained on the composite rice husks -cement.

By observing figures 5-C and 5-D, we find that for the dosage D_1, the recorded resistance in traction on specimen of the composite *borassus aethiopum mart*- cement is higher than that of the specimen of the composite of rice husks- cement, as for the dosages D_2 and D_3, the higher resistances are obtained on the composite rice husks-cement.

In general, we can claim that compared to composite rice husk-cement, the composite cement- fiber of *borassus* *aethiopum mart* is more resistant in compression and as for the resistance in traction, and the composite rice husk-cement is more resistant than the composites *borassus aethiopum mart*- cement for some cement higher dosage. But for low dosages of cement, we recommend the composite of fibers of *borassus aethiopum mart*-cement.

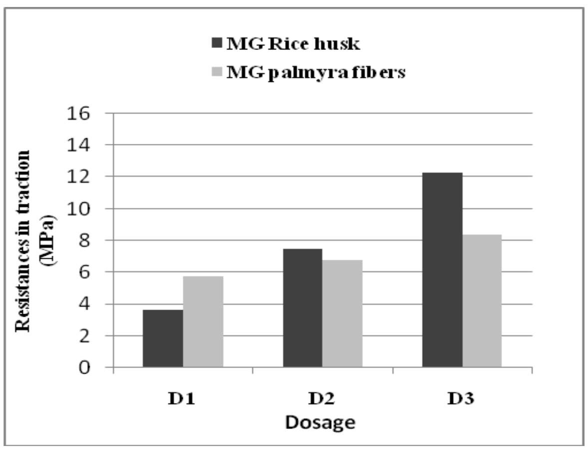


A

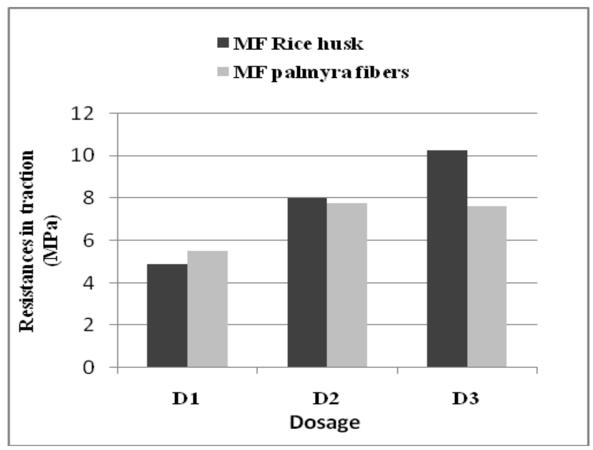


B

FIG.4 – Change of resistances in compression in function of dosage for the rough mixing (A) and the fine mixing (B) of two composites.



C



D

FIG.5-Change of resistances in traction versus dosage for the rough mixture (C) and the fine mixture (D) of the two composites

4. Conclusion

Taking into account the environmental impact of buildings raises questions and proposes alternative materials of construction. Within this framework we propose to characterize the resulting composite mixture of a cementitious matrix with vegetable fibers of *borassus aethiopum mart* and rice husks. In the first time, it was shown that untreated fibers are compatible with the used cement. The obtained results have permitted to establish the existence of optimal values for the amount of binder and the amount of corresponding water to the best mechanical resistances. It appears from this study that the composite fibers of *borassus aethiopum mart*-cement presents some physical and mechanical characteristics which are best compared to those of composite rice husk-cement. Although the absorption capacity of materials are important, the noticed lightness is a recognized asset opening many perspectives on the possible applications of composites .Thus, the formulated composites can be used in the ceiling and walls realization.

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