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The Effect of Wood Ash and Sawdust Admixtures on the Engineering Properties of a Burnt Laterite-Clay Brick

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Abstract: The effects of the addition of sawdust (for burning out) and wood ash admixtures to a 70:30 parts by weight laterite-clay mix were investigated. The admixtures were added in various combinations of proportions by volume (from 0 to 10%). It was discovered that the major contribution of the sawdust admixture is the reduction in the dry density of the finished burnt brick product (from 1755 kg m^{-3} for the control mix without admixtures to 1512 kg m^{-3} for mix with 10% sawdust content). The wood ash admixture, in line with its pozzolanic nature, was able to contribute in attaining denser products with higher compressive strengths, higher softening coefficients, lower water absorption rates, lower saturation coefficients and lower abrasion indexes. Increasing contents of sawdust in the mixes produced the opposite results in the finished products, mainly due to its effect of producing a less compact structure in the finished product.

Key words: Burnt brick, engineering properties, pozzolanic admixtures

INTRODUCTION

Bricks are masonry units composed of inorganic non-metallic material and are widely used as building components all over the world. The bricks could be sun-dried or burnt. Burnt bricks are usually stronger than sun-dried bricks, especially if they are made of clay or clayey material. This is because the burnt bricks, as a result of the heat to which they are usually subjected (about 800-1180°C), become homogeneous, harder and stronger from the ceramic bond produced through the fusion of the silica and alumina clay constituents. It has been ascertained that soils having a clay fraction of between 30 to 40% are considered satisfactory for brick production, with the absence of processing defects after drying and firing such as cracks, fracture, deformation and volume change, while those having a clay fraction of more than 80% are unsuitable for brick making (Adeola, 1997). The raw material for the production of burnt bricks therefore needs to be of appropriate composition. Especially in the tropics where prevailing conditions favour the formation of laterite and lateritic soils, these are the materials mainly used for the making of the bricks. Also, laterites and lateritic soils have been shown to encompass a wide range of soils of varying structural and mineralogical composition. An unsatisfactory clay fraction content or grain-size distribution of the soil for the production of the bricks would require proportioning, which is the addition of other material to alter the composition of the mixture. Often, two separate soils (a lateritic soil without adequate fines and a predominantly clayey soil) that would be unsuitable for burnt brick production on their own are usually blended together in the appropriate mix to produce good material for burnt brick production. The presence and addition of the clayey material would provide material for fusion during firing. The presence and addition of the coarser grains perform functions similar to that of aggregates in Portland cement concrete, namely, to provide strength and increase resistance to crushing and abrasion. Apart from the coarse-grained lateritic soils, other materials in this category of admixtures are fine sands, ground furnace slag, ground shells, grog (fired and pulverized clay products) and other non-plastic materials.

It is also common that certain admixtures are added to burnt brick raw mixes to produce different effects in the finished product. A second category of admixtures includes organic matter, such as rice husks, sawdust, coal, etc., which burn out when the bricks undergo firing. This category of admixtures serves two purposes. As they burn out they leave pores in the product. This permits the control of the bulk density of brick products and help in producing lighter and more porous bricks. The second purpose is that they result in more uniformly burnt bricks, especially where the firing is being done outside of factory conditions, in which case inability to reach the minimum desired temperature of 1000°C results in unburnt cores especially in solid bricks. The pores produced as the admixtures are burnt out permit the heat to reach into the innermost part of the core, thereby avoiding unburnt cores, while the admixtures on their own part serve as extra fuel which provides more heat for the firing. Overall, there is a reduction in fuel and power expenditures. The temperature to which the brick is fired during burning is of paramount importance. The higher the firing temperature, the higher is the quality of the finished product.

The third category of admixtures is the consolidating substances or fusing agents. These admixtures are added to increase the bond between the particles and thus the strength of the brick. Such admixtures are either cementitious or pozzolanic materials. Pozzolanic materials include the traditional lime. The recent nontraditional pozzolanic admixtures used for brick production include rice husk ash, sawdust ash and wood ash.

MATERIALS AND METHODS

Preparation of sample mixes: The study was conducted in the Ado region of Ekiti State in Southwestern Nigeria. The region lies between latitudes 7°30'N and 7°50'N and longitudes 5°00'E and 5°20'E. It has been shown (Okunade, 2007) that the conditions enhancing the formation of laterites and lateritic soils are prevalent in the region and in fact there is a preponderance of such soils there, making them to be a readily available and useful source of building material. Moreover, the grain size distribution of lateritic soil samples collected from three different locations within the region in another study (Okunade, 2007) and reproduced in Table 1, indicate that the total fines content (clay and silt fraction sizes less than 0.075 mm) are generally less than 10%. The samples were collected at a depth of about 2.0 m below the ground surface at locations along different road axes from Ado, the state metropolis. Sample L1 was collected at km 6+400 along the Ado-Iworoko Road; Sample L2 was collected at km 8+200 along the Ado-Ijan Road; while Sample L3 was collected at km 8+600 along the Ado-Ikere Road. After collection, the soil samples were spread out in the laboratory for a few days for air-drying, after which the clods were broken down and the samples well pulverized. Thereafter, employing standard procedures, the samples were tested for their classification and index properties, their consistency properties and their compaction and strength characteristics.

These soils, with clay content generally less than 30%, are very good for the production of adobe bricks (Kratzer, 2003) but unsuitable for the production of burnt bricks. As mentioned earlier, Adeola (1997) has ascertained that soils having a clay fraction of between 30 to 40% are considered satisfactory for burnt brick production, resulting in the absence of processing defects after drying and firing such as cracks, fracture, deformation and volume change.

Table 1: Grain-size distribution and physical properties of lateritic soil samples from Ado region

Physical property / Description		Sample L1: Dark-brown well-graded sand	Sample L2: Light-brown clayey sand	Sample L3: Light-brown well-graded sand
Grain size distribution (percentage passing sieve sizes)	4.750 mm	94.60	98.40	98.80
	2.360 mm	68.50	86.60	88.50
	1.180 mm	51.80	62.10	68.20
	0.600 mm	36.40	42.40	53.50
	0.425 mm	28.50	31.90	42.40
	0.300 mm	22.00	22.60	32.00
	0.150 mm	12.60	12.80	14.20
	0.075 mm	7.80	8.00	6.40
Specific gravity		2.56	2.52	2.54
Liquid limit (%)		46.40	44.60	42.80
Plastic limit (%)		26.30	28.20	26.60
Plasticity index (%)		20.10	16.40	16.20
Optimum moisture content (standard proctor) (%)		16.50	16.80	16.00
Maximum dry density (standard proctor) (kg m^{-3})		1868.00	1890.00	1854.00
AASHTO classification		A-2-7	A-2-7	A-2-7
Group index		0	0	0
Universal soil classification		SP-SC	SW-SC	SP-SC

In view of the above, it was found expedient to mix purely clayey soils (with a high clay fraction content) with the lateritic soils to obtain the desirable combined clay fraction content for the purpose of burnt bricks production. Clay soil samples were collected from two different well-known extensive clay deposits located within the Ado region, both at a depth of 1.5 m below ground level. Sample C1 was collected near Ire, about 25 km North-East of Ado, while Sample C2 was collected at Ikere, about 12 km south of Ado, the metropolis. During and after the procuring of the samples, care was taken to preserve them so as to retain their natural moisture content. Thereafter, employing standard procedures, the samples were tested for their classification and index properties, as well as their consistency properties. The fractional composition was determined through sedimentation test (hydrometer analysis). The results are shown in Table 2.

Employing methods outlined in O'Flaherty (1974) for blending two or more different aggregates to get desired final gradations that fall within given grain-size specifications, 70% by weight of lateritic soil from Sample L1 were thoroughly mixed with 30% by weight of clay soil from Sample C1 to obtain the laterite-clay blend with the gradation shown in Table 3.

The sawdust admixture belongs to the second category of admixtures as mentioned earlier. It was added for the main purpose of leaving pores in the brick to produce lightweight and porous bricks and to permit more uniform firing of the brick after its burning out. Sawdust is a solid wood waste that is obtained in large quantity in

Table 2: Grain-size distribution and physical properties of clay soil samples from Ado region

Physical property / Description		Sample C1: Highly plastic, yellowish clay, with stripes of brownish clay	Sample C2: Highly plastic, grayish clay
Grain size distribution (percentage passing sieve sizes)	4.750 mm	100.00	100.00
	2.360 mm	100.00	100.00
	1.180 mm	100.00	100.00
	0.600 mm	98.20	100.00
	0.425 mm	95.70	97.60
	0.300 mm	94.10	96.30
	0.150 mm	91.40	94.20
	0.075 mm	89.60	90.80
Specific gravity		2.59	2.61
Liquid limit (%)		63.20	68.70
Plastic limit (%)		16.70	20.40
Linear shrinkage (%)		3.00	3.60
Plasticity index (%)		46.50	48.30
Optimum moisture content (standard proctor) (%)		32.50	29.60
Maximum dry density (standard proctor) (kg m^{-3})		1955.00	2014.00
AASHTO classification		A-7-6	A-7-6
Group index		20	19
Universal soil classification		CH	CH

Table 3: Final grain-size distribution (percentage passing bs sieve sizes) of combined lateritic and clay soil samples

BS sieve sizes (mm)	Laterite, sample L1 = 70%	Clay, sample C1 = 30%	Laterite-clay, Sample X
4.75	94.6×0.7 = 66.22	100.0×0.3 = 30.00	96.22
2.36	68.5×0.7 = 47.95	100.0×0.3 = 30.00	77.95
1.18	51.8×0.7 = 36.26	100.0×0.3 = 30.00	66.26
0.600	36.4×0.7 = 25.48	98.2×0.3 = 29.46	54.94
0.425	28.5×0.7 = 19.95	95.7×0.3 = 28.71	48.66
0.300	22.0×0.7 = 15.40	94.1×0.3 = 28.23	43.63
0.150	12.6×0.7 = 8.820	91.4×0.3 = 27.42	36.24
0.075	7.8×0.7 = 5.460	89.6×0.3 = 26.88	32.34

sawmills where timber is being converted into its useful forms. Commercial timber falls into two main classes, generally known as softwoods (gymnosperms) and hardwoods (angiosperms). Both classes are found in great variety in many parts of the world. However, there are important differences in the structure between softwoods and hardwoods, with the hardwoods being more preferable for use and therefore more common in the sawmills. Examples of hardwood trees are the teak, ebony, African cedar mahogany, iroko and obeche. Apart from the burning off application, Ravindrarajah *et al.* (2001) have used sawdust in the production of lightweight concrete. The sawdust used in this study was light brown in colour and passing through sieve 0.2 mm aperture. It was derived from the iroko hardwood and procured from one of the sawmills in Ado.

The wood ash admixture belongs to the third category of admixtures earlier mentioned. It was added mainly for the purpose of increasing the bond between the particles because of its pozzolanic properties. Wood ash is a solid residue of the combustion of sawdust or wood in air and is composed of carbonates and oxides of metals, e.g., calcium and potassium, originally compounded in the plant's woody tissues that are present in the residue. Misra *et al.* (1993) found the major elements in wood ash to be calcium, potassium and magnesium, while sulfur, phosphorus and manganese are present at around 1% and iron, aluminium, copper, zinc, sodium, silicon and boron are present in relatively smaller amounts. They found the chemical compositions of wood ash to be mainly carbonates and oxides of the alkali metals, namely $CaCO_3$, $K_2Ca(CO_3)_2$, $Ca(OH)_2$, MgO, CaO, $Ca_4Mn_3O_{10}$, K_2SO_4 and others. Naik *et al.* (2003) have tested many sources of wood ash from the USA and Canada and have found their specific gravity to be between 1.6 and 2.8 and unit weight between 365 and 980 kg m^{-3}. They have also found the major elements in wood ash to be carbon, calcium, potassium, magnesium, phosphorus and sodium, all in various proportions. In its chemical composition, they found present in wood ash from different wood types SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, TiO_2, K_2O, SO_3, organic matter, moisture and available alkali, all with significant variations. Abdullahi (2006) found the specific gravity of wood ash obtained from a bakery in Minna, Niger State, Nigeria to be 2.13 and the bulk density 760 kg m^{-3} and his analysis showed the chemical constituents as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, TiO_2, K_2O, SO_3 and organic matter (loss on ignition LOI = 27%).

Because of its being usually rich in calcium carbonate, which is a good binding agent and its other chemical components, wood ash acts as a pozzolana with good stabilizing properties. Naik (2000) performed some investigations into the properties of wood ash from different sources and established their potential for being used in cement-based construction materials. Naik *et al.* (2003), in an investigation into the use of wood ash in cement-based materials, found that wood ash could be utilized in making self-compacting Controlled Low-Strength Materials (CLSM), air-entrained and non-air-entrained concretes and bricks/blocks/paving stones. Initial test results indicated that wood ash could be successfully used in making: (1) CLSM (with up to 90% of total materials); (2) air-entrained structural-grade concrete up to 28-day compressive strength of 50 MPa with wood or its blends (up to 40%) of wood ash and coal fly ash; (3) non-air-entrained structural-grade concrete (up to 60 MPa 28-day compressive strength) with wood ash or its blends with coal fly ash (up to 40%) as partial replacement of cement and (4) good quality bricks/blocks/paving stones with wood ash or its blends with coal fly ash (up to 35%) as partial replacement of cement. Employing the Pozzolanic property of sawdust ash, it has been used by Elinwa and Ejeh (2004) and with acceptable results as partial replacement for Portland cement in the production of cement mortar. Udoeyo and Dashibil (2002) utilized it as partial replacement for Portland cement in concrete. Though the compressive strength of specimens with sawdust ash was lower at the 28th day, it was observed to gain rapid strength at later ages, indicating a pozzolanic activity of the ash. Abdullahi (2006) successfully used a wood ash obtained from a bakery in Minna, Niger State, Nigeria as partial replacement for Portland cement in the production of concrete.

With regards to the usage of wood ash for soil stabilization, according to Andres and Honkala (1978), wood ash is one of the oldest stabilizers known. It is a good waterproofer and its binding properties are adequate for stabilizing traditional adobe. It provides strength to the block and prevents cracking because of its chemical composition especially the potassium components, which aid the bonding properties. Fajobi and Ogunbanjo (1994) have used wood ash to impart greater strength to traditional adobe bricks and have determined that the amount of wood ash to be added to soil for optimum compressive strength is about 10% by weight, while Amu *et al*. (2005) have used wood ash in the stabilization of lateritic soil.

The wood ash used in this study was derived from iroko sawdust from the same source as the sawdust used in the burning off application. The sawdust was light brown in colour, passing through the sieve 0.2 mm aperture, derived from the iroko hardwood and procured from one of the sawmills in Ado. The wood ash was gotten by combusting the sawdust in the oven at a temperature of 600°C.

Different sample mixes were obtained by mixing the 70:30 parts by weight laterite-clay blend with varying proportions (by volume) of sawdust and wood ash admixtures, as shown in Table 4. Sample X, the control mix, was pure laterite-clay, with 0% additions of sawdust and wood ash.

Table 4: Proportions of laterite-clay mix and sawdust and wood ash admixtures in prepared samples

Samples	Laterite-clay mix,volume (%)	Sawdust, volume (%)	Wood ash, volume (%)	Total, volume (%)
X	100	0.0	0.0	100
A	90	0.0	10.0	100
B	90	2.5	7.5	100
C	90	5.0	5.0	100
D	90	7.5	2.5	100
E	90	10.0	0.0	100

Preparation and testing of brick specimens: The dimensions of the brick size commonly employed in the local building industry, in the standard order specified by the BIA (1993) for listing brick dimensions in specifications (of width first, followed by height, then length), are 225×150×300 mm. This, incidentally, is equal in length and approximate in height to one of the modular brick sizes given by them (BIA, 1993). ASTM C 67: Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile (ASTM, 2001) also requires that the brick specimen for the compressive strength test be full height and width and approximately one-half of a brick in length, plus or minus 25 mm (i.e., an approximate half-brick). Thus, the moulds were of dimension 225×150×150 mm. The laterite-clay blend was thereafter mixed thoroughly with an adequate amount of water to a uniform consistency and a workable state. The moulding was done using the sand-moulding method to ensure easy release of the brick from the mould without the deformation of the brick as obtained with the slop-moulding method. The plastic soil was pressed into individual moulds and given light compaction through repeated ramming with prismatic wooden blocks.

After the moulding, the bricks were first air-dried in the laboratory for a total period of 48 h, with their being turned on edge after 24 h. Afterwards, they were placed outside in the open for sun-drying for a further period of fourteen days. This is to permit development in the bricks of some strength before the firing is done and to avoid the development of cracks that might result from a fast and high rate of dehydration. It is desirable that the drying should be relatively slow. The rate at which moisture evaporates from the surface should not be faster than the rate at which it can diffuse through the fine pores of the green brick. During the period of sun-drying, the bricks were given protective mulch covering (with leaves and grass placed on them) to avoid rapid drying out. And though the study was carried out during the dry season period when rainfall was nil, yet adequate care was taken to protect the samples from precipitation from dew or occasional rainfall by covering them up with waterproof material during the nights.

Clays have plate-like molecules with charges on their surfaces (Ashby and Jones, 1986). The charges draw water into the clay as a thin lubricating layer between the plates. With the right moisture content, clays are plastic and can be moulded and carved. But when dried, they have sufficient strength to be handled and stacked in kilns for firing. Green bricks, without any drying, are likely to be crushed in the kiln under the weight of those piled on top; they can shrink and crack under firing; the water driven off can condense on cold bricks away from the heat source; steam may be developed, building up excessive pressures within the bricks and finally, too much fuel will be required to drive out the remaining water. The green clay even after preliminary drying contains as much as 10% by weight water, which is lost rapidly as the kiln temperature rises above 100°C.

The temperature to which the firing is taken is very significant in the firing of bricks. Firing transforms raw clay bricks into a rigid, continuous (although porous) ceramic by way of a complicated succession of physical and chemical changes. When clay is fired, the water it contains is driven off and reaction between the components of the clay produces two phases: a crystalline phase (mostly aluminosilicates) held together by a glassy phase based, as always, on silica (SiO_2). The glassy phase melts and is drawn by surface tension into the interstices between and around the surface of the particles of the inert, but strong, crystalline phases of the clay, like water into a sponge, bonding them together. Clays for brick are usually a blend of three constituents which occur together naturally: pure clay, such as the kaolinite mineral ($Al_2O_3.2SiO_2.2H_2O$), a flux (such as feldspar) which contains the Na or K to form the glass; and a filler such as quartz sand, which reduces shrinkage but otherwise plays no role in the firing. Low-fire clays contain much flux and can be fired at 1000°C. High-fire clays have less and require temperatures around 1200°C.

The application of heat was gradual to avoid the formation of cracks. The temperature was measured by means of a pyrometer, whose operation is based on the principle of the thermocouple (Clews, 1969). The desired temperature for the project was a minimum of 1000°C. This temperature was attained after about 8 h of firing and then maintained for a further 40 h. The placement of a Serger Cone No. 5a (Singer and German, 1966) into the kiln and its eventual fusion affirmed that a minimum temperature of 1180°C (the squatting temperature of Serger Cone No. 5a) was reached. The bricks were left in the kiln to cool for a further 24 h before being removed.

The brick samples were thereafter tested. Tests required, according to BIA (1988), are the compressive strength, the 24 h cold water absorption, the 5 h boil absorption, the saturation coefficient and the initial rate of absorption (suction), though the last is evidently not relevant for tropical environments where there exist no problems with freezing temperatures. Also tested for is the dry density of the finished brick product. The testing, as far as was relevantly applicable in the circumstances, was done in accordance with ASTM C 67: Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile (ASTM, 2001). The compressive strength test was conducted with each sample being loaded along its shortest axis. This is because the bricks are usually placed in walls in the stretcher position.

RESULTS AND DISCUSSION

The average of five test results for each engineering property for bricks made from the different sample mixes are shown in Table 5.

The effects of the different proportions of the admixtures on each of the engineering properties of the bricks produced from the different mixes are discussed below.

Density: The density of a material will normally influence other properties such as compressive strength, durability, thermal conductivity, porosity, etc. and depends on the mineral composition. Average density of the burnt bricks made from the control mix was 1755 kg m^{-3}. Shestoperov (1983) specifies the density of special masonry as ranging between 1200 and 2400 kg m^{-3}. The introduction of the admixtures brought about a sharp decline in the value of the dry densities, with the highest content of sawdust (10%) producing the least dry density of 1512 kg m^{-3}.

Table 5: Engineering properties of brick specimens produced from the admixed soil samples

Properties	Sample X	Sample A	Sample B	Sample C	Sample D	Sample E
Clay-sand mix (70:30 weight) volume (%)	100	90	90	90	90	90
Sawdust, volume (%)	0	0	2.5	5	7.5	10
Wood ash, volume (%)	0	10	7.5	5	2.5	0
Dry density (kg m^{-3})	1755	1578	1603	1582	1571	1512
Dry compressive strength (MN m^{-2}) (psi)	18.42 (2671.50)	19.15 (2777.37)	13.39 (1941.99)	12.67 (1837.56)	11.97 (1736.04)	10.26 (1488.03)
Wet compressive strength (MN m^{-2}) (psi)	15.16 (2198.69)	17.34 (2514.87)	8.84 (1282.09)	8.02 (1163.16)	6.71 (973.17)	4.88 (707.76)
Softening Coefficient (k_s)	0.82	0.91	0.66	0.63	0.56	0.48
24 h cold water absorption (%)	12.7	5.8	10.3	12.4	13.8	15.4
5 h boil absorption (%)	15.4	8.7	13.4	14.9	16.5	17.7
Saturation coefficient	0.82	0.67	0.77	0.83	0.84	0.87
Abrasion index	0.48	0.21	0.53	0.67	0.79	1.03

Compressive strength: The compressive strength is a mechanical property used in brick specifications, which has assumed great importance for two reasons. Firstly, with a higher compressive strength, other properties like flexure, resistance to abrasion, etc., also improve. Secondly, while other properties are relatively difficult to evaluate, the compressive strength is easy to determine (Adeola, 1977). From quality control point of view, the compressive strength of bricks is the accepted measure of the quality of most brick works. Generally, compressive strength decreases with increasing porosity but strength is also influenced by clay composition and firing.

The dry and wet compressive strengths of bricks made from the control mix were 18.42 and 15.16 MN m^{-2}, respectively. There was a marked decrease in the compressive strengths of the brick with the addition of sawdust and wood ash. This decrease is even sharper for the wet compressive strengths. However, the trend is that the compressive strengths increased slightly with increases in the wood ash content. This is due to the pozzolanic action of the wood ash. In fact, the compressive strengths of bricks made from mix Sample A (with 0% sawdust and 10% wood ash) were higher than the compressive strengths of bricks made from the control mix Sample X.

Water absorption (porosity): Water absorption is the property of a material to be saturated with water. It is closely associated with the porosity of the material. Water absorption WA may be converted to porosity n through:

$$n = WA.\rho/(100.\rho_w)$$

where, ρ and ρ_w are the densities of the material and water, respectively. However, not always may all pores of a material be filled with water when its water sorption is being determined. This fact is attributable to the size, volume, configuration and mutual arrangement of pores in the material.

The average 24 h cold water absorption and 5 h boil absorption of bricks made from the control mix were 12.7 and 15.4%, respectively. The influence of the sawdust admixture is to increase the porosity and thus the water absorption, while that of the wood ash admixture is to markedly decrease the porosity. The saturation coefficient is the ratio of the 24 h cold water absorption to the 5 h boil absorption.

Durability: The durability of a material is its ability to withstand a particular recurrent weathering effect without failure. It is often measured by the softening coefficient, k_s, which is the ratio of the wet compressive strength to the dry compressive strength. The durability of a masonry structure under severe weather conditions (wind, rain, heat, etc.) is dependent upon the quality of the unit materials. Higher contents of sawdust resulted in lower values of the softening coefficient.

Abrasion resistance: The resistance of a masonry unit to abrasion is often measured by the abrasion index. This is obtained by dividing the 24 h cold water absorption by the dry compressive strength (expressed in psi) and then multiplying by 100. Higher and higher contents of sawdust resulted in further and further decrease in the value of the abrasion index (Table 5).

CONCLUSION

From the test results, it can be deduced that the effect of the addition of sawdust is mainly in producing lightweight and more porous burnt brick. The addition of wood ash on its own would also result in the production of lightweight and more porous products, but the very high temperatures to which the firing was taken ensured completion of the pozzolanic reactions instituted by the wood ash and the production of dense compounds acting as filler within the pores in the brick mass. This has resulted in denser products with higher compressive strengths, higher softening coefficient, lower water absorption rates, lower saturation coefficient, lower abrasion index, especially with addition of wood ash admixture solely. It can also be safely concluded that increasing contents of sawdust in the mixes produced the opposite results in the finished products, mainly due to its effect of producing a less compact structure in the finished product.

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