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Engineering Properties of Lateritic Adobe Bricks for Local Building Construction and Recommendations for Practice

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Abstract: The engineering properties of adobe bricks produced from lateritic soils taken from three different locations in the Ado region in Southwestern Nigeria were investigated. An analysis of the index properties of these soils revealed that they are suitable for the production of adobe bricks. Relatively high values of the compressive strengths of the bricks (between 1.94 and 2.18 MN m^{-2}) were attained due to controlled compaction during moulding and adequate monitoring during the curing process. It was observed that the water absorption capacities were very low and that in fact the compressive strengths gained during drying were completely reversible upon rewetting. Consequently, clear-cut recommendations for practice on construction with adobe bricks were provided to ensure the safety and durability of the structures.

Key words: Adobe bricks, lateritic soils, engineering properties, recommended practice

INTRODUCTION

The provision of affordable housing for its citizens is one of the cardinal programmes of every government, especially in the developing countries. In this regard, the trend has been towards the utilization of cheap and readily available materials in the building industry. In the tropics, four main types of building block are in common use. These are the sandcrete blocks, the soilcrete blocks, burnt clay bricks and the adobe bricks. The astronomical rise in the cost of Portland cement has taken the usage of sandcrete and soilcrete blocks beyond the reach of the common man, while the technology involved in the production of burnt clay bricks has either made it impossible for individual potential house owners to produce them themselves or increased the cost of acquiring them from the burnt brick plants. This has made the usage of the adobe in local building construction, especially in indigent communities, to become prominent. Adobes are large, sun-baked unburnt bricks used in some tropical and semi-arid countries for building construction. Of course, adobes are not as strong as the sandcrete or soilcrete blocks with extra bonds provided by the cementing agents, nor are they as strong as the burnt bricks which, as a result of the heat to which they are usually subjected (about 800-1100°C), become homogeneous, harder and stronger from the ceramic bond produced through the fusion of the silica and alumina constituents. However, with cases of building collapse becoming rather rampant within the construction industry in recent times, there is the need to appraise the stability of buildings constructed with adobe, or specify modes of application that would ensure adequate safety of such buildings. This can be done through the determination of the engineering properties of the adobe and the evaluation of their compliance with values specified in the relevant building codes and standard specifications.

This study presents the results obtained from the collection of lateritic soil samples from three different locations within the Ado-Ekiti region in Southwestern Nigeria, determination of the average physical and geotechnical properties of the soils and the determination of the engineering properties of adobes moulded from the different soil samples at their respective optimum moisture contents as a means of evaluating their suitability for construction purposes and finally stipulating types of structure and modes of application for which they would be suitable.

LATERITES AND LATERITIC SOILS

Ola (1983) has given a general definition of laterites and lateritic soils in terms of the ratio of silica to sesquioxides, represented by $SiO_2/(Fe_2O_3+Al_2O_3)$, present in the soil. Ratios less than 1.33 are indicative of laterites, those between 1.33 and 2.00 of lateritic soils and those greater than 2.00 of non-lateritic soils. However, in view of the inconvenience of this definition from an engineering point of view particularly where adequate facilities for laboratory testing are not readily available, he has given the more popular definition of lateritic soils (comprising both laterites and lateritic soils as identified above) as "all products of tropical weathering with red, reddish brown or dark brown colour, with or without nodules or concretions and generally (but not exclusively) found below hardened ferruginous crusts or hard pan." His investigations revealed that Nigerian lateritic soils are composed predominantly of kaolinite with some quartz. Significant is the absence of any swelling mineral type, e.g. vermiculite or montmorillonite.

Lateritic soils are products of weathering and contain principally oxides of iron, aluminium, titanium and magnesium. They are formed under conditions that lead to removal of silica, alkalis and alkaline earths. They are not uniquely associated with any particular parent rock, geologic age, method of formation, geographical region or climate per se. They are rock products resulting from a set of physico-chemical conditions which include an iron-containing parent rock, a well-drained terrain, abundant moisture for hydrolysis during weathering, relatively high oxidation potential and persistence of these conditions over thousands of years. Clay minerals of the kaolinite group are typically associated with and are generally related to, lateritic soils. Lateritic soils vary from soft, earthy, porous materials to hard, dense, rocky stuff. The colour depends on the content of iron oxides and ranges from white to dark red brown.

Laterites and lateritic soils cover a large portion of the earth's surface. They are generally found in tropical and subtropical climates with high temperatures, abundant rainfall and seasonal, or at least some months of, marked dryness. Natural relief necessary to create drainage conditions is also associated. These conditions enhancing the formation of laterites and lateritic soils are prevalent and therefore the soils are found almost everywhere, in Nigeria, making it to be a useful source of building material.

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. Soil samples were collected at a depth of about 2.0 meters below the ground surface from three different locations within the region, along different road axes from Ado. Sample A was collected at km. 6+400 along the Ado-Iworoko Road, Sample B was collected at km. 8+200 along the Ado-Ijan Road, while Sample C 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. The results are shown in Table 1.

Kratzer (2003) affirms that soils which contain far too much clay are not well-suited to adobe brick making. Such soils tend to shrink and crack severely as they dry. Desirable soils for brick-making are those texturally classified as loamy sands, sandy loams or sandy clay loams. These textural names are given to soils that contain sand, clay and silt within the ranges of percentages shown in Table 2.

A very important point to note about these soil descriptions is that in none of the classifications does the clay content of the soil exceed 30%, or roughly one-third of the components and that the major portion of each class, never less than 50%, is sand.

In most systems of soil classification, the silt and clay grain sizes comprise the fraction passing the 0.075 mm sieve size, while the sand fraction comprises grains

Table 1: Physical properties of soil samples

Physical property description		Sample A Dark-brown well-graded sand	Sample B Light-brown clayey sand	Sample C Light-brown well-graded sand
Grain size distribution (percentage passing sieve sizes):	4.75 mm	94.6	98.4	98.8
	2.36 mm	68.5	86.6	88.5
	1.18 mm	51.8	62.1	68.2
	0.600 mm	36.4	42.4	53.5
	0.425 mm	28.5	31.9	42.4
	0.300 mm	22.0	22.6	32.0
	0.150 mm	12.6	12.8	14.2
	0.075 mm	7.8	8.0	6.4
Specific Gravity		2.56	2.52	2.54
Liquid Limit (%)		46.4	44.6	42.8
Plastic Limit (%)		26.3	28.2	26.6
Plasticity Index (%)		20.1	16.4	16.2
Optimum Moisture Content (%) (Standard Proctor)		16.5	16.8	16.0
Maximum Dry Density (kg m^{-3}) (Standard Proctor)		1868	1890	1854
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

Table 2: Composition of soils that make good adobe bricks (After Kratzer, 2003)

Soil textural name	Sand (%)	Silt (%)	Clay (%)
Loamy sand	70-85	0-30	0-15
Sandy loam	50-70	0-30	15-20
Sandy clay loam	50-70	0-30	20-30

passing the 2.36 mm sieve size and retained on the 0.075 mm sieve size. Applying the criteria above to the three samples in Table 1 indicate that all are suitable for the production of adobe bricks.

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 is equal in length and approximate in height to one of the modular brick sizes given by 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 soil samples were mixed with enough water to bring them to near optimum moisture content and thoroughly mixed to get to a state of uniform consistency. The soil samples were then placed in the moulds, whose inside had been pre-wetted with water, in three layers of equal thickness, each layer being well rammed with blows from a 2.5 kg hammer falling from a height of 30 cm. To reproduce conditions similar to that obtained for the Standard Proctor test, each layer was given 100 blows from the hammer.

Afterwards, to avoid the development of cracks that might result from a fast and high rate of dehydration, the bricks were 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 for sun-drying. Though the study was carried out during the dry season period when rainfall was nil, yet adequate care was taken to ensure that precipitation from dew or occasional rainfall did not fall on the samples by covering them up with waterproof material during the nights.

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. 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. The compressive strength test was performed on sun-dried samples after 7 and 14 days after moulding, while on the 28th day, the compressive strength tests were performed on both sun-dried and oven-dried (for 24 h) samples. The average of 5 results each for the compressive strength tests are presented in Table 3.

Table 3: Average dry compressive strength of the adobe bricks

	Sample A	Sample B	Sample C
7-day strength (sun-dried), MN m^{-2}	0.65	0.84	0.72
14-day strength (sun-dried), MN m^{-2}	2.02	1.92	1.79
28-day strength (sun-dried), MN m^{-2}	2.18	2.12	1.94
28-day strength (oven-dried), MN m^{-2}	2.16	2.14	1.97

Table 4: Values of various properties for the adobe bricks

Property	Samples A, B and C
Wet compressive strength, MN m^{-2}	0
24 h cold water absorption, %	100
5 h boil absorption, %	100
Saturation coefficient, %	100
Weight loss (Durability), %	100

Thereafter, some specimens were soaked in water for the purpose of determining the wet compressive strengths and the 24 h cold water absorption. The result was that the samples disintegrated completely after a few h of immersion in the water. The same result was obtained for the 5 h boil absorption test. Thus, the values of these properties for the bricks are recorded as indicated in Table 4, while those in Table 3 above are the dry compressive strength values only.

DISCUSSION OF TEST RESULTS AND RECOMMENDATIONS FOR PRACTICE

Despite their advantages of high fire resistance, good thermal performance, cheapness and amenability to unskilled production, sun-dried bricks are generally known to be of low compressive strength, high shrinkage and low durability. The main reason for the poor quality, not taking into consideration the lack of extra cementing bonds provided by chemical stabilizing agents or extra ceramic bonds from vitrification as in burnt bricks, is the absence of sufficient mechanical compaction. The moulded blocks are at best tampered by hand or rammed with wooden blocks. Previous researchers - Ola (1983) and

Oguara (1985), amongst others-have established that controlling the moulding water content and applying higher compaction pressures during moulding give rise to bricks of higher strength, lower porosity and better durability.

The compressive strength of samples tested by Florek and Ejeh (1985) gave an average strength of 0.363 MN m^{-2}. Ola (1983) reported that the compressive strength of this type of unburnt bricks from Ghana (normal size 12×6 ×25 cm) tested flat ranged from 0.621-1.034 MN m^{-2}. Jekayinfa (1986) tested some samples produced in Ibadan area of Nigeria and obtained values ranging from 1.80-2.15 MN m^{-2}. The average values obtained in this study, as indicated above for the 28-day dry tests, range between 1.94 and 2.18 MN m^{-2}, which are relatively high values for adobe bricks. The wide range in values in these studies is mostly attributable to differences in compactive efforts applied and the degree of divergence from the optimum moisture content during moulding rather than to differences in the nature and properties of the soils used for their production.

Many national Standards (Nigerian, British, American) specify a minimum value for the compressive strength of bricks of 5.2 MN m^{-2} for load bearing walls and 1.4 MN m^{-2} for non-load bearing walls. The adobe bricks thus satisfy the condition and are suitable, for non-load bearing walls. However, as Ola (1983) has reported, for a one-storey structure with light roofing, a compressive strength of only about 0.207 MN m^{-2} is required. The adobe bricks in practice actually are being used mainly for bungalows and one-storey buildings with light roofing, for which they are adequate. However, their usage can be extended in higher structures to non-load bearing walls up to three or four storeys in height (panel walls, curtain walls, enclosure walls in skeleton frame construction, *etc.*) without any fear of structural collapse of the wall under its own weight.

It was observed that the average 7-day compressive strength of the bricks for the three soil samples range between 0.65 and 0.84 MN m^{-2}, while the 14-day compressive strength values have increased to between 1.79 and 2.08 MN m^{-2}. Thereafter, there were slight increases in the compressive strengths up to the 28th day, but it should be noted that the 14-day values are from 85-92% of the 28-day strengths. Also, it was noticeable that there was not much difference between the 28-day air-dried test results and the oven-dried ones. One may conclude that not less than 80% of the full strengths of the adobes had been attained by the 14th day. The rate of strength gain was of course dependent on the rate of drying (in this case the amount of sunshine available) and the care taken of the specimens during the curing period.

From the observations above, it is being recommended that before lateritic bricks are employed for building in the construction industry, a minimum period of at least 14 days should be allowed from the time of moulding. This is to permit the development of enough strength by the bricks. Advisably, a period of at least 28 days should be allowed, not so much as to increase the strength, but for enough drying and loss of moisture to have taken place which would ensure less heavy bricks easier to handle and also to guarantee enough drying and strength gain in case adequate care has not been taken to ensure a maximum rate of drying during the curing process.

In view of the above results and observations, it is being recommended that construction with adobes should be in line with the following principles:

- Adequate care should be taken to ensure that the moisture content of the soil mix during moulding is not too divergent from the optimum moisture content of the soil. Also, provision should be made for adequate mechanical compaction of the bricks in the moulds.
- The adobe bricks should be allowed to cure for a minimum of two weeks (preferably four weeks) to allow for adequate strength gain before their being used. Care should be taken to protect the curing bricks from rainwater and other moisture during the curing process.
- The bricks prior to their being used for erection should be stored off ground to avoid contamination by mud and should be covered for protection from the elements.
- As seen above, the strengths gained by the bricks from drying are completely reversible on rewetting. In this regard, prior to and during erection, the adobes must be protected from precipitating rainwater, or given adequate opportunity to dry again before being used.
- The following job conditions (BIA, 1988) should be kept for the protection of the work:
  - During erection, the top of the wall should be covered with strong waterproof membrane at end of each day or shutdown.
  - Partially completed walls should be covered when work is not in progress.
  - The cover should be extended a minimum of 60 cm down both sides and should be held securely in place.
- In view of the low compressive strength of adobes, they should be limited to erection of bungalows and one-storey buildings with light roofing and short

non-load bearing walls (dwarf walls, partition walls, parapet walls, *etc.*). However, their usage can be extended in higher structures to non-load bearing walls up to three or four storeys in height (panel walls, curtain walls, enclosure walls in skeleton frame construction, *etc.*).

- To permit the jointing material to gain adequate strength before the application of load, uniform floor or roof loading should not be applied for at least 12 h after completion of the masonry walls or columns, while the minimum period before application of concentrated loads should be at least 3 days (BIA, 1988).
- Since the wearing and weathering characteristics of unstabilized soil under abrasive conditions are very poor, the adobes preferably are to be used in interior walls where there is little possibility of contact with the elements and consequent wall erosion, when the walls will not be rendered.
- In exterior walls or walls enclosing kitchens, toilets and bathrooms, to eliminate the effect of rainwater or water from domestic use splashing on the walls, the walls are to be rendered preferably with Portland cement mortar or other cement-based renders. There is also the possibility of covering with ceramic wall tiles. Other types of suitable finishes include (Aggarwal and Holmes, 1983) fibre reinforcement, bitumen emulsions, epoxy resin coatings, silicon waterproofers and various synthetic resin cement mixes.
- The overhang of the eaves should extend reasonably well beyond the exterior walls to prevent rainwater from splashing on the walls.
- Where there is a possibility of perpetual or seasonal influx of capillary water into the foundation area, the foundations must be constructed from cement concrete and the entire foundation walls from sandcrete or soilcrete blocks before using the adobes in walls above the ground floor level.
- The surrounding areas of the exterior of buildings are to be paved to prevent rainwater percolating if the foundation and foundation walls are built with adobes.

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