Improving the Structural Characteristics of Earth Blocks as an Input of Affordable Housing for Low-Income Northern Communities of Ghana

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Abstract: ***There is a high incidence of poverty in the three northern regions of Ghana, and as a result many of the inhabitants cannot afford the high cost of cement-based building materials such as sandcrete blocks. Buildings are therefore predominantly constructed with earth occasionally stabilized with cow-dung. Such buildings suffer rapid deteriorations due to the prevalent adverse weather conditions and rampant events of flooding, especially in low-lying areas. To forestall this perennial problem, this study investigatedthe structural characteristics of earth blocks stabilized with cement and cow-dung. Three different types of earth blocks were prepared from cow-dung only; cow-dung and cement and cement only. For the cow-dung-only earth blocks, four samples were prepared with cow-dung additions of 5%, 10%, 15% and 20% by volume. Also, for the cow-dung and cement earth blocks, four samples were prepared with cow-dung additions of 3%, 8%, 13% and 18% with 2% cement added to each sample; whilst for the cement-only earth blocks, one sample was prepared by adding 2% cement to earth. The blocks were cured for 28 days and tested for compressive strength. The 28-daysaverage compressive strength of cow-dung-only earth blocks were 0.36N/mm^2, 0.37N/mm^2, 0.53N/mm^2, and 0.43N/mm^2 for 5%, 10% 15% and 20% cow-dung additions respectively. Similarly, for the cow-dung and 2% cement earth blocks, the results were 0.85N/mm^2, 0.95N/mm^2, 0.62N/mm^2, and 0.33N/mm^2 for the 3%, 8% 13% and 18% cow-dung additions respectively. Finally, for the 2% cement-only earth blocks, the compressive strength was 0.72N/mm^2. It was concluded that the compressive strength of cow-dung stabilized earth blocks improves significantly when nominal amounts of cement are added; and hence should be adopted for affordable and sustainable housing delivery in the three northern regions of Ghana where cow-dung abounds.***

Keywords: Affordable housing, Cement, Compressive strength, Cow-dung, Earth blocks

1. Introduction

Nearly all African countries are confronted with acute housing problemsas a result oftheir akindevelopmental challenges [1]. The high growth of population, low Gross Domestic Product and the generallylow purchasing power are some of the factors that contribute to increaseddecline of housing provision in developing economies, including Ghana. As part of the efforts geared towards finding solution to the housing problem in low income communities of developing economies, the use of un-stabilised earth (laterite) is likely to continue in rural areas where it is freely available (dug on site) and the cost of construction is primarily determined by the cost of labour, which is considered free in a self-build situation [2].

A large proportion of low-income communities in the three northern regions of Ghana cannot afford the high cost of conventional building materials such as cement and other inputs of concrete due to the high incidence of poverty. Buildings are therefore mostly constructed with earth blocks, occasionally stabilized with cow-dung, a material that abounds in the area as a result of extensive cattle rearing, adominant occupation of the inhabitants. However, structures erected with earth blocks moulded in this fashion suffer rapid deterioration, and almost every year the inhabitants keep on labouring to maintain or put up new houses as a result of serious deteriorations in existing ones resulting from the effects of the weather. Also, in the events of flooding which results from the heavy down pours that are common characteristics of the area, many of these earth buildings, especially in low-lying communities, experience total collapse since the earth-block houses cannot withstand wet conditions.

This frustrates the inhabitantsof the three northern communities and hence, there is a need to find appropriate technologies that can fairly improve and expand the life-span of earth-block buildings constructed in the area,and at the same time ensuringaffordability. This study investigated the structural characteristics of earth blocks manufactured by combining cement and cow-dung, with the view of improving the strength and durability characteristics of earth-block buildings the three northern communities of Ghana,namely Northern, Upper West and Upper East regions. Specifically, the compressive strength as well as permeability of earth blocks manufactured by adding cement and cow-dung were determined and compared with those made from cow-dung only or cement only.

2. Properties of Earth and Cow-Dung

2.1 Earth (Lateritic) Materials

Earth materials for walling construction are usually based on a material called laterite. It consists of natural gravels as well as sand, clay and silt [3]. It is usually found in hot and wet tropical zones where natural drainage is obstructed[4]. Laterite is a product of tropical weathering with red, reddish-brown and dark-brown colour, with or without nodules or concretions and generally (but not exclusively) found below hardened ferruginous crusts or hard pan [5]. Generally, the degree of laterization is estimated by the silica sesqui-oxides (S-S) ratio (SiO_2/Fe_2O_3). S-S ratio less than 1.33 are indicative of laterites; those between 1.33 and 2.00 are lateritic soils and those greater than 2.00 are non-laterite types [6].

Laterite as a material has been used extensively for walling construction around the World, particularly in developing countries. It is the most readily available and affordable material for the construction of walls in rural housing delivery[7]. According to Gidigasu[5], 70% of the land surface of Ghana is covered by laterite. It is also estimated that approximately 30% of the world's present population still lives in earth (laterite) structures [8]. It is easy to work with, requires less skill and as such,enables unskilled individuals and group of people to participate in the housing construction process on self-help basis.

2.2 Properties of Cow-Dung

Cow dung is the undigested residue of plant matter which has passed through the animal's gut. The resultant faecal matter is rich in minerals. Colour ranges from greenish to blackish, often darkening soon after exposure to air. It is a material that is rich in nitrogen, potassium, phosphorous and calcium [9]. A study carried out by Garg and Mudgal[10] concluded that cow-dung has a relatively high carbon to nitrogen ratio. According to the study, chemical composition of cow-dung reveals that there is no difference in the organic matter (OM), nitrogen (N), and manganese (Mn). Contents of calcium (Ca), phosphorus (P), zinc (Zn) and copper (Cu) were higher by 10.8, 10.0, 84.1 and 21.7 per cent respectively in the dung.

According to Chandy[11], the chemical composition of cow-dung is as shown in Table1 below. The table indicates that, the highest composition of fresh cow-dung is water. However, the most important chemical component of cow-dung that imparts cementitious properties is lime with a composition of 0.36% in the sample. Thus, cow-dung when added to earth improves the structural performance by increasing the compressive strength and durability of the wall by virtue of the addition of lime. Notwithstanding, according to Autonopedia[12], lime stabilised mortars are susceptible to weathering when used for outside rendering on walls. This explains why cow-dung stabilised earth block houses, especially in low-lying areas, usually fail during heavy downpours in the three northern regions of Ghana where the technology is commonly in practice.

Table 1: Average Nutrient Content of Cow-Dung

Item	Ingredient	Percentage Content
1	Water	80.4
2	Organic matter	15.2
3	Mineral matter	3.6
4	Nitrogen	0.30
5	Phosphorus	0.18
6	Potash	0.18
7	Lime	0.36

2.3 Cow Dung as a Building Material

Cow dung has been used traditionally as a construction material by low-income communities in many developing countries[13],[14]. Basically, it is used for two purposes: as a binder in moulding of earth blocks and in other instances as a render on walls and floors. As a plaster on walls, the people of the three northern communities of Ghana have been using a mixture of cow-dung, mud (earth) and the juice from the boiled empty locust bean tree pods for a very longtime [15]. As a binder, it is added to earth to stabilize it for walling purposes in earth (adobe) block production.

Soil stabilization is a technique that uses other materials to improve the durability of soil by increasing its strength and resistance to water [16]. Conventionally, materials used to stabilize soils include cement and lime. Other materials, usually waste products that can be added to cement or lime for soil stabilization are called pozollans and they include Pulverized Fuel Ash (PFA), Ground Granulated Blast Furnace Slag (GBFS), Silica Fume, Rice Husk Ash, Natural Pozzolana, and Volcanic Pozzolans[17]-[19].Cow-dung when added to clay improves the plasticity of the clay and acts as reinforcing agent reducing concentrated cracks that can lead to breakage within freshly moulded bricks [20].

In a study by Simango and Lyson[16], cow-dung was used as a soil stabilizer in a soil stabilization investigation for the construction of adobe bricks.The investigation consisted of mixing cow-dung with sandy clay soil in the cow-dung/soil ratio 0:1, 1:6, 1:5, 1:4, 1:3, 1:2, and 1:1. The adobe bricks were evaluated for compressive strength, permeability, erosion and cracking. The results showed that the 1:4 ratio had the highest compressive strength and the highest resistance to erosion. The highest resistance to water penetration after a period of three hours was shown by the cow-dung/soil ratio 1:5, and there was minimum cracking in all the treatments.

In addition, comparing the performance of various farm waste materials such as groundnut shells, sawdust and garadseeds in clay bricks, cow-dung recorded the highest compressive strength of 16.7 – 17.7 N/mm^2[20]. Thus, it can be concluded from the foregoing that cow-dung when added to earth (laterite) stabilizes the earth material, which contains some amount of clay, to produce more efficient building blocks than earth-only blocks.

3. Materials and Methods

Series of activities and different materials were used to carry out moulding of earth block samples for subsequent laboratory testing in this study.

3.1 Materials Used

The under- listed materials were used in moulding the earth block samples:

- Cement - ordinary Portland cement from Ghacem, Tema,
- Earth (laterite) materials – samples were obtained from Zuarungu in the Upper East Region of Ghana,
- Cow dung - samples were obtained from a kraal in Zuarungu,
- Water - portable water was obtained from the Ghana Water Company main distribution system.

3.2 The Moulding Process of Earth Blocks

Three different block samples of dimensions 450mm x225mm x150mm were moulded with the following combinations:

- Earth and cow dung,
- Earth, cement and cow dung,
- Earth and cement.

3.3Batching of Materials

Tables 2, 3 and 4 show the ratios and quantity of each component material, in litres, used for moulding two blocks for each type of the three categories of blocks. Also each table contains the amount of water used for the mixes. The mix ratios were arbitrarily chosen to combine the constituent materials for the disparate earth blocks in order to find the material combination that produces the optimum strength.

This was done because, traditionally, there is no literature on material combinationfor the moulding of cow-dung earth blocks, as practitioners use personal experience in mixing component materials. Similar ratios were then chosen for the cow-dung, cement and earth blocks by replacing portions of the cow-dung with 2% cement. Finally, the same proportion of cement, that is 2%, was applied to mould the cement-only earth blocks.

3.4 Mixing of Constituent Materials

The constituent materials were initially measured according to their required volumes and were placed on a cleanconcrete platform for mixing.Mixing of materials was carefully carried out to ensure uniform distribution of material components for each mix. In the case of earth and cow dung block samples, the cow dung was first added to the earth and carefully kneaded together by hand until there was a uniform mix (Figure 1). Water could not be added since the moisture content of the fresh cow-dung was enough to produce the required workability in the mix.

Figure 1: Mixing of Cow-dung with Laterite

For the earth, cow-dung and cement samples, the earth and cow-dung were first kneaded with the hand, followed by the introduction of the cement. The mix was then carefully turned several times until there was a uniform mixture. This was to ensure that the cow dung, being moisture laden, was made to coat the earth particles adequately before cement was introduced for hydration to begin. Visual inspection was done to ascertain the amount of water to be sprinkled, taking cognisance of the water content of the cow-dung.

Table 2: Volume of Constituent Materials for Cow-dung:Earth Block Sample

Type of Material	*Volume of Material (Cow-dung: Laterite) in litres*				
	5:95	*10:90*	*15:85*	*20:80*	*Total Volume (L)*
Cow-dung	2.0	4.0	6.0	8.0	20.0
Earth	38.0	36.0	34.0	32.0	140.0
Water	0.0	0.0	0.0	0.0	0.0

Table 3: Volume of Constituent Materials for Cow-dung:Cement:Earth Block Sample

Type of Material	*Volume of Material (Cow-dung: Cement: Laterite) in litres*				
	3:2:95	*8:2:90*	*13:2:85*	*18:2:80*	*Total Volume (L)*
Cow-dung	2.0	4.0	6.0	8.0	20.0
Cement	0.8	0.8	0.8	0.8	3.2
Earth	38.0	36.0	34.0	32.0	140.0
Water	2.0	1.0	0.0	0.0	0.0

Table 4: Volume of Constituent Materials for Cement:Earth Block Sample

Type ofMaterial	*Volume of Material (Cement:Earth) in litres*	
	2:98	*Total Volume (L)*
Cement	0.8	8.0
Earth	38.0	38.0
Water	3.0	3.0

For the cement and earth samples, the constituents were dry-mixed with the use of a shovel until there was a uniform mixture. Water was then sprinkled on the mixture and mixing continued until the sample became adequately damp for moulding.

3.5 Moulding of Blocks

The manual block moulding machine was positioned on a hard level surface and the inner face of the mould oiled. The mould was half-filled with the already mixed material and the corners compacted with a piece of metal.The mould box was filled completely and again the corners compacted with a piece of metal rod.

Further compaction was done on the material by repeatedly banging the heavy metal lid on the sample until the lid fitted exactly in its lowest position. The lid was then opened wide and the handle pressed downwards to push the moulded block out of the mould (Figure 2).

Figure 2: Moulding of Blocks in a Manual Block Machine

The block was then removed by holding the pallet under it and set in place for hardening and curing under a shed. To avoid rapid hardening or excessive loss of moisture from the blocks, the samples were cured by sprinkling water on them for the first 14 days and allowed to dry up till 28 days when they were assembled for compressive strength test.

3.6 Compressive Strength Test on Block Samples

Compressive strength test was conducted on the blocksamplesat 28 days. Testing apparatus used include:

- Electronic balance,
- Automatic compressive strength testing machine.

3.6.1 Testing Procedure

The blocks were first cut into two halves, to produce blocks with dimensions 225mm by 225mm by 150mm. The blocks were then placed in the compressive strength testing machine, one after the other, after their dimensions had been entered in the machine's transduceras shown in Figure 3. Load was then applied by pressing a knob until they were crushed. The compressive strength was displayed on the transducer of the machine which was read and recorded for each sample.

3.7Permeability Ratio Test

To test for the permeability of the blocks, and to determine their suitability for out-door use, the uncrushed halves of each of the samples were weighed and recorded as W_1, after which they were immersed in water for 24 hours (Figure 4). The blocks were later removed and re-weighed and recorded as W_2. The permeability ratio (PR), which represents the ratio of the quantity of water absorbed, was expressed as a percentage of the weight of the original block.

Figure 3: Blocks Placed in Compressive Strength Testing Machine for Crushing Test

Figure 4: Blocks Placed in Water for Permeability Tests

4. Results and Discussions

4.1 Compressive Strength

Compressive strength is the resistance of a unit to crushing forces and it is the major parameter for measuring the strength and robustness of load carrying walling units such as building blocks.

4.2 Compressive Strength of Cow-dung:Earth Blocks

The 28 days compressive strength test performed on the cow-dung:earth block samples yielded results as presented in Table 5. The average compressive strength of the blocks with cow-dung percentages of 5%, 10%, 15% and 20% to earth were 0.36N/mm^2, 0.35N/mm^2, 0.53N/mm^2, and 0.43N/mm^2 respectively. The results show that, at 5% and 10% cow-dung contents, the blocks recorded very low average compressive strengths of 0.36N/mm^2 and 0.37N/mm^2 respectively. The strength however increased to a maximum of 0.53N/mm^2 when the cow-dung percentage was increased to 15%. The average compressive strength, however, reduced at cow-dung percentage of 20% at 0.43N/mm^2.

This implies that, the compressive strength of earth blocks increases as cow dung is added. However, the strength begins to fall after a certain optimum content of cow-dung. The initial strength increase can be explained by the presence of lime in the cow-dung which possesses binding properties[1], [18], [20].However, as the cow-dung percentage is increased beyond the optimum value of 15%, the compressive strength begins to fall as a result of increased organic content of the mix.

4.3 Compressive Strength of Cow-dung:Cement:Earth Blocks

Again, the 28-days compressive strength test performed on the cow-dung:cement:earth block samples yielded results as recorded in Table 6. For each of the cow-dung:cement:earth block samples, the cow-dung proportion was reduced by 2% by volume and was replaced by equal cement content, whereas the earth proportions remained unchanged. The cow dung percentages of 3%, 8% 13% and 18%, with 2% cement addition, recorded average compressive strength values of 0.85N/mm^2, 0.95N/mm^2, 0.62N/mm^2, and 0.33N/mm^2 respectively.

Here, the strength increased initially from 0.85N/mm^2 to a maximum of 0.95N/mm^2 at 3% and 8% cow-dung proportions respectively. It, however, began to fall as the cow-dung percentage was increased to 13% and 18% when the strength recorded values of 0.62N/mm^2 and 0.33N/mm^2 respectively. Thus, when 2% cement was made to replace similar proportions of cow-dung, the blocks developed a maximum average compressive strength of 0.95N/mm^2, which occurred at 8% cow-dung.

4.4 Compressive Strength Test Results for Cement: Laterite Blocks

The cement: laterite blocks recorded 28-days average compressive strength of 0.72N/mm^2 at 2% cement input as shown in Table 7. This indicates that the average compressive strength of this sample is only 75% of the highest recorded strength for the cow-dung: cement:earth block samples but is 35% higher than the strongest sample among the cow-dung only blocks.

4.5 Comparison of Compressive Strength of Samples

Comparing the compressive strength values obtained for the three different mixes of cow-dung:earth, cow-dung:cement:earth and cement:earth; it is observed that the combination of cow-dung:cement:earth offers the greatesthopefor affordable and sustainable housing delivery (Figure 5). This is because, the highest compressive strength of this material combination, with a compressive strength value of 0.95N/mm^2, is about 80% higher than the highest compressive strength recorded for the cow-dung:earth blocks with a value of 0.53N/mm^2 (p-value = 0.08). It is also 30% higher than the cement:earth blocks which recorded a strength value of 0.72N/mm^2 (p-value = 0.28), although the cement content in both samples was 2% by volume. This high strength could be attributed to the combination of lime from the cow-dung and cement, since high compressive strength mortars can be produced with lower cement inputs when lime is added, compared to cement-only mortars as shown in Table 1 of [21].

This indicates that, when a nominal amount of cement is added to cow-dung, a stronger earth block is formed. That is, replacing a certain minimal content of cow-dung with cement leads to substantial improvement in the compressive strength characteristics of earth blocks. This offers hope for affordable and sustainable housing construction for the people of the three northern regions of Ghana, since stronger earth blocks can be produced at minimal costs by adding cow-dung and nominal amounts of cement to earth. The production of earth blocks in this way for the housing sector will increase the robustness of earth houses built in this area of the country, where cow-dung abounds and the high cost of cement and incidence of poverty mostly discourage builders from using cement blocks for housing construction.

Table 5: 28-Days Compressive Strength Test Results for Cow-dung:Earth Blocks

Mix ratio	5:95	15:85	10:90	20:80
Dimensions (mm)	225x150x230	225x150x230	225x150x230	225x150x230
Compressive strength (N/mm^2)	0.33	0.35	0.57	0.40
	0.38	0.39	0.48	0.47
Average compressive Strength(N/mm^2)	0.36	0.37	0.53	0.43

Table 6: 28-Days Compressive Strength Test Results for Cow-dung:Cement:Earth Blocks

Mix ratio	3:2:95	8:2:90	13:2:85	18:2:80
Dimensions (mm)	225x150x230	225x150x230	225x150x230	225x150x230
Compressive strength(N/mm^2)	0.83	0.99	0.61	0.27
	0.86	0.90	0.62	0.38
Average compressive Strength(N/mm^2)	0.85	0.95	0.62	0.33

Table 7: 28-Days Compressive Strength Test Results for Cement:Earth Blocks

Mix ratio	2:98
Dimensions (mm)	225x150x225
Average Crushing Loa(KN)	37.0
Compressive Strength (N/mm^2)	0.85
	0.58
Average Compressive Strength (N/mm^2)	0.72

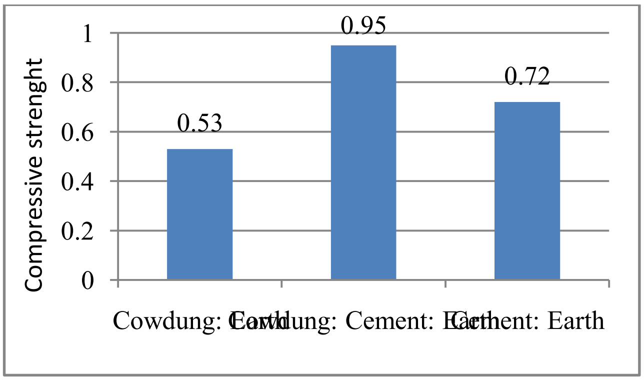

Figure 5: Comparison of Compressive Strength of the Strongest Samples among the three Categories of Blocks

4.6 Permeability of Blocks

Permeability of a block is an indication of how porous the block is or the extent to which it can absorb water. The permeability of a building block is a measure of its durabilitycharacteristics, since water absorption usually leads to deterioration of blocks. The higher the permeability ratio (PR) of a block sample, the lower its resistance to deterioration, and hence durability[22].

Table 8 shows the permeability ratio of cow-dung:laterite blocks. For the first three percentages of cow-dung:laterite samples of 5%, 10% and 15%, the block weight could not be measured at the end of the 24 hours, since they completely dissolved in the water. This means that the permeability ratio is 100% and that the blocks are too permeable and hence not durable.

The only sample that could be weighed under this type of blocks was the 20% cow-dung sample which recorded a permeability ratio of 21.7%. This could be explained by the high content of cow-dung in this sample that provided relatively higher amounts of lime for bonding of the earth particles. This further explains why building structures made of earth and cow-dung collapse when there is a heavy downpour that leads to flooding in the three northern regions of Ghana.

For the cow-dung:cement:earth blocks, the results show that for the cow-dung percentages of 3%, 8%, 13% and 18%, the permeability ratios of the blocks were 5.5%, 11.0%, 11.8% and 12.7% respectively as shown in Table 9. This indicates that when 2% cement was made to replace portions of the cow-dung, a relatively less permeable earth blocks were produced, which further implies that the resulting blocks will be more durable than earth blocks formed from cow-dung only, especially when exposed to water.

Also, for the 2% cement only earth blocks, the permeability ratio was 2.7% as shown in Table 10. Comparing this value to the strongest blocks of the other categories of blocks, it can be deduced that, relatively, cement-only earth blocks produce very low permeability ratios as opposed to blocks with cow-dung inclusions and hence will be more durable.

Table 8: Permeability Ratios (PR) for Cow-dung:Laterite Blocks at 28-days

Mix ratio	Cow-dung : Laterite					
	Initial Wt.	Ave. Initial Wt. (W1) Kg	Final Wt.	Ave. Final Wt. (W2) Kg	W2-W1 Kg	PR (%)
5: 95	13.4 13.2	13.3	0.0 0.0	0.0	-13.3	-100.0
10: 90	13.4 13.2	13.3	0.0 0.0	0.0	-13.3	-100.0
15: 85	12.5 12.7	12.6	0.0	0.0	-12.6	-100.0
20: 80	12.8 12.8	12.8	14.4 14.2	14.3	1.4	21.7

Table 9: Permeability Ratios (PR) for Cow-dung:Cement:Laterite Blocks at 28-days

Mix ratio	Cow-dung : Laterite					
	Initial Wt.	Ave. Initial Wt. (W1) Kg	Final Wt.	Ave. Final Wt. (W2) Kg	W2-W1 Kg	PR (%)
3: 2:95	13.0 12.4	12.7	13.4 12.7	13.1	0.7	5.5
8: 2:90	12.9 12.5	12.7	14.0 14.2	14.1	1.4	11.0
13: 2:85	13.2 12.8	13.0	14.9 14.0	14.5	1.5	11.8
18:2:80	12.8 13.3	13.1	14. 4 15.2	14.8	1.7	12.9

Table 10: Permeability Ratio (PR) for Cement:Earth Blocks at 28-days

Mix ratio	Cow-dung : Cement: Laterite					
	Initial Wt. (W_1) Kg	Ave. Initial Wt. (W_1) Kg	Final Wt. (W_2) Kg	Ave. Final Wt. (W_2) Kg	W_2-W_1 Kg	PR (%)
2:92	14.8 14.6	14.4	14. 5 15.5	15.0	0.4	2.7

However, cow-dung:cement blocks will perform better than cow-dung-only earth blocks in areas where the blocks are exposed to water, since the former has lower permeability ratios than the latter (Figure 6).

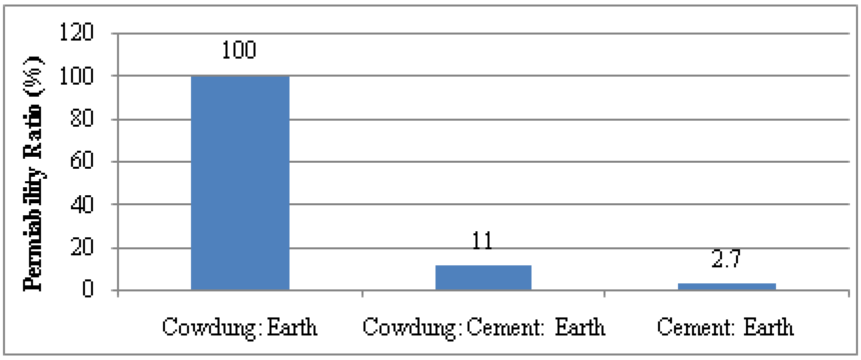

Figure 6: Permeability Ratios of the Strongest Samples among theThree Categories of Blocks

5. Conclusions and Recommendations

From the results obtained in the study, the following conclusions can be drawn:

- The highest average compressive strength obtained in the study was 0.95N/mm^2 and this was recorded for the 8% cow-dung with 2% cement earth blocks.

- The average compressive strength recorded for the strongest cow-dung with 2% cement block was 80% higher than the strength of the strongest earth block formed from cow-dung-only earth blocks. It was also 30% higher in strength than the 2% cement-only earth blocks. This indicates that combining nominal amounts of cement and cow-dung to form earth blocks improves the compressive strength characteristics of the blocks more than using cow-dung or cement only. This offers hope for affordable and sustainable housing since the cost of walling units could be reduced appreciably by adding cow-dung and nominal amounts of cement to form strong and durable earth blocks for the housing sector in the three northern regions of Ghana, where cow-dung abounds.
- For cow-dung only earth blocks, maximum compressive strength occurred at 15% cow-dung content in the study.
- Cow-dung-only earth blocks are very permeable to water and this accounts for the rampant collapse of building structures made of earth and cow-dungwhenever there is flooding in the three northern regions of Ghana as a result of heavy downpours.
- The permeability of earth blocks with cow-dung decreases with increasing additions of cow-dung to the laterite. However, when cement is added to the cow-dung, the permeability of the resulting earth block increases with increasing cow-dung contents, making the blocks less durable at high percentages of cow-dung inputs.

Based on the above conclusions, the following recommendations are made:

- Earth blocks made from cow-dung and nominal amounts of cement should be adopted to produce affordable and durable buildings in the three northern regions of Ghana to reduce the cost of housing and rampant collapse of building structures in the area due to flooding.
- When using cow-dung only for earth block production, relatively higher percentages of cow-dung are required to form stronger and less permeable blocks.
- Further studies should be carried out on the content area with wider scope of material combinations to ascertain the proportion of cement and cow-dung that may produce high-strength blocks, which should be published for use by the three communities since there is no published literature on the subject.

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