Study of Compressive Strengths of Laterite-Cement Mixes as a Building Material

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Abstract

Variation of compressive strengths with cement contents for laterite-cement mix as an economical building material was investigated. The aim of this study was to determine the minimum quantity of cement required to achieve adequate strength for buildings in a mix of laterite-cement and to know the upper limit at which cement can be added to laterite to produce high quality mix with maximum strength. Thirteen different mixes of laterite-cement at varying percentage of cement content were produced, molded in cubes of 100mm size and cured for 7, 14, 21 and 28 days. The variation was from 0 to 24% of the weight of laterite at a constant interval of 2%. Twenty cubes were molded for each mix, totaling 260 cubes produced manually. Five cubes from each mix were crushed at particular curing period and the average compressive strength of the five cubes was calculated. Curing was done inside the laboratory under atmospheric condition with all the doors and windows opened for proper circulation of air. It was found that the compressive strength of laterite-cement mix cubes increased with increase in cement content up to 20% but decreased at cement contents above 20%. Also it was found that the minimum quantity of cement required to achieve adequate strength was 10% of the weight of laterite.

Keywords: Curing, Building, Cubes, sandcrete blocks.

Introduction

Traditionally, soils with some percentage of silt and clay have been used for building non-load bearing walls. Such buildings still exist in villages and some ancient cities today. They exhibit a lot of cracks within a short time due to lack of binding materials such as cement and some times due to considerable amount of shrinkage. Also the use of the mud blocks is generally limited to bungalows.

In Nigeria today, an appreciable percentage of the entire population cannot afford to build their own houses, especially the modern types due to high cost of building materials. Sandcrete blocks constitute important building materials widely used today for walls of our domestic, industrial or commercial buildings. The cost of sandcrete blocks continues to increase due to high cost of cement and demand for this material. Mixing together cement and sand in certain proportion with water produces these sandcrete blocks (NIS 87: 2004). Now cement price has been on the steady increase at an alarming rate. Also the price of river sharp sand used in the production is ever increasing due to shortage of it and cost of water used for mixing is high due to demand for production and curing. As a result of this ever-increasing cost of these constituent production materials, coupled with the increasing high demand, the price of sandcrete blocks has correspondingly increased. Greater percentage of the country’s population finds it difficult or almost impossible to afford the cost.

The aim of this study is to determine the minimum and maximum quantity of cement in terms of the percentage of the quantity of laterite at which adequate compressive strength can be achieved for both non-load bearing and load bearing walls. It is known that addition of cement to laterite improves the quality in terms
of strength but the proper mix ratio has not been well established. The first step in this study was to establish that the sample used was laterite. This was done by carrying out Atterberg limits test, to establish the plastic limit, liquid limit, plasticity index and the grain size distribution test. These results were compared with already determined standard properties for laterite. Laterite exists in most parts of this country and a good proportioned mix of laterite and cement may prove to be quite suitable for buildings. Often one of the problems encountered in the study of laterite is the basic definition of what is laterite. Many people usually define laterite as a type of red soil used in road construction especially in the tropics. Although laterite physically has element of red color, the above definition is not a clear and true one in that some soils such as red sandy-clay soil can easily be mistaken as laterite (Madu 1984). Laterite may be defined as that class of pedogenics in which the cementing materials are the sesquioxides and constitute not less than 50% of its constituents when the sample is chemically analyzed (Madu 1977). Sesquioxides are those chemical substances with empirical formula $M_2O_3$ where $M = \text{ potassium (K), rubidium (Rb) or cesium (Cs)}$. At ordinary temperatures and pressure below 100 mm mercury, potassium peroxide combines with oxygen to give the sesquioxides, $K_2O_3$. Study of laterite shows that it contains hydrated aluminum and iron oxides. The presence of iron can be noticed by the characteristic color produced by iron in the soils. The aluminum is generally in the form $Al_2O_3.nH_2O$, which is called bauxite, an ore of aluminum. The ore appears to be developed when intense and prolonged weathering removes the silicon from the clay minerals and leaves a residue of hydrous aluminum oxide (Gidigasu 1971).

Before carrying out chemical analysis for complete definition of laterite, a soil may be suspected to be laterite by observing some of the physical properties. Usually, laterite is reddish brown in color and gravelly in texture. The reddish color becomes predominant when wet while the brown color becomes distinct when dry. Some of the particles stick to the palm of the hand when wet and they can easily be dusted off when dry. Also some laboratory index property tests are used to classify laterite. Such tests are the Atterberg limit, grain size distribution, compaction, specific gravity and linear shrinkage (Madu 1975). The results of these tests are used to compare with the already determined standard index properties for laterite. Laterite is generally used as foundation material and in road construction as base material.

### Materials Used and Methods of Testing

#### Soil

The laterite sample used was collected at a depth of 1.5 to 2.5 m from an existing borrow pit behind Nigerian Television Authority station at Independence layout Enugu, using method of disturbed sampling. An investigation into the geotechnical and engineering properties of some laterite of Eastern Nigeria by Madu (1977) showed that the sample collected was laterite and the index properties are summarized in Table 1.

#### Cement

The cement used was ordinary Portland cement (NIS 444, 2003) bought from cement depot at Enugu, Nigeria.

#### Water

Clean tap water free from contaminants either dissolved or in suspension (BS 3148, 1980) was used to prepare the specimen cubes at various moisture contents.

### Laboratory Tests

All laboratory tests carried out which included determination of natural moisture content of the laterite, particle size distribution of laterite, liquid limit for the laterite, plastic limit for the laterite, linear shrinkage of the laterite, specific gravity of the laterite, dry density/moisture content relationship for laterite and laterite-cement mix were in accordance with (BS 1377 1975).
Mix Proportioning

The term proportioning in this content refers to the estimation of different quantities of laterite and cement as well as water required for the mix. The following calculations were carried out for the proportioning:

Water/cement ratio adopted was 0.5;
Size of laterite-cement cube for the test was 100mm x 100mm x 100mm;
Volume of laterite-cement cube = 0.1 x 0.1 x 0.1 = 0.001 m³;

For cement content of 10% of dry weight of laterite, the mix ratio was 1:10,
Laterite, \(L = 10C\)  
(1)
Also from the water/cement ratio of 0.5,
Water, \(W = 0.5C\).  
(2)

Using Absolute Volume Method,
\[
W/1000 + C/1000Gc + S/1000G_l = 1 \text{m}^3, \tag{3}
\]
where \(L\) is weight of laterite, \(C\) is weight of cement, \(G_l\) is the specific gravity of laterite and \(G_c\) is the specific gravity of cement. Determined \(G_l\) was 2.64 and \(G_c\) was 3.15.

By substitution of Eqs. (1) and (2) into Eq. (3):
\[
0.5C/1000 + C/1000 x 3.15 + 10C/1000 x 2.64 = 1, \quad C = 217.16kg;
\]

From Eq. (1), \(L = 10 \times 217.16 = 2171.6kg\);
From Eq. (2), \(W = 0.5 \times 217.16 = 108.58kg\);
Volume of one laterite-cement cube = 0.001 m³;
For 20 cubes, volume = 20 x 0.001 = 0.02 m³;
1 m³ of the mix contained 217.16 kg of cement; 0.02 m³ = 0.02 x 217.16 = 4.343 kg of cement;
Add for waste, 1% = 0.01 x 217.16 = 2.172 kg;
Total weight of cement required = 6.515 kg;
Weight of water = 0.5C = 0.5 x 6.515 = 3.258 kg;
Weight of laterite, \(L = 10C = 10 \times 6.515 = 65.15\) kg.
Quantities of the materials used to mold 20 laterite-cement cubes of 100mm x 100mm x 100mm were:
Cement = 6.52 kg;
Laterite = 65.15 kg;
Water = 3.26 kg.
The above calculations were repeated for each of the thirteen mixes.

Determination of dry density/moisture content relationship was carried out on each of the thirteen mixes in accordance with BS 1377 (1975). The compaction test was done as rapidly as possible after mixing the cement and water and before the hydration of cement has gone very far (Madu 1984). This is because test results are affected by partial hydration of cement which can cause an increase in the optimum moisture content and a decrease in the maximum dry density. For this reason, once a laterite-cement mix was compacted in the mold, it was thrown away and a new mix was taken for the next compaction.

Mixing and Molding

The quantities as calculated above were measured, mixed and molded for each mix ratio. First the laterite and cement were properly mixed manually before the addition of water. For the purpose of this research, small size cube molds of 100mm by 100mm by 100mm were used. Sufficient quantity of laterite-cement mix prepared as described was placed in the mold to fill it approximately one-third when compacted. To ensure even distribution of blows, approximately 100mm square sheet of plywood was placed on the mixture in the mold and compaction was done on it using 28 blows of a standard rammer of weight 2.5 kg which, was falling from effective height of 30 cm (BS 1377 1975). Then the mold was filled with two additional layers of laterite-cement and the same 28 blows were given to each layer. A wooden collar which was removed after compaction was used for the last layer to ensure that the mold was full of compacted laterite. The surface of the compacted mixture was trimmed off level with the top of the mold with a straight edge. A total of two hundred and sixty cubes were molded for the tests.

After the compaction of first and second layers, the smooth surfaces were scarified with a spatula to ensure proper bonding or cohesion with the next layer (Aderibigbe et al. 1984). There was the tendency for the laterite-cement mixture to stick to the sides of the mold and cause tearing during extrusion. This problem was taken care of by properly oiling the inside surfaces of the molds before each casting (Aderibigbe et al. 1984). It was also ensured that the molds were filled in three equal layers.
Curing and Crushing

The cubes when extruded were cured in the laboratory under atmospheric condition with all the doors and windows opened to allow proper circulation of air for 7, 14, 21 and 28-days, respectively before crushing. Five cubes from each of the thirteen mixes were crushed in a particular day and the average compressive strength was calculated. Care was properly taken to ensure that the cubes were not disturbed during curing and that extrusion was cautiously done to ensure that there was no breakage. Extra care was taken to ensure that the critical dimensions of the cubes were not disfigured, to maintain constant surface area of the cubes in contact with the crushing machine. During crushing, proper care was taken to ensure that the cubes were perfectly positioned and aligned with the axis of the thrust of the compression machine to guarantee uniform loading of the cubes.

Results and Discussion

The geotechnical index properties of the natural soil are summarized in Table 1 while Figs. 1(a)-(c) show the particle size distribution of the soil. It was reddish brown, well graded soil with a relatively high plasticity of 20.5% and clay content of not more than 14%. These are typical characteristics of laterites of eastern Nigeria (Madu 1975).

The results of the compaction tests on the thirteen laterite-cement mixes are presented in Figs. 2, 3 and 4. Normal compaction curves were obtained indicating the maximum dry density and the optimum moisture content for various cement contents.

Fig. 5 shows the relationship between optimum moisture content and the cement content for laterite-cement mixes. Slight steady increase in optimum moisture content was observed with increase in cement content up to 20%, from where it continued to decrease. The optimum moisture contents for the laterite-cement mixes were found to be in the range of 11.44 to 14.83%.

Fig. 6 shows the relationship between maximum dry density and cement content. It can be seen that the maximum dry densities increased steadily with increase in cement content up to 14% and decreased continuously for cement contents above 14%. The maximum dry densities for the various mixes of laterite-cement were found to be in the range of 2,020 to 2,155kg/m³.

The effect of cement content on the compressive strength of laterite-cement mix is presented in Fig. 7 for 7, 14, 21 and 28-days age of curing. The compressive strength of laterite-cement increased steadily with increase in percentage of cement content up to 20%. The compressive strength decreased at cement contents above 20% and this can be attributed to too much fine particles caused by the cement and clay put together.

The laterite-cement mix consistently showed a definite pyramidal pattern type of failure and this conical shape was found to be the same as that of concrete cubes subjected to compression test (Neville 2000). This is an indication that houses built of laterite-cement mix will show a considerable deformation before total failure. The laterite cubes recorded some strength below 1N/mm² for all the ages tested at 0% cement content. That is a proof that laterite naturally has some cementing material that can bind the particles together. The grain size distribution curve Fig. 1(a) clearly shows that laterite contained both silt and clay, which have some adhesive quality. It is an indication that only laterite can be used in certain areas of building requiring no load bearing.

<table>
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<tr>
<th>Table 1. Properties of the natural laterite.</th>
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<td>Characteristics</td>
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<tr>
<td>Natural moisture content (%)</td>
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<td>Percentage of gravel (%)</td>
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<tr>
<td>Percentage of sand (%)</td>
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<td>Percentage of silt (%)</td>
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<td>Maximum dry density (kg/m³)</td>
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<td>Optimum moisture content (%)</td>
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<td>Specific gravity</td>
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<td>Condition of sample</td>
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Fig. 1(a). Particle size distribution of laterite for particles below 0.02mm.

Fig. 1(b). Particle size distribution of laterite for particles between 0.063 and 2mm.

Fig. 1(c). Particle size distribution of laterite for particles between 2 and 10mm.

Fig. 2. Dry density/moisture content relationship for laterite.

Fig. 3. Dry density/moisture content relationship for laterite-cement mix at 2, 4, 6, 8, 10 and 12% cement contents.

Fig. 4. Dry density/moisture content relationship for laterite-cement mix at 14, 16, 18, 20, 22 and 24% cement contents.
Conclusion

The overall conclusions emerging from this study are that:

The compressive strengths of laterite-cement mix increased with increase in percentage of cement content up to 20% but decreased at cement contents above 20%.

Laterite-cement mix recorded adequate compressive strength for both load bearing and non-load bearing walls at 10% cement content. The Nigerian Industrial Standard NIS: 87: 2004 recommends a minimum of 2.5N/mm² and 1.8N/mm² for load bearing and non-load bearing blocks respectively. The maximum strength of laterite-cement mix was achieved at moisture content slightly greater than or equal to the optimum moisture content for the particular mix. The optimum moisture contents for the laterite-cement mixes at various cement contents were found to be in the range from 11.44 to 14.83% while the maximum dry density was found to be in the range from 2,020 to 2,155kg/m³.

Since adequate strengths for buildings were achieved with less cement content, it was concluded that this laterite-cement mix is an economical building material since the cost of blocks depends largely on the cement content.

References

Madu, R.M. 1977. An investigation into the geotechnical and engineering properties of