Thermal and Mechanical Characteristics of Mortars Produced with a Binder Containing Two Ashes of Cow Dung and Industrial Fly Ash

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Abstract— This work is a comparative study of thermal and mechanical behavior of 04 different mortars including a reference mortar made from commercial binder (Portland cement CEMII / A-LL 42.5 R) and sand, three other mortars made from industrial fly ash (based on bituminous coal), ash obtained by incineration of cow dung in laboratory and ash obtained by artisanal incineration of cow dung. In order to better appreciate the influence of ashes incorporation in mortars, various assays were carried out : 0 %, 5 %, 10 %, 15 %, 20 % and 25 % of each ash. Thermal conductivity and resistance of mortars were measured with FOX200 device, in accordance with ASTM C518-04 (Standard Test Method for Steady-State Thermal Transmission Properties by Heat Flow Meter Apparatus). Compressive strength of mortars was determined with Tecno Test device, in accordance with NF EN 12390-01 standard. The results obtained showed that thermal conductivity and resistance vary from 0.6132 $\mathrm{W.m^{-1}.K^{-1}}$ to 0.3782 $\mathrm{W.m^{-1}.K^{-1}}$ respectively, and from 0.0498 $\mathrm{m^2.K.W^{-1}}$ to 0.0877 $\mathrm{m^2.K.W^{-1}}$. Thermal conductivity decreases and thermal resistance increases as ash content increases. In addition, the lowest thermal conductivity and therefore the highest thermal resistance were obtained with bituminous coal ash mortar. It is also observed that thermal resistance of cow dung ash mortars are very close between 0 and 5 % of ash, but beyond 5 %, thermal resistance of artisanal ash mortar is greater than that of mortar based on laboratory ash. Mechanical results showed that mortars compressive strengths of 28 day and 90 day decrease as the ash content increases. Compressive strength varies from 24.35 MPa to 35.56 MPa at 28 days, and 29.65 MPa to 37.89 MPa at 90 days. Highest compressive strength was obtained with reference mortar, and the lowest with artisanal ash mortar.

Key words: Cow dung ash, fly ash, thermal conductivity, thermal resistance, compressive strength

NOMENCLATURE

R_{th}	$m^2.K.W^{-1}$
S_0	Calibration factor of fluxmeters, $W.m^{-2}.\mu V^{-1}$
T	Temperature, K
T_{cold}	Cold plate temperature, K
T_{hot}	Hot plate température, K
X	Space variables, m

Greek letters:

λ	Thermal conductivity, $W.m^{-1}.K^{-1}$
ϕ	Heat flux density, $W.m^{-2}$

I. INTRODUCTION

In the interest of saving energy in the building while providing the occupants with better thermal comfort, the recent research work has been fundamentally focused on eco-materials or local building materials. The techniques for producing these materials are many and varied, so we distinguish between materials mainly based on various traditional and industrial waste, vegetable matter such as vegetable fibers, sawdust, and so on. [1-3-4-5]. In addition to the need for energy saving and thermal comfort, the use of these basic raw materials is not only motivated by the concern for the protection of the environment but also by the concern for the development of local natural resources. With this in mind, we have previously shown that the incorporation of a moderate amount of sawdust or cow dung in stabilized clay bricks makes it possible to obtain a material with acceptable thermal and mechanical properties in the building sector [1-3]. Other authors such as Pavithra in 2016, Milligo and al in 2016 and Pascal in 2010, have shown that apart from its quality of ornamental material and its therapeutic virtues, cow dung plays both a role binder and insulation in the building sector [8-10]. Some studies have already been done on the mechanical properties of mortars and concretes containing ashes of ash and especially of cow dung ash [5-6-7-8].

The main objective of this work is to measure and make a comparative study of the thermal and mechanical properties of mortars made from three types of ash: an industrial fly ash based on bituminous coal, an ash produced by incineration of dung cow in the laboratory and an ash obtained by artisanal incineration of cow dung. To achieve this, mortars based on sand, cement and various dosages (0 %, 5 %, 10 %, 15 %, 20 % and 25 %) of each ash were made. Thermal tests based on the measurement of conductivity and thermal resistance were performed with the FOX200 in accordance with ASTM C518-04 (Standard Test Method for Steady-State Thermal Transmission Properties by Heat Flow Meter Apparatus). The compressive strength of the mortars was also determined with the Tecno Test device, in accordance with standard NF EN 12390-01 [5].

II. MATERIALS

A. Basic materials

1) Cement

The cement used is of the Portland CEM II/A-LL 42.5 R type. It is a Portland cement-limestone with high initial strength. According to EN 197-1: 2002, it mainly consists of clinker (80-94 %) and mixed admixture of 6-20 %.

2) Cow dung ash produced in laboratory

Cow dung produced in the laboratory is obtained by incineration of cow dung taken from a cattle breeding site of the University of Abomey-Calavi (UAC-Benin). Cow dung is collected fresh and pre-dried in the sun to constant mass (Figure 1). It is then incinerated at a temperature of 550 ° C by means of an oven [5].

Dried cow dung | Ground cow dung ready for incineration in laboratory

Fig. 1: Dried and ready cow dung for incineration

3) Cow dung ash artisanaly produced

The hand-produced cow dung ash is produced by the artisanal incineration of cow dung taken from the same site and which has undergone the drying process [5]. The dried dung was burned and sieved. The maximum diameter of the particles is 120 µm. The material thus produced is in powder form similar to that produced in the laboratory. Figure 2 shows the artisanal incineration of cow dung.

Fig. 2: Artisanal incineration of cow dung [5].

B. Commercial fly ash

The commercial fly ash used is class F, obtained from bituminous coal. It is commonly used for the commercial production of mortars and concretes. The physical properties and chemical composition of the three ashes are presented in Table 1.

Properties	LCDA	ACDA	FA
Physical properties			
Density			
- Specific density (kg/m^3)	1234	1118	-
- Apparent density (kg/m^3)	683	647	-
Fineness - Specific area, Blaine, (m^2/kg)	362	349	-
Chemical analysis (%)			
- Silica (SiO_2)	66,86	64,26	51,3
- Alumina (Al_2O_3)	4,56	4,28	25,0
- Iron (Fe_2O_3)	3,92	3,16	15,7
- Lime (CaO)	13,99	14,59	1,5
- Magnesia (MgO)	0,92	2,02	0,9
- Potassium (K_2O)	1,23	2,93	0,4
- Alkali equ. (Na_2O+0.658 K_2O)	1,0	1,0	2,3
- Titanium (TiO_2)	0,87	0,65	0,8

Table 1: Ashes properties and chemical composition.

1) Water reducer adjuvant

Sika-Fluid is the water reducer adjuvant used. It is a new generation of water-reducing additive that increases the mechanical strength of mortars and concretes. It complies with standard NF EN 934-2. Its density is 1.15, its pH is 7.4, its content in Cl^- ion is less than 0.1 %. The dosage range indicated by the manufacturer is from 0.1 to 5.0 % of the weight of the binder or cement according to the desired fluidity and performance.

2) Sand

Figure 3 presented the granulometric characteristic.

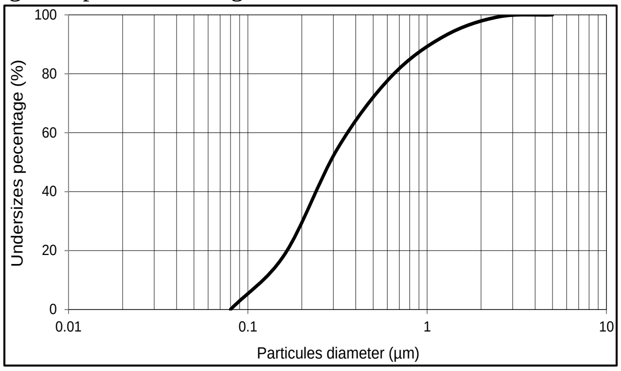

Fig. 3: Grain size curve of used sand

All mortars were produced with siliceous alluvial sand having a density (SSS) of 2.67, absorption of 0.6 % and a fineness modulus of 2.59. The maximum particle diameter is 5 mm and has a spread particle size.

C. Samples making

1) Mixtures codification

The reference mortar is coded Control. The mortars containing the ash are coded by capital letters that indicate the nature of the ash (CFA = Commercial Fly Ash, LCDA = laboratory cow dung ash mortar and ACDA = artisanal cow dung ash mortar) and two numbers that indicate the proportion of substitution in ash (eg LCDA-10 = 10 % mortar of laboratory cow dung ash).

2) Mortar dosing

Tables 2, 3 and 4 show the composition of the mortars. The quantities of sand indicated are in the saturated dry surface (SSS) state. For all mortars, the water/binder ratio is 0.5 and the water / cement ratios vary depending on the ash content. The water/cement ratios are between 0.5 and 0.67. All mortars contain 5 $kg.m^{-3}$ of water reducer, ie a dosage of 0.1 % of the total weight of the binders. The densities measured are between 2012 $kg.m^{-3}$ and 2139 $kg.m^{-3}$ with an average of 2061 $kg.m^{-3}$. The workability of the mortars is measured with the Abrams mini-cone test. The values obtained for the subsidence tests are 75 mm and 95 mm. The temperatures measured on fresh concrete are between 20 °C and 21 °C.

	Contr.	Laboratory cow dung ash mortar (LCDA)				
		5%	10%	15%	20%	25%
Cement (kg/m^3)	470	440	410	381	357	333

Ash (kg/m^3)	-	23	45	67	89	111
Total (kg/m^3)	470	463	455	448	446	444
Water (kg/m^3)	237	232	228	224	223	221
Ratiot (E/C)	0,50	0,53	0,56	0,59	0,62	0,66
Sand (kg/m^3)	1426	1409	1381	1357	1354	1342
Density (kg/m^3)	2139	2109	2069	2034	2028	2012
Temperature (°C)	20	20	21	20	21	20
Subsidence (mm)	80	80	85	85	90	95

Table 2: Composition and characteristics of laboratory ash mortars

	Control	Artisanal cow dung ash mortar (ACDA)				
		5%	10%	15%	20%	25%
Cement (kg/m^3)	470	442	414	380	358	336
Ash (kg/m^3)	-	25	47	63	91	114
Total (kg/m^3)	470	467	461	443	449	450
Water (kg/m^3)	237	234	230	221	223	224
Ratiot (E/C)	0,50	0,53	0,56	0,58	0,62	0,67
Sand (kg/m^3)	1426	1422	1379	1361	1350	1336
Density (kg/m^3)	2139	2128	2075	2030	2027	2015
Temperature (°C)	20	20	20	21	20	19
Subsidence (mm)	80	75	75	80	80	85

Table 3: Composition and characteristics of artisanal ash mortars

	Control	Commercial fly ash mortar (CFA)				
		5%	10 %	15 %	20 %	25 %
Cement (kg/m^3)	470	448	408	356	368	356
Ash (kg/m^3)	-	24	41	57	74	89
Total (kg/m^3)	470	472	449	435	442	445
Water (kg/m^3)	237	236	225	218	221	222
Ratiot (E/C)	0,50	0,53	0,55	0,58	0,62	0,62
Sand (kg/m^3)	1426	1422	1364	1371	1359	1366
Density (kg/m^3)	2139	2145	2043	2029	2027	2038
Temperature (°C)	20	21	20	19	20	19
Subsidence (mm)	80	75	75	75	80	75

Table 4: Composition and characteristics of fly ash mortars

Making and curing of samples

All mixtures are produced in a Hobart type mixer. The sand is introduced first into the mixer, then comes half of the mixing water, the binder and finally the second half of the mixing water containing the water reducer. Each material introduced is kneaded until homogenization. The specimens for the compression tests are $(4 \times 4 \times 16)\ cm^3$. They are made according to standard NF EN 12390-01, and are kept in a humid environment (wrapped in wet jute). They are placed in a drying condition (50 % relative humidity) 24 hours before being subjected to the compression tests. Figure 4 shows the characterized samples.

Fig. 4: Characterized samples

III. METHODS

A. *Thermal characterization*

The thermal characterization of the mortars was carried out after 28 days of age, with the FOX200 experimental heat flux system (Figure 5). The general principle of the device is based on Fourier's law :

$$\phi = -\lambda \frac{dT}{dx} \quad (1)$$

If a flat sample is placed between two flat isothermal plates held at two different temperatures, and a uniform one-dimensional temperature field is established, the temperature field of the sample should be uniform throughout the sample volume (the size of the sample). Plates are assumed to be much larger than the thickness of the sample). The average temperature gradient can then be determined by :

$$\frac{dT}{dx} \cong \frac{\Delta T}{\Delta x} = \frac{T_{hot} - T_{cold}}{e} \quad (2)$$

Before starting the tests on a sample of unknown thermal conductivity, the flux meters used are calibrated using a reference sample having a known and reliable value of thermal conductivity λ_0. The electrical signal of the transducer Q (μV) is proportional to the heat flux density:

$$\phi = \lambda_0(T) \frac{\Delta T_0}{\Delta x_0} = S_0(T).Q \quad (3)$$

Since the physical properties of the transducer change with temperature, calibration of the instrument temperature using a reference material is still required to obtain the temperature dependent calibration factor $S_0(T)$. Each of the two transducers has its own temperature, S_0 the calibration factors must be related to the actual temperatures of the transducers. Two separate sets of calibration factors are measured during calibration. The knowledge of the calibration factor S_0 and of the temperature gauge makes it possible to obtain the thermal conductivity:

$$\lambda_0(T) = S_0(T).Q.\frac{\Delta x_0}{\Delta T_0} \quad (4)$$

Each plate having its calibration temperature, the thermal conductivity of the material is then the average of the conductivities obtained with the calibration factors of the two plates. The thermal resistance is calculated by :

$$R_{th} = \frac{e}{\lambda} \quad (5)$$

Fig. 5: FOX200 experimental device for conductivity and thermal resistance measurement

B. *Mechanical characterization*

The compressive strength tests are carried out at 28 days and at 90 days, in accordance with standard NF EN 12390-3, using the device of Figure 6.

Fig. 6: Experimental device of compressive strength measurement

IV. RESULTS

Table 5 shows compressive strengths at 28 and 90 days. Table 6 shows the conductivity and thermal resistance of the characterized mortars. The values presented are the arithmetic means of three tests.

		Control	**Laboratory cow dung ash mortar (LCDA)** 5%	10%	15%	20%	25%
28 days	**Strength**	**35,56**	**33,37**	**31,92**	**31,78**	**29,56**	**27,59**
	Deviation	1,51	0,90	1,33	1,43	0,89	0,82
90 days	**Strength**	**37,89**	**36,54**	**35,71**	**35,42**	**34,98**	**34,12**
	Deviation	0,99	1,38	1,38	0,92	1,23	1,40
		Control	**Artisanal cow dung ash mortar (ACDA)** 5%	10%	15%	20%	25%
28 days	**Strength**	**35,56**	**33,12**	**30,48**	**26,98**	**25,59**	**24,35**
	Deviation	1,51	0,99	0,72	1,73	0,71	1,03
90 days	**Strength**	**37,89**	**36,73**	**35,64**	**33,68**	**31,22**	**29,65**
	Deviation	0,99	0,94	1,38	1,54	0,95	1,63
		Control	**Commercial fly ash mortar (CFA)** 5%	10%	15%	20%	25%
28 days	**Strength**	**35,56**	**33,78**	**30,75**	**29,63**	**30,13**	**27,23**
	Deviation	1,51	1,12	0,93	1,38	1,71	1,93
90 days	**Strength**	**37,89**	**36,93**	**36,28**	**32,84**	**33,48**	**31,82**
	Deviation	0,99	1,34	1,73	1,24	0,95	1,93

Table 5: Mortars compressive strength at 28 days and 90 days

		Control	Laboratory cow dung ash mortar (LCDA) **5%**	**10%**	**15%**	**20%**	**25%**
Thermal conductivity (W/mK)	Upper	0,5935	0,5308	0,4816	0,4592	0,4260	0,4153
	Lower	0,5920	0,5568	0,5306	0,4957	0,4833	0,4374
	Aver.	**0,5927**	**0,5438**	**0,5061**	**0,4775**	**0,4547**	**0,4264**
Thermal resistance (m^2K/W)		**0,04984**	**0,0559**	**0,0652**	**0,0693**	**0,0604**	**0,0727**
		Control	Artisanal cow dung ash mortar (ACDA) **5%**	**10%**	**15%**	**20%**	**25%**
Thermal conductivity (W/mK)	Upper	0,5935	0,5638	0,4678	0,4428	0,4032	0,3838
	Lower	0,5920	0,6625	0,5598	0,4894	0,4652	0,4446
	Aver.	**0,5927**	**0,6132**	**0,5138**	**0,4661**	**0,4342**	**0,4142**
Thermal resistance (m^2K/W)		**0,04984**	**0,0498**	**0,0719**	**0,0743**	**0,0816**	**0,0843**
		Control	Commercial fly ash mortar (CFA) **5%**	**10%**	**15%**	**20%**	**25%**
Thermal conductivity (W/mK)	Upper	0,5935	0,4538	0,4087	0,3643	0,3689	0,3764
	Lower	0,5920	0,5299	0,4294	0,4179	0,4026	0,3799
	Aver.	**0,5927**	**0,4919**	**0,4191**	**0,3911**	**0,3858**	**0,3782**
Thermal resistance (m^2K/W)		**0,04984**	**0,0498**	**0,0857**	**0,0866**	**0,0877**	**0,0789**

Table 6: Mortars thermal conductivity and thermal resistance

V. ANALYSIS & DISCUSSIONS

Figures 7 and 8 respectively show compressive strengths at 28 days and 90 days. Figures 9 and 10 respectively show the conductivities and thermal resistances of the characterized mortars.

The analysis of figures 7 and 8 shows that the compressive strength of the mortars decreases as the ash content increases. The values of compressive strengths at 28 days are between 24.35 and 35.56 MPa, while those at 90 days are between 29.65 and 37.89 MPa (Table 5). It is further observed that for each assay, the lowest resistances (24.35 MPa at 28 days and 29.65 MPa at 90 days) are obtained with the mortars of 25 % artisanal ash, this is clearly observable at 28 days (Figure 7) and beyond 15 % at 90 days (Figure 8).

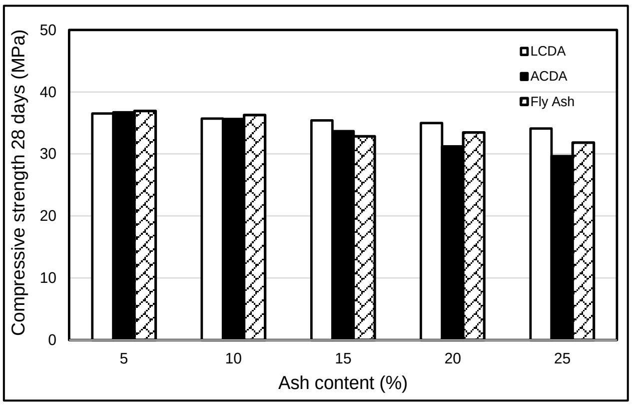

Fig. 7: Mortars compressive strength at 28 days

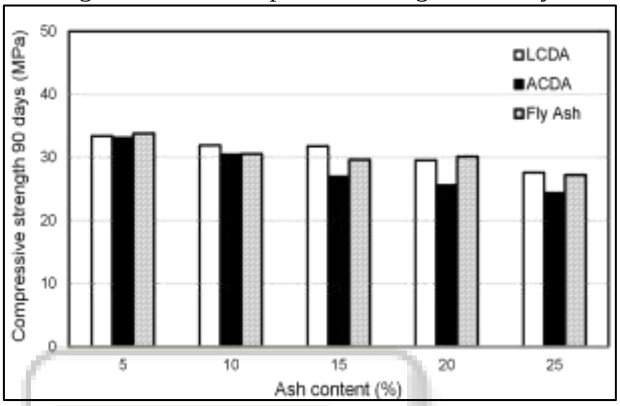

Fig. 8: Mortars compressive strength at 90 days

The greatest resistances are obtained with reference mortar without ash: 35.56 MPa at 28 days and 37.89 MPa at 90 days (Table 5). For mortars containing ash, the greatest strengths are obtained with 5 % of each ashes. The high values of the resistances obtained testify to the durability of the characterized mortars. The relative deviations from the reference mortar (31.52 % at 28 days and 21.74 % at 90 days) indicate that the results obtained are conclusive. From the analysis of figures 9 and 10, there is a decrease in conductivity and an increase in thermal resistance as the ash content increases.

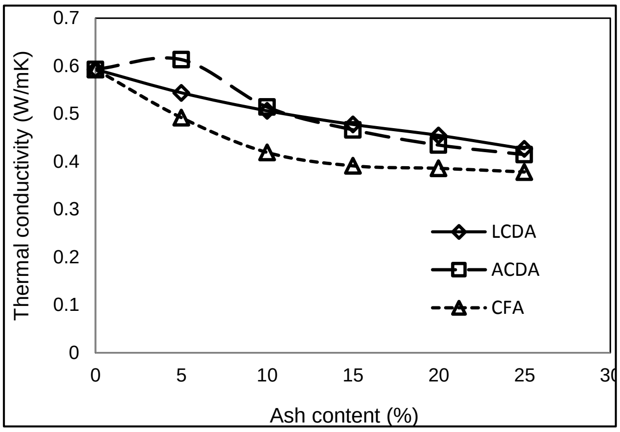

Fig. 9: Mortars thermal conductivity

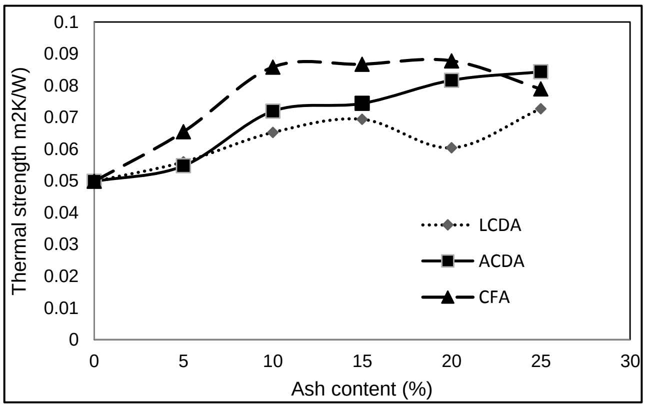

Fig. 10: Mortars thermal strength

The values of the thermal conductivity obtained are between 0.3782 and 0.6132 ($W.m^{-1}.K^{-1}$) while those relating to the thermal resistance are between 0.04984 and 0.08778 ($m^2.K.W^{-1}$). It is also observed that the lowest conductivities and therefore the greatest thermal resistances are obtained with industrial fly ash mortar. The highest thermal conductivity (0.613 $W.m^{-1}.K^{-1}$) obtained with 5 % artisan cow dung ash and the lowest (0.3782 $W.m^{-1}.K^{-1}$) obtained with 25 % fly ash (Table 6), shows that the ashes studied could have a very positive impact on the energy saving in the habitat. The large values of the thermal resistance obtained show that the ashes studied give the mortars a high insulating power. They will better mitigate the fluctuations of the internal thermal wave of buildings with a significant thermal phase shift.

VI. Conclusion

From the present study, it is noted that the three different ashes studied can be valued in the field of building construction. Mechanical results obtained, it can be remembered that with a substitution of not more than 15 % ash, the characterized mortars offer compressive strengths acceptable in the field of building. Above 15 %, the compressive strength decreases significantly. These results confirm the trend of previous studies on the mechanical properties of ash containing mortars. The values of conductivity and thermal resistance obtained indicate that the mortars studied have a better insulating capacity compared to ordinary mortars, and can therefore contribute effectively to energy saving and improving thermal comfort in building. The results of the study thus conclude that the use of lab-produced cow dung ash, hand-made cow dung ash and fly ash improves the thermal properties of mortars. The overall results will help to convince and reassure the designers.

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