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Engineering Properties of Locally Manufactured Burnt Brick Pavers for Agrarian and Rural Earth Roads

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Abstract: This study explored the possibility of employing burnt bricks produced locally by completely traditional methods as pavers on unpaved agrarian and rural earth roads in indigent communities. The pavers would eliminate the problems on such roads of being waterlogged and impassible during the rainy season months and those of environmental and health hazards from raised dust during the dry season months. Three clay soils were investigated in the Ado region of Western Nigeria. Burnt brick pavers were produced using entirely traditional methods readily available in the indigent and rural environments. The engineering properties of the brick pavers were determined and it was found that they satisfied the requirements stipulated by ASTM C 902 Specification for Pedestrian and Light Traffic Paving Brick, thus making them suitable for usage on the earth roads.

Key words: Burnt brick pavers, engineering properties, earth roads

INTRODUCTION

Traditionally, many agrarian and village roads in undeveloped countries in the tropics are left unpaved. This poses problems throughout the year, in both the rainy and dry seasons. During the rainy season months, because there exists little or no provision for adequate surface or subsurface drainage of the roads, the roads become waterlogged and impassible. During the dry season months, dust raised by the wheels of passing vehicles becomes a major environmental and health hazard. The normal solution of applying a bituminous surfacing (either a surface treatment or an asphalt concrete wearing course) would eliminate the problems of dust encountered during the dry season, but its effect on the problem of impassibility when the roads are waterlogged is minimal, since these roads are seldom properly designed at the beginning in the first place. Moreover, the indigence of the concerned communities and the general unavailability of the resources required (finance, plant and materials) usually preclude the application of such solutions.

The usage of paving blocks (pavers) would go a long way in eliminating the problems posed in both seasons simultaneously. These are available commercially, but the problem of scarcity of financial resources to procure and haul them to site would still be a major impediment to their application. Burnt clay brick pavers could be manufactured locally, though without the sophisticated technology now available and with which they are being manufactured industrially. The aim of this study is to explore the possibility of using locally manufactured burnt brick pavers on rural and agrarian earth roads as an alternative by comparing their engineering properties with those stipulated in standards and specifications for the industrially produced pavers.

PHYSICAL PROPERTIES OF THE SOILS INVESTIGATED

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. The clay soil samples were collected from three different well-known extensive clay deposits located within the region, all at a depth of 1.5 m below ground level. Sample A was collected near Ire, about 25 km north-east of Ado, the state metropolis. Sample B was collected at Igbemo, about 20 km east of the metropolis, while Sample C was collected at Ikere, about 12 km south of 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 1.

Table 1: Physical properties of soil samples

Physical property Description	Sample A Highly plastic, yellowish clay, with stripes of brownish clay	Sample B Plastic, brownish clay, with some organic matter	Sample C Highly plastic, grayish clay
Clay fraction (smaller than 0.002 mm) (%)	75.2	40.0	73.1
Silt fraction (from 0.002 to 0.06 mm) (%)	14.4	24.0	22.8
Sand fraction (from 0.06 to 2 mm) (%)	10.8	36.0	4.1
Specific gravity	2.59	2.56	2.61
Liquid limit (%)	63.2	51.4	68.7
Plastic limit (%)	16.7	19.6	20.4
Linear shrinkage (%)	3.0	3.4	3.6
Plasticity index, (%)	46.5	31.8	48.3
Optimum moisture content (Standard proctor) (%)	32.5	15.2	29.6
Maximum dry density (Standard proctor) (kg m^{-3})	1955	2045	2014
AASHTO Classification	A-7-6	A-7-6	A-7-6
Group Index	20	6	19
Universal Soil Classification	CH	CH	CH

BRICK PAVER PRODUCTION PROCESS

Structural and refractory bricks are made by processes which, though automated, differ very little from those employed two thousand years ago[1]. All are made from clays, which are formed in the wet, plastic state and then dried and fired. After firing, they consist of crystalline phases (mostly aluminosilicates) held together by a glassy phase based, as always, on silica (SiO_2). The glassy phase forms and melts when the clay is fired and spreads around the surface of the inert, but strong, crystalline phases, bonding them together. The approach of this study was to completely employ, throughout, rudimentary processes that would be readily available in any undeveloped and rural community in the production of the burnt brick pavers.

After procuring the clay, it was prepared for the production of the bricks in conformity with the procedures outlined by Stulz and Mukerji[2] and recommended for societies embarking on self-help projects in developing countries. The preparation included sorting, crushing, sieving and proportioning. Sorting involved picking out roots, stones and other impurities, after which the material was spread out to dry. Crushing involved pulverizing the hard lumps formed by the hard clay, while sieving involved the removal of all particles larger than 2 mm. No proportioning was done in this study. Proportioning is usually required if the clay content or grain-size distribution is unsatisfactory, in which case to the clay is added other material to alter the composition of the mixture. In some cases rice husks, which serve as fuel, are added to the clay in order to obtain lighter and more uniformly burnt bricks, thereby avoiding unburnt cores.

After the preparation, the clay was mixed thoroughly with an adequate amount of water to a uniform consistency and a workable state. To permit proper firing, Shestoperov[3] had prescribed maximum standard dimensions for paving bricks of length 220±5 mm, width 110±3 mm and thickness 65±3 mm. In accordance with this, the wooden moulds were built to produce bricks having a length of 220 mm, a width of 110 mm and a thickness of 65 mm. These dimensions are similar to one of the standard sizes specified by the BIA[4]. 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 air-dried for a period of two weeks to permit some curing or drying before being placed in the kiln for firing. Clays have plate-like molecules with charges on their surfaces[1]. 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.

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. The natural drying was done in the open under the sun, with protective mulch covering (leaves and grass) placed on them to avoid rapid drying out. The study was conducted during the dry season, adequate care was taken to cover the bricks with plastic sheeting during the nights in case of occasional rainfall.

The temperature to which the firing is taken is very significant in the firing of the bricks. Firing transforms raw clay bricks into a rigid, continuous (although porous) ceramics by way of a complicated succession of physical and chemical changes. When clay is fired, the water it contains is driven off and a silicate glass forms by reaction between the components of the clay. The glass melts and is drawn by surface tension into the interstices between the particles of clay, like water into a sponge. 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 kiln design was of the scove type, built with 150 mm thick walls and plastered on all sides, both inside and outside, with mud. The design is able to withstand very high temperatures. Since the firing was to be done using locally available methods (gas and electricity most likely being unavailable), fuel for the firing was provided from firewood piled underneath the kiln. The bricks were arranged into the kiln with spaces in between them for proper circulation and the entrance sealed before the firing commenced.

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[5]. 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[6] 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.

ENGINEERING PROPERTIES OF BRICK PAVER SPECIMENS

The engineering properties tested for in the brick paver specimens included density, compressive strength, water absorption, durability and abrasion resistance. The engineer is primarily concerned with mechanical behaviour, water absorption (porosity, permeability and suction), weathering resistance and abrasion resistance. The average of 5 results each for the engineering properties for brick pavers produced from the three studied soil samples are shown in Table 2.

Table 2: Average values of the engineering properties of brick pavers

Engineering property	Sample A	Sample B	Sample C
Dry density (kg m^{-3})	1826	1985	1870
Compressive strength, MN m^{-2} (psi)	18.2 (2640)	15.4 (2233)	17.4 (2524)
24 h cold water absorption (%)	12.6	9.5	11.5
5 h boil absorption (%)	16.1	11.4	15.0
Saturation coefficient	0.78	0.83	0.77
Abrasion index	0.48	0.42	0.46

DISCUSSION OF TEST RESULTS

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 brick pavers made from the three soil samples ranged between 1826 and 1985 kg m^{-3}. Shestoperov[3] specifies the density of special masonry as ranging between 1200 and 2400 kg m^{-3}.

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[7]. Generally, compressive strength decreases with increasing porosity but strength is also influenced by clay composition and firing.

The compressive strength of the samples all ranged between 15.4 and 18.2 MPa. Of the three weathering paver classes (SX, MX and NX) found in ASTM C 902 Specification for Pedestrian and Light Traffic Paving Brick, the pavers in this study belong to the MX class (pavers intended for exterior use where freezing conditions are not present). For the MX paver class, ASTM C 902 states that the minimum average compressive strength required is 20.7 MPa (individual 17.2 MPa). The compressive strengths of the brick pavers are mostly above the required minimum individual values and within an acceptable range of the required minimum average values.

Water absorption (Porosity): The average 24 h cold water absorption of the fired brick samples ranged between 9.5 and 12.6%. This is within the acceptable

Table 3: Maximum abrasion index for traffic types

Traffic type	Maximum abrasion index
I	0.11
II	0.25
III	0.50

limits, because for the MX paver class, ASTM C 902 states that the maximum average 24 h cold water absorption required is 14% (individual 17%). The 5 h boil absorption values ranged between 11.4 and 16.1%.

Durability: The durability of a material is its ability to withstand a particular recurrent weathering effect without failure. The durability of a pavement under severe weather conditions (wind, rain, heat, etc.) is dependent upon the quality of the unit materials and the drainage efficiency of the pavement. The durability of a paving brick is measured using combinations of its compressive strength, 24 h cold water absorption and saturation coefficient. For the MX paver class, ASTM C 902 states that the minimum average compressive strength required is 20.7 MPa (individual 17.2 MPa), the maximum average 24 h cold water absorption required is 14% (individual 17%), while there is no limit for the maximum average or individual saturation coefficient[8].

Abrasion resistance: Paving bricks are exposed to the continual abrasive effect of pedestrian and vehicular traffic. Abrasion resistance is a measure of the resistance of paving brick to the wearing action due to traffic. ASTM C 902 lists two ways in which the abrasion resistance of brick pavers can be determined. The first method of using an abrasion index calculated by dividing the 24 h cold water absorption by the compressive strength (units of psi) and then multiplying by 100, is adopted for this study. According to ASTM C 902, there are three classes of pavers based on the type of traffic to use the roads. Type I pavers are appropriate for areas receiving extensive abrasion, such as commercial driveways and entrances. Type II pavers are intended for walkways and floors in restaurants and stores. Type III pavers are used for residential floors and patios[9]. Also, the abrasion requirements for pavers by traffic type are given as in Table 3.

The traffic type for which the brick pavers in this study will be used can b e classed as Type III. The abrasion index values for the specimens range between 0.42 and 0.48, which is less than the maximum abrasion index for type III pavers.

CONCLUSION

The engineering properties of the locally manufactured burnt brick pavers fall within the limits and ranges stipulated for light traffic paving brick, such as are required in applications on agrarian and rural earth roads. Thus, the brick pavers would adequately meet the purpose earlier identified of serving as surfacing for the earth roads all the year round.

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