Proceedings of Engineering & Technology -PET Vol 96, pp.8-15 **Advances in Energy Transition and Environmental Impacts**

Improving the thermal characteristics of fired compressed earth bricks by adding industrial waste (recycling corrugated cardboard sludge)

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***Abstract*— Responsible management of the recycling of industrial by-products and use of local resources, including clay bricks, is imperative if we are to build homes sustainably. Maintaining a clean environment and supporting sustainable growth around the world is only possible if we take this approach. Our research aimed to determine the impact of replacing clay with industrial by-products, such as paper and slag-based waste. We found that the rate of waste substitution in fired bricks varies between 10% and 30%. The bricks are fired in a kiln at 900°C for six hours. A 4×4×16 cm³ mold is used. Introducing industrial paper sludge resulted in a significant decrease in compressive and flexural strength. There was also a significant reduction in thermal conductivity.**

***Keywords*— Paper slag, fired bricks, industrial by-products, Thermal Conductivity**

I. INTRODUCTION

The utilisation of natural materials is of paramount importance in minimising the environmental impact of a construction project. Such materials offer several advantages and are adept at adapting to the technical limitations of the building. Such materials are recyclable, robust, less polluting, and, in certain circumstances, cost-effective. Masonry bricks represent the oldest and most commonly used construction element, and continue to play a significant role in the mechanical resistance and thermal insulation of walls [1]. Furthermore, fired bricks are highly fire-resistant, have a long lifespan, and require minimal maintenance [2].

This research aims to develop an innovative, environmentally friendly solution that addresses both issues head-on: improving the thermal properties of CEB by incorporating recycled corrugated cardboard sludge as an insulating additive. The objective is to transform a stream of industrial waste into a valuable resource, creating a new, sustainable building material with high thermal performance while reducing pressure on natural resources and landfill space. This approach aligns with the principles of the circular economy and eco-design. The addition of lightweight materials (such as sawdust, pozzolan, or paper waste) is a known method of improving the porosity and thus the thermal insulation capacity of earth bricks, at the potential expense of their mechanical strength [3, 4].

The added value of this study lies in the in-depth characterisation (physical, mechanical, and thermal) of CEBs enriched with cardboard sludge in order to determine the optimal dosage that offers an acceptable compromise between thermal performance, sufficient mechanical strength for non-load-bearing (or low-load-bearing) applications, and durability[5-7].

It is of the utmost importance that we adopt an environmentally responsible approach to the recycling of industrial by-products and utilise local resources, including clay bricks, in the construction of residential properties. This is the only way we can maintain a clean environment and support sustainable growth on a global scale. The objective of our research was to determine the effect of substituting clay with industrial by-

ISSN: 1737-9334

products, such as paper-slag. The rate of waste substitution in fired bricks has been found to range from 10% to 30%. The fired bricks are calcined in a kiln for 6 hours. A mould with dimensions of 4×4×16 cm³ is employed. The incorporation of industrial paper slag resulted in a notable reduction in compressive and flexural strength. Additionally, a notable decline in thermal conductivity was observed.

II. MATERIALS AND METHODS

A. *Clay*

This research employed clay from the eastern region of Algeria. Laser particle sizing was used to determine the particle size distribution. Fig. 1 illustrates the particle size distribution of the clay used in our study. Fig. 2 shows the same. The findings show that the material is made up of 15% clay, 72% silt and 13% sand. The Atterberg limits of the fine fraction were calculated using the specifications of NF P94-051 [8], which states a liquid limit of 34.10% and a plasticity index of 22.3%. The substance is medium plasticity silty clay according to the unified soil classification system Fig. 3. Furthermore, the brick's particle size distribution and plasticity comply with the established requirements set out in XP P13-90 [9]. Table 1 shows the clay's chemical composition.

TABLE 1 PHYSICAL PROPERTIES AND PARAMETER VALUES OF CLAY

Material	Atterberg limits (%)			Methylene blue value (g/100 g soil)	Modified Proctor test		Physical appearance
	Liquid limit (L_l)	Plasticity limit (L_p)	Plasticity index (I_p)		Optimum water content (%)	Dry density (g/cm^3)	
Clay	34.10	22.30	11.8	2.6	11.74	2.11	Red

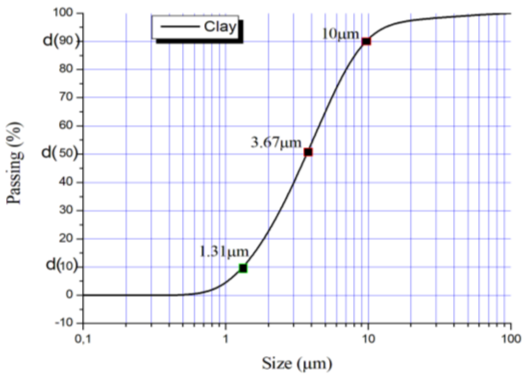

Fig.1 Laser particle size analysis of clays

Fig.2 red clay

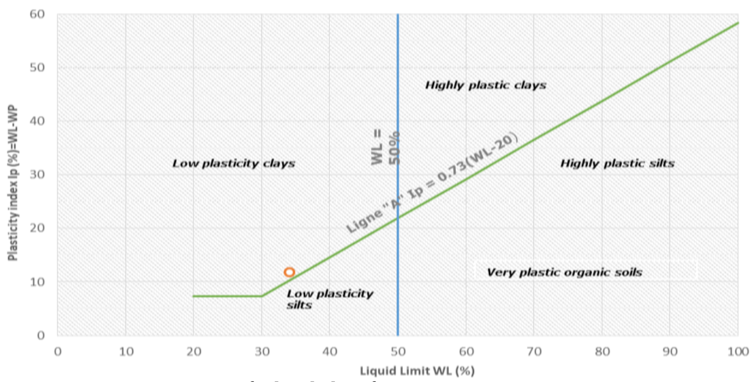

Fig.3 Unified soil classification system's category

B. *Paper sludge-based industrial waste*

ISSN: 1737-9334

Paper sludge waste is collected from paper recovery and processing plants in Algeria.
This waste is recycled in the form of sludge in clay-based materials. Several research studies have been conducted on the valorising of this waste. Fig. 4 and Table 2 display the chemical composition of paper sludge.

Fig.4 Paper sludge-based industrial waste

TABLE 2 CHEMICAL COMPOSITION OF CLAY AND PAPER SLUDGE

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	TiO_2	Na_2O	Cl	LOI
Clay	46.18	16.69	9.05	1.15	3.86	0,05	1.92	0,69	1.20	0.01	9.66
Paper sludge	0,64	2,72	0,72	0,73	0,03	1,36	0,03	4,77	<0,01	2.73	94.94

C. Methods

Four sets of clay samples were prepared with the addition of 1.25% to 5% paper sludge. Following a 30-minute dry mixing period, an approximate 12% water content was added to facilitate the plasticisation of the raw ingredients. The raw bricks were produced using hydraulic presses and a steel mould measuring (4 x 4 x 16) cm at 10 MPa. The optimal pressure for the production of high-quality bricks is in excess of 10 MPa. The objective of this study was to assess the compressive strength of the entire brick. The compression tests were conducted using the MATEST 250 KN Compression Testing Machine.

The incorporation of waste material has been shown to significantly enhance the thermal conductivity and resistance properties of fired clay bricks. A CT meter was employed to quantify the thermal conductivity of the bricks, thereby ensuring the precision of the results in accordance with the NFE993-15 standard.

A scanning electron microscope (SEM, F.E.I. Quanta200 in the laboratory of materials technology of the University of Bejaia) was employed to analyse the morphology of the materials. The samples were soaked in anhydrous ethanol to halt the process of hydration and subsequently dried at 50 degrees Celsius for a period of 12 hours. They were then coated with 20 nm of gold in order to render them conductive (see Figures 5 and 6).

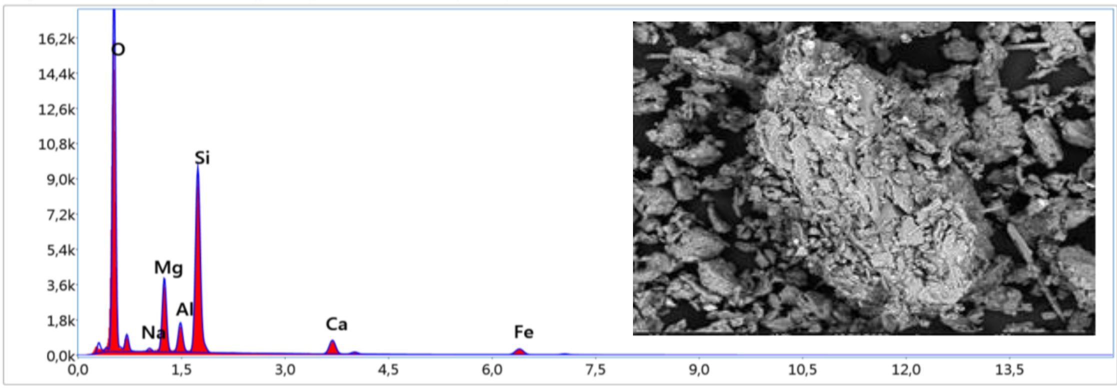

Fig.5 the SEM-EDAX of Clay

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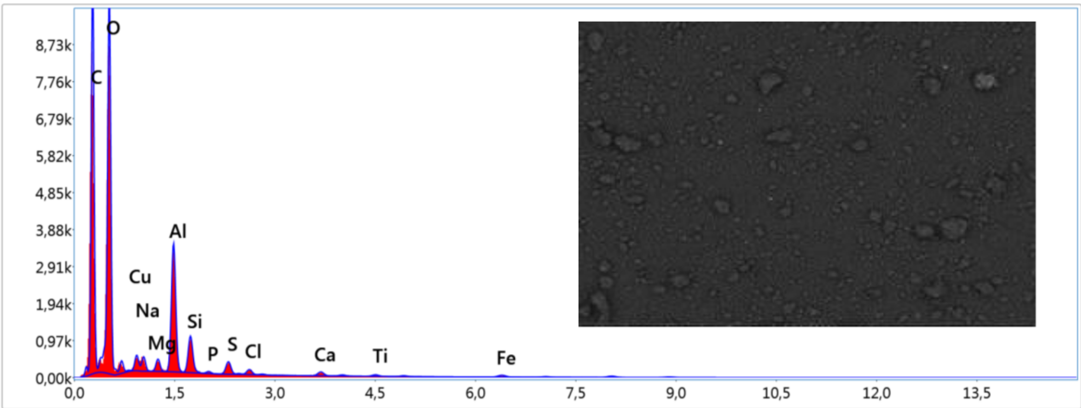
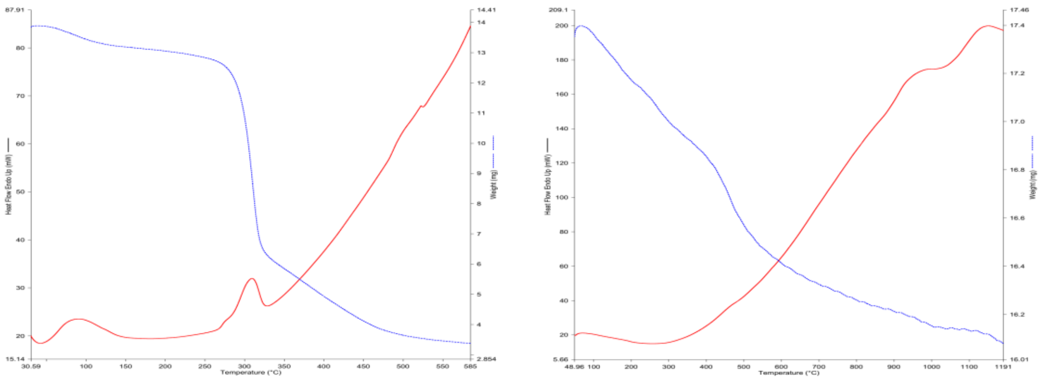


Fig.6 the SEM-EDAX of paper sludge waste

Soil characterisation is finally completed with TGA. The analysis was performed by an SDT Q600 V20.9 Build 20 apparatus. The temperature program set was a linear ramp with an increase of 30 °C/min up to 1199 °C. The mass loss of each analysed sample is recorded against the increase in temperature. Fig. 7



a) sludge paper b) clay

Fig. 7 thermogravimetric curves (TG) of the raw materials

III. RESULTS AND DISCUSSIONS

A. compressive strength

The control samples (bricks without paper sludge) demonstrate a maximum compressive and flexural strength value of 9.02 MPa and 1.12 MPa, respectively, at a firing temperature of 900 °C. In contrast, the minimum compressive and flexural strength values for bricks with paper sludge are 3.61 MPa and 0.96 MPa, respectively, at the same temperature (Fig. 8 and 9). The compressive and flexural strength values exhibited a notable decline with an increase in paper sludge content, potentially resulting from the high compactness and the subsequent reduction in pore number.

ISSN: 1737-9334

10.051103/PET.260196702

Proceedings of Engineering & Technology -PET Vol 96, pp.8-15

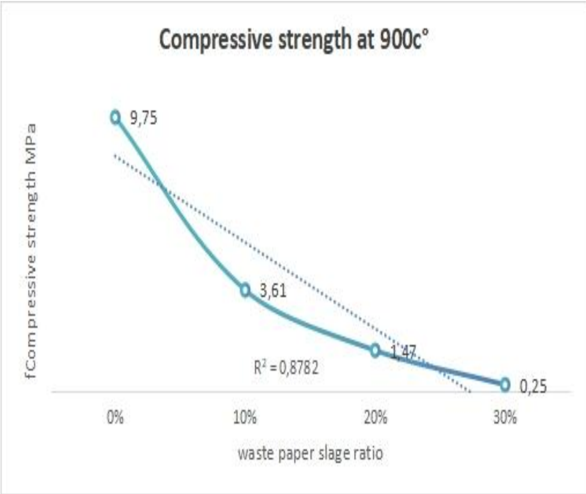


Fig.8 Compressive Strength as function of paper sludge content

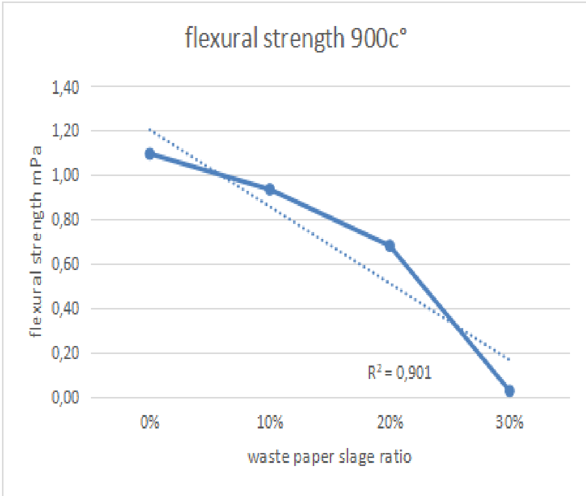


Fig.9 Flexural Strength as a function of paper sludge content

B. *Thermal conductivity*

Materials with lower thermal conductivities provide the best insulation, reducing heat transfer into and out of buildings. It is therefore essential to obtain bricks with good thermal properties [10]. Fig. 10 clearly shows the thermal conductivity of bricks made with varying percentages of paper sludge. The thermal conductivity of the control bricks fired at 900 °C was found to be 0.43 W/m K. It is clear that the substitution of clay with paper sludge results in a decrease in thermal conductivity. The value of 0.38 W/m K was obtained when clay was replaced with 5% paper sludge, demonstrating a significant reduction in thermal conductivity. It can be confidently stated that the decrease in thermal conductivity observed in these specimens is due to the increase in porosity of the fired clay bricks

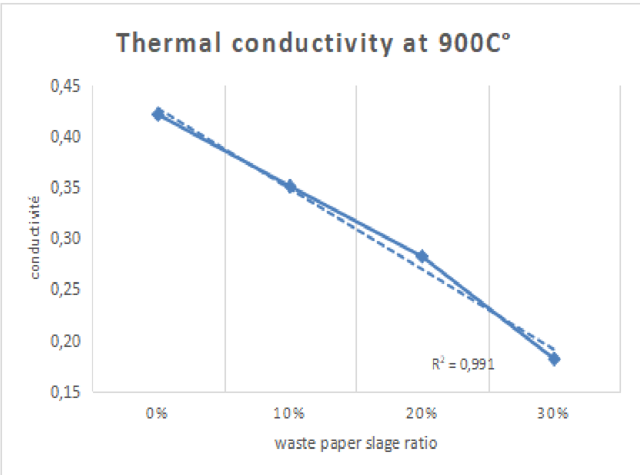


Fig.10 Thermal conductivity variation

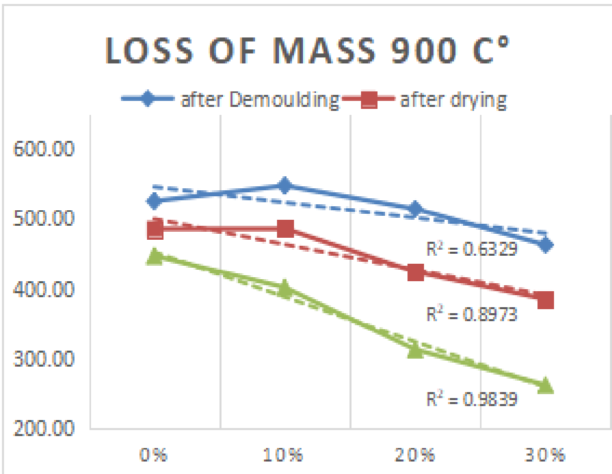


Fig.11 Loss of mass at 900°C

C. *Loss of mass*

ISSN: 1737-9334

Figure 11 illustrates the mass loss for two treatment conditions (‘after demoulding’ and ‘after drying’) as a function of concentration, measured at 900 °C.

After demoulding, the mass loss is significantly higher than after drying across the entire concentration range. This is logical, as samples after demoulding are likely to contain more free water and/or other volatile components that evaporate at 900 °C than those that have already been dried.

After drying, the initial mass loss is lower, indicating that the initial drying process has already removed some of the volatile mass (probably water).

The green curve, which represents the mass loss after firing, follows the same decreasing trend with increasing concentration, but at an even lower level.

In conclusion, concentration is a key factor influencing the mass loss of samples at 900°C, and the drying stage significantly reduces the total amount of mass lost during heat treatment. The effectiveness of concentration as a predictor of mass loss (indicated by R^2 increases with the level of treatment (more thorough drying).

IV. Conclusions

This study will determine the impact of paper sludge content and brick firing temperature on;

The compressive and flexural strength values exhibited a notable decline with an increase in paper sludge content, potentially resulting from the high compactness and the subsequent reduction in pore number.

The thermal conductivity of the material inevitably decreases as the concentration of paper sludge increases. The use of paper sludge makes it possible to produce lightweight composite materials with improved thermal insulation properties, making them suitable for sustainable construction applications.

Acknowledgment

The authors would like to express their gratitude to the Ministry of Higher Education and Scientific Research for providing financial support for this research project. The authors would like to express their gratitude to the technicians specialising in engineering processes at the LGCA laboratory, University of Bejaia, for their invaluable assistance in processing the data.

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ISSN: 1737-9334

Proceedings of Engineering & Technology -PET Vol 96, pp.8-15 **Advances in Energy Transition and Environmental Impacts**

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ISSN: 1737-9334