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Partial Replacement of Lateritic Soil with Crushed Rock Sand (Stone Dust) in Compressed Earth Brick Production

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***Abstract*—**Affordable housing has long been one of the basic necessities of life to man. The ever rising prices of building materials are one of the major causes of housing shortage in many developing countries. Breaching the gap of housing needs in developing countries like Nigeria is an awaiting task longing for attention. This is due to lack of research in the development of local materials that will suit the troubled economies of these countries. The use of earth material to meet the housing needs is a sustainable option and its material is freely available universally. However, people are doubtful of using the earth material due to its modest outlook and uncertain durability. This research aims at enhancing the durability of Compressed Earth Bricks (CEBs) using stone dust as a stabilizer. The result indicates that partial replacement of lateritic soil with stone dust at 30% improves its compressive strength along with abrasive resistance.

***Keywords*—**Laterite, stone dust, compressed earth bricks, durability.

I. Introduction

EARTH has been used in building construction in various forms as a building material since early civilization. Buildings of earth date back to 12,000 BC [1]. There are many examples of earth building that stood the taste of time but are mostly located at the drier climatic areas which on other climatic regions are perceived as inferior materials [2]. Nigeria has a population of over 200 million people, and with this figure, it can be seen that the provision of adequate and affordable housing for all is a cause for concern. The housing-for-all program initiated during the military regimes did not come close to achieving its target, but at least created a new form of awareness and modern mortgage industry in Nigeria [3]. Adejumo also notes that, the Federal Housing Authority estimates indicated that there is about 10,000 units of new houses constructed a year in Nigeria and that in order to meet the ever-growing demand, the country needs ten times more or at least 100,000 new housing units annually. Another problem to be recon with in the provision of adequate and affordable housing in Nigeria is challenged by the continuing unprecedented urbanization process estimated at about 5% per annum [4]. This creates a cement revolution dominating the construction industry. Over 95% of private and public buildings in Nigeria use cement in the construction of all new buildings in urban areas [5]. The development of cement production in Nigeria dates back to 1957 when three cement plants were built by the then regional governments of the three geopolitical zones of Nigeria – Northern, Eastern and Mid-Western [5]. This dramatically created a shift in building technology from the use of traditional materials to a modern technology that is often becoming more and more expensive for use by the common man.

The ever rising prices of construction materials are probably directly or indirectly responsible for housing shortage in the country. In [6], it was observed that despite the effort of government, public and private individual in solving the need of low-income earners housing problems in Nigeria, the input are with high technology and imported materials that make the cost of the housing delivery higher and unaffordable for the lower class. Providing affordable housing is a challenge around the world, and local soil has always been the most readily available material for earth construction in Nigeria [7].

As opined by [8], acquisition of indigenous building materials is the way out of the widening gap in housing need in Nigerian urban centers. There was limited housing shortage when earth was the dominant walling material and consumers could easily build their houses according to their capability [9]. Recently there has been an increasing research interest towards eco-friendly and sustainable building materials [10]. Some of the major factors limiting the use of earth materials are poor water resistance and uncertain durability. Traditional building materials such as adobe, CEBs and the Interlocking Stabilized Soil Block can be used as alternative construction materials which allow a minimized usage of cement [11]. The earth technology has advanced in the form of stabilized CEBs [5]. According to [12], the CEB house costs 32% less than the houses built with sand-cement blocks. Moreover, [13] showed that the large thermal capacity of earth walls improves their thermal properties above that expected by consideration of R-values alone. According to [1], earth construction is also responsible for an indoor air relative humidity beneficial to the human health. These characteristics of earth material make it suitable and environmentally friendly to the climatic conditions in hot tropical regions. Nonetheless, there is lack of interest at both the local and the governmental level in developing the technology that will transform the earth material to give it a modern outlook that will make it acceptable for use in a larger scale. The need for affordable and sustainable construction materials to cement in developing countries cannot be under emphasized [14], and it is therefore logical to consider alternative building materials.

Durability has in the recent years become a key metrics in

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the assessment of buildings from a holistic perspective [2]. However, new houses built of earth are rare in the urban environment in Nigeria, compared to the baked bricks in the United Kingdom and France while sandcrete block-walls presently dominate the building construction industry in Nigeria [5]. However, the incidence might have been occasioned by the rising cases of flooding in many parts of Nigeria and beyond. Flooding occurrences is as a result of the ever changing climatic conditions such as wind, temperature and amount of precipitation which affects the durability of materials used in the building envelope [15]. The durability of Earth construction requires special consideration as many buildings in the sub-urban region still utilize the earth material. Modern context of durability in CEBs should not be assessed by how long an earth construction stands without falling but also how well the integrity of the original texture of exposed surfaces lasts with no deterioration which is probably the reason for less patronage from Nigerians with weak financial status who strives to build with the expensive, sand–cement blocks that are widely known for durability, reliability and pleasant aesthetic effect. [5]. Therefore, to achieve an economic and affordable housing for all, the need for more indigenous research and development is necessary.

Stone dust is a byproduct from the crushing process during mining activities for crushed rock aggregates and is also called quarry dust [16]. The physical characteristics of stone dust is observed as grey color fine aggregate consisting of medium to fine sand size particles and of angular shape with rough surface texture [17]. During quarrying activities, the rock is crushed into various sizes and the dust generated (as waste) is called quarry dust where it was found to improve the mechanical properties along with the elastic modulus when used as sand replacement material [18]. Moreso, it was also observed by [19] that, the use of stone dust or crushed rock sand is very much effective in improving the properties and stability of expansive soils.

II. Materials and Method

The research commenced with the study of different soil samples to identify appropriate soils for earth construction in and around the study area. The common CEBs were produced with the suitable soil samples while the cement content is maintained at 10%. The soil is partially replaced with stone dust at 0%, 15%, 30%, 45% and 60%, respectively, by weight with the aim of identifying the optimum stone dust content for that particular type of soil. The CEBs so produced were subjected to capillary (water) absorption test, abrasion test and compressive strength test.

Table I describes the experimental design for this research work. Laterite is partially replaced with stone dust at different percentages (0, 15, 30, 45 & 60%) in order to identify the optimum dosage required for improving the physical properties of CEBs. The cement content was maintained at 10% for the various mixes prepared. Three bricks were produced for each of the test namely; compressive strength, Abrasive strength and Capillary absorption tests which are to be conducted after seven days. Therefore, a total of 45 bricks were produced at the same date for the purpose of this experiment.

A. Production of CEBs

After identifying the right soil for the production of CEBs from the nearest environment, the production process begins with preparing the soil. This includes sieving the soil through a BS sieve 5 mm in order to remove larger particles that are considered as gravelly and which will eventually cause weakness when present in a finished brick. Lumps in the soil are broken further and sieved through again. The soil is then measured by volume in liters using a graduated rubber bucket. Cement is also added at a constant ratio to all the different mixes by measuring 10% of the total measured volume of sand (i.e. laterite + stone dust). The three constituents are then mixed thoroughly until there is homogeneity in mixture and color before introducing the mixing water. Water is then added by sprinkling while the mixing process continues until water is adequate. In order to determine whether the water is adequate or not, the drop test is used at intervals during mixing so as not to exceed the required mixing water. As soon as the mixing is thorough, laboratory specimens of the usual CEBs were produced by filling the mold in the machine with a uniform measure.

TABLE I
EXPERIMENTAL DESIGN

	Batching by Volume (liter)			Tests on CEB			Number of Sample Produced
	Laterite	Stone dust	Cement (10%)	Compressive strength	Abrasive resistance	Capillary absorption	
0%	65.00	0	6.5	3	3	3	9
15%	58.50	6.50	6.5	3	3	3	9
30%	45.50	19.50	6.5	3	3	3	9
45%	35.75	29.25	6.5	3	3	3	9
60%	26.00	39.00	6.5	3	3	3	9
TOTAL							45

B. Curing of CEBs

Immediately after the production process is complete, the bricks are laid close to each other on a leveled ground surface under a shade and then cured. The curing process is by covering the samples with a polythene sheet in order to ensure that moisture is trapped for seven days. The bricks are stacked in a two-by-two form by crossing two bricks onto another two such that air drying is allowed to take place after removing the polythene sheets. The samples are subsequently transferred to the laboratory for testing.

A block size of 295 mm × 140 mm × 96 mm was adopted for this study for ease of handling and adequate compressibility with a manually operated CEB molding machine. The production process and testing methods for the CEBs are in accordance with the published guide "Technologies Series" of Center for the Development of Industries CDI/Center for the Development of Enterprises CDE in partnership with the African Regional Organization for Standardization [20].

III. Result and Discussion

TABLE II
COMPRESSIVE STRENGTH TEST RESULT

	Failure Load (N)	Compressive Strength (N/mm^2)
Control	39933	1.94
15%	91600	4.47
30%	97366	4.78
45%	41633	2.04
60%	39266	1.96

Table II contains the failure load along with the compressive strength for each set of experimental group. The result of the compressive strength of CEBs is produced at different dosage of stone dust content replacement from 0% to 60%. The failure load recorded in Newton (N) is the load at which the representative sample fails or is crushed.

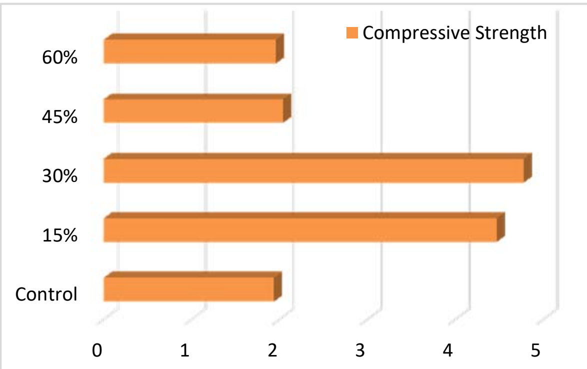

Fig. 1 Compressive Strength Distribution chart

Fig. 1 shows the result for the compressive strength of CEBs produced in Newton per millimeter square (N/mm^2) against the percentage (%) increase of stone dust content.

The result shows that there is a uniform strength distribution of around 2 N/mm^2 for the 0%, 45% & 60% stone dust content respectively. A uniform increase in strength is observed from 0% to 30% stone dust content although the increase in strength is observed to have peaked at 30% stone dust content.

Table III describes the result of the Abrasive Resistance for different dosage of stone dust replacement as in Table II. The surface area brushed and the mass of material loss is shown in column 2 & 3 respectively. The Abrasion Coefficient is the ratio of the surface area brushed by the mass of the material loss the sample brushed.

TABLE III
ABRASIVE STRENGTH TEST RESULT

	Surface Area Brushed	Mass of Loss Material	Abrasion Coefficient
control	75.72	10.67	7.95
15%	75.72	12	8.63
30%	75.72	4.33	17.65
45%	76.7	18.33	5.11
60%	75.71	15.33	5.41

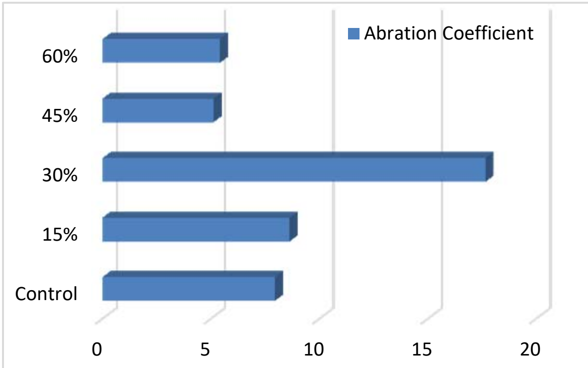

Fig. 2 Abrasive Resistance chart

Fig. 2 shows the result for the coefficient of Abrasive Resistance against the percentage (%) increase of stone dust content.

The result of the abrasion coefficient indicates a uniform increase from 0% to 15% although there is a sudden spike in the coefficient at 30% increase of the stone dust content. The value of the abrasion coefficient is highest at 30% replacement from where the result shows a decrease at 45% and 60% replacement, respectively. Though there is some disparity in the amount of material losses.

TABLE IV
CAPILLARY ABSORPTION TEST RESULT

	Mass of Water Absorbed	Average Capillary Absorption
control	163	12.48
15%	158	12.12
30%	91	6.97
45%	84	6.46
60%	380	29.09

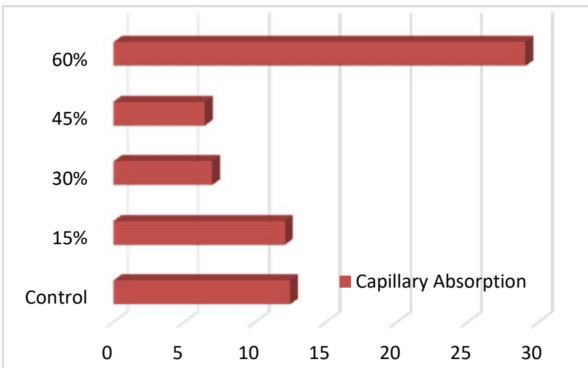

Fig. 3 Capillary Distribution chart

Table IV presents the result of the mass of water absorbed by the sample in a given time period along with the average capillary absorption of the three block sample for each of the percentage replacement of stone dust.

Fig. 3 shows the result for the Capillary Absorption against the percentage (%) increase of stone dust content.

The capillary absorption result indicates a uniform decrease in value with the increase in the quantity of stone dust from 0% down to 45%. At 30% & 40% respectively, the absorption capacity is around 7 while at 0% & 15% the absorption capacity is around 12. The absorption capacity shows a sudden and drastic increase at 60% stone dust content.

IV. Conclusion

The purpose of this research paper is to enhance the properties of CEBs using stone dust by evolving a model that gives extra consideration to durability and surface texture within the framework of affordable housing and social consciousness of average Nigerians. The results obtained have indicted the effect of various proportion of stone dust content when used in producing CEBs for housing development. The tests conducted are compressive strength, abrasion resistance and capillary absorption tests respectively.

The result of compressive strength indicates that the optimum dosage for using stone dust in improving the compressive strength of CEBs is at 30% replacement although, replacement at 15% has also shown a very high compressive strength outcome similar to that of the optimum dosage. Moreover, the optimum dosage of stone dust content required to improve the abrasive resistance of CEBs is also shown to be at 30% replacement although, replacement at 15% has also shown to be the next higher strength.

The result of the capillary absorption has shown a gradual reduction from 0% down to 45% after which the absorption showed a rapid change at 60% replacement. Therefore, from the above mentions with regards the use of crushed rock sand (stone dust) by partial replacement of lateritic soil with crushed rock sand, has shown a positive result towards improving the durability of CEBs. It can be used effectively in improving the durability of CEBs in order to improve the provision of social housing for the general public.

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