



RESEARCH ARTICLE

PHYSICAL AND THERMAL CHARACTERIZATION OF CEMENTITIOUS COMPOSITES BASED ON PLANT-BIOMASS

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Abstract

This paper presents the results of an experimental study on the evaluation of physical and thermal properties of cementitious composites based on plant biomass (rice husks and palm tree fibers). Composites produced are cement mortars with total replacement of sand by aggregates of rice husks (B) or palm tree fibers (F). Three cement content (D_1 , D_2 and D_3) and two granulometries of biomass (coarse mixture and fine mixture) were used for the manufacturing of studied samples. After 28 days of curing, dry density, water absorption by capillarity and thermal conductivity of mortars were measured. The results show that dry density and thermal conductivity of composites increase with cement content while water absorption by capillarity decreases with an increase of cement content regardless of biomass size particle. In addition, thermal conductivity increases with dry density and decreases with water absorption by capillary. For all studied mixtures, composites based on palm tree fibers give better results (high dry density, low water absorption coefficient and low thermal conductivity) than those based on rice husks. The results also indicate that the replacement of sand by aggregates of rice husks or palm tree fibers in mortars is an interesting option to be considered to produce new materials with low thermal conductivities (less than 0.50 W/mK).

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Introduction:-

Nowadays, the development of innovative energy-efficient building materials is a key issue in building construction in the context of sustainable development. Indeed, construction sector, which is an important consumer of energy and natural resources, is responsible for considerable carbon dioxide emissions [1][2]. However, due to the rise of environmental consciousness and negatives effects of industrial pollution on the climate, there are increasing efforts to accelerate the shift from classical building materials to environmentally friendly and energy-efficient materials [3]. So, a particular attention is paid to materials with low environmental impact ([4][5][6]). Much research is carried out on the use of natural fibers (coconut fibers, sisal, hemp, wood chips, diss fibers, etc.) in cementitious materials ([7][8][9][10]). The results indicate that incorporation of plant fibers in these materials significantly improves their physical and mechanical properties relatively to composites based on synthetic fibers. Ozerkan et al. [11] showed that integration of plant fibers as the secondary reinforcement in cement matrix allowed to control cracking induced by humidity or temperature variation. Therefore, a combination of interesting physical and mechanical properties of vegetable fibers has been the main reason for their use as alternative materials for

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conventional reinforcements. Furthermore, the addition of cellulosic fibers can reduce free plastic shrinkage [12] and thermal conductivity [13] of cementitious materials. Savastano et al. [14] showed that the use of sisal waste as reinforcement in concrete improve the mechanical properties of these composites. Asasutjarit et al. [15] indicated that the best pretreatment of coir fibers was to boil and wash them before their mix into cement paste. This treatment enhances some of their mechanical properties.

In Europ, many research works ([16][17][18]) are conducted on adding hemp fibers in cementitious composites. The results indicated various advantages such as: increase in mechanical properties, acceptable thermal and acoustic insulating properties compared to traditional materials (concrete, glass fibers, etc.).

In west African countries, dehulling rice generates over 30% of waste consisting mainly of rice husks. These husks are rot-proof and cannot be used in livestock feed. Zongo and Konin [19] showed that a way to reuse this waste can be in cementitious composites. Palm tree (*Borassus aethiopum* mart.) is a rot resistant plant, abundant in sub-saharan Africa [20]. Krikeret al. [21] have shown that it can be used as reinforcement in concrete. However, literature concerning these biomasses seems to indicate an insufficient technological valorization, particularly in the field of cement composites.

This paper aims to investigate the influence of rice husks and Palm tree fibers content on physical and thermal properties of plant biomass-based materials.

Materials And Methods:-

Materials

The cement used in this study was a Portland Pozzolana Cement CEM II/B 32,5 N manufactured by CIM Faso (Burkina Faso). Physical properties of cement were given in table 1.

Table 1:- Physical properties of cement.

	Density (g/cm^3)	Blaine specific surface (cm^2/g)
CEM II/B 32,5 N	3,01	3 155

Biomass aggregates come respectively from the grinding of the palm tree trunk (figure 1.a) and from a rice husking plant (figure 1.b) in Burkina Faso. The particles obtained are dried in an oven at 105 °C until a constant mass is reached. these aggregates are sorted by sieving into 4 granular classes and mixed according to the granular compositions presented in Table 2. These compositions allow to obtain 2 types of biomass aggregates: a fine mixture and a coarse mixture.



Figure 1.a:- Rice husk aggregate.



Figure 1.b:- Palm tree fibers aggregate.

Table 2:- Proportions of biomass used in granular mixtures.

Particle/fibers size (mm)	Retained percentage (%)	
	Fine aggregate	Coarse aggregate
5,00	16,67	40,00
2,50	16,67	30,00
1,25	33,33	20,00
0,63	33,33	10,00

Preparation of biomass cement mortar

The biomass cement composites were prepared using Portland Pozzolana cement, biomass, and water. Biomass were used as aggregates in the mix. The mortars formulation results from the modifications made to the composition proposed by Asasutjarit et al. [15] based on the optimization of physical and mechanical properties of these composites.

For each biomass, two mortars were casted by varying cement content. The compositions of the mortars studied are presented in Table 3. Biomass mortars are designated B for composites based on rice husk and F for those based on palm tree fiber. Index 1 corresponds to mixtures with fine aggregates and 2 for those with coarse aggregates.

Table 3:- Constituent's weight ratio in the mix.

Components	Cement ($D_1 = 400 \text{ kg/m}^3$)		Cement ($D_2 = 450 \text{ kg/m}^3$)		Cement ($D_3 = 500 \text{ kg/m}^3$)	
	Weight ratio	Designation	Weight ratio	Designation	Weight ratio	Designation
Cement	1	B ₁ -D ₁	1	B ₁ -D ₂	1	B ₁ -D ₃
Rice husk	0,5		0,45		0,24	
Water	0,35		0,35		0,30	
Cement	1	B ₂ -D ₁	1	B ₂ -D ₂	1	B ₂ -D ₃
Rice husk	0,5		0,45		0,22	
Water	0,35		0,35		0,35	
Cement	1	F ₁ -D ₁	1	F ₁ -D ₂	1	F ₁ -D ₃
Palm tree fibers	0,5		0,40		0,23	
Water	0,5		0,5		0,35	
Cement	1	F ₂ -D ₁	1	F ₂ -D ₂	1	F ₂ -D ₃
Palm tree fibers	0,5		0,40		0,25	
Water	0,5		0,5		0,35	

The mixing of cement and biomass aggregate was the first step in the preparation of the mixture. Then, water was added. Mixing was carried out until homogeneous mixture was obtained. The quantity of water was adjusted to obtain a slump value equal to 10 cm on the fresh mortar. The biomass cement mixture was cast in a standard prism with dimensions of 40 x 40 x 160 mm. Consequently, consolidation was made for mixture by a vibrating table. The

samples were demolded after 24 hours and placed for 28 days in ambient air. After curing, the specimens were used for physical and thermal testing. Each parameter value is the average of three measurements.

Methods of physical and thermal testing of biomass cement composite specimens

Dry density of biomass composite specimens after 28 days of curing was determined in accordance with French standard NF EN 1015-10/A1[22]. This property is determined by the quotient of specimen's mass in the dry state obtained in an oven at 105°C by the volume it occupies when immersed in water in the saturated state.

For evaluation tests of water absorption by capillarity, the specification NF EN 1015-18[23] was considered. Samples were cured in 20°C water for 28 days and then dried in an oven until a stable mass value achieved. After cooling, they were placed in contact with 5 mm of water film. Finally, successive weighing was performed on each specimen for 24 hours.

Thermal property measurements of biomass composite were carried out by the hot ribbon method. The measuring device scheme is shown in figure 2 below.

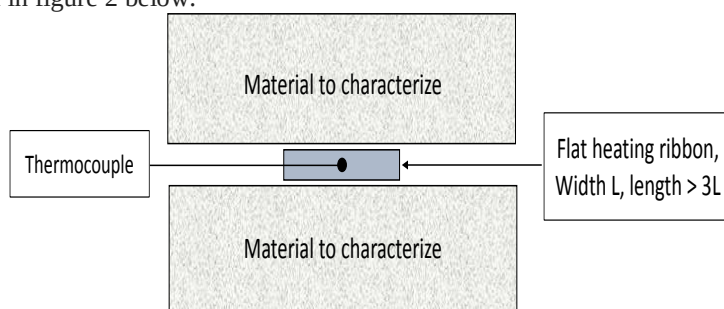


Figure 1:- Scheme of hot ribbon method device.

The mean values of density, water absorption by capillarity and thermal properties of each specimen were calculated as the average of three measured values.

Results And Discussion:-

Dry density

Dry density was determined on biomass cement composites after 28 days of curing. The results are presented in Table 4. As it can be seen, the density of composites increases with aggregates size in the mixture regardless of biomass nature. The increase ranges from 8% to 12% for mixtures based on rice husks and from 6% to 8% for those based on palm tree fibers. However, it is noted that the density of biomass-based composites increases slightly with cement content. Indeed, for an increase of 12% in cement content, the increase in the density of specimens is less than 10%. This suggests the existence of a limit value of density for plant biomass composites. These results corroborate those obtained in previous studies ([24][25]) and allow the classification of biomass-based composites in the category of lightweight concrete.

Table 4:- Average dry density values of the biomass composites.

Type of composite	Type of aggregate	Dry density (g/cm ³)		
		Cement ratio D ₁	Cement ratio D ₂	Cement ratio D ₃
Rice husk mortars	B ₁	1,08	1,17	1,36
	B ₂	1,21	1,27	1,32
Palm tree fibers mortars	F ₁	1,18	1,20	1,42
	F ₂	1,19	1,26	1,44

Water absorption by capillarity

It is well known that a good quality mortar possesses the lower capillarity absorption coefficient, which corresponds to a less porous mortar. According to Figure 3 below, the water absorption coefficient values decrease with an increasing cement content. The decrease varies from 10% to 30% for an increase in cement of around 10%. Furthermore, the values obtained on rice husk composites are higher than those obtained on palm tree fibers. This

shows that rice husks are more hydrophilic than palm tree fibers. These results are in accordance with measurements of dry density obtained on these composites.

Additionally, the water absorption coefficients obtained are greater than 20% for the two composites. These results agree with those obtained by Nguyen et al.[26] on hemp concrete.

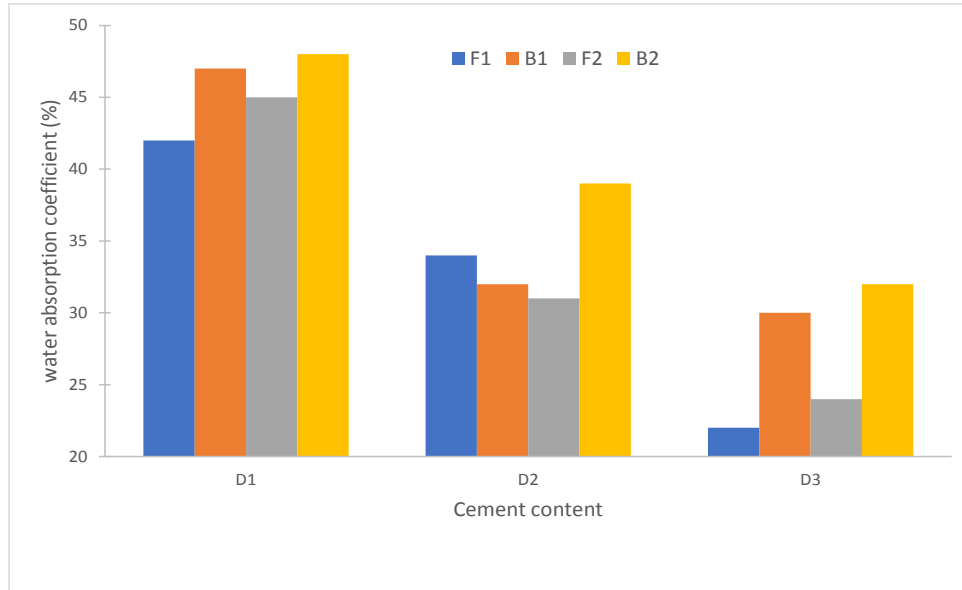


Figure 2:- water absorption coefficient of biomass mortars.

Thermal conductivity

The thermal conductivity values of the different mortars are presented in Figure 4 below. For both biomasses (F_i and B_i), values increase with cement content. For an increase in the cement content of about 10%, the thermal conductivity increases by an average 15%. These results confirm those of Dokoet al.[27] who obtained similar results on concrete based on palmyra aggregates.

Moreover, composites based on rice husks have lower thermal conductivities in the order of 10% to 30% as those based palm tree fibers. This means that these composites are better thermal insulators than others. However, for all composites, the thermal conductivity values remain lower than those of cement mortars and like those of oak wood [28].

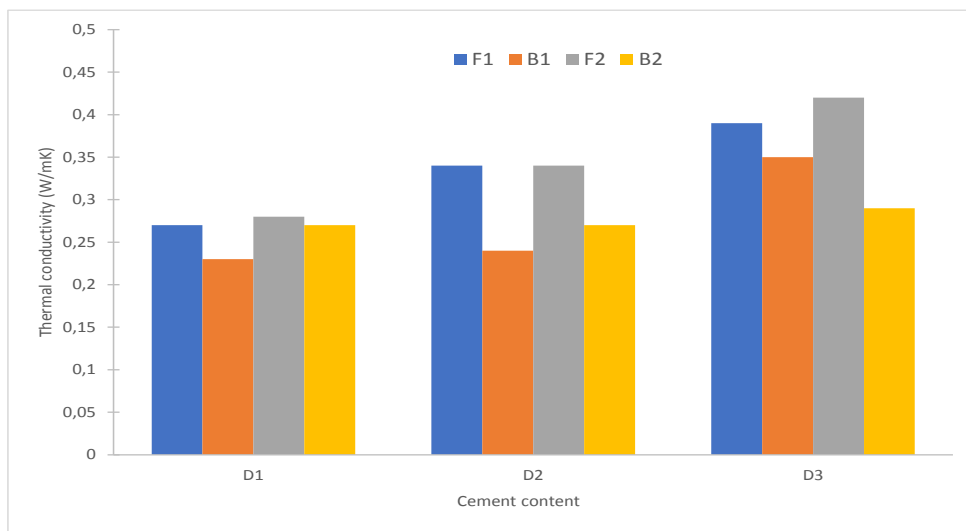


Figure 3:- Thermal conductivity of biomass mortars.

Variation of thermal conductivity versus dry density

According to the results presented, thermal conductivity increases with an increase in dry density. Figure 5 shows that thermal conductivity of composites increases with their density, which is due to an increase in cement content. However, for a given density, thermal conductivity of mortars contained palm tree fibers is higher (at least 15%) than those based on rice husks. These results highlight the effect of type of biomass on thermal properties of mortars made from plant waste[29].

Furthermore, figure 5 shows that for each mortar, a linear relationship can be established between thermal conductivity and dry density in accordance with previous works[30].



Figure 4:- Thermal conductivity vs dry density of studied specimens.

Variation of thermal conductivity versus water absorption by capillarity

It is well known that an insulating material is one which has low thermal conductivity. Considering the tests carried out, Figure 6 shows that thermal conductivity of the two composites decreases with the increase in water absorption coefficient by capillarity. This result was predictable because the samples with low water absorption coefficient are those with a high cement content (see Figure 3). Indeed, an increase in the cement content leads to a more compact mortar, therefore to a lower coefficient of water absorption by capillarity but to a high thermal conductivity.

Also, the shape of the curves presented in Figure 6 shows that it is possible to establish a mathematical relationship between thermal conductivity and the coefficient of water absorption by capillarity.

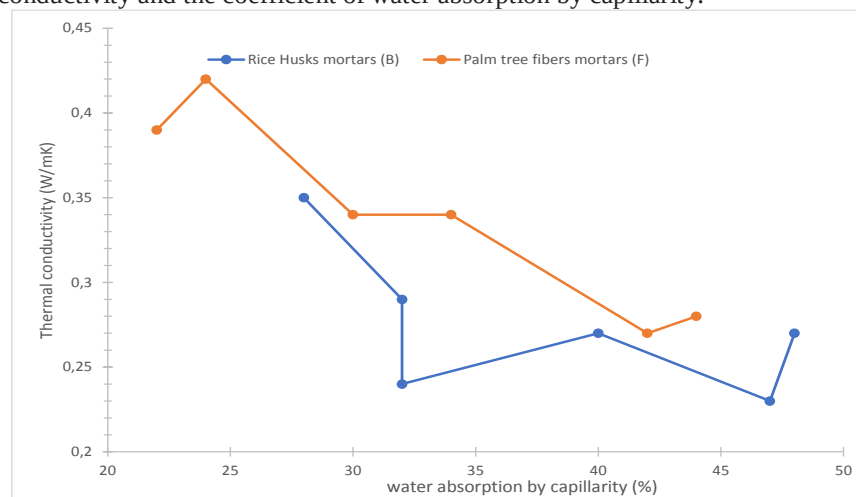


Figure 5: Thermal conductivity vs water absorption by capillarity.

Conclusion:-

Considering that the amount of rice husks and palm tree fibers waste produced annually is an environmental problem on planet, the manufacture of mortar with rice husks and palm tree fibers waste as aggregate, is an interesting option to be studied. The results in this study allow to conclude that:

1. The dry density of composites increases with biomass aggregate size regardless of biomass type;
2. The water absorption coefficient decreases with an increase in cement content;
3. The Thermal conductivity for both composites is lower than 0,5 W/mK;
4. The thermal conductivity for both composites increases with their dry density and decreases with an increase in water absorption coefficient;
5. The results obtain on mortars based on palm tree fibers are better than those obtained on rice husks based-mortars.

According to results obtained in this study, the use of rice husks and palm tree fibers waste as aggregate in the manufacture of biomass-based composite is a highly effective possibility. The results allow to consider a revaluation of these wastes in cementitious materials to make concrete having a low thermal conductivity.

Data availability

All data used to support this study are available from the corresponding author upon request.

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Funding statement

Not applicable

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Not applicable

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