

# Determination of the Thermophysical Characteristics of the Composite Material Clay Cement Paper

A. Ouargui, N. Belouaggadia, M. Ezzine

**Abstract**—In Morocco, the building sector is largely responsible for the evolution of energy consumption. The control of energy in this sector remains a major issue despite the rise of renewable energies. The design of an environmentally friendly building requires mastery and knowledge of energy and bioclimatic aspects. This implies taking into consideration of all the elements making up the building and the way in which energy exchanges take place between these elements. In this context, thermal insulation seems to be an ideal starting point for reducing energy consumption and greenhouse gas emissions. In this context, thermal insulation seems to be an ideal starting point for reducing energy consumption and greenhouse gas emissions. The aim of this work is to provide some solutions to reduce energy consumption while maintaining thermal comfort in the building. The objective of our work is to present an experimental study on the characterization of local materials used in the thermal insulation of buildings. These are paper recycling stabilized with cement and clay. The thermal conductivity of these materials, which were constituted based on sand, clay, cement; water, as well as treated paper, was determined by the guarded-hot-plate method. It involves the design of two materials that will subsequently be subjected to thermal and mechanical tests to determine their thermophysical properties. The results show that the 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%. Measurements of mechanical properties such as flexural strength have shown that the enrichment of the studied material with paper makes it possible to reduce the flexural strength by 20% while optimizing the conductivity.

**Keywords**—Building, composite material, insulation, thermal conductivity, paper residue.

## I. 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 CO<sub>2</sub> emissions [1].

In Morocco, the energy consumption generated by buildings represents around 36% of total final energy consumption [2].

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Reducing the energy consumption of buildings has therefore become a priority for them to achieve its greenhouse gas reduction targets [3].

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 [4]. 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/m<sup>2</sup>K [5].

Thermal insulation of envelopes is a very important area of research. It has been developed in recent years. Several numerical and experimental studies have been conducted on eco-materials. Among these, the Chakirou cement and the incorporation of 2% straw have better thermal performance and therefore have good thermal comfort. In addition, the work done so far reveals that paper waste has made it possible to manufacture several environmentally friendly insulation materials. Among these materials the paper binder (papercrete) [6] is a poorly developed product based on 60% of recycled paper, from 20 to 30% of sand, and from 10 to 20% of lime. As a result, the thermal conductivity becomes 0.06 [W/m.°K] comparable to the mechanical strength which becomes 140 kg/cm<sup>2</sup> or 13.5 Mpa for cellulose wadding granulate [7] that is obtained with a mixture of paper, sand and cement. This product can be used as sound insulation and "patching" dry to make up for flatness defects on old floors and the thermal conductivity of cellulose wadding in aggregate is 0.069 [W/m.°K] [8].

In this work, we chose as raw material a paper-based by-product to be integrated with cement or clay to enhance their thermal insulation quality. 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.

## II. MATERIAL AND EXPERIMENTAL METHOD

### A. 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 the elements 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. The second prototype consists of the following constituents: clay, paper waste, sand and water. The preparation protocol is the same as that of the "paper cement".

### B. Geometry and Conditioning of the Samples

The "cement-paper" and "clay-paper" plates were prepared by molding in the form of a square of 20 cm of side with a thickness of 2 cm. Table I gathers the physical and geometrical characteristics of the various 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 cm<sup>2</sup> 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 °C. Finally, the whole was treated in an oven at a temperature of 300 °C for 3 hours.

TABLE I  
DENSITY OF THE CONSTITUENTS OF THE COMPOSITES

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



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

The methodology followed in our study consists of 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 varying water from 25%-30%.

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  $\lambda$ -Meter EP 500 [9] apparatus according to the method of the guarded hot plate. Measurements were carried out at 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.

TABLE II  
COMPOSITION OF THE PLATES PREPARED ACCORDING TO THE MASS COMPOSITION OF PAPER

Plates	Components	%	$\rho$ (g/cm <sup>3</sup> )	V (cm <sup>3</sup> )	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 III  
COMPOSITION OF SPECIMENS PREPARED ACCORDING TO PAPER MASS COMPOSITION FOR FLEXURAL TESTS

Specimens	Components	%	$\rho$ (g/cm <sup>3</sup> )	V (cm <sup>3</sup> )	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

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) [10]. The test piece is held on two simple supports, distant of L = 16 cm. A charge Fr is applied at a point equidistant from the two supports.

### III. RESULTS AND DISCUSSION

According to the thermo-mechanical tests on the "cement paper" and "clay paper" plates, we obtained the following results in Figs. 2 and 3.

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 paper-cement ratio 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 IV). It can also be noted that the breaking force, FR and the breaking stress  $\sigma_r$ , 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.

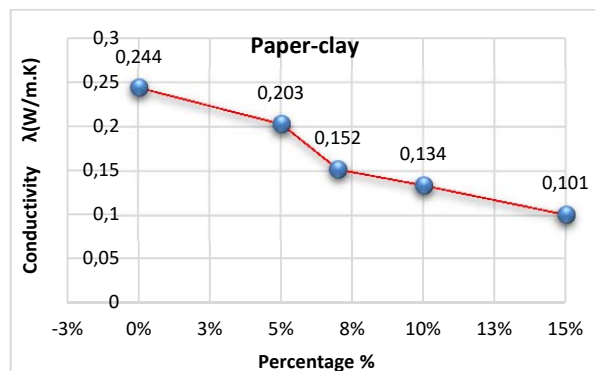


Fig. 2 Evolution of the thermal conductivity of paper-clay

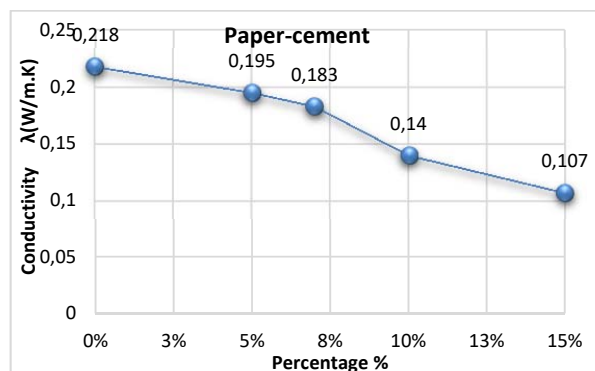


Fig. 3 Evolution of the thermal conductivity paper-cement

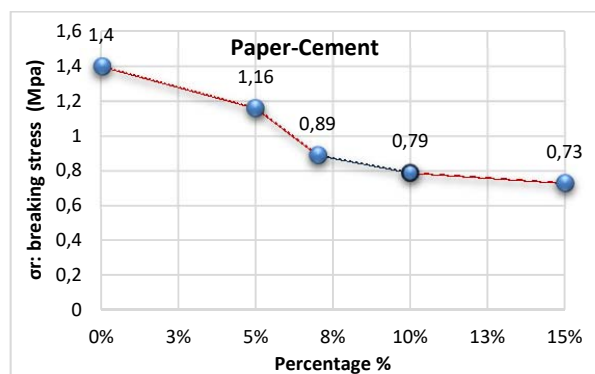


Fig. 4 Evolution of the mechanical properties of the specimens: paper-cement (σ: breaking stress)

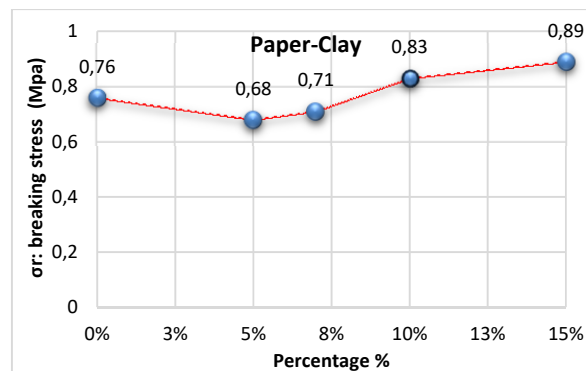


Fig. 5 Evolution of the mechanical properties of the specimens Paper-Clay (σ: breaking stress)

TABLE IV  
RESULTS FOUND

materials	physical and thermal properties	Paper	P1/E1	P2/E2	P3/E3	P4/E4	P5/E5
paper-cement	λ(W/m.K)	0,068	0,218	0,195	0,183	0,14	0,107
	FR (KN)		7,84	6,51	5,01	4,4	4,14
	σ (Mpa) FR/S		1,4	1,16	0,89	0,79	0,73
Paper-Clay	λ(W/m.K)	0,068	0,244	0,203	0,152	0,134	0,101
	FR (KN)		4,28	3,8	4,01	4,65	5,01
	σ (Mpa) FR/S		0,76	0,68	0,71	0,83	0,89

#### IV. 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. Using TRNsys software we will compare the experimental and numerical results. 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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