

Mechanical and Thermal Performance of Cement Bricks with Millet Admixture for Sustainable Building

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Abstract - Wastes recycling offers both ecological and economic potentials on wastes disposal sites and ultimately the sustainability of our natural resources. Experimental evaluation of the mechanical and thermal performance of locally made cement bricks with millet waste as an additive aimed towards improving thermal comfort in buildings is presented. The hot box derived method comprising of a wooden box of dimension $480 \times 350 \times 250 \text{mm}^3$ was used. Seven test samples were made with Sample A having zero millet waste content (MWC) and the remaining six having varying MWC. The transient thermal performance of the resulted bio-bricks reveals a uniform behavioural trend for the seven samples, though with different ranges of temperature increase. While the sample with zero MWC appreciably conducts heat faster with its temperature increasing from 28-45.1 degree Celsius within 15 minutes, sample G (with the highest MWC) presents the lowest heat conduction with the temperature range of 28-30.5 degree Celsius over the same period. In addition, the thermal behaviour of the resulted bio-bricks shows that the millet waste inclusion has an inverse effect on its thermal performance as its temperature decreases with increase in MWC, 500grams being the optimum. This is an indicator of the insulating potential of the resulted bio-bricks. The investigation into its mechanical performance shows that its compressive strength decreases with increase in MWC. It is then imperative to mention that MWC should be carefully added both on purpose and to specification so that the mechanical strength of the resulted bio-brick is not compromised unnecessarily.

Keywords: Millet, Bio-bricks, Cement, hot box-derived method, Transient.

I. INTRODUCTION

Sustainable development, environmental protection and economizing energy are altogether the primary concerns of the contemporary world. Conversely, the outset of technology and its advancement has always prompted man to crave for improved living by constantly making their houses unnecessarily active which in return has adversely resulted in

increased global consumption of the limited primary energy. Buildings consume more than 70% of the world energy, the production of which generates an important quantity of greenhouse gases. This has been a serious challenge to the building industry and designers. Hence, the need for energy-efficient buildings without compromising the necessity of thermal comfort. The thermal insulation of a building envelope is very germane to its energy performance and efficiency as it helps in the reduction of the thermal load on it and thereby enriching it with better passive thermal comfort without the need for incurring cost through active cooling technologies.

Admixing of a building material like bricks with an insulating or fibrous material like millet waste is one of the sustainable ways of improving its thermal insulating properties because it is expected that the millet waste additive will highly modify the thermal capacity of the bricks because of its high heat resistance and low density (mass reduction) which is a good factor for the improvement of its resistance to earthquake forces. Another motivation behind this work is that these wastes are available in rising and unchecked volumes in our local communities. Hence, the need for the exploration of waste minimization strategies such as waste reduction, reuse and recycling. Bricks are the world's most versatile, durable and reliable construction material. Conventional bricks are produced from clay with high temperature kiln firing or from ordinary Portland cement (OPC) concrete, and thus contain high embodied energy and have large carbon footprint [1].

Brick belongs to the wide family of construction materials since it is mainly used for the construction of outer and inner walls in buildings. The brick industry is the most indicated technological activity sector to absorb solid wastes due to the large quantity of raw material used by the sector as well as by the large volume of final products in construction [2, 3, 4].

Many researchers had made efforts in recycling various forms of waste inclusive of liquid wastes, solid wastes, agricultural wastes and organic residues in the production of bricks with the aim of sustainable development.

[5] Conducted an experimental investigation on the effects of polystyrene foam addition and firing process temperature on the density, water absorption and compressive strength of bricks. The tests revealed that while an increase in the polystyrene foam additive led to reduction in the compressive strength and the density of the resulted brick, its water absorption capacity increased. The authors added that caution should be taken in specifying the density reduction extent so as not to reduce its strength unnecessarily because just 2% addition of recycled polystyrene foam is sufficient to make the compressive strength of the resulted bricks suitable for load bearing like ordinary bricks which are in compliance with the Iranian standard. The results also revealed that higher firing temperatures led to higher compressive strengths and less water absorption capacity while the thermal conductivity of the resulted lightweight polymeric bricks made of 1.5% recycled polystyrene foam was $\frac{1}{4}$ of that of ordinary bricks which is a good energy saving factor in building.

The result of an experiment on the water content dependence of porosity, density and thermal capacity of laterite based bricks with millet waste additive was presented by [6]. Models developed to represent the density $\rho(X, Y)$ and the thermal capacity $\rho c(X, Y)$ of the samples as functions of the water content X and of the millet mass content Y showed a very good agreement with the experimental results with a mean deviation of 1.2% for the density and 3.3% for the thermal capacity.

[7] Experimentally investigated the effects of 0–10 weight percent of olive mill waste (OMW) additive on the physio-mechanical and thermal parameters of porous clay bricks fired at 850, 950 and 1050 °C. The results showed that 10% OMW decreased the bulk density of the specimens up to $1450\text{kg}/\text{m}^3$. Increase in the OMW content from 0% to 10% with increasing firing temperature caused a gradual increase up to 32.5% in the water absorption of the manufactured specimen thereby increasing its porosities from 30.8% to 47.0% respectively but the compressive strength, on the other hand, reduced from 36.9 MPa to 10.26 MPa at a burning temperature of 950 °C. It can be concluded from the result that OMW could be used as a pore maker in brick production.

A performance evaluation of 3-10% partial replacement (by weight) of clay with diatomaceous earth residues (DER) (vegetable oils and brewing refining) as a raw material for bricks production was conducted by [8]. Samples were molded and burnt at 850, 950 and 1050°C firing temperatures. The test results proved that DER addition in brick making increased the porosity by 37 volume percent and reduced the bulk density by 10% as compared to the conventional clay bricks. However, the tensile strength increased from 7 MPa to

7.8 MPa at the first 3% waste addition after which and it steadily reduced to 5 MPa at 10% waste addition. Meanwhile, at 10% waste addition at 950°C and 1050 °C firing temperature, there was a decrease of the compressive strength between 9.5 and 11.7 MPa while the thermal conductivity decreased with increased waste addition and increased sintering temperature.

[9] Did the analysis of the viability of mixing 10-30% of both rice husk ash (RHA) and wood ash (WA) wastes in the production of fired clay bricks under different firing temperatures ranging from 900–1000 °C for four hours. The results showed that the addition of RHA would significantly increase the linear shrinkage and open porosity up to 10.8 volume percentage and water absorption up to 32.9% while WA addition would significantly increase the linear shrinkage and open porosity up to 7.3 volume percent with water absorption up to 21.2% of the resulted bio-base bricks irrespective of the process firing temperature. Besides, the addition of RHA and WA would respectively decrease the bulk density up to 25.1% and 9.8%. While the addition of 30% weight of RHA at 900 and 1000 °C would respectively reduce the compressive strength to 13.5 and 17.5 MPa, 30 % weight of WA would cause a reduction of 34.3 and 42 MPa in the compressive strength at 900°C and 1000 °C firing temperature respectively. The authors then concluded that, the optimal proportion of biomass ash waste that meets the standard properties specification for clay masonry units is 10 % weight of RHA and 20 % weight of WA.

[10] Conducted an experimental study to investigate the potential of hemp in composition with earth-clay without any stabilization with focus on the acoustic, thermal and mechanical characteristics of the bio-base materials. It was observed from the results of the study that: (1) the samples showed an acoustical absorption of sound with a percentage range of 20-30% on a frequency range of 50-6400Hz, hence there would be needs to find a composition which increases the number of pores of the final material in order to increase the hemp-clay sound absorption coefficient. (2) while the density of the samples ranged from 966 to $1060\text{kg}/\text{m}^3$ the thermal conductivity range was 0.092-0.18W/mk. Due to the observed fact that the values obtained for the density were not linear with the values of thermal conductivity; the authors recommended that more investigation studies would need to be further done on those mixtures of hemp and clay. (3) while the values for flexural strength ranged from 0.1 to 0.5 N/mm^2 , the sample with the ratio of 1:1 binder-hemp happened to offer the best performance. With the compressive strength ranging from 0.1 to $1\text{N}/\text{mm}^2$, sample A+C3 with the ratio of 1:3 binder-hemp offered the highest value. Ultimately, for the reason that the obtained values for the three

compositions of the hemp and clay were low, the possibility of stabilizing them with others binders for improvement of their compressive and flexural strength was suggested.

Evidently speaking, the past studies had shown different efforts made in recycling various forms of waste in fired brick making which often involves intensive consumption of energy resources as electricity or fossil fuel but there is a need to intensify efforts especially in the exploration of these wastes in the production of non-fired bricks for a considerable reduction in the global limited energy thereby achieving higher sustainability especially in developing countries where access to the grid electrical power is limited.

II. EXPERIMENTAL METHODOLOGY

a) Experimental device and materials

The locally available materials used for this study consist of: Locally made ad-hoc wooden box of internal dimensions $480 \times 350 \times 250 \text{ mm}^3$ as the test rig to accommodate both the heating element and each of the test samples, two multi-meters, clay soil, cement, millet pods, a wooden mold of internal dimension $250 \times 115 \times 75 \text{ mm}^3$ and a weighing balance.

b) Preparation of Samples

The solid millet pods were sun-dried, grinded and proportionally mixed with the chosen quantity of the mixture of dried clay and cement. Seven different test samples (A to G) were made as shown in table 1 and figure 1 for the purpose of investigating the effects of the millet additive on the resulted bio-bricks. Equal amount of cement (Dangote cement as readily available) as a binder was chosen for each sample and the clay soil used was extracted directly from the soil in Ado-Ekiti, Nigeria. Each sample was continually mixed as water was being added until a consistent and even bio-paste was attained after which the paste was manually pressed into the mold. The test samples after removal from the mold were properly sun-dried.

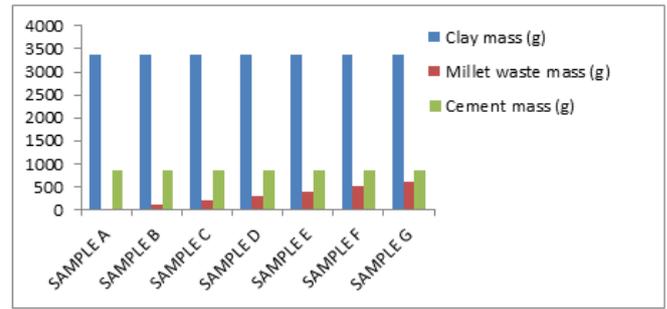


Figure 1: Charts of the test samples constituents

c) Thermal conductivity measurement method

The samples thermal conductivities were measured using a hot box derived method. After the rig (having a fixed heat source that was constantly supplying heat at 1200 J/s) had been properly checked for holes to prevent infiltration, each test sample at a time was carefully placed in it. An initial temperature of 28°C was ensured for each of the samples (A-G). A K-type thermocouple, made with two wire probes of 1.5 mm each, was made to come in contact with each sample whose temperature was monitored and recorded at 5 minutes interval of time from the readings of the connected multi-meters. Wood was chosen on purpose for the construction of the hot box being an insulating material so that its thermal contribution to the system can be assumed to be negligible. For the purpose of achieving minimum possible experimental errors, the two multi-meters temperature readings were monitored and recorded and the mean taken for each of the test samples at each time interval.

d) Compressive strength

The compressive strengths of various samples as a function of the millet content were determined with the aid of the compression test machine available at the Civil Engineering Laboratory of Ekiti state University, Nigeria. With the compression loads applied to the surface area of each sample, their compressive strength was determined in terms of cracking and breaking points.

III. RESULTS AND DISCUSSIONS

As regards to the compressive strength of the resulted bio-brick as a function of the MWC, it is obvious from the trend of the results as shown in figure 2 and table 2 that as compared to the sample without additive (sample A), the compressive strength, in terms of the cracking and breaking stresses, decrease with the increase in the MWC. This indicates that the quantity of millet waste added to each sample would determine the intensity of the force required to crack or break the resulted bio-brick. It is then imperative at this point to add that the addition of millet waste content should be carefully

TABLE I

Mix proportions of the different test samples

Sample	Millet waste mass (g)	Clay mass (g)	Cement mass (g)
A	0	3380	845
B	100	3380	845
C	200	3380	845
D	300	3380	845
E	400	3380	845
F	500	3380	845
G	600	3380	845

executed both on purpose and to specification so that the required mechanical strength of the resulted bio-brick is not compromised unnecessarily.

TABLE II
Mechanical behaviors of the samples with variation in millet weight

Sample	Cracking strength kPa	Breaking strength kPa
A	5.70	41.70
B	5.30	11.30
C	4.50	10.00
D	3.20	7.60
E	2.70	6.40
F	1.90	5.10
G	1.50	4.80

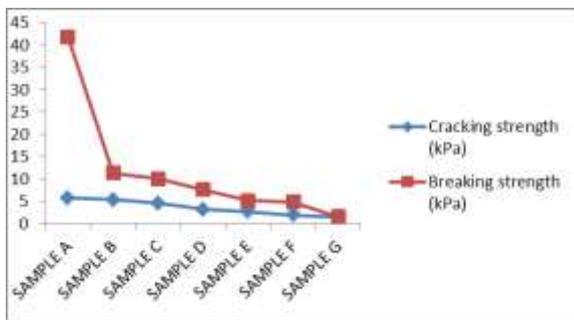


Figure 2: Mechanical behavioral trends of the samples as a function of millet weight

TABLE III
Experimental data of transient temperature variation with the mass of millet waste

Sample	Time (Minutes)					
	0			5		
	T1	T2	T_{mean}	T1	T2	T_{mean}
A	28.0	28.0	28.00	36.0	37.0	36.50
B	28.0	28.0	28.00	31.0	31.2	31.10
C	28.0	28.0	28.00	30.5	30.6	30.55
D	28.0	28.0	28.00	30.2	30.2	30.20
E	28.0	28.0	28.00	29.9	30.0	29.95
F	28.0	28.0	28.00	29.5	29.5	29.50
G	28.0	28.0	28.00	29.4	29.5	29.45

Sample	Time (Minutes)					
	10			15		
	T1	T2	T_{mean}	T1	T2	T_{mean}
A	42.0	43.0	42.50	45.0	45.1	45.05
B	34.1	34.3	34.20	35.9	36.0	35.95
C	33.0	33.2	33.10	34.8	34.8	34.80
D	32.3	32.2	32.25	32.0	34.0	33.00
E	31.5	31.5	31.50	31.9	32.0	31.95
F	30.5	30.4	30.45	31.3	31.2	31.25
G	30.0	30.2	30.10	31.0	31.1	31.05

Relating to the thermal behaviour of the samples, the experimental results related to the variation of temperature of the different samples (A to G) with time as a function of the MWC are presented in table 3. As revealed in table 3 and figure 3, it is interesting to notice that the millet waste inclusion has an inverse effect on the thermal performance of the bio-bricks in the sense that, the samples temperatures (starting from zero to 15minutes) decrease with an increase in the MWC irrespective of the amount. This is an indicator of the insulating potential of the resulted bio-bricks. Obviously, at all the time intervals, the samples temperatures decrease noticeably between samples B and F (100-500 gram of waste content). On the contrary, an almost constant trend is noticed between samples F and G at all the intervals which may likely imply that further millet waste addition may not necessarily yield any considerable temperature reduction. It can then be concluded that 500g of millet waste is the optimum mass for the locally made bio-brick in this work.

Thermal behavioural trends of the bio-bricks with variation in millet waste n

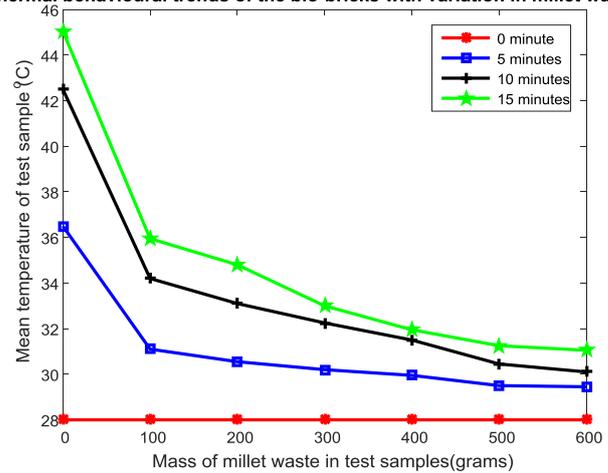


Figure 3: Thermal behavioural trends of the bio-bricks with variation in millet waste mass

Transient thermal behaviour of the resulted bio-bricks is presented both in table 3 and figure 4. It can be noticed that the sample temperatures increase with time. This behavioural trend is noticed to be uniform to all the samples though with different ranges of temperature increase. The sample with zero waste content is noticed to appreciably conduct heat faster with its temperature increasing from 28-45.05°C within 15minutes while sample G (with the highest waste content) has the lowest heat conduction with the temperature increase range of 28-30.45 °C over the same period. This is easily noticeable from the wide gap between it (sample A) and samples B to G in figure 4. The ranges of temperature increment for samples B-F were 28-35.95°C , 28-34.80°C, 28-33.00°C, 28-31.95°C, and 28-31.25°C respectively for the said

period of heat energy transfer. The mean temperature is taken to two decimal places for accuracy purpose.

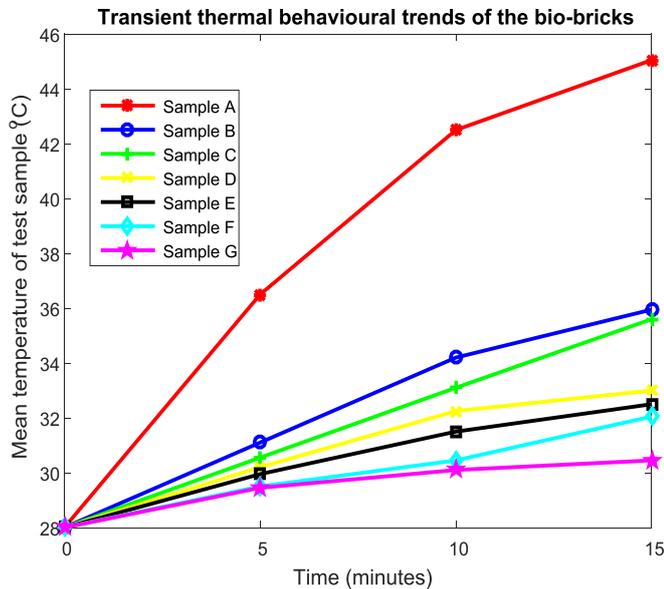


Figure 4: Transient thermal behavioural trends of the bio-bricks

IV. CONCLUSION

For the purpose of making a modest contribution to the sustainable building and development of my local community, a laboratory scale cement based bio-brick has been produced from locally available materials. The experimental investigation into its mechanical performance shows that its compressive strength, in terms of cracking and breaking strength, decreases with increase in the MWC. It is then imperative to mention that addition of MWC should be carefully executed both on purpose and to specification so that the mechanical strength of resulted bio-brick is not compromised unnecessarily.

The transient thermal performance of the resulted bio-bricks reveals a uniform behavioural trend of temperature increase with time for the seven test samples of varying MWC, though with different ranges of temperature increase. While the sample with zero MWC appreciably conducts heat faster with its temperature increasing from 28-45.1 °C within 15minutes, sample G (with the highest MWC) presents the lowest heat conduction with the temperature increase range of 28-30.5 °C over the same period.

Investigation into the thermal behaviour of the resulted bio-brick shows that the millet waste inclusion has an inverse effect on its thermal performance as its temperature decreases with an increase in the MWC, 500g being the optimum mass. This is an indicator of the insulating potential of the resulted bio-bricks. The results of this work are in good agreement

with the trend in the literature. However, for its wide application and macro-scale production in order to meet the desired aim, there is need for further study on standardization and government policy.

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Citation of this Article:

Modupe A. Oluleye, "Mechanical and Thermal Performance of Cement Bricks with Millet Admixture for Sustainable Building" Published in *International Research Journal of Innovations in Engineering and Technology (IRJIET)*, Volume 3, Issue 8, pp 1-6, August 2019.
