Construction and Building Materials 18 (2004) 437–443

Construction and Building MATERIALS

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Thermo physical characteristics of economical building materials

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Received 21 October 2002; received in revised form 8 March 2004; accepted 9 March 2004

Abstract

An experimental study was carried out in order to determine the properties of local materials used as construction materials. Cement stabilized compressed bricks were tested. The thermal properties of lateritic soil based materials were determined. The objectives of work reported in this paper are to determine the effect of addition of pozzolan or sawdust in lateritic soil brick on the thermal properties. It was shown that the effect of incorporation of pozzolan or sawdust is the decreasing of the thermal conductivity and density. The moisture content of these materials can modify their thermal performance. Thus a study of the influence of the water content on the thermal conductivity k and the thermal diffusivity α is presented. The thermal conductivity as a function of water content increases rapidly between 0 and 12% for lateritic soil. The thermal diffusivity curve presents a maximum for values of water content of 15% for lateritic soil and 8% for lateritic soil–pozzolan or lateritic soil–sawdust. However, the composite materials used for building shielding must present sufficient mechanical strength to be suitable for constructions. According to the experimental results the effect of adding cement or pozzolanic stabiliser is expressed in increase of strength of samples studied.

Keywords: Lateritic soil bricks; Pozzolans; Thermophysical properties

1. Introduction

The cost of building materials is often exorbitant, particularly when most of the materials have to be imported. It is preferable to build with locally available material that may have limited durability, but where cost is within the reach of rural people. In tropical climates heat poses an important consideration that must be factored into the design of suitable and affordable housing in such an environment. Earth blocks have been used in home construction in many countries for a long time. Research has shown that it is possible to provide construction materials and methods that are appropriate for such environments and are also affordable. Recent efforts [1,2] have shown that blocks and bricks made from lateritic local soil can be improved upon to produce masonry units with strengths high enough to meet building standards. Akinmusura in 1985 [3] has shown that the inclusion of grids of wood or bamboo cores significantly improves the bending strength of earth walls built for appropriate use by rural dwellers.

This study shows that the compressive strength can be further increased by the addition of ordinary Portland cement to the lateritic soil mix. Adesanya [4] has conducted a study to determine the effect of using corn ash (pozzolanic waste byproduct of corn cobs) as a cost-reducing additive in blended cement One of the important requirements of a building material is that it allows the passage of as little heat as possible. In hot climates, the thickness of the walls sometimes must be increased to reduce the passage of heat. A study of the thermal properties of the materials used for these walls is essential in order to relate the strength qualities of the walls to the corresponding thermal comfort. The aim of the work reported in this paper is to determine the effect

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doi:10.1016/j.conbuildmat.2004.03.10

of addition of pozzolan or sawdust in laterite brick on the thermal properties, i.e. thermal conductivity and thermal diffusivity and to determine how the water content affects these thermal properties. The objective is the valorization of local materials: important quantities of sawdust are lost in form of burning in main forestry regions.

2. Experimental device and principle of the method

2.1. Identification of materials

The materials were lateritic soil, natural pozzolan and sawdust.

- Laterite soils are commonly found in Cameroon and are usually traditional building materials. Yet untreated laterite materials have presented many problems in building construction.
- The chemical analysis of natural pozzolan determined by X-ray fluorescence [5] is reported in Table 1. The reasons for partially replacing cement in earth block with natural pozzolan are diverse. They include strength enhancement in, for example the production of high-strength silica fume concrete improvement in durability such as increased sulfate resistance and improved resistance to alkali aggregate reaction [6]. There are clear environmental advantages in reducing the quantity of cement used in construction building materials.
- The cement used for stabilization of lateritic soil is cement 325 that contains 80–85% of clinker, 10–15% of natural pozzolan and 5% of gypsum.
- The quantity of industrial wood wastes generated in Cameroon is very important and will increase in the near future. The conversion of industrial wood residues to usable building materials is a contribution to the protection environment.

The studied samples were:
Mix 1: lateritic soil with 8% of cement.
Mix 2: 45% of lateritic soil, 45% of natural pozzolan, 10% of cement.
Mix 3: 81% of lateritic soil, 9% of sawdust, 10% of cement.

2.2. Effect of cement on water absorption

The use of cement stabilization of lateritic soil had been reported in an unpublished report on tests carried out at the Ecole Nationale Supérieure Polytechnique de Yaoundé. The addition of cement had an effect on water absorption. Fig. 1 shows the variation of water absorption rate with time at different cement contents. Water absorption rate decreases with increasing cement content. For a cement content of more than 8% the supplementary addition of cement has no effect on the water absorption.

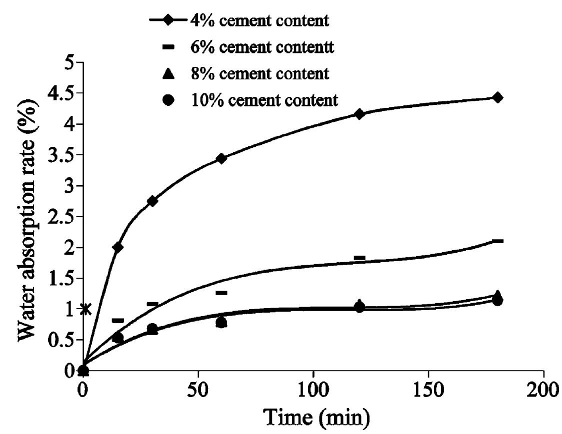

Fig. 1. Variation of water absorption rate with time for different cement contents.

2.3. Thermal conductivity measurements

The thermal conductivity measurements are based on steady-state heat transfer. The experimental setup is shown in Fig. 2. It consists on an isothermal enclosure with glycol maintained at low temperature by a cryostat. Each box has a heater and two atmospheres below and above the sample. The geometry of the sample and the precaution taken in order to limit the lateral heat lost allow us to consider the unidirectional heat transfer.

The energy balance equation for each box can be written as follows

$$\frac{V^2}{R}=\frac{kA}{e}(T_1-T_2)+C_1(T_i-T_a) \tag{1}$$

where: $\frac{V^2}{R}$: Power supplied by the electric resistance, $\frac{kA}{e}\times(T_1-T_2)$: Thermal conduction through the sample, $C_1(T_i-T_a)$: Heat flow exchanged between internal and external atmospheres.

Table 1
Chemical analysis of natural pozzolan

Constituents	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	P.F.
Content (%)	45.79	15.68	12.83	0.17	6.26	9.60	3.54	1.39	2.84	0.60	0.31

The expression of the thermal conductivity is deduced from the Eq. (1) and is given by

$$k=\frac{e}{A(T_1-T_2)}\left[\frac{V^2}{R}-C_1(T_i-T_a)\right] \tag{2}$$

In the expression (2), temperatures T_1, T_2, T_i and T_a are measured using platinum resistances.

2.4. Thermal diffusivity measurement

The principle of the experimental method is to generate a signal on one face of the sample and examine the response on the other face. The entrance signal can be an impulse as in the flash method [7], periodic or a step function. The measurement apparatus used in this study is the same as that for thermal conductivity measurement. In addition, it has an incandescent lamp as shown in Fig. 3. Diffusivity measurement is undertaken by using a flash method. An uniform short pulse of energy is applied to one side of the sample, and then with the theoretical model of Degiovani [8] the thermal diffusivity is evaluated from the temperature variation of the other side of the sample. This model considers the heat lost by convection.

3. Results and discussion

The experimental results for the three mixes of studied materials are presented.

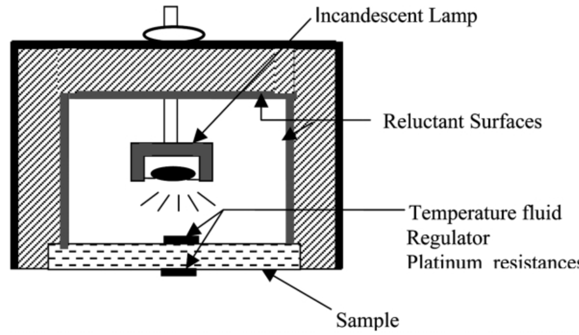

Fig. 3. Thermal diffusivity measurement apparatus.

3.1. Thermal conductivity

Table 2 presents the values of thermal conductivity k of different samples, obtained experimentally by the box method.

The measurements of thermal conductivity of lateritic soil (Mix 1) give values between 0.75 and 1.15 W m^{-1} K^{-1}. The thermal conductivities of Mix 2 and Mix 3 are less than that of laterite soil. The effect of incorporating natural pozzolan or sawdust in Mix 1 is to decrease the thermal conductivity and the density of these materials. As natural pozzolan is more porous material than laterite, the presence of pores containing air whose thermal conductivity is very small compared to that of laterite could explain this phenomenon. Sawdust is fibrous material and consequently is an insulator.

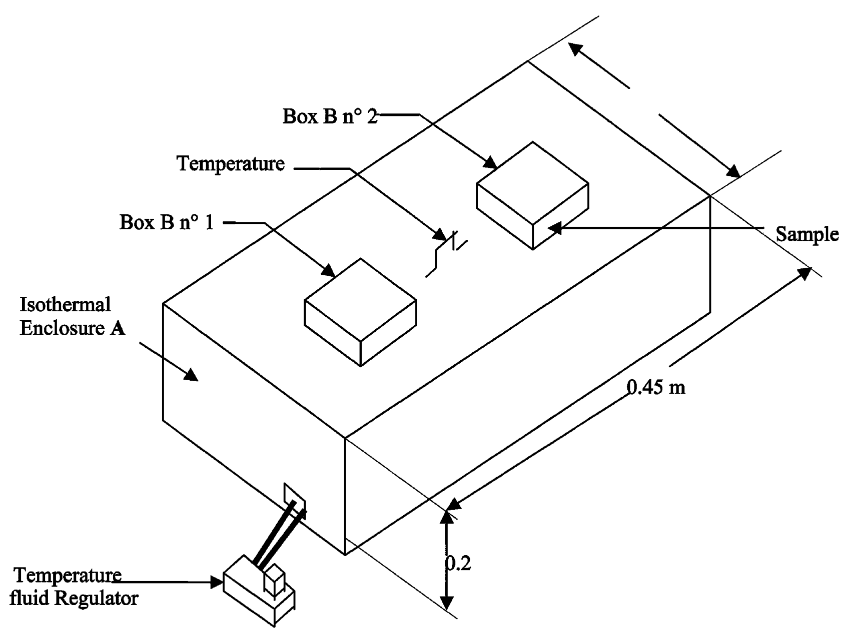

Fig. 2. Experimental setup of the box method.

Table 2
Experimental thermal conductivity and density of the tested samples

Sample	Compacting pressure (MPa)	ρ (kg m^{-3})	k (W m^{-1} °C^{-1})
Mix 1	5.3	1491	0.75
	6.7	1807	0.95
	8.5	1966	1.15
Mix 2	4.1	1329	0.65
	5.8	1576	0.69
	8.9	1643	0.71
Mix 3	6.5	1050	0.50
	7.1	1098	0.51
	9.6	1207	0.65

3.2. Thermal diffusivity

Thermal diffusivity can also be obtained by calculation using the following relation.

$$\alpha_1 = \frac{k}{\rho C} \tag{3}$$

In the relation (3), the thermal conductivity k is measured using box method and the specific heat C has been determined experimentally using calorific method.

Table 3 compares the results of thermal diffusivity measured by flash method and that obtained using relation (3).

Table 4 compares the values of specific heat measured using calorimetric method and those obtained by relation (3), where values of k and ρ are obtained experimentally. The compared results of thermal conductivity measured with box method and flash method are presented in Table 5.

3.3. Influence of water content on thermal conductivity

Fig. 4 shows the variation of the thermal conductivity of the three tested materials with water content. The thermal conductivity increases with water content. A moist material, therefore conducts more heat than a dry one. This phenomenon is due to the fact that the lateritic soil is a porous medium. The thermal conductivity coefficient of water is higher than that of air. Rapid increase of thermal conductivity can be explained by the presence of thermal 'gap' number in the interstitial space for a low water content. The maximum thermal conductivity coefficient reached can be explained by the value of thermal conductivity coefficient of water 0.6 W m^{-1} K^{-1} [9].

3.4. Influence of water content on thermal diffusivity

The variation of thermal diffusivity with water content is shown in Fig. 5. The curves are similar to published

Table 3
Comparison between thermal diffusivities measured by two methods

	ρ (kg/m^3)	ω (%)	C (kJ/kg °C)		α_1	α_2
			Drier sample	Wet sample	10^{-7} m^2/s	10^{-7} m^2/s
Mix 1	2023	3.45	1.013	1.12	4.19	4.68
	1930	3.41	0.898	1.01	4.87	5.18
	2070	3.34	1.1	1.20	3.82	4.60
	average	3.40	1.00	1.11	4.30	4.82
Mix 2	1734	2.71	0.951	1.04	3.79	4.01
	1777	2.82	0.909	1.0	3.85	3.83
	1772	2.38	0.969	1.04	3.71	3.75
	average	2.64	0.943	1.03	3.78	3.86
Mix 3	1220	3.25	0.816	0.922	4.92	3.03
	1274	3.69	0.905	1.02	4.26	2.71
	1241	3.76	0.912	1.03	4.33	2.54
	average	3.57	0.878	0.99	4.50	3.02

α_1: relation (3) with experimental thermal conductivity.
α_2: experimental results (flash method).

Table 4
Comparison between specific heats measured by two methods

	Mix 1			Mix 2			Mix 3		
Pc (MPa)	2	1.5	1	2	1.5	1	2	1.5	1
k (W/m °C)	1.03	0.87	0.79	0.56	0.49	0.46	0.46	0.43	0.36
C_1 (kJ/kg)	1.02	0.97	1.02	0.96	0.96	0.98	1.07	1.17	1.10
Average C (relation 3)			1.02			0.97			1.12
C_2 (calorimetric method)			1.11			1.03			0.99
Relative difference (%)			8			6			11

C_1: relation 3.
C_2: experimental (calorimetric method).

Table 5
Comparison between thermal conductivities obtained using box method and flash method

	Compacting pressure (bar)	k_1 (box method) (W m^{-1} °C^{-1})	k_2 (flash method) (W m^{-1} °C^{-1})	Relative difference (%)
Mix 1	20	1.03	1.04	1
	15	0.87	1.01	14
	10	0.79	0.89	11
Mix 2	20	0.56	0.62	10
	15	0.49	0.60	18
	10	0.46	0.58	21
Mix 3	20	0.46	0.44	4
	15	0.43	0.38	12
	10	0.36	0.34	6

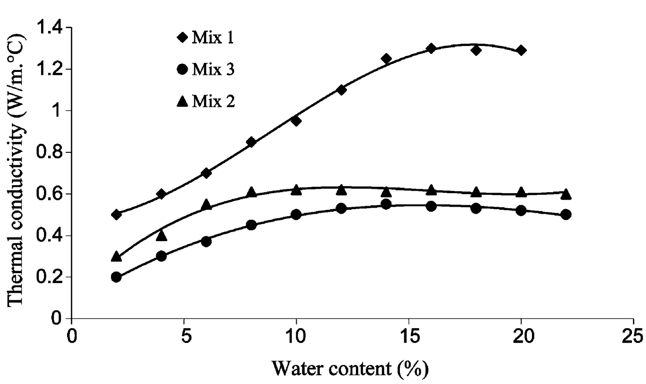

Fig. 4. Thermal conductivity of the three tested materials as a function of water content.

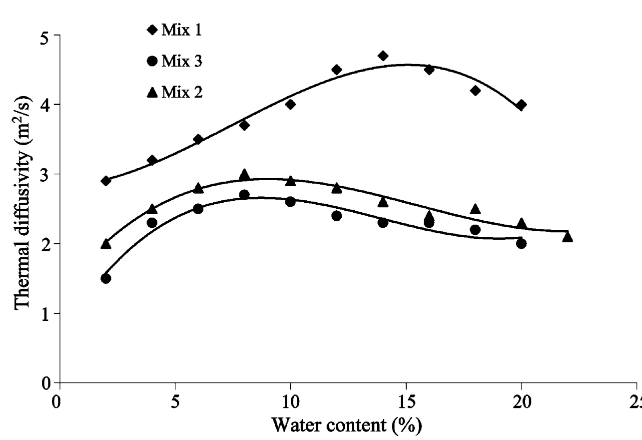

Fig. 5. Thermal diffusivity as function of water content.

results [9]. A maximum of thermal diffusivity is observed for values of water content of 14% for Mix 1 18% for Mix 2 and Mix 3. This maximum value of thermal diffusivity with increase of water content can be explained by the fact that the velocity of heat diffusion cannot increase indefinitely.

3.5. Influence of relative humidity on the three tested materials blocks

The behaviour of samples made from the three studied materials in a high relative humidity medium are presented in Fig. 6. The sorption curves show that Mix 3 material, which contains sawdust, absorbs water vapor more than Mix 1 and Mix 2 materials. It can be explained partially by the fact that sawdust, a wood waste, is a very hygroscopic material.

4. Mechanical properties

Earth blocks are generally used in domestic constructions. Most codes specify a requirement on the material's minimum compressive strength. In order to cope with

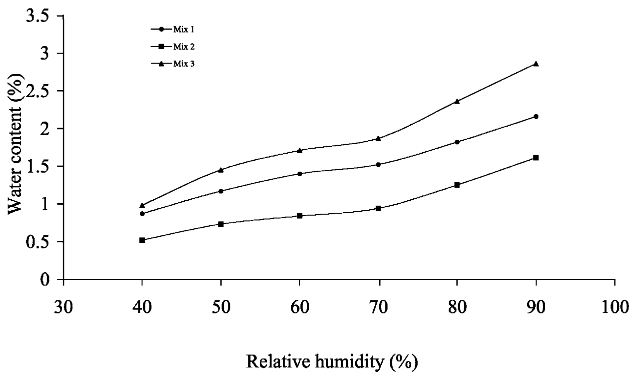

Fig. 6. Sorption curves of the three studied materials.

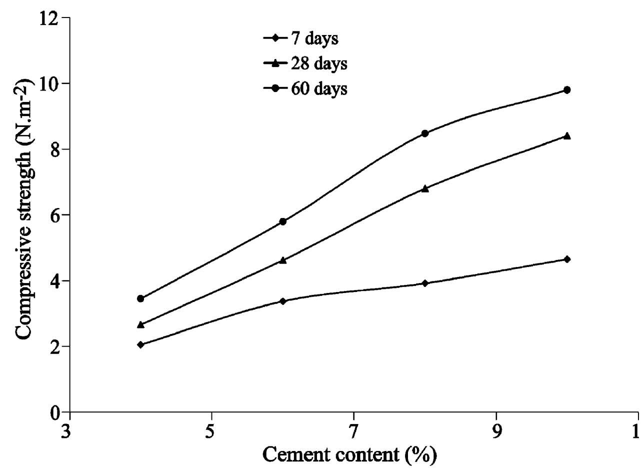

Fig. 7. Compressive strength as function of cement content.

the higher loads imposed by two- or three-storey houses and to increase durability, cement stabilized, pressed earth blocks are frequently used. The blocks are made of earth stabilized with up to 10% of cement. It is well known that the strength of stabilized blocks depends on the type and amount of stabilizer used, level of compaction, curing conditions and temperature in the early days after casting. The results of mechanical tests carried out in order to assess the compressive strengths of the three studied materials are included between 2.50–3.5 MPa for Mix 1, 1.5–2.5 MPa for Mix 2 and 2.75–4 MPa for Mix 3. These results are comparable to those published by Solomon-Ayeh [10]. The compressive strength of stabilized laterite blocks (8% of cement) varied between 2 and 6 MPa. The relative small values of compressive strength for Mix 2, Laerite+Pozzolan, can be explained by the presence of air into it pores. The variation of compressive strength with cement and pozzolanic stabliser contents in shown in Figs. 7 and 8, respectively. The strength of laterite increases with the content of each of these two stabilizers. The compressive strength of stabilized earth blocks also increases with age.

5. Conclusions

An experimental study was carried out on the thermal properties of bricks made from lateritic soil. In order to limit water absorption and to increase durability cement has been added to the earth blocks. Experiment shows that cement content up to 10% is enough to limit water absorption. The effect of the addition of natural pozzolan or sawdust is the decrease of their thermal conductivity. It has been shown that water content is major variable affecting thermophysical properties of the tested samples. The coefficients of thermal conductivity and thermal diffusivity were strongly influenced by the material's water content. The thermal properties as a

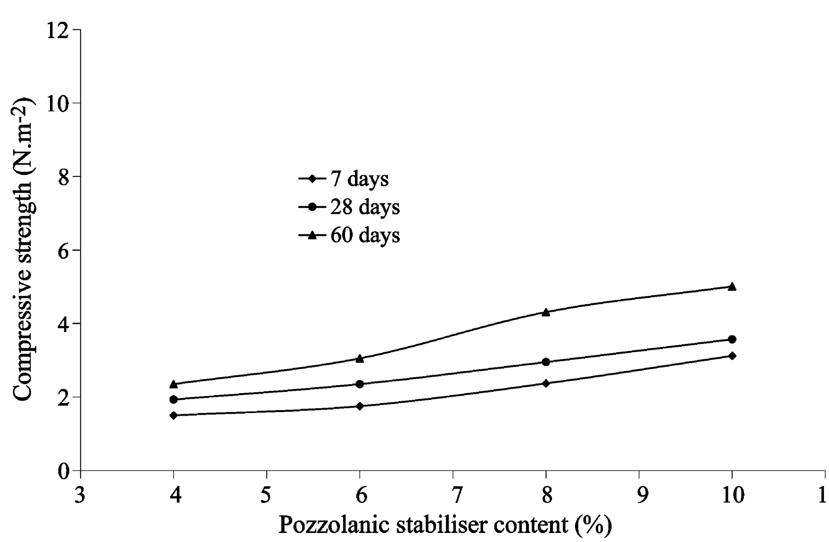

Fig. 8. Compressive strength as function of pozzolanic stabilizer content.

function of water content give non-linear relations. The obtained behaviors show a rapid increase for low water content and a maximum diffusivity for a water content of 14% for laterite and 8% for laterite with addition of natural pozzolan or sawdust. The addition of natural pozzolan or sawdust in bricks made from laterite leads to maintain their strength while decreasing their density and their thermal conductivity. The effect of the incorporation of cement or pozzolanic stabilizer is the increase of compressive strength. Numerical studies will strength the experimental results and give arguments to the choice of stabilized clay bricks in building components.

6. Nomenclature

A	Area	m^2
C	Specific heat	kJ kg^{-1} °C^{-1}
C_1	Over all heat transfer coefficient	W m^{-2} °C^{-1}
e	Thickness of sample	m
k	Thermal conductivity	W m^{-1} °C^{-1}
Pc	Pressure	MPa
Rc	Compressive strength	MPa
T_1	Temperature of upper face of sample	°C
T_2	Temperature of down face of sample	°C
T_a	Ambient temperature	°C
V	Potential difference	V
α	Thermal diffusivity	m^2 s^{-1}
ω	Water content	%
ρ	Density	kg m^{-3}

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