

Development of a cellulose-based insulating composite material for green buildings: Case of treated organic waste (paper, cardboard, hash)

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Abstract. Buildings are responsible for 36% of the final energy consumption in Morocco [1-2], and a reduction of this energy consumption of buildings is a priority for the kingdom in order to reach its energy saving goals. One of the most effective actions to reduce energy consumption is the selection and development of innovative and efficient building materials [3]. In this work, we present an experimental study of the effect of adding treated organic waste (paper, cardboard, hash) on mechanical and thermal properties of cement and clay bricks. Thermal conductivity, specific heat and mechanical resistance were investigated in terms of content and size additives. Soaking time and drying temperature were also taken into account. The results reveal that thermal conductivity decreases as well in the case of the paper-cement mixture as that of the paper-clay and seems to stabilize around 40%. In the case of the composite paper-cement, it is found that, for an additives quantity exceeding 15%, the compressive strength exceeds the standard for the hollow non-load bearing masonry. However, the case of paper-clay mixture seems to give more interesting results, related to the compressive strength, for a mass composition of 15% in paper. Given the positive results achieved, it seems possible to use these composites for the construction of walls, ceilings and roofs of housing while minimizing the energy consumption of the building.

1. Introduction

The economy of the energy is increasingly a major challenge in the world because of economic and ecological concerns. Globally, the building sector alone accounts for 32% of final energy consumption and accounts for around a third of CO₂ emissions [3-4].

In Morocco, the energy consumption generated by buildings represents around 36% of total final energy consumption [5-6]. Reducing the energy consumption of buildings has therefore become a priority for the kingdom to achieve its greenhouse gas reduction targets. Among the priority actions, emphasis focused on selection and development of innovative building materials with interesting thermal and mechanical properties. Similarly, the conditions of thermal comfort in a room also depends on the activity in the neighboring premises. In the case of industrial activities, this generates thermal conditions that are difficult to mitigate by the construction products normally used in the



separation walls. This leads to large variations in the temperature of the surrounding premises and requires significant energy to maintain them at their thermal comfort level. For example, the Moroccan Construction Thermal Regulation (RTCM) states that, depending on the location and climate, the walls should be made of material with a heat transfer coefficient of between 0.55 and 1.20 W / m² K [6-7]. In this work, we have chosen as raw material a by-product of paper to be integrated with cement or clay in order to reinforce their quality of thermal insulation. The mechanical and thermal properties of the composite blocks were studied according to the amount of additives, the time of soaking in water and the drying temperature.

2. Material and experimental method

2.1. Materials and implementation

Our work consists of developing two types of paper-based composite materials. These two composites will be subjected thereafter to thermal and mechanical tests.

For the first prototype called "paper cement», the main constituent elements are paper waste mixed with cement, sand and water. Each component itself was subjected to initial preparation, starting with mixing with water followed by purification before mixing. The mixing process allows the transformation of waste paper into granulates. The latter will be wet before being dried at room temperature. For the second prototype, it consists of the following constituents: clay, paper waste, sand and water. The preparation protocol is the same as that of the "paper cement".

2.2. Geometry and conditioning of the samples

The "cement-paper" and "clay-paper" plates were prepared by molding in the form of a square of 20cm of side with a thickness of 2 cm. The following table gathers the physical and geometrical characteristics of the various constituents of the composites.

Table	Component	Mass volume g /cm ³	Range (mm)	Thickness Plate (cm)	L=l(Cm)	1.
	Paper	0,77	1.5			
	Clay	1,7	1.5			
	Sand	1,6	1	2	20	
	Cement	1.15	--			
	Water	1	--			

Density of the constituents of the composites.

The plates thus prepared were made in order to test the thermal conductivity. For mechanical bending tests, specimens were molded and prepared; these have the following characteristics: an area of (4*4

cm²) with a length of 16 cm. Both types of specimens were then dried for 2 hours in an oven at a temperature of $T = 105^{\circ}\text{C}$. Finally, the whole was treated in an oven at a temperature of 300° during. Both types of specimens were then dried for 2 hours in an oven at a temperature of $T = 105^{\circ}\text{C}$. Finally, the whole was treated in an oven at a temperature of 300° during.



Figure 1 Specimens made by addition of paper treated with cement and clay.

The methodology followed in our study consists in following the thermal conductivity and the mechanical rigidity of the samples prepared according to the ratio of additives. For this, the tests carried out consisted of samples using the following proportions of paper (0%, 5%, 7%, 10%, and 15%), with a fixed percentage (10%) of sand and a varying one (25-30%) of water.

Table 2. Composition of the plates prepared according to the mass composition of paper.

Plates	Components	Paper-Cement			
		%	$\rho(\text{g}/\text{cm}^3)$	V (cm ³)	m(g)
P1	Paper	0	0.77	0	0
	Cement	100	1.15	800	920
P2	Paper	5	0.77	40	31
	Cement	55	1.15	440	506
P3	Paper	7	0.77	56	44
	Cement	53	1.15	424	490
P4	Paper	10	0.77	80	62
	Cement	50	1.15	400	463
P5	Paper	15	0.77	120	92.4
	Cement	45	1.15	360	414

Table 3. Composition of specimens prepared according to paper mass composition for flexural tests.

Specimens	Components	Paper-Cement			
		%	$\rho(\text{g}/\text{cm}^3)$	V (cm ³)	m(g)
E1	Paper	0	0.77	0	0
	Cement	100	1.15	256	295
E2	Paper	5	0.77	13	10
	Cement	55	1.15	138	159
E3	Paper	7	0.77	18	14
	Cement	53	1.15	136	157
E4	Paper	10	0.77	26	21
	Cement	50	1.15	129	149
E5	Paper	15	0.77	39	31
	Cement	45	1.15	116	134

The thermal conductivity measurements were performed for the "cement-paper" and "clay-paper" plates after an adequate treatment of their surfaces. All the tests were carried out with a λ -Meter EP 500

apparatus according to the method of the guarded hot plate. Measurements were carried out at a temperature of 25 ° C, with a temperature difference of 10 K between the plates. The steady state is considered to be reached when the conductivity varies by less than 1% during a time interval of 60 minutes.



Figure 2 The hot plate machine keeps λ -METER EP500e [8].

For rectangular specimens, a flexural test was used to evaluate the maximum stress at break, the latter was determined by three-point bending on bars of length $l = 20$ cm and thickness ($e=2$ cm). Maximum stress was achieved using a KERNEL SISTEML brand machine (0 + 400 kg), (see figure 3). The test piece is held on two simple supports, distant of $L = 16$ cm. A charge F_r is applied at a point equidistant from the two supports.



Figure 3 Machine brand KERNEL SISTEML (0 + 400kg) [9].

3. Results and discussion

The results of thermal and mechanical measurements made on the "cement-paper" and "clay-paper" plate are summarized in table 4:

Table 4. Evolution of the thermal conductivity according to the mass composition of paper.

		Paper	P1	P2	P3	P4	P5
Paper-cement	λ (W/m.K)	0.068	0.218	0.195	0.183	0.140	0.107
Paper -clay	λ (W/m.K)	0.068	0.244	0.203	0.152	0.134	0.101

We have noted that the thermal conductivity of both "paper cement" and "paper-clay" specimens increases steadily as the percentage of paper increases in the matrix. It reaches about 40% when the weight ratio paper / cement is 15%. Similarly, the mechanical tests were carried out on a Hounsfield H50KS press, the bending and compression tests were carried out at the respective displacement speeds of 0.3 mm / min and 0.5 mm / min. Two samples were tested for every deadline. The flexural performance of the composites reinforced by the treated paper was determined (see Table 5). It can also be noted that the breaking force, FR and the breaking stress σ_r , decrease regularly as the percentage of paper increases in the cement. On the other hand, these two properties are improved in the case of clay; which suggests that in the latter case, the paper incorporation leads to the improvement of the mechanical behavior of the composite, increasing its ductility compared to the fragile behavior of the matrix alone. On the other hand, these two properties are improved in the case of clay. This suggests that in the latter case, the paper incorporation leads to the improvement of the mechanical behavior of the composite, increasing its ductility compared to the fragile behavior of the matrix alone.

Table 5. Evolution of the mechanical properties of the specimens (FR: breaking force, σ_r : breaking stress, S: surface of the specimens).

Specimens		Paper	E1	E2	E3	E4	E5
Paper - Cement	FR (KN)	--	7.84	6.51	5.01	4.40	4.14
	S (cm ²)	--	56	56	56	56	56
	σ_r (Mpa)	FR/S	1.4	1.16	0.89	0.79	0.73
Paper - Clay	FR (KN)	--	4.28	3.80	4.01	4.65	5.01
	S (cm ²)	--	56	56	56	56	56
	σ_r (Mpa)	FR/S	0,76	0,68	0,71	0,83	0,89

4. Conclusion

The main objective of this work is to evaluate the influence of the different percentages of paper on two clay components and cement in order to undertake a benchmarking study of these two composites,

and to determine the best insulator among its two materials, based on the parameters bending strength and thermal conductivity. The results obtained show that the "cement-paper" matrix composites are less resistant to fracture and the conductivity. However, the composite "clay-paper" paper has a higher and more reliable conductivity for use in thermal insulation. The results obtained show that the "cement-paper" matrix composites are less resistant to fracture and the conductivity against the composite "clay-paper" paper has a higher and more reliable conductivity for use in thermal insulation.

Abaqus software modeling counts among our future projects to compare the experimental results and numerical ones. In addition, we intend to make flow variation tests on the samples in a machine as a building containing a source of heat inside in order to study conduction transfer on walls.

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