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Building Performance Simulation for Thermal Insulate Materials: Experimental Study

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Abstract The development trend of building materials science is aimed at energy and resource conservation, as well as the creation of green composites. The search for more sustainable construction materials has led researchers to reconsider ancient techniques, such as earth-based construction materials (EBCMs). Design buildings respectful of comfort and well-being of all while seriously reducing energy used is the challenge to all players in industry construction. Fired clay brick have the advantage of being solid (high strength), inert (resistant to chemical and biological attacks), non-flammable, good thermal and acoustic regulators. This scientific work would achieve optimization of thermal and mechanical properties of fired clay brick through the incorporation of adjuvant (rice hulls) which contribute to the improvement of intrinsic properties. This research provide a solution for sustainable construction materials in Sahelian zones; the use of rice balls as adjuvant is to ameliorate the building energy performance. It has been concluded that the addition of adjuvants (rice hulls) barely influences fired clay brick conductivity, thermal and mechanical properties which range from 3.4 MPa to 5.2 MPa. Thermal conductivity and density are slightly reduced which leads to lighter materials and higher insulation values. The increasing of the heat let us think about the building energy performance. Rice husks are incorporate into the fired clay brick to create pores. Specimens are made with adjuvants using different size cuts of 1000-500 microns, 500-315 microns and 315-125 microns in proportions of 0%, 2%, 4%, 6%, 8% and 10%. The specimens are then fired at respective temperature of 900°C, 1000°C and 1100°C.

Keywords: *building energy performance, thermophysical properties, thermal insulation, material efficiency, sustainable construction materials*

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1. Introduction

Recent studies show that half of the world's population lives in houses built with earth. During the first half of the twentieth century, and mainly in the post-world war II period, the introduction of new materials and techniques in current constructions, led to a decline in the use of earth [1-16]. Earth-based construction materials (EBCMs) have been used for building by mankind since ancient times and are still being used, not only in low-income economies but in middle economies and developed countries as well. From historical buildings to modern designs, one can find several examples of earth-based building designs [8-16]. Besides, the number of studies related to such building materials have been geometrically increased during the last decade. The current approach to sustainable development favors the maintenance of performance over time. Wall as the roof, terracotta offers this advantage by extending the life of the reported insulation and maximizing the energy performance of buildings. This material has been observed in the last decades, both for modern constructions and retrofitting of old buildings, largely due to ecological concerns. Fired clay brick is a natural material, very accessible with significant amount and has extraordinary properties of strength, waterproofing and durability in raw or fired form. Fired clay bricks are constructive solutions that significantly reduce energy consumption by a very efficient insulation [1-8]. Saharan and northern regions of Cameroon have a warm and dry climate in the dry season, cold and dry in the rainy season. Construction Materials commonly used in these regions are the concrete or mortar which has poor thermal properties. In order to manufacture fired clay brick with good mechanical and thermal properties, this scientific work focuses on two broad areas of applied science: Mechanics and Thermal comfort of the building. In general, the type of organisation of a ceramic layer or deposit greatly changes its macroscopic properties such as thermal conductivity and mechanical properties [1-8]. With the temperature variations and the porosity changing, also the crystal growth and densification, are the parameters which strongly influence the intrinsic properties of fired clay bricks. In order to improve the mechanical properties, it seems interesting to try to control the organisation of microstructure. Among, the many lines of research have already been tried. Choose to study the influence of porosity and rice husk content on thermal comfort of Sahelian buildings is the major aim of this research work.

The study focuses on the fired clay brick chosen as reference materials which we associate rice husks playing the role of adjuvant. We use rice husks to create pores in the fired clay brick. Specimens are made with added rice balls three size cuts 1000-500 microns, 500-315 microns and 315-125 microns; at amounts of 0%, 2%, 4%, 6%, 8% and 10%. The objective here is to formulate optimize fired clay brick which present a good energy efficiency. The value of this research is to show that the use of rice husk as adjuvant can effectively improve the thermal conductivity, the energy efficiency and thermal properties of fired clay bricks. The results show that the increase in percentage of rice husk is beneficial for optimizing thermal and mechanical properties of fired clay bricks. Our studied specimens have a good porosity percentage. Their thermal characteristics are measured for temperatures between ambient and 900°C. In this case, only the lattice vibrations contribute to the thermal conduction. Thus, raw or heat-treated materials clay is presented to highlight their characteristics.

2. Energy Performance

Soil-based building material has been used since ancient times but lately it has been mainly considered for restoration purposes of traditional architecture instead of an eco-friendly construction material for new buildings [15,16,17]. Energy performance is very important for decreasing the consumption of energy-intensive buildings. The building and construction are energy-intensive, accounting for about 40% of the total energy consumption. In order to save building energy and reduce pollution emissions, more and more researchers pay attention to zero energy/emission buildings (ZEB) [14-22]. The primary objective of ZEB is to reduce energy consumption and increase renewable energy production, also to reduce emissions of greenhouse gases (GHG) [16]. Among them, improving the energy efficiency of buildings has become one of international problems [8-16]. Energy consumption (EC) and discomfort level (DL) are two main objectives which must be considered in building energy saving design.

3. Presentation of Study Area: Northern Part of Cameroon

The modeling and current soil of northern part Cameroon reflect and translate that hydro-climatic history is different from that of West Africa. Wholesale interdependent following facts are observed: the abundance of leveling glaze; the absence of armoring and induration ferruginous; received little shoals of networks; less well-drained soil; the presence of significant land-fillings; a corresponding scarcity of groundwater alterities; plenty of inselbergs.

The soils are formed on a colluvium mantle that can make 5 meters thick. Generically, the following sequence is observed: at the base, there are a few meters from quartz-feldspathic arenas more or less rich in dark minerals (needed for the possible genesis of swelling clay). The arena can hold a discontinuous groundwater. Above, you can see (on less than 2 meters) mottled kaolin clay that can be locally indurated shell or ironstone gravel or release. At the top of 1 to 2 meters, is a sandy clay layer often colluvium gravel layer (quartz) at its base. This colluvium layer gave birth to a “ferruginous leached hydromorphic soil” seems to be the most common soil of the region and has the following general characteristics: The color is brownish-gray to yellowish-gray, sometimes mottled rust from 60 cm. The organic matter content (0-20 cm) is of the order of 1 to 2%. In nature, these soils are subject to significant biological activity. This activity is probably related to the temporary presence of a perched water table. The texture is silty-sandy to silty clayey sand surface (12-25% clay); is sandy clay (35-45% clay) from 60 cm deep. The clumps are usually tabular and form trays perched marrying the horizontal stratigraphy of rocks. These are dominated by quartz sandstone, but these sandstones are interspersed with many benches conglomerate (quartz) and softer sandstone shale-based banks. Sandstone outcropping are sometimes altered and “ferruginous” in shell, imbuing the rock and locally releasing ferruginous gravel. Glazes account for most of the landscapes of the Far North Region Cameroon. The glaze-slopes represent those of the northern part Cameroon [1-8].

4. Incorporation of Additives in Fired Clay Brick: Specific Case of Rice Husks

Rice husks are materials of organic origin, derived from the processing of rice. They constitute the protective casing of the latter during its growth phase. After the protection of the seed, rice hulls are designed for other purposes including those related to the building, as they serve as adjuvant in the formulation of fired clay bricks for improved thermal and mechanical properties of latter [12-28]. For a more cost-effective implementation energetically in the building, it makes sense that we ensure the availability, reliability, and reduced cost of rice husks. This requires an industrial production evaluation of rice husks in Cameroon. This with a view to better assessment of the impact of rice husks on finished product. Figure 1 below gives an overview of rice husks used additives in the manufacture of fired clay brick in northern Cameroon.

Figure 1. Overview of rice hulls to incorporate into fired clay brick

4.1. Production of Rice Husks in Cameroon

Cameroon has three irrigated rice production areas. That of Yagoua and Maga in the Far North Region Cameroon, and the Ndop in Northwest Cameroon Region. These basins produce rice in industrial quantities oscillating between 100,000 and 170,000 tons per year, not including the artisanal production. According to Garoua Quality Centre (rice husking mill), the yield of paddy husking a bag 100 kg around 50 to 60% of rice. Hence the amount of rice balls ranging between 66,666 and 113,233 tons per year. Which therefore justifies the availability of this material in the northern part of the country, and in addition, its low cost of purchases. Rice husks are generally used as fuel by the peasant population, and as nutrients for herds animal [1-16].

4.2. Properties of Rice Husks

Light and bulky, density ranges between 132 and 140 kg/m^3 and is virtually impervious to insects. The nutrient content is low (3.3% protein and 1.1% fat), cellulose represents 45% of the mass. Ashes, composed almost entirely of silicon oxide, are environ17%. These ashes could be additional benefits in improving the mechanical properties of the bricks lands [12-67].

5. Building Brick

Developing local high-performance masonry materials is one of the most challenges facing humankind today to achieve positive-energy homes. Indeed, the buildings and building construction sectors constitute a major issue for green growth, which count for around 36% of the total energy consumption and 40% of CO2 emissions [18-25]. Therefore, innovative construction alternatives for achieving sustainable development are gradually becoming a necessity to promote the roadmap for zero-net energy buildings. In fact, Earth has long been the eco-material most often used in construction. Even today, 30% of the population is installed in earthen structures, mainly built of adobe [17,18,19]. Despite the high thermal inertia of earth, two key factors for a highly efficient earth-based building envelope still need to be improved, namely the thermal insulation and the mechanical strength. For this reason, many studies [22-71] have been done on the improvement of fired clay bricks using adjuvants.

Build and simultaneously isolate constitutes a gamble implemented by the clay through G19 block of land, namely a brick bearing a large number of cell rows quinconcées walls. It serves as a building material and has excellent qualities of rigidity and mechanical strength. Its 37.5 cm thick and 19 rows of cells lengthen the thermal path, reducing energy losses. This insulation block of land distributed has a conductivity coefficient $\lambda = 0.46$ W/ m°C for a shard standard terracotta, and $\lambda = 0.37$ W / m°C for a shard lightened by incorporation of sawdust or rice hulls. Its high inertia allows good control of the temperature and preserves freshness of the premises. Combustible, it does not give off toxic gases in case of fire. Moreover, it is not hazardous and solves the problems of recycling [56-62].

6. Thermal and Physic-mechanical Properties of Fired Clay Brick

While the fired clay bricks are used more for their thermal properties as mechanical properties, a minimum of mechanical resistance is indispensable. Indeed, it is necessary that a building envelope made of terracotta bricks can withstand at least its own weight. Therefore compression and bending tests are carried out to determine the strength of the materials studied. The fired clay bricks in general and those hollow in particular, have a density ranging from 1750 to 2050 kg/m^3. Their water absorption coefficient is <15% and its compressive strength is from 4 to 8 MPa. Those fired and against perforated have a density of 1650-2000 kg/m^3. Their water absorption coefficient varies between 30-80%. Their compressive strength yet remains very high: 12.5 - 40 MPa. However, the thermal resistance of solid clay bricks, hollow and perforated, varies depending on the thickness thereof. The thermal conductivity of the solid clay bricks remains equal to 1.15 (W/m°C). Outside the thermal and physic-mechanical properties of clay bricks, it is also necessary to know the main benefits of environmental and ecological point of view of this material. In fact, the environmental point of view, the earth absorbs and releases moisture in the air. It also regulates the temperature by thermal inertia and is also a very good sound insulation. Ecologically, land uses little water phase transformation and is therefore an abundant and renewable local resource. Earth construction uses only 3% of the energy used in concrete construction [63-69].

7. Contribution of Rice Husks in the Manufacture of Fired Clay Brick

Rice husks mixed with clay before firing have the function of promoting the thermal insulation of finished product. Indeed, rice hulls gasify during baking, thus creating micro cells within the clay brick. These cells microphones will contain stale and stagnant air that will create a result, heterogeneity in the clay brick and thus promote the thermal insulation. Fired clay brick with addition of fuels such as rice balls are called “insulating bricks” and are referred to in the trading system by Poro-brick, Iso-brick, or Thermo-brick. These insulating bricks generally have a density and mechanical strength to the reduced compression. So there are a multitude of additives are incorporated into the clay to the formulation of fired clay brick. These include slimming additions that constitute the skeleton of clay brick. These are intended firstly to reduce the drying shrinkage of mud bricks and the firing shrinkage of fired bricks. And secondly, to limit the deformation of finished products. As diet impurities include sand, slag and sawdust. Size slimming additions must, however, be between 0.3 and 1 mm. We also have quartz which improves the mechanical cleanings fired clay brick. Among the additives, there are metal oxides which reduce the refractory power of fired clay brick and are also responsible for the color of burnt bricks. As example we have iron, cobalt and chromium. However, the clay in which pore-forming additions are made to the example of clayey marl, dolomite or sawdust, have the final pore and a lesser weight [70-97].

8. Clay Bricks Forming Humidity Whose Adjuvant Rice Husks

The humidification process gives the products a plastic consistency with optimum water content. However, it varies depending on the percentage of the particle size fraction used for adjuvant. Determining the amount of water to the formulation specimens containing rice husk, is evaluated from the optimal amount of water samples. The amounts of water are measured by the following test and found optimal malleability of the material. Figure 2, Figure 3 and Figure 4 below, show the different water contents of the two samples respectively formulated at the particle size cuts: 1000-500µm, 500-315µm, 315-125µm; in proportions of 2%, 4%, 6%, 8%, and 10% of rice hulls.

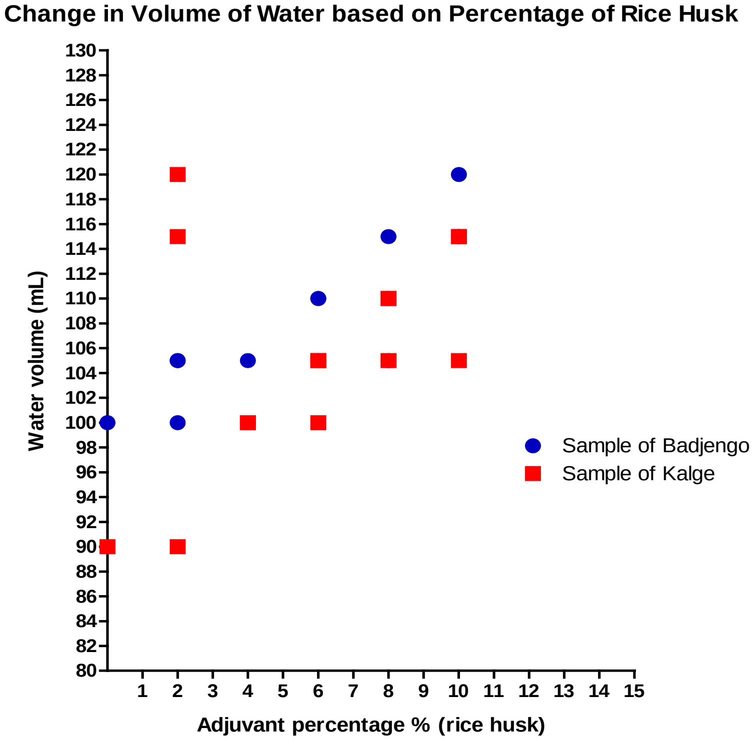

Figure 2. Change in volume of water according to the percentage of rice husks

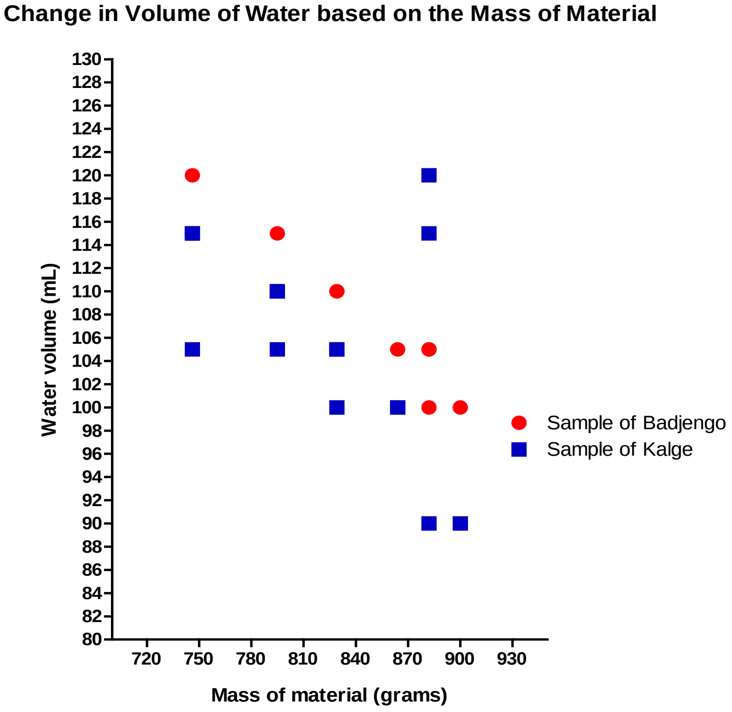

Figure 3. Change in volume of water based on the mass of material

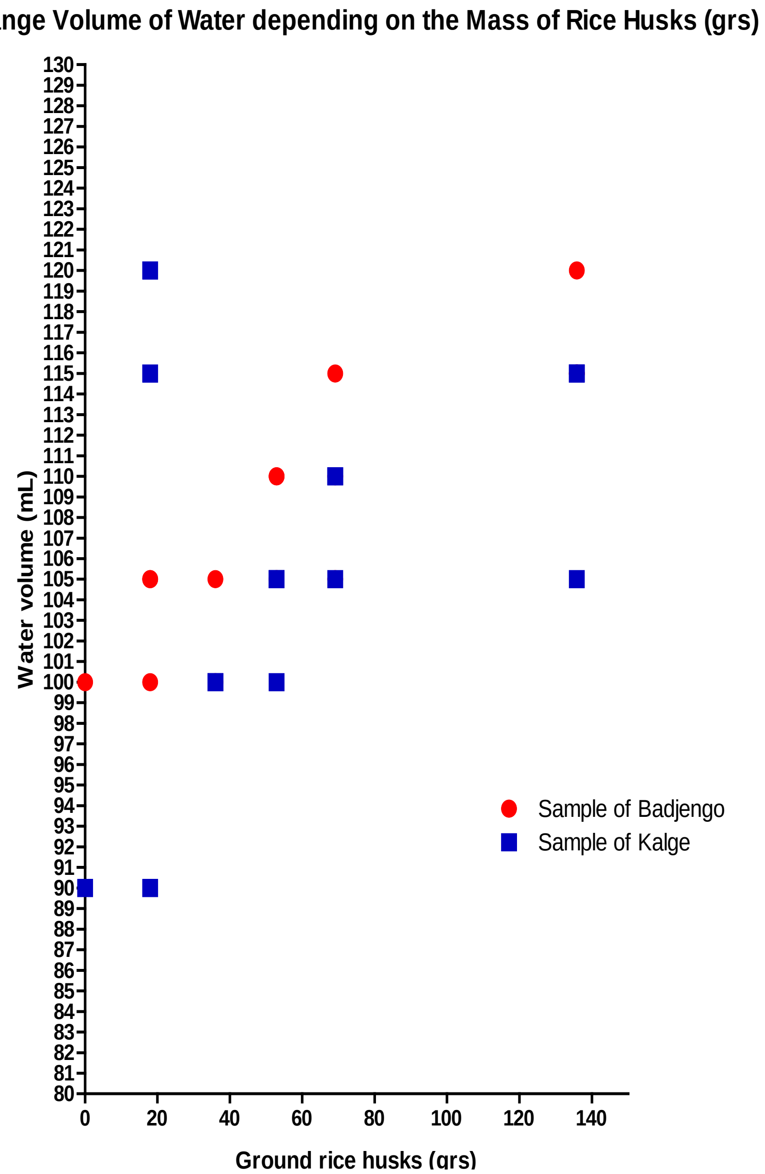

Figure 4. Change in volume of water based on the mass of rice husks

These results show that the water content changes with size of the particle, and the percentage of cuts rice husk. This water increase is justified by the fact that rice hulls are degreasers and contribute to the reduction of the sample plasticity. Reducing the plasticity, malleability and makes the shaping difficult sample, hence the need for additions of water to facilitate molding.

Furthermore, we also note that the volume of water is a function of the mass of adjuvant, and therefore the mass of clay brick material. This effectively justifies the need and important role played by rice husks in the formulation of fired clay brick.

9. Formulation of Fired Clay Brick Specimens with Addition of Rice Hulls

Samples are sieved through a sieve of 1 mm in diameter. Figure 5 below presented samples from the respective areas of Badjengo and Kalge.

Figure 5. Rice Balls Samples from Badjengo (photo above) and Kalge (photo below)

Three cuts granulometric according of 1000-500µm intervals, 500-315µm and 315-125µm rice hulls are added to the two previous samples to proportions of 0%, 2%, 4%, 6%, 8% and 10%. Figure 6 below shows us clearly and concisely the homogenization of rice husks in different proportions with clay in northern part Cameroon.

Figure 6. Respective particle size cutoff Rice Balls 1000-500µm (photo above left), from 500 to 315µm (photo above right), of 315-125µm (photo below left), and finally the mixture over rice balls clay (photo below right)

Shaping of specimens is to different water contents, and the layout by means of a cylindrical mold of 4.2 cm diameter and 8 cm in height. This is also what we illustrated in Figure 7 below.

Figure 7. Cylindrical mold (photo above) and mold reliability (photo below)

In this study, five specimens are formulated by percentages additions rice balls. Or 25 specimens per particle size cuts, which give us a total of 80 specimens per firing temperature. 240 specimens for the three firing temperatures, and 480 samples made for both samples. As a result, the specimens undergo a natural curing period of two weeks to promote the removal of water gradually; this is what we show in Figure 8.

Figure 8. Respective specimens of Badjengo (picture above) and Kalge (photo below) in curing period

At the end of treatment period, the specimens are placed in an oven for faster drying to facilitate departure of the absorbed water. The oven is set at a temperature of 105°C for a period of 24 hours. Figure 9 below shows us clearly the specimens in an oven.

Figure 9. Specimens of bricks in an oven set at a temperature of 105°C

Upon exiting the oven, clay brick of specimens are placed in an electric oven for baking at the respective temperatures of 900, 1000 and 1100°C. The firing speed by 5°C/min for three firing temperatures.

10. Pore Influence on the Quality of Fired Clay Brick

Pores play a similar role to that of impurities with respect to the migration of grain boundaries. It is for this reason that the granular growth generally occurs during the late stages of sintering in which there are fewer pores to hinder the grain boundaries. At the end of sintering, not only the grains grow but the pores begin to coalesce. This process can result from a phenomenon known as Ostwald ripening: the small pores disappear to unite with the larger pores by diffusion. It may also happen that several small pore size meet because of the disappearance of a small grain. A pore moves carriage of diffusing surface by the crystal lattice or transportation vapor phases. The migration of atoms that control the grain growth is not affected by the pores. The knowledge of the heat capacity and thermal conductivity of industrial materials used to evaluate the energy, required for baking or uniformity in temperature within a room. Moreover, understanding the main factors influencing the evolution of the heat capacity and thermal conductivity can be used to predict thermal and physical properties of the final specimens [70-98].

11. Transfer of Thermal Heat

According to the International Energy Agency, the building sector consumes about 32% of the global energy demand. About 37% of this energy consumption is spent to heat or cool indoor spaces [15-28] and strongly depends on the thermal efficiency of the building envelopes. A thermally insulating envelope can significantly reduce indoor heat losses during winter and indoor heat gains during summer. The large hygro-thermal inertia of raw earth originates from its fine network of nanopores (i.e. pores with a diameter smaller than 10 nm) and from the high specific surface of the clay fraction, which enhance the tendency of this material to adsorb and release vapor from humid and dry environments, respectively, while liberating and storing latent heat [16,28].

Heat transfer, more commonly known as heat, is transferred disordered microscopic energy. This actually corresponds to a transfer of thermal motion between particles at the mercy of random shocks that occur at the microscopic scale. The most common example of a situation involving a heat transfer system is made up of two bodies in contact and having different temperatures. The hottest body gives off energy in the form of heat to the colder body. There is heat transfer between the two bodies. May occur to a heat transfer system in which the temperature remains constant, for example in the case of a change in physical state. In general, thermal transfers can be made in three ways: convection, radiation and conduction. Convection occurs only in fluids media having a macroscopic movement. It acts in particular in heat exchange between a fluid and a solid wall. The radiant energy transfer is in the form of electromagnetic waves; can take place in a vacuum, it requires no specific medium. Finally, the conduction phenomenon occurs due to a temperature difference in one body or environment. In the case of a solid, the heat transmission takes place mainly by conduction ensured by the electrons and vibrations of atoms. However, measurement of the thermal conductivity of a material can account for convection or radiation, for example we have a porous material [70-98].

12. Conductivity and Heat Capacity

The thermal conductivity, the thermal diffusivity, the thermal effusivity and the specific heat capacity of liquids, powders and solids can be deduced by monitoring the time-dependent temperature evolution through the samples. Thermal conductivity (proportionality constant) indicates the resistance of a body opposed to the heat flow. It is always positive and corresponds to the density of the heat flow through, steady homogeneous body subjected to a temperature gradient of 1 Kelvin (or 1°C) per meter. It depends essentially on the nature of the material and the temperature. The heat capacity is in turn the amount of heat that can store a material with respect to its volume. It is defined by the amount of heat required to raise 1°C temperature of 1 cubic meter of the material. More the heat capacity is, the higher amount of heat that can store the material is high [18-90]. The thermal conductivity of developed composites ranges from 0.89 to 0.62 W/m K, representing a drop of about 30%. The thermal conductivity increases with density. Therefore, since the sample's density decreases with increasing adjuvants, fired clay brick can be useful in the development of thermal-efficient lightweight building materials.

13. Results and Discussions of Study of the Porosity Fired Clay Brick

Increasing the density of the pores with rice hulls rate is combined with shrinkage of the solid wall between adjacent pores. Thus the mean free path in the solid phase decreases significantly depending rice balls rates up to a level of 15%. Excess rice balls beyond this rate no longer affect the thickness of material which ensures the cohesion of the material, support the applied load and prevents crack propagation. Phenomenologically, the mean free path in the solid phase is able of being connected to a parameter characterizing the fragility of the material. This is also what we illustrated in Figure 10, Figure 11, Figure 12, Figure 13, Figure 14 and Figure 15 below.

Absorption is a measure of porosity, because the traditional ceramics comprise in their structure of closed pores always occupied by air. Northern Cameroon clay brick specimens are placed in cold water, and then boiled for 2 hours time. This in order to expel the air in the clay brick pores while saturating the same time by the water. The porosity of the fired clay brick therefore varies from 15 to 30% [84-98].

The above results also show an increase of porosity depending on the growth in content of rice hulls; including a decrease in porosity as a function of the temperature rise. It is also noted after boiling, a saturation of the closed pores with water. The deduced with the views of the previous results that the specimens having a porosity greater than 30% does not meet the production of fired clay bricks. These include: Badjengo specimens formulated to 10% of rice husk granulometric cuts 1000-500µm and 500-315µm, firing temperature corresponding to 900°C; regarding Kalge specimens, inadmissible formulations relate specimens formulated at 10% of rice husk granulometric cuts 1000-500µm, and corresponding to the firing temperature of 900°C and 1000°C. Also, the specimens made in 10% of rice hulls to a temperature of 900°C corresponding to the particle size cutoff of 500-315µm.

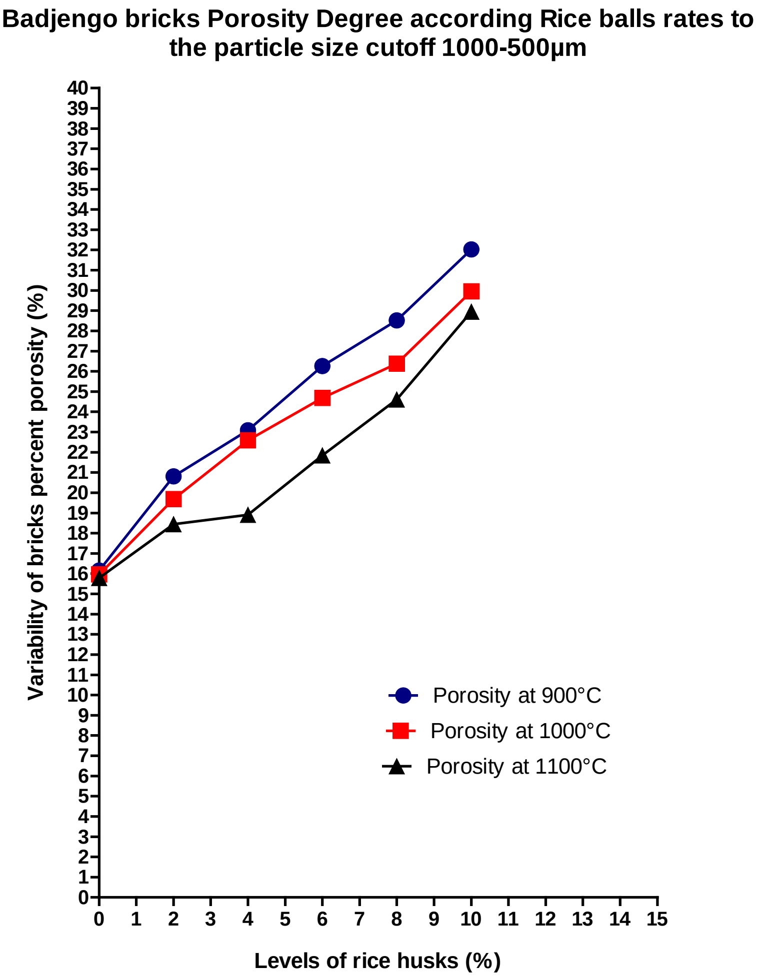

Figure 10. Influence of adjuvant and firing temperature on porometric properties of fired clay bricks

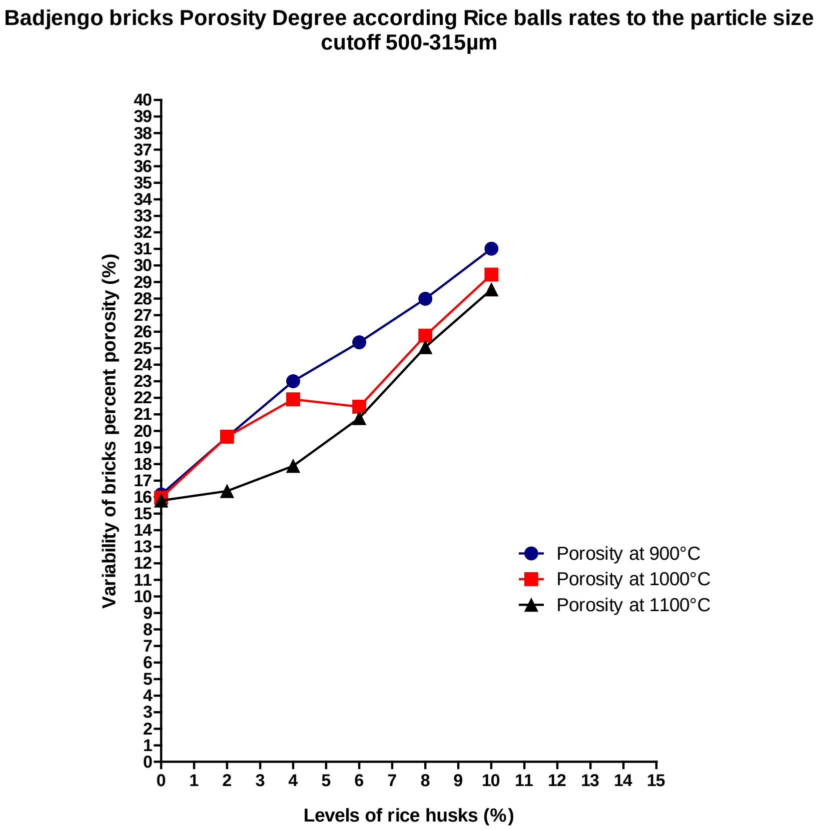

Figure 11. Influence of adjuvant and firing temperature on porometric properties of fired clay bricks

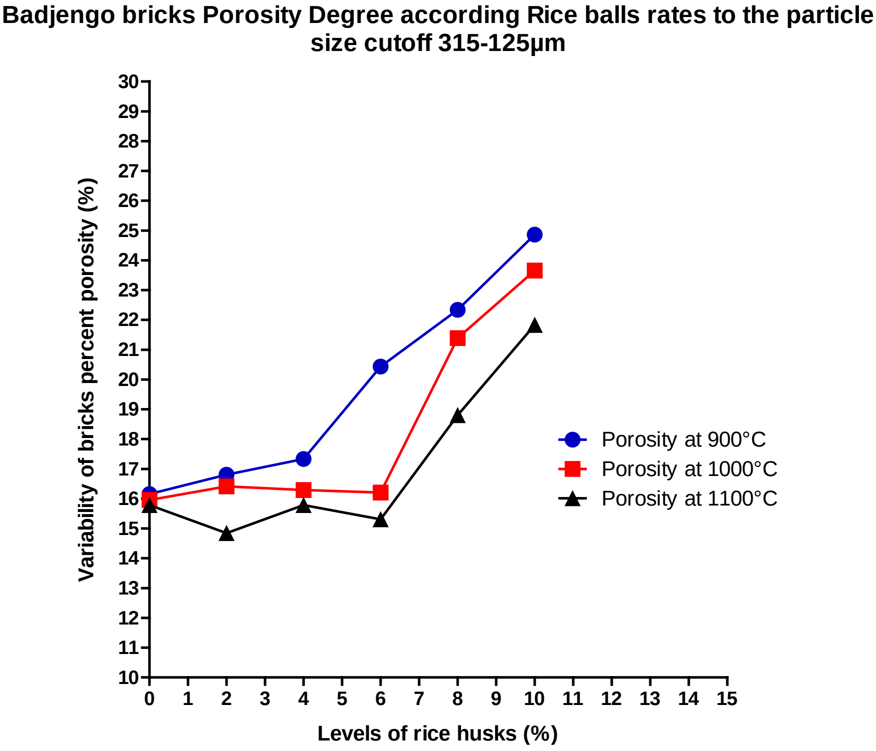

Figure 12. Influence of adjuvant and firing temperature on porometric properties of fired clay bricks

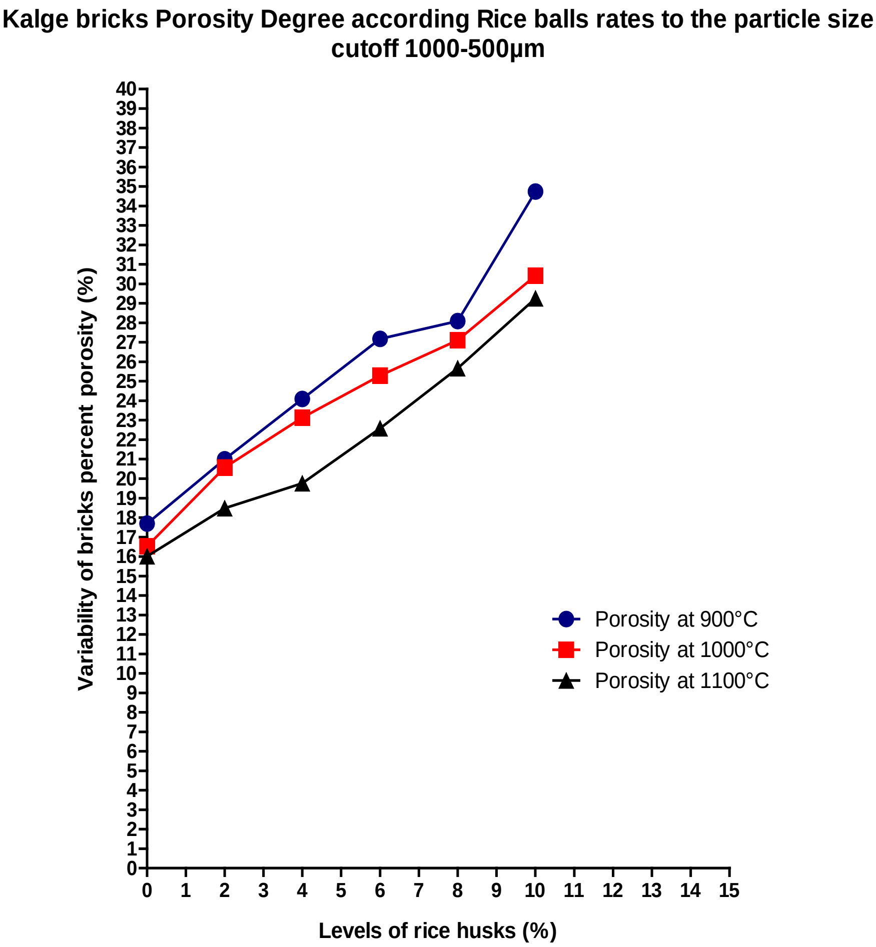

Figure 13. Influence of adjuvant and firing temperature on porometric properties of fired clay bricks

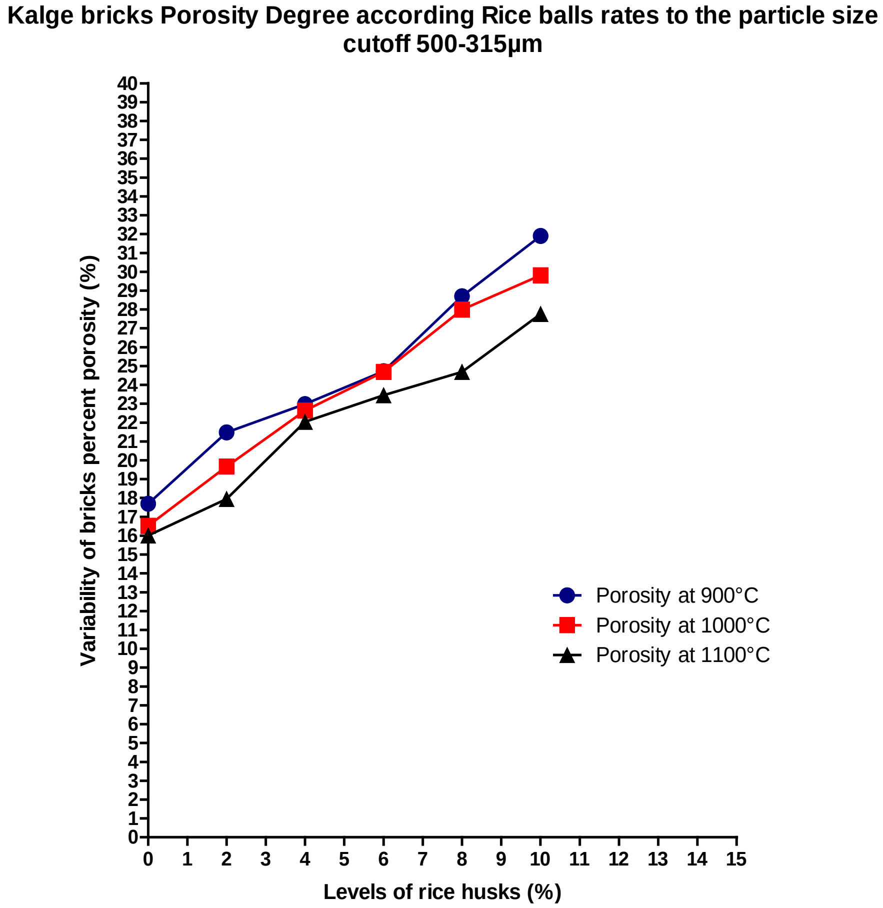

Figure 14. Influence of adjuvant and firing temperature on porometric properties of fired clay bricks

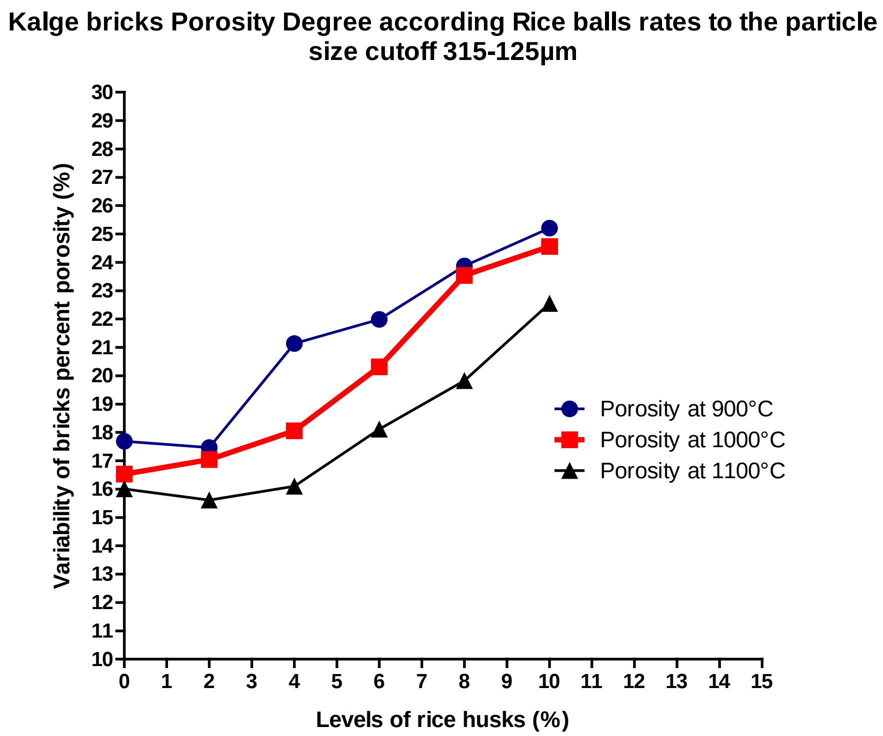

Figure 15. Influence of adjuvant and firing temperature on porometric properties of fired clay bricks

14. Conclusion

After this research, we agree that it is now possible to obtain performance fired clay bricks by incorporating rice husk as adjuvant. For samples of Badjengo we recommend 4% particle size cutoff 1000-500μm rice balls, 6% particle size cutoff 500-315μm rice balls, and finally 8% particle size cutoff 315-125μm rice balls all corresponding to an ideal temperature baking of 900°C. For samples of Kalge we recommend 4% particle size cutoff 1000-500μm rice balls, and 6% levels cut rice husk 315-125 microns all corresponding to an ideal cooking temperature of 900°C. And finally 500-315μm also corresponding to an ideal cooking temperature of 1000°C. The use of rice hulls as an additive to materials clay Badjengo and Kalge aims at "downsizing" of the kaolinitic clay. The firing shrinkage becomes much more controllable. Moreover, during the sintering of the carbonate mixtures, derived from the decomposition of rice hulls; rice husks promote the formation of new crystalline phases such as gelignite and anorthite. For a low rate of addition rice husk, the material obtained is consolidated mechanically. With 5% rice hulls, toughness remains good and breaking stress is increased, but the dispersion of values of the latter is important. Beyond that rate, it develops an important porosity. The decrease in mechanical properties is correlated with the porosity. Thermal conductivity controls the temperature distribution in a room during a heat treatment. It is obtained from the heat capacity values and thermal diffusivity. These were measured by the laser flash method between room temperature and 900°C. However, the porosity difference between the heat-treated samples has an effect on the values obtained during the study.

This study bearing some gaps in the literature on the study of thermal comfort Sahel zone habitats, notably with incorporation of rice husk as adjuvant. To enrich the present work, some additional studies would be considered, including that of the study of material clay with incorporation of plant or organic fibers. Although it is possible to increase the thermal phase shift of fired clay bricks by incorporating insulating materials, this does not preclude conducting future reflections on the behaviour of the latter. Especially in the presence of other insulating materials such as vegetable fibers, or polymers as regards in plastic waste to reduce the environmental damage caused by them.

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