

Effect of Coal on Engineering Properties in Building Materials: Opportunity to Manufacturing Insulating Bricks

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Abstract—The objective of this study is to investigate the effect of adding coal to obtain insulating ceramic product. The preparation of mixtures is achieved with 04 types of different masse compositions, consisting of gray and yellow clay, and coal. Analyses are performed on local raw materials by adding coal as additive. The coal content varies from 5 to 20 % in weight by varying the size of coal particles ranging from 0.25mm to 1.60mm.

Initially, each natural moisture content of a raw material has been determined at the temperature of 105°C in a laboratory oven. The Influence of low-coal content on absorption, the apparent density, the contraction and the resistance during compression have been evaluated. The experimental results showed that the optimized composition could be obtained by adding 10% by weight of coal leading thus to insulating ceramic products with water absorption, a density and resistance to compression of 9.40 %, 1.88 g/cm³, 35.46 MPa, respectively. The results show that coal, when mixed with traditional raw materials, offers the conditions to be used as an additive in the production of lightweight ceramic products.

Keywords—Clay, coal, resistance to compression, insulating bricks.

I. INTRODUCTION

BRICKS are widely used in building construction as the most common building materials in Algeria. Many manufactures of construction products based on clay minerals have substantial difficulties in getting good technological properties for raw materials [1], [2].

The production of lightweight clay bricks with higher thermal insulation properties is possible by using organic residues in appropriate amounts and particle sizes.

One of the materials used for this purpose is coal. Each coal particle which is dissipated during firing process and leaves behind it a cavity can improve the thermal insulation properties of the brick. The coal is, therefore, used as a pore forming material in the brick body to reduce the thermal conductivity and also the density of bricks which leads to the reduction of the mass of building and an improvement of its resistance.

If some organics residues are added to the raw material, it is possible to increase the volume of the voids with controlled operating modes. By increasing the volume of the empty spaces, the weight of the bricks is reduced. This leads to

specific properties e.g. increased thermal resistance in the finished product.

A mixture of clay with sawdust or other organic materials is necessary. These substances are consumed during firing which increases the formation of pores which contain confined and movable air enabling insulation.

Manufacturers of bricks seek more and more to reduce thermal conductivity of their products to obtain high thermal resistances of walls and increase the porosity of the potsherd [3]. To this list of products could be added another element which large storage capacity and recovery of heat could be a thermal and acoustical insulation of walls, floors and roofs with good air tightness.

The coal belongs to the type of organ - detrital sedimentary rock from very varied plants (various plants, ferns, fungi, algae) composed of different tissues (leaves, stems, bark, resin, pollens ...) [4]. It is a heterogeneous rock containing enough carbon to be usable as fuel and others. These main current uses are electricity production in the industrial sectors (steel) and the steam production without neglecting the residential sector, which gives to the latter to be used in new lightweight products [5].

The nature of coal depends on its volatile matter characteristics: calorific value, density etc. The use of coal in the field of ceramics remains to be explored. However some researches on the use of coal fly ashes as an addition to the raw clay have been discussed.

For example, the mixtures of coal fly ashes and clay used for the firing process technology for the dry pressed ceramic tiles were developed experimentally, using kaolin stoneware clay as the basic raw material and the fly coal ashes at classical high temperature [6], [7].

The ceramic for building can be produced from masses containing as much as 80- 90% of coal fly ashes and 20-10% of plastic clays or bentonite. At more than 20-30% in weight of fly ashes increases, the content of mullite increases and improves clearly the properties of stoneware products [8]. The use of coal ashes for glass-ceramic production has also been studied these recent years [9], [10].

The aim of this study was to test the possibility of adding coal to be used in the production of insulating ceramic bricks.

The investigation included a review of different mixtures, their behavior during firing and the production of ceramic pastes containing amounts of coal on a laboratory scale as a preliminary step before further tests on the industrial scale.

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The transition from a lightweight concrete product to a baked clay product is determined by the launching of a range of manufacturing bricks that fulfill certain properties that will be adapted to the contemporary construction and modern architectural trends. This transition is carried out by using a mixture of two types of clays (gray and yellow clay hereafter called GC and YC respectively) and by adding a pore-forming agent "coal" which, under the influence of the heat of the firing ovens, creates thus pores, are sublimed. This adaptation made it possible to develop a formulation for the manufacturing and the appropriate designing of bricks, by considering a more economical method of production and obtaining a material of better quality.

Four mixtures were studied (M1- M2- M3- and M4) respectively corresponding to the proportions of 50% - 55% - 60% - and 65% for the first type of clay (GC) and 30% remain constant for the second type of clay (YC). The concentrations of coal corresponding to each mixture are respectively: (5, 10, 15 and 20% in weight) with variable sizes of particles (0.25, 0.5, 1 and 1.60 mm).

The mixture with the size of coal particles of 1.60 mm enables to obtain interesting mechanical properties such as the resistance to compression of the order of 35.46 MPa corresponding to a density of 1.88 g/cm³.

This element of light construction with baked clay cumulates the structural properties and insulating qualities. Furthermore, this type of materials, because of its porosity, contributes to a good indoor air quality, including an effective hygrometric regulation. As well, according to one study of CSTB (Scientific Center of Building and technique), a single wall of t cellular baked clay can absorb a volume of water vapor five times more than a concrete block wall, without losing its initial qualities.

II. EXPERIMENTATION

Analyses were carried on local raw materials (GC and YC) and coal as an addition. Initially, we have determined the natural moisture of every raw material at a temperature of 105 °C from a laboratory oven of Memmert UL50 Type.

Clays and Coal used as local raw materials were obtained from different regions in Algeria. The coal used in this research is a form of amorphous carbon and highly porous residues of microcrystalline graphite remains (Fig. 1).

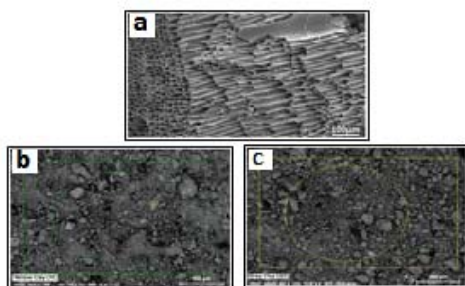


Fig. 1 Microscopic Images of (a) Coal and (b), (c) Clays (Yellow and Gray)

The chemical analysis and the ignition loss (IL) of local clay were carried out prior to the sequential characterization by the Siemens ray spectrometer type SRS 303. Water supply: 3V min. Air supply: 2V min, water pressure: 4-8 bars, Air pressure: 4.5 to 10 bars. The main minerals and clays combined with the nature of phases are determined by X-ray diffract meter of Siemens type "500D"- 20mA - 40k Volt with CRT Cu.

The chemical composition of local clay and coal is given in Table I. The mineralogical composition of raw clay (Table III) and coal were obtained using an X-ray diffract meter technique (XRD: X' Pert MPD PRO, Philips, Netherland). The major crystalline phase found in coal contains quartz and cristobalite (Fig. 3), of local clay (see Table III) are quartz, calcite, illite, kaolinite and montmorollinite. Microstructures of the baked clay bricks (Fig. 2) were examined using SEM (JEOL JSE-5410 LV).

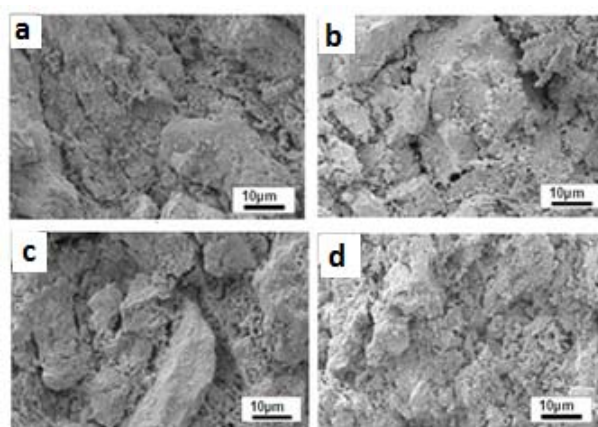


Fig. 2 Scanning Electron Micrograph Images of Specimens with Various Amounts of Coal Were Fired at 950°C: (a) 5%; (b) 10%; (c) 15% and (d) 20%

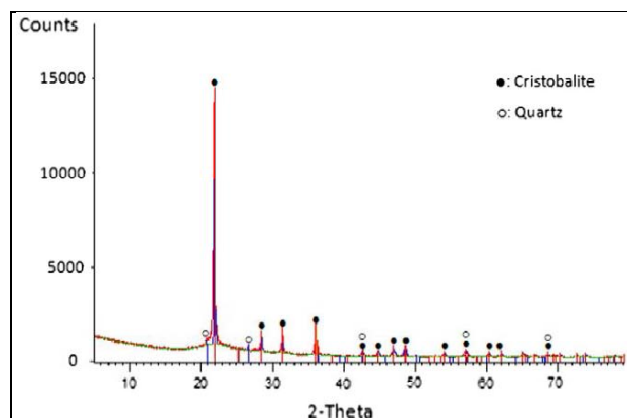


Fig. 3 X-Ray Diffraction Patterns of Coal

The particle size analysis has been determined by wet process using a series of screens with different diameters ($\phi = 5$ mm, 2, 1, 0.63 and 0.20) and by pipette of «Robinson» taking into account the following fractions (1 to 0.063 mm),

(0.063 to 0.01 mm), (0.01 to 0.005 mm), (0.005 to 0.001mm) and 0,001 those <0.001mm.

In order to determine the extent of the pore-forming effects of charcoal, the addition of coal was dry sieved step by step through sieve meshes n°. 35, 40 and 45 and finally the sizes of coal particle obtained were less than 1.60 mm. Then added coal was added to raw clay bricks and divided into four compositions of different masses (M1 - M2 - M3 - M4) mixed with 4 different percentages of coal additives: 5.0%, 10%, 15% and 20%. Each mixture was mixed in a porcelain ball mill in order to ensure homogenous mixing. The following proportions of masse compositions were respectively: 50% - 30% - 20%), (55% - 30% - 15%), (60% - 30% - 10%), (65 % - 30% - 5%).

Then, each was mixed with 20–30% of water in order to enhance the plastic condition of mixture and to obtain the desired shape during its moulding by hand with a rectangular test device for the shaping. The test briquettes were air dried at room temperature for 24 h, and then over dried at $110 \pm 5^\circ\text{C}$ for another 24 h to remove water content. Then, each group of green specimens was fired at temperatures of 950°C with 2 h soaking time in a gas furnace. The specimens were naturally cooled down to room temperature in the furnace. The characterization of mechanical and physical properties is focused on the dry shrinkage and fired, the absorption, the porosity, the density, and the specific mass. The mechanical strength is determined on a device of bending Type 401NEZSCH EN100.

III. RESULTS AND DISCUSSIONS

The results of careers moisture of considered materials are reported in Table I.

TABLE I
NATURAL HUMIDITY VALUES OF RAW MATERIALS

| Types of material | GC | YC | Coal |
|---------------------|------|------|-------|
| Humidity career (%) | 5.65 | 15.1 | 10.85 |

It is observed that the GC contains less moisture than the YC; this is due to the summer season of its extraction. The second type of clay drying is necessary before any use to avoid problems of clogging of equipment during processing.

The results of chemical analysis of clays and coal are shown in Tables II.

According to chemical analyzes, we note that both types of clays have one common characteristic. On the one hand, the rate of Al_2O_3 in both cases is <14% which can classify these clays in the group of acidic clays and secondly, the rate of limestone is between 6 - 20% to be classified in the group of marl clays where products are fired yellow [11].

Elements K_2O , Na_2O acting as energetic fluxes, have a slightly higher rate for the YC (Yellow Clay), giving it therefore better properties of firing. The main element which distinguishes these two clays is SiO_2 , which is higher in the YC. This observation points out that this type of clay is sandier and therefore plays the role of degreasing agent.

One also notices that the rate of CaO , SO_3 is higher in the case of GC (Gray Clay) that is in exact correlation with the high rate of ignition loss. The mineralogical analysis results (Table III) show that yellow and gray clays are of illite / montmorillonite and illite / kaolinite / chlorite type respectively. Table IV shows the particle size analysis of the two types of clay.

TABLE II
CHEMICAL COMPOSITION OF CLAYS AND COAL

| Mass content, wt% | Material | | |
|-------------------------|----------|-----------|-------|
| | Clay: GC | Clay : YC | Coal |
| SiO_2 | 48.02 | 51.28 | 1.44 |
| Al_2O_3 | 10.63 | 12.34 | 0.32 |
| Fe_2O_3 | 4.68 | 4.76 | 0.17 |
| CaO | 13.49 | 11.39 | 3.70 |
| MgO | 1.67 | 1.48 | 0.34 |
| MnO | - | - | 0.014 |
| SO_3 | 1.23 | 0.95 | 0.05 |
| K_2O | 1.51 | 1.67 | 0.29 |
| P_2O_5 | - | - | 0.035 |
| Na_2O | 0.61 | 0.57 | <0.05 |
| Cl | - | - | 0.06 |
| LOI | 17.34 | 14.72 | 93.50 |

TABLE III
MINERALOGICAL ANALYSIS OF CLAYS

| Principal minerals | Content (%) | |
|---------------------------|----------------|------------------|
| | Gray Clay (GC) | Yellow Clay (YC) |
| Quartz | 32 | 27.5 |
| Calcite | 21 | 18 |
| Dolomie | 3 | 2 |
| Feldspar: potassium | 1 | 1 |
| Feldspar: sodium, calcium | 2.5 | 2.5 |
| Semi hydrate gypsum | 2 | 2 |
| Ferruginous minerals | 4.5 | 4.5 |
| Illite | 13.5 | 15 |
| Kaolinite / chlorite | 12 | 13.5 |
| Montmorillonite | 8.5 | 14 |

TABLE IV
GRANULOMETRIC ANALYSIS OF GRAY AND YELLOW CLAYS

| Coal type | Particle size (mm) "By Robinson pipette" | | | | |
|-----------|---|---------------|---------------|----------------|---------|
| | 1 to 0.063 | 0.063 to 0.01 | 0.01 to 0.005 | 0.005 to 0.001 | < 0.001 |
| | Content (%) | | | | |
| GC | 14.65 | 30.99 | 13.20 | 11.00 | 30.16 |
| YC | 12.40 | 25.28 | 13.28 | 22.72 | 26.32 |
| | Mesh size of screen (mm) "by wet process" | | | | |
| | 5.00 | 2.00 | 1.00 | 0.63 | 0.20 |
| | Content (%) | | | | |
| GC | 0.00 | 0.00 | 0.03 | 0.03 | 0.10 |
| YC | 0.00 | 0.00 | 0.00 | 0.1 | 0.03 |

According to Table IV (Granulometric analysis of clays by Robinson pipette), we observe that the gray clay contains much more clay particles than clay yellow this is in correlation with the data in Table I.

According to Table IV (Granulometric analysis of clays by wet process) we observe that refusal rate of yellow clay is

lower than that of gray clay. Furthermore, the yellow clay consists of much more small particles, which is probably due to montmorillonite that is associated to clay what is correlated with the results in Table III.

Referring to the soil textural classification, we see that the gray clay is so-called composed of "fine sand", and yellow clay character is "Limon". Fig. 4 shows the variation of moisture of making the various mixtures (M1, M2, M3 and M4) according to the addition of coal and its particles size.

Coal tends to play the role of a degreaser. For each carbon addition and depending on its content and particle size, there is a decrease in clay mixture moisture. From a content of 10% and a particle size of 0.50 mm, the linking power becoming lower and lower. For the same particle size and a carbon content of 20 wt%, the amount of water for shaping reaches the value of those used to moisten the powders intended for pressing. In this type of variants (proportions of mixtures) are attributed a low mechanical resistance. The comparative Results of physical and mechanical properties of the products are summarized in Table V.

TABLE V
COMPARATIVE RESULTS OF PHYSICO-MECHANICAL CHARACTERISTICS OF THE PRODUCTS OBTAINED WITH 5 AND 10% OF COAL AND 0.50 AND 1,6 MM OF PARTICLE SIZE

| Physico-mechanical characteristics | Coal content 5 wt% | | Coal content 10 wt% | |
|------------------------------------|----------------------|-------|---------------------|-------|
| | Moisture shaping (%) | 22.50 | 19.60 | 18.70 |
| Shrinkage on dry (%) | 8.70 | 8.00 | 7.20 | 6.70 |
| Shrinkage on firing (%) | 0.30 | 0.67 | 0.80 | 0.91 |
| Absorption (%) | 2.90 | 5.20 | 7.60 | 9.40 |
| Open porosity (%) | 6.20 | 10.70 | 15.00 | 17.70 |
| Closed porosity (%) | 5.30 | 7.01 | 10.30 | 11.90 |
| Total porosity (%) | 10.50 | 17.70 | 25.30 | 29.60 |
| Density (g/cm ³) | 2.14 | 2.06 | 1.98 | 1.88 |
| Specific Mass (g/cm ³) | 1.92 | 1.75 | 1.52 | 1.45 |
| Bending strength (MPa) | 15.1 | 14.26 | 11.92 | 9.04 |
| Compressive strength (MPa) | 60.41 | 57.04 | 47.7 | 35.46 |
| Particles size (mm) | 0.50 | 1.60 | 0.50 | 1.60 |

The physical and mechanical properties studied and reported are firing shrinkage, water absorption, and porosity, and apparent density, resistance to compression and to bending. The briquettes fired for the tests were formed from local clay with the average particle size distribution of 2–0.001 mm, while charcoal particle sizes were less than 1.6 mm.

Figs. 5-8 show the results of physical and mechanical properties of the obtained products.

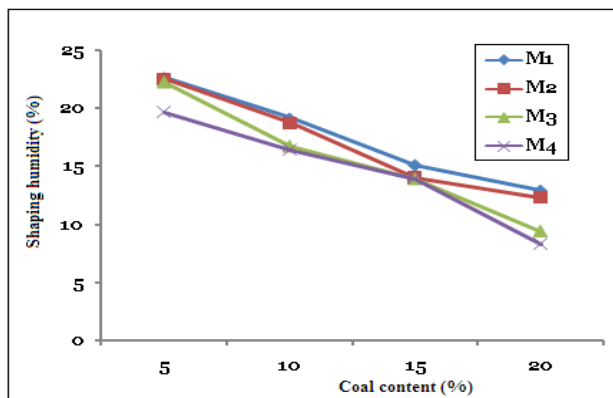


Fig. 4 Shaping humidity of different mixtures according to the coal content

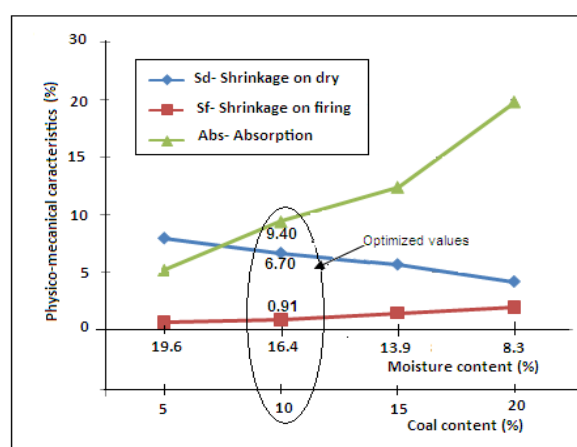


Fig. 5 Shrinkage variation and absorption in relation with moisture of mixtures according to the particle size (1.60 mm) and coal content

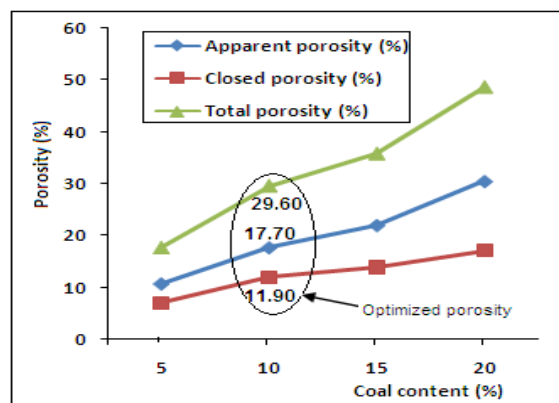


Fig. 6 Optimized value of porosity according to the particle size (1.60 mm) and coal content

In general, shrinkage enabling to shape clay bricks occurs because of the leaking of water from clay body. To minimize shrinkage, the firing temperature which is an important parameter affecting the degree of shrinkage must be controlled during the firing process [12]

An increase in the temperature results in an increase in shrinkage. Normally, a good quality of bricks shows a shrinkage below 8% [13]. In this study, test briquettes were fired at the temperatures of 950°C. The results indicated that shrinkage occurring in the test fired briquettes was in the range of 0.67–2%. As shown in Table VI, the percentage of shrinkage rises with an increase in the amounts of coal addition.

The dry shrinkage varies in the same way as moisture of shaping. The corresponding values for the dry shrinkage are significantly above normal for coal particle sizes within the range of 0.25, 0.50 to 1.00 mm with a coal content of 5%. The recorded values of dry shrinkage are respectively: (9.00 to 8.70 and 8.50%). The dry Shrinkage reached the desired values for the particle size in the order of 1.60 mm. For coal content higher than 5%, the recorded values fall within the range of standards.

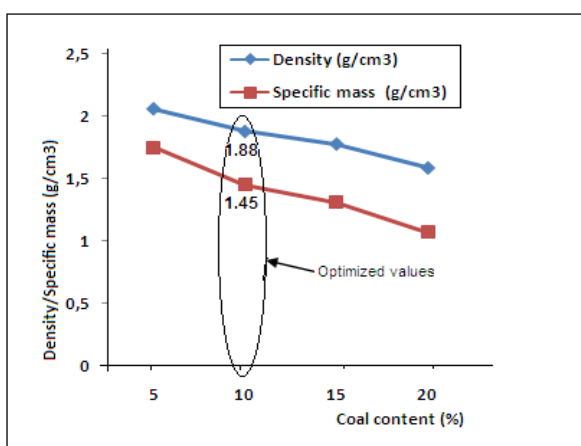


Fig. 7 Optimized values of density and specific mass according to the particle size (1.60 mm) and coal content

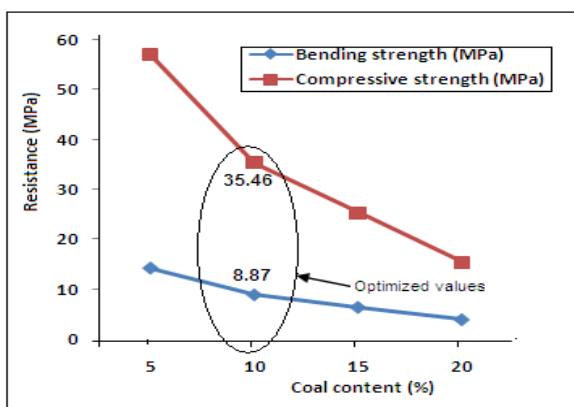


Fig. 8 Optimized values of bending and compressive strengths according to the particle size (1.60 mm) and coal content

It should be noted that the coal addition of over 8%, causes problems of production. It is conceivable that moisture gradients during drying through the product will generate the

movement during the early drying stages and therefore constraints on the quality of products [3].

The variations of baking shrinkage are proportional to particle size and coal content. For a particle size of 1.60 mm and a coal content of 5 - 10 - 15 - and 20 wt%, the corresponding shrinkage values are respectively 0.67- 0.91 - 1.50 - and 2% (Table VI). High values are due to the release of CO₂ and other volatiles gases such as SO₃, Chlorine (See Table I). These reactions are accompanied by a rearrangement of particles and an ordered orientation in the crystal lattice leading to a consolidated texture compared to the initial state followed by "shrinkage" [14], [15].

Comparative results for coal contents of 5 and 10 wt% and for particle sizes of 0.50 and 1.60 mm (Table V), we suggest that the humidity rate of 16, 40% will be considered as the amount of water necessary to obtain a mouldable mass taking into account the natural water contained in the coal. Therefore, it should be noted that the element responsible for major dry shrinkage (see Table V) is due to the high amount of water which is combined with the natural water of coal. Thus, the yield limit is exceeded leading to an important shrinkage.

Figs. 2 to 5 include the physical and mechanical properties of various mixtures in relation with coal content.

The density of clay bricks depends on several factors which are specific gravity of the raw material used, the method of manufacturing and the degree of burning [12]. As the density of a clay brick decreases, its strength also decreases, while its water absorption increases. In this study, the bulk density of fired test briquettes was inversely proportional to the quantity of charcoal added into the mixture. The apparent volume mass of specimens decreased with an increase in the amounts of charcoal ranging from 5% to 20%. The apparent volume mass is related to water absorption and durability of bricks.

Moreover, considering the values shown in Table V and Fig. 7, we observe that the density and the specific mass decrease and the carbon content increases with the size of its particles.

The internal structure of bricks must be dense enough to stop the intrusion of water. To increase density and decrease water absorption of bricks, the firing temperature must be raised. In this study, the quantity and the size of coal added in the test briquettes fired at firing temperature of 950°C, has increased the water absorption rate in a linear manner. According to Table V, the water absorption of the test briquettes fired at the temperatures of 950°C was in the range of 2.9 - 9.4%. Water absorption was directly proportional to the apparent porosity. Therefore, similar trends were observed in water absorption and porosity. The study reveals, from the tests results that the fired test briquette showed various apparent porosity depending to amount coal addition. The highest porosity was 48.6% with 20% of charcoal addition, and the lowest 17.71% with 5% of coal addition. This result revealed that the higher percentage of charcoal added in the specimens, more than the porosity in specimens which occurred (Table VI). Consequently, the porosity in the fired test briquettes occurred when the added coal was burnt out

during the firing process. These results were in agreement with the literature reviewed.

In conclusion, the apparent density varies depending on the quantity and size of coal grains added in a clay body at firing temperature. Thus charcoal was an appropriate agent used as an organic additive which came with briquettes having a finished smooth surface and other required properties. The results shown in Table V indicate that the apparent density of specimens varied from 2.14 to 1.88 g/cm³ fired at 950°C.

To values of porosity and a high absorption corresponded a low resistance (Figs. 5, 6 and 8).

The compressive strength test is the most important test to ensure the technical quality of a building material. In this study the result indicated that the strength of test briquettes greatly depended on the quantity of coal additive and the firing temperature. The results of compressive strength (Tables V and VI) indicated that the compressive strength of fired test briquettes has decreased with the increasing of coal content. An increase in the compressive strength was due to a decrease in porosity and an increase in apparent density (Table V). The results revealed that the compressive strength was in the ranges from 15.46 to 57.04 MPa when coal addition varied from 5% to 20% at a firing temperature of 950°C (Table VI).

TABLE VI
VARIATION CHARACTERISTICS OF VARIOUS MIXTURES ACCORDING TO THE PARTICLE SIZE (1.60 MM) AND CONTENT (10 WT%) COAL OPTIMIZED

| Physico-mechanical characteristics | Coal content (wt %) | | | |
|------------------------------------|---------------------|--------------|-------|-------|
| | 5% | 10% | 15% | 20% |
| Moisture shaping (%) | 19.60 | 16.40 | 13.90 | 8.30 |
| Shrinkage on dry (%) | 8 | 6.7 | 5.7 | 4.2 |
| Shrinkage on firing (%) | 0.67 | 0.91 | 1.5 | 2 |
| Absorption (%) | 5.2 | 9.4 | 12.4 | 19.8 |
| Open porosity (%) | 10.7 | 17.7 | 22 | 30.5 |
| Closed porosity (%) | 7.01 | 11.9 | 13.8 | 17 |
| Total porosity (%) | 17.71 | 29.6 | 35.8 | 48.6 |
| Density (g/cm ³) | 2.06 | 1.88 | 1.78 | 1.59 |
| Specific Mass (g/cm ³) | 1.75 | 1.45 | 1.31 | 1.07 |
| Bending strength (MPa) | 14.26 | 8.87 | 6.34 | 3.86 |
| Compressive strength (MPa) | 57.04 | 35.46 | 25.38 | 15.46 |
| Particles size (mm) | 1.6 | 1.6 | 1.6 | 1.6 |

Generally, in traditional ceramic system, as the porosity increases, the strength properties decrease [16].

The properties sought in this study are to have a product with a low density, a high porosity and a better mechanical resistance. The optimized physical parameters (Table VI), allowing the grouping of these three properties, are taken into account in the mixture M2 with a size of coal particles of 1.60 mm.

The SEM results of the vitrification specimens at 950°C and of different quantities of additive coal are shown in Figs. 2 (a)–(d). The images show that as coal content increases, the micro-pores of the specimens also increase. This is the main reason of the increase in water absorption. Thus, when the firing temperature increases the water absorption of the specimens decreases. However, the compressive strength was reduced when the content of charcoal increased because the

compressive strength was increased due to a decrease in porosity and an increase in the apparent volume masse with the firing temperature [17].

IV. CONCLUSION

Currently, the ceramic industries bear more and more their looks on the lighter insulation products.

The effect of coal additions on the properties of insulating ceramic bricks has been studied. The physical-mechanical properties of insulating bricks were affected by the additions; however, compositions of up to 20 wt% of coal had sufficient strength for handling.

The addition of Coal was mixed with clay in different proportions to investigate good qualities of baked clay briquettes and, potentially, clay bricks as modern construction material. In fact, the study on the effects of adding coal was mainly aimed at producing light and more porous baked clay bricks. The value of apparent porosity and water absorption for specimens increased linearly with an increase in the amount of coal mixed.

Generally as the porosity increases, the mechanical strength properties decrease in the traditional ceramic system. In this study 950°C was the most appropriate firing temperature for test briquettes because the fired test briquettes were more durable, porous and stronger when compared with current commercial brick specimens that were tested. A comparative study of optimization between the different mixtures allowed us to deduce that the mixture meeting the desired criteria, provides a density of 1.88 g/cm³ corresponding to a value of compressive strength of 35.46 MPa.

Thus, coal could be used as a pore former in clay mass. Conclusively, the results revealed that coal could be regarded as a potential addition to raw materials used in the manufacturing of light baked clay bricks.

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