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Improvement on the Design and Construction of Interlocking Blocks and its Moulding Machine

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Abstract : *Production of blocks used for wall construction have different techniques adopted which could be in form of hollow or solid blocks produced in varying shapes laid with mortar. An improved form of mortar-less blocks which is an innovative structural component for masonry building construction called interlocking block which can be produced mechanically or manually using interlocking block production machine, particularly an improved interlocking block machine with dual mould. This brings about economical production, reduced cost of labour and appreciation of available local materials for construction of structures for both rural and urban development in the world today, thereby eliminating the use of mortar in laying of blocks. The blocks are neatly fixed through the aid of grooves and protrusion on the blocks to restrain movement when assembling the interlocking block from top and or bottom of one to another forming safe, stable, economical and aesthetic bonding for walls. It can be widely used for both temporary and permanent structures. The top blocks, middle blocks and toe blocks have different forms of projected and engraved part achieved by the aid of pallet placed at the bottom of mould and replaceable mould lid. The assembling does not require much skill, and more so, faster, neater with improved efficiency. The dismantling in the case of temporary wall is, also, easier, faster and economical which do not involve destroying any part of the wall.*
Keywords : *Blocks, Interlocking, Moulding machine, concrete, construction*

I. Introduction

Building Blocks are made of aggregates (such as stabilized soil, river sand, Bama or Madube gravel, that is, uncrushed stones/rocks, etc) mixed with Portland cement (or lime) and water of desirable ratio for targeted strength and admixture if necessary. It is primarily used for wall construction such as boundaries or demarcation of apartment in buildings. Blocks are produced in a form which can be laid either with mortar or assembled as interlocking blocks which is rather mortar-less. The former block can either be hollow or solid blocks. The later saves ample amount of mortar, which implies that, it does not require the use of mortar along the vertical and horizontal alignment to assemble the blocks but have grooves and protrusions to key them. Interlocking block can be produced with vertical holes or as solid interlocking block which this research is specifically concerned with. A standard dual mould of an interlocking block machine is used to replicate the interlocking blocks with appropriate dimensions, shapes and sizes. Interlocking block production machine can be mechanically or manually operated. The former are normally incorporated with vibratory mechanism which enhances adequate compaction of the fresh stabilized mixture within the moulds before hardening to achieve higher compressive strength after curing. The later does not achieve the compaction as in the former due to the fact that it is manually operated. Palettes are placed in the mould to form the grooves and protrusions for the top, middle and toe blocks. The production can be made in a small scale on site/laboratory or in a large unit in the industries. The concepts or techniques of interlocking block provide neat, fast and economical assembling of walls which is of great advantage over blocks laid with mortar. In the other hand, the dismantling is also very economical. Furthermore, interlocking blocks have reliable resistance to impact and penetration of sharp objects or external forces. Ring beam below window level, ring lintel beam and overhead course beam should be provided to enhance the binding of the structure.

1.1 Concept of Interlocking Block

The block's sizes are modular and rectangular (250 mm length, 210 mm wide and125 mm high) in shape. Corner or junction block is required to maintain right angle corner or a proper T-junction. The interlocking block is different from conventional blocks or bricks since they do not require mortar for its laying work. Because of this characteristic, the process of building walls and other structures are faster as the blocks are laid dry and lock into place. Almost any type of building can be constructed with interlocking blocks, which has projection and depression to key each other. The toe blocks have flat bottom and partly projected top to properly rest on the base mortar and at the same time receive the middle blocks to rest on it. The middle blocks have bottom depression and top projection to receive subsequent middle blocks and finally the top blocks. Before placing or forming the first course in a mortar bed, the blocks must be laid dry on the foundation around the entire building (that is, the forming process), in order to ensure that they fit exactly next to each other, the main design constraints being that the plan should be rectangular and all wall dimensions and openings must be multiples of the length of the block type used. All other principles of design and construction, such as dimensioning of foundations, protection against rain and ground moisture, construction of ceilings and roofs, among other things remains the same as in other standard buildings *(German Appropriate Technology Exchange, 1995).*

The concept of interlocking blocks is based on the following principles: (a) the blocks were shaped with protruding parts, which fit exactly into recess parts in the subsequent lateral blocks and blocks placed above, such that they are automatically aligned horizontally and vertically respectively – thus block assembling is possible without specialized block laying skills (b) since the blocks can be laid dry, no mortar is required and a considerable amount of cement and cost of labour are saved (c) each block could necessarily be provided with vertical holes, which serve four purposes - (i) to reduce the weight of the block (ii) to insert steel rods or bars for reinforcement (iii) to act as conduit for electrical and water/fluid piping etc (iv) to pour liquid mortar or grout into the holes, which run through the full height of the wall. Thus, sealing the wall and making a permanent solid wall, increasing its stability otherwise could be solid interlocking blocks without vertical holes which this research is particularly concerned with.

This work objectively aims at (i) the Construction of a dual mould interlocking block machine with high compaction effort (ii) Sampling of soils from reliable burrow pit and various laboratory tests on sampled soils so as to ascertain their properties for production of interlocking blocks and (iii) Production of interlocking block with adequate compressive strength using available local materials such as aggregates (stabilised lateritic clay, river sand, Bama or Madube gravel), lime or Portland cement and water.

II. Review Of Related Literatures

Conventional concrete block walls are laid up by a time-consuming difficult procedure which involves making a layer of concrete mortar onto a level concrete or stone base or the like, or the top of a course of previously laid blocks and then setting blocks one at a time on the mortar layer, in each instance also applying mortar between the blocks and to the end course/walls to ensure proper binding of the blocks together. This procedure is continued until the required number of courses is laid. Great care must be taken to keep each course perfectly horizontal and or vertical and straight. Few people have the skill to carry out such a procedure in a competent manner; therefore the cost of such construction is always high. Various types of interlocking blocks have been devised in the past to facilitate the construction of block walls and other structures. Most such blocks have been very expensive to produce since the interlocking portions, usually grooves or protrusions, are normally cut into the blocks after they have been formed by moulding. Moreover, it is difficult to maintain the required tight tolerance for accurate construction of large walls or other structures through the moulding and cutting steps. The prior blocks often required additional finishing or grinding steps to meet the required tolerance. Interlocking mortar less building blocks overcoming many of these deficiencies are described in U.S. Patent Nos. 3,888,060 and 4,640,071. Those blocks have been used successfully for many years. These blocks are assembled in courses, with the block joints staggered and continuous vertical open cells into which reinforcing bars and wet (fresh) concrete can be inserted. While highly effective, these blocks require that the reinforcing bar be inserted in lower courses, with blocks in later courses lifted over an end of the reinforcing bar as the structure advances and wet concrete is periodically poured into the cells containing the reinforcing bar. However installing blocks over the reinforcing bar can be a significant problem with tall structures. Therefore, continuous need for improvements in mortarless building block systems to permit lower cost of block manufacture, and lower cost and more rapid structure assembly from the blocks became necessary. It would also be desirable to be able to provide an improved mortarless building block system featuring improved adaptability, strength and economy. The design of the block should be such that it can be readily moulded and released from the forming mould with full detail preserved, obviating any subsequent reshaping, finishing, etc. Furthermore, the block should be easily strengthened with reinforcing materials, if needed, and be capable of being fabricated in a full array of sizes and shapes

The interlocking block configurations were first developed by Etherington *(1985)* from compressed mixtures of Portland cement, stone dust and water. The interlocking blocks also follow the same pattern to have tongues and grooves on the top and bottom surfaces of the blocks respectively to restrain horizontal movement when laying interlocking block on top of one another without the use of mortar joints. Installing some reinforcement and grouting mortar in the grout holes increases the wall strength. Thus, the wall could be made strong enough to carry upper floor loads similar to conventional load-bearing walls. Construction is simple enough for unskilled labour to build walls without mortar bedding which is great advantage of the interlocking block wall. The axial load resistance of interlocking block walls has not been clearly specified in any standard codes. Notwithstanding, a single mould interlocking block machine which produces an interlocking block, of dimension 250mm length, 230mm width and 125mm height, at a time was constructed by Department of Civil

Engineering, University of Maiduguri, using available local materials such as river sand, Bama gravel, Portland cement and water *(Arinze, Nkechi, et al, 2009).*

In this research, the stated problems have been resolved by the introduction of ample compressive strength solid interlocking block (with no vertical opening), produced by dual mould interlocking block machine as an improvement of the single mould interlocking block machine. It is advisable to support the wall with ring beam below window level (or special blocks for window sills), ring lintel beam, and ring beam below roof to improve the wall strength and can be achieved by channel blocks. Channel blocks have channels along the long axis, into which reinforcing steel and concrete can be placed to form lintels or ring beams. Obviously, interlocking blocks were moulded and later on the grooves and protrusions were made on them for the blocks to key, but this is time and labour consuming, so it was improved by the use of palettes in a single mould interlocking block machine which was achieved by the previous students of the above mentioned University. In this project, a dual mould interlocking block machine was achieved with about 15mm protrusions and grooves for proper locking of the key. More so, various laboratory tests were carried out to ascertain the properties of the interlocking blocks produced from locally available materials with effective compaction efforts.

2.1 Shapes and Sizes

A variety of interlocking blocks have been developed during the past years, differing in shapes and sizes, depending on the required strengths and uses. The system developed has the following shapes and forms:

- (i) Full blocks (300 x 125 – 150 x 100 mm) for all standard walls (single or double block thick).
- (ii) Half blocks (150 x 125 - 150 x 100 mm), which can be moulded to size, or made by cutting freshly moulded full blocks in half.
- (iii) Channel blocks, same sizes as full and half blocks, but with a channel along the long axis, into which reinforcing steel and concrete can be placed to form lintels or ring beams.
- (iv) The vertical sides of the blocks can be flat or have recesses, and the vertical grout holes can be square or round.
- (v) Inserts for electrical switch housing and conduits as well as water piping outlets can be incorporated.
- (vi) Special blocks for window sills.

2.2 Soil

Soil is a natural aggregate of mineral particles, sometimes including organic constituents; it has solid, liquid and gaseous phases. Soil itself is defined as uncemented aggregates of minerals grains and decayed organic matter with liquid and gaseous occupying the void spaces between the solid particles. Soil is used as uncemented materials in various civil engineering projects and it support the foundation of structures. Soil has been used for building in a great variety of ways, which vary according to climate and type of soil available. The properties and use of soil as a building material must therefore be studied by anyone concerned with building materials. In recent times, the potential of soil as a building material has been considerably underestimated. There seems to be two main reasons for this. Firstly, the enormous variety of naturally occurring soils has made specification for any particular set of property difficult, and engineers have therefore tend to prefer the more predictable manufactured materials; secondly, many soils in their untreated states lack strength and dimensional stability, this has led to the believe that soil is a generally inferior material of short life and requiring high maintenance. The development of science of soil mechanics and other related testing and classification of soil types has made possible the selection and specification of soil for building purposes with some precision; and the techniques of stabilization, first developed for use in roads, airfields and dams, can now be used to convert soil into a building material whose properties are entirely adequate for most building purposes, and are often fully comparable with other available building materials. If soil is to be used successfully, it is important, as with other building materials, that its engineering properties should be clearly understood. These derived from the origin and condition of formation of soils.

2.2.1 Formation of Soils

Soil is formed from the by-disintegration of parent rocks by weathering, which may be stationary or transported to other places by ice, water, wind and gravity. There are three types:

(i) Residual Soil (topsoil, laterites and saprophyte):

The soils formed by weathered product at the place of origin are called residual soils. An important characteristics of residual soils is the presence of fine grain soil at the surface, grain sizes increases with depth down to the bedrock. At larger depth angular rock may be formed. Laterites are formed by chemical weathering under warm, humid tropical condition when rain water leaches out the soluble rock materials leaving behind the insoluble hydroxide and magnesium given the characteristic reddish brown or dark brown colour. The lateritic interlocking block was made from lateritic-clay and not lateritic-gravel.

(ii) Transported Soil (gravel, silt and clay):

This may be classified into several groups depending on their mode of transportation and deposition such as: (a) Glacial soils: these are formed by transportation and deposition of glaciers (b) Alluvial soils: these are transported by running water and deposited along the stream (c) Marine soils: these are formed by deposition in the sea (d) Lacustrine soils: these are formed by deposition of quiet lakes (e) Aeolian soils: these soils are formed by transportation and deposition by wind (f) Colluvial soils: these are soils formed by the movement and deposition due to gravity such as land slide from its original place.

(iii) Organic Soils:

These soils contain large amount of organic plants and animals matter. They are usually dark in colour and give up a distinct odour. Deposit of organic silts and clays have usually been created in river or lake sediments. Peat is a special kind of organic soil and is dark brown spongy materials which almost entirely consist of light vegetable matter. It exits in one of the three forms a) Fibrous b) Pseudo fibrous c) Amorphous. Taking them singly;

a.) Fibrous peat: - non-plastic with a firm structure only slightly affected by decay.

b.) Pseudo fibrous: - peat in this form still has fibrous appearance but it is softer and plastic than fibrous peat. Their change is due more to prolong submerge in airless water than to decomposition.

c.) Amorphous peat: - with this type of peat, decomposition has destroyed the original fibrous vegetable so that it has virtually become organic clay.

Peat deposits occur extensively throughout the world (local examples; Lagos and Port-Harcourt areas) and can be extremely troublesome when encountered in civil engineering works.

2.2.2 Types and Properties of Soil

(i) Sand and Gravel: - these are cohesionless aggregates of rounded, sub-rounded or angular fragments of rocks or mineral grains. Particles of size from 0.06mm (or 0.075mm) to 2.0mm (or 4.75mm) are referred to as Sand and those with a size of from 2.0mm (or 4.75mm) to 60mm (or 76mm) as Gravel (ii) Cobbles: - are rounded or sub-angular stones of sizes between 60mm to 200mm (iii) Silt: - these are fine grain soils with little or no plasticity. Silt may be organic or inorganic. Particle sizes ranges between 0.002mm to 0.06mm (iv) Clay: - this is an aggregate of mineral particles of microscopic and sub-microscopic range. Particle sizes less than 0.002mm (v) Inorganic clay: - is more plastic than organic clay. Organic clays are more compressive (vi) Bentonite: - this is clay formed by the decomposition of volcanic ash with a high content of montmorillonite (vi) Varved clay: - these clays are made of thin alternate layers of silt and fat clays of glacial (moving ice) origin (vii) Kaolin: - this is a very pure form of white clay used in the ceramics industries (viii) Peat:- this is a very compressible organic soil composed of fibrous aggregates of finer fragments of decayed vegetable matter (ix) Loam: - this is a mixture of sand, silt and clay (x) Black cotton soil: - the colour of this soil varies from dark grey to black. It is characterised by its high expansive and shrinkage properties. This soil occurs locally in Borno state (new Marte, Biu, Hawul, Gamboru Ngala), parts of Gombe state, Adamawa state (Numan), as well as different parts of Africa and India (*C. M. O. Nwaiwu, 2008*).

As mentioned earlier, the soils used for this project are lateritic-clay, river sand and Madube gravel as aggregates. How the soil of civil engineering materials will support the stresses upon it or respond to movement in the course of engineering construction and under loading depends upon its properties—

1. Index properties of soils: these include particles size distribution, water content, Atterberg limits (liquid limit, LL; liquidity index, LI; plastic limit, PL; plasticity index, PI; shrinkage limit, SL), relative density or specific gravity.
2. Internal friction: the resistance of a soil mass to sliding is inversely related to the amount of moisture in the soil and, thus, is greater in sand and gravel than clay.
3. Cohesion: molecular attraction between soil particles, much higher in clay than sand or silt.
4. Consolidation: this is the process of reduction of soil mass in volume due to expulsion of pore water under load.
5. Compressibility: the degree to which soil may be made denser by various means including tamping and vibration, and thus able to support greater loads.
6. Elasticity: the ability of soil to re-expand after being compressed.
7. Permeability: is the degree to which a soil will conduct flow of water, that is, the property of soil to permit the percolation of water through its pore space in soil.
8. Shear strength: is the maximum resistance to shearing stress.
9. Capillarity: the degree to which water is drawn upward from the normal water table.

2.2.3 Soil Stabilization Techniques

The soil properties can be modified by adding other material to improve its durability. This process is called soil stabilization. Soil stabilization has been used widely since the 1920s mainly for road construction and slope stability. When a soil is successfully stabilised one or more of the following effects will be evident: (i) Increase in the strength and cohesion of the soil (ii) Reduction in the permeability of the soil (iii) The resulting soil will be made water repellent (iv) Increase in the durability of the soil (v) Less shrinkage and expansion of the resulting soil in dry and wet conditions.

With respect to the general classification and stabilization methods, there are a number of different techniques for soil stabilization and many additives which have been or can be used as stabilizers. It is possible to divide the stabilizing action into three main classes: (i) Stabilization by mechanical or manual compaction (ii) Stabilization by addition of a binder (iii) Stabilization by addition of water proofer. Almost all stabilization techniques used in practice use one or more of these actions. The effect of mechanical or manual compaction is to increase the density of the soil mass. This has two beneficial effects: it increase the strength of the soil and at the same time reduces the proportion of the air void or water space, it restricts the passage of water entering into the soil from the surface and thereby reduces both the softening effect and the dimensional changes associated with the changes in water content. The compaction density is sensitive to the water content at the time of compaction; and of course, the density increases with increasing compaction effort. The best soil-building techniques are undoubtedly those in which mechanical compaction has been used. But for the most effective stabilization, compaction can be combined with either a binder (as used in the production of the interlocking block of this project) or a waterproofer. Binders are materials which act on a soil in such a way as to form a rigid skeleton within the soil, binding the soil particles together, thus increasing the strength and reducing swelling and shrinkage. Both cement and lime are in the same category, although they work in rather different ways. Waterproofers are materials which impart a water-repellent property to the soil, in order to restrict softening and dimensional changes. The most important properties required in a stabilized soil are strength, resistance to weathering and dimensional stability. Strength may be measured by compressive strength test - using cubes, cylinders or complete building blocks of soil. The crushing strength obtained in the compressive strength test will be very much affected by both the size and shape of the test specimen and its condition at the time of testing. Strength test should always be carried out with the specimen in a saturated condition because strength is very much influenced by water content and the size and shape of the specimen reported with the average crushing strength.

Soil Stabilization with Cement

The action of cement in soil-cement is precisely the same as concrete. It reacts with water in the mixture to form an insoluble cementation colloidal gel, a material which is able to disperse itself to fill the available pore spaces, where it sets and hardens, forms a continuous matrix of great strength which surround the particles of the soil and bind them together. In fact, the difference between concrete and soil-cement is that in concrete all materials that are finer than 0.1mm diameter are excluded, whereas in soil-cement they are tolerated. A small amount of clay present in soil-cement is an aid to compaction, but also has disadvantages. The clay particles are considerably finer than the cement particles, and they tend to form a continuous matrix through the soil causing swelling and shrinkage. This tendency cannot be completely counteracted without rather large amounts of cement, but can be limited to a tolerable level with quite small quantities. The best soils for cement stabilization are therefore, those which have only small clay content, and consist mostly of sand and gravel particles. The properties of soil-cement are, of course affected by the type of soil, the compaction effort used, the density of the soil-cement mixture and the proportion of the cement used. It is very important to note that compressive strength depends on mixing methods (the more complete the mixing, the higher the strength) and is also adversely affected by any delay between mixing and compaction.

Soil Stabilization with Lime

The action of lime in a stabilized soil is very different from that of cement, since lime is not itself a cementation material, and cannot therefore form a rigid skeleton with the soil. But a reaction of the pozzolanic type can take place between lime and certain clay materials in the presence of water, which forms an insoluble gel like that formed by Portland cement. The reaction however, is slow, produces a cementation material of rather lower strength than Portland cement and of course depends on the presence of a suitable soil mineral. The best soils for stabilization with lime are therefore those with significant amount of clay minerals, however, lime has an additional effect on the soil, by a process known as cation exchange (the exchange of the metallic ions on the surface of clay particles which control the water absorption tendency), it reduces the expansibility of the clay lattice and thereby lowers the soil's liquid limit and plasticity, it makes the soil more suitable for compaction and increases its compressive strength.

2.3 Composition of Interlocking Block

The composition of block depends on the availability of materials and its use. The major components of interlocking block include:

Cement: Cement has the property of setting and solidifying upon mixture with water. Cements are widely used in construction firms in design of structures, and having varieties, with Portland cement as the most common type of cement in general usage. It is a basic component of concrete, block, mortar or plaster. Cement consists of a mixture of oxide of calcium silicon and aluminium. Portland cement is made by heating limestone (a source of calcium) with clay and grinding this product (called clinker) with a source of sulphate most commonly called gypsum (*Niel Jackson and Ravindra K. Dhir*).
Water: Water combines with cement and aggregates to begin the process of hydration, and adequate water-cement ratio provides good consistency. The cement paste glues the aggregate together, fills voids within it and allows it to flow more easily. The use of clean pure water is always recommended for use in block production to prevent adverse harmful effect of salt, turbidity and other impurities. Impure water used to make block can cause problem when setting or in causing premature failure of interlocking block walls.
Aggregates: Fine and coarse aggregates made up the bulk of interlocking block mixture. Various types were explained above under 'properties and types of soil'. It can occur naturally or made artificially in industries (uncrushed or crushed). The size of aggregate affects the strength and load bearing capacity of interlocking block.

2.4 Block Strength

The compressive strength of compressed stabilized soil blocks (CSSB) depends on the soil type, type and amount of stabilizer and the compaction pressure used to form the block. The maximum compressive strengths of the block are obtained by proper mixing of suitable materials and proper compacting and curing. Thorough mix is essential in the production of uniformly high quality block. Therefore, equipments and methods adopted should be capable of effective mixture. However, hand mixing is likely to produce a block with lower strength than machine mixed block of similar proportions.

2.5 Wall Construction

Before placing the first course in a mortar bed, the blocks must be laid dry on the foundation around the entire building, in order to ensure that they fit exactly next to each other (leaving no gaps). When laying the first course in the mortar bed, care must be taken that the blocks are perfectly horizontal and in a straight line, or at right angles at corners and joints (T-junction). Once the base course is properly hardened, the blocks are stacked dry, with the help of a mallet to knock the blocks gently into place. Up to ten layers can be placed at a time. The ring beam below window level, at lintel and below roof level is necessarily constructed to enhance bonding of the assembled blocks. This can be achieved by the aid of channel blocks placed around the building at positions where the ring beams are required for the installation of ring beam, which enhance bonding of the assembled blocks. Interlocking blocks are ideally suited for load-bearing wall constructions, even for two or more storey buildings.

2.6 Advantages of Interlocking Block

The advantages of interlocking Block are: (i) Construction with interlocking block saves time and ample amount of mortar concrete compared to conventional masonry block laid with mortar (ii) Areas prone to earthquake uses hollow interlocking block with the strength improved with grout and reinforcement throughout the height of the wall to resist the effect of earthquake, thus, providing adequate structural stability against collapse (iii) Having formed the base course, other course can be assembled by unskilled labour (iv) Dismantling of the blocks in case of temporary structure does not incur much damages as in blocks laid with mortar (v) Cost of construction is relatively less.

2.7 Disadvantages of Interlocking Block

The disadvantages of interlocking block include (i) A standard skilled masonry labour is required to ensure proper horizontal and vertical alignment of the blocks, and that the corner and junction (T-joints) are right angled, especially at the base course (ii) Due to wind and rain seepage effect the block wall need be rendered (iii) The mould, palettes groove or/and protrusion edge may affect the dimension of the block; consequently hamper the alignment and stability of the wall, if not adequately observed (iv) It is difficult to maintain the required tight tolerances for accurate construction of large walls or other structures through the moulding and cutting steps.

III. Materials And Method

Civil engineering materials which include lateritic clay, river sand and Madube/Bama gravel (uncrushed) of various zones are common in Borno state. These constitute the major materials used for production of the interlocking block in this project. For the purpose of design, their analysis is important as well as laboratory determination of grain size analysis, atterberg limit, compressive strength and compaction effort. In order to promote economical importance, required standard must be met for the anticipated strength, stability, life span and aesthetics. Cost analysis of the various materials was made base on feasibility study with regards to social and economical factors.

3.1 Grain Size Analysis (Sieve Analysis)

The aim of this analysis is to determine the various particle sizes of soil samples. The apparatus used include Weighing balance, sets of sieves, weighing pan and oven. Sieve analysis consists of shaking a known weight of dried soil sample through a set of sieves that have being arranged in descending order of aperture sizes in a mechanical shaker for five minutes or manually for about ten minutes. This was carried out on the soil sample to classify the various soils. Wet and Dry Particle Size Distribution: this analysis expresses quantitatively the proportion by weight of the various particle sizes present in fine and coarse soil respectively. Soil has wide range of particle sizes with different properties ranging from; Gravel 60 – 2.0 (mm) equivalent particle diameter, Sand 2.0 – 0.06 (mm) equivalent particle diameter, Silt 0.06 – 0.002 (mm) equivalent particle diameter and Clay 0.002 (mm) equivalent particle diameter. For each of these materials, there is a grading envelope which it falls according to classification standard.

Procedure (Wet Sieve Analysis): (i) Weigh 500g of the lateritic soil sample using a weighing balance (ii) Wash the weighed sample thoroughly through British standard sieves of 1.18mm and 75µm or 65µm, until it is very clean and clear (iii) Dry the sample retained on the two sieves in the oven at a temperature of 105°C (iv) Arrange the set of sieves in descending order of aperture sizes (say 1.18mm, 425µm, 300µm, 150µm and 65µm) using the British standard set of sieve (v) Re-weigh the oven dried sample and place it on the topmost sieve and shake manually for about five minutes (vi) The samples retained on each sieve are weighed and recorded against the aperture sizes (vii) The results are computed.

Procedure (Dry Sieve Analysis): (i) Weigh 500g of the soil sample using a weighing balance (ii) Arrange the set of sieves in descending order of aperture sizes (say 4.75mm, 2.38mm, 1.18mm, 425µm, 300µm, 150µm and bottom pan) using the British standard set of sieve (iii) Place the measured sample on the top sieve and shake manually for about five minutes (iv) The samples retained on each sieve are weighed and recorded against the aperture sizes (v) The results are computed.

Table 1.0: Wet Sieve Analysis for Sample 'A' (Lateritic Clay)

Sieve Aperture	Weight Retained (g)
1.18mm	4
425µm	58
300µm	10
150µm	46
65µm	214
Total	332

Table 2.0: Wet Sieve Analysis for Sample 'B' (Lateritic Clay)

Sieve Aperture	Weight Retained (g)
2.38mm	6
1.18mm	10
425µm	54
300µm	10
150µm	44
65µm	196
Total	320

Table 3.0: Dry Sieve Analysis for Sample of River Sand

Sieve Aperture	Weight Retained (g)
4.75mm	24
2.38mm	64
1.18mm	110
425µm	146
300µm	48
150µm	68
Pan	38
Total	498

Table 4.0: Dry Sieve Analysis for Sample of Gravel

Sieve Aperture	Weight Retained (g)
9.5mm	56
4.75mm	284
2.38mm	240
1.18mm	20
Total	600

3.2 Atterberg Limit

The Atterberg limit is mainly divided into three types of tests; (1) Liquid Limit: - This is the moisture content at which the material being grooved by 12mm in cassagrande machine comes together at the application of blows (11 – 49) (2) Plastic Limit: - This is the moisture content at which the material can be rolled to 3mm thickness without breaking (3) Shrinkage Limit: - This is moisture content at which the material taken at 25 blows is considered and oven dried to determine the percentage shrinkage. The difference in initial length and the final length is determined and the shrinkage obtained.

3.2.1 Liquid Limit, Ll (Cassagrande Method)

The aim of this method is to determine liquid limit. The apparatus include: Cassagrande apparatus, grooving tool, glass plate, palette knives and water can. The Cassagrande apparatus consist essentially of a brass clip, rubber base and the handle for lifting the cup 10mm and dropping it (that is, applying blows). Details of the apparatus are given in BS 1377; 1975.

Procedure: (i) Soil samples passing 425 μ m sieve was collected and placed on the glass plate and mixed thoroughly with water using palette knives (ii) Some of the mixture was placed on the cassagrande machine cup and the grooving tool was used to make a 12mm groove on the mixture (iii) Blows were applied to the soil on the cup ranging from 11 to 49 blows before the materials come together (iv) The number of blows before the soil comes together was recorded and some of it was oven dried at a temperature of 105°C to determine its moisture content.

Table 5.0: Liquid Limit for Sample 'A' (Lateritic Clay)

Type of test	**LL**		**LL**		**LL**		**LL**	
No. of blows/shrinkage	11		25		36		42	
container No.	Rpy_2	Spy_7	Spy_1	Spy_6	Spy_8	Spy_2	Mp_2	Spy_5
Wt. of wet soil & container, (a) g	33.88	31.44	31.99	33.74	31.61	37.31	29.90	34.56
Wt. of dried soil & container, (b) g	31.06	28.50	29.07	30.42	28.94	33.79	27.64	31.75
Wt. of container, (c) g	23.32	20.89	20.85	21.15	21.12	23.55	21.03	23.58
Wt. of moisture, (a-b) = (W_m)g	2.82	2.94	2.92	3.32	2.67	3.52	2.26	2.81
Wt. of dried soil,(b-c) = (W_d)g	7.74	7.61	8.22	9.27	7.82	10.24	6.61	8.17
Moisture content(W_m/W_d)%	36.43	38.36	35.52	35.81	34.14	34.38	34.19	34.39
Average moisture content%	37.53		35.67		34.26		34.29	

Table 6.0: Liquid Limit for Sample 'B' (Lateritic Clay)

Type of test	**LL**		**LL**		**LL**		**LL**	
No. of blows/shrinkage	17		25		37		41	
container No.	Rpy_1	Rpy_2	Rpy_3	Spy_3	Spy_2	Mpy_2	Mp_2	Mpy_5
Wt. of wet soil & container,(a) g	31.57	38.46	33.26	32.07	33.59	30.63	38.41	32.51
Wt. of dried soil & container, (b) g	31.36	33.76	28.77	29.99	31.18	28.23	35.42	30.35
Wt. of container, (c) g	20.99	20.56	20.97	23.44	23.51	20.95	25.18	23.42
Wt. of moisture,(a-b) = (W_m)g	0.21	4.7	4.49	2.08	2.41	2.40	2.99	2.16
Wt. of dried soil,(b-c) = (W_d)g	10.37	13.20	7.80	6.55	7.67	7.28	10.24	6.93
Moisture content (W_m/ W_d) %	2.03	35.61	57.56	31.76	31.42	32.97	29.20	31.17
Average moisture content %	35.61		44.66		32.20		30.18	

3.2.2 Plastic Limit, PL

Procedure: (i) Soil samples passing 425 μ m sieve is collected and placed on the glass plate and mixed with water (ii) Some of the mixture is rolled on the plate using hand to about 3mm diameter without rupture (ii) It is oven dried at a temperature of 105°C to determine its moisture content.

Table 7.0: Plastic Limit for Sample 'A' (Lateritic Clay)

Type of test	**PL**	
Container No.	PL_2	PL_4
Wt. of wet soil & container, (a) g	22.14	22.28
Wt. of dried soil & container, (b) g	21.92	22.06
Wt. of container, (c) g	20.88	20.92
Wt. of moisture, (a-b) = (W_m) g	0.22	0.22
Wt. of dried soil, (b - c) = (W_d) g	1.04	1.14
Moisture content (W_m/ W_d) %	21.15	19.30
Average moisture content %	20.22	

Table 8.0: Plastic Limit for Sample 'B' (Lateritic Clay)

Type of test	PL	
Container No.	PL_7	PL_6
Wt. of wet soil & container, (a) g	26.27	25.16
Wt. of dried soil & container, (b) g	26.14	25.04
Wt. of container, (c) g	25.54	24.50
Wt. of moisture, (a-b)=(W_m) g	0.13	0.12
Wt. of dried soil, (b-c)=(W_d) g	0.60	0.54
Moisture content (W_m/ W_d) %	21.67	22.22
Average moisture content %	21.95	

3.2.3 Plasticity Index, PI

This is the difference between liquid limit, LL and plastic limit, PL.

PI = LL – PL

Plasticity index for sample 'A'

PI = 35.80 – 20.22 = 15.58

Plasticity index for sample 'B'

PI = 37.50 – 21.95 = 15.55

3.2.4 Linear Shrinkage, LS

Linear shrinkage, LS = [(Lo – L_1) / Lo] ×100

Where; Lo = initial length

L_1 = final length

Table 9.0: Linear Shrinkage for Samples 'A' and 'B'

Remark	Calculation	Result
Sample 'A'	(126 - 117) / 126 × 100 = 7.14%	7.14%
Sample 'B'	(127 - 117) / 126 × 100 = 7.87%	7.87%

3.3 Compaction Effort (CE)

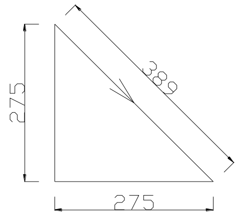
$$\mathbf{CE} = \frac{\text{No. of blows per layer} \times \text{weight of hammer} \times \text{height of drop}}{\text{Volume of mould}}$$

Weight of hammer = 11.13 kg

Volume of mould = 5.7500×10^{-3} m^3

Acceleration due to gravity, g = 9.81 m/s^2

Table 10.0: Compaction Effort

Remark	Calculation	Result
Height of drop	= $\frac{1}{2}((275^2 + 275^2)^{1/2})$= 195mm	195 mm
Force Compaction Effort	 11.13× 9.81= 109N (1 × 109 × 0.195) / 5.7500×10^{-3} = 3687 J/ m^3 = 3.687 kJ/m^3	109 N 3.687 kJ/m^3

3.4 Compressive Strength

Determination of the cube strength of hardened. The apparatus used include: Weighing balance and crushing machine. The compressive strength of interlocking block is the maximum compressive load it can carry per unit area. The strength depends on thorough mixture of aggregates and binder, cement type, mix proportion, compaction effort and curing conditions.

Procedure: (i) The cubes can be cured for like 7 days (possibly for more, for example 14, 21 and 28 days) afterwards are removed from the complete immersion in water and dried (ii) After air drying, it should be loaded at constant rate onto the compression testing machine to determine the force and compressive strength of the interlocking block.

Formulae: Compressive Strength (N/mm^2) = Compressive Load / Area

Table 11.0: Computations for Area of Contact

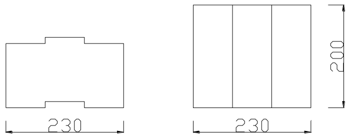
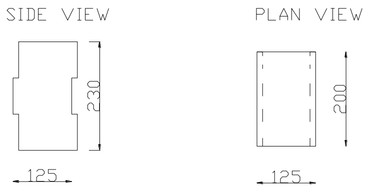
Remark	Calculation	Result
Area of contact for vertical loading	Effective length $200 \times 76.7 = 15,340$ mm^2	15, 340 mm^2
	Effective length $2(200 \times 76.7) = 30,680$ mm^2	30, 680 mm^2
	Average Area $(15,340 + 30,680)/2 \approx 23000$ mm^2	23000 mm^2
	Side and plan view respectively	
Area of contact for horizontal loading	 $125 \times 200 = 25000$ mm^2 	25000 mm^2

Table 12.0: Compressive Strength Computation

Sample	Size of sa specimen	Mix proportion	Curing condition	Wt. of sample (Kg)	Volume of sample (m^3)	Density of sample (Kg/m^3)
Concrete cube	150 × 150× 150	1:3:1	IMMERSION IN WATER	7.2	0.0034	2117.6
		1:3:1		7.2	0.0034	2117.6
		1:3:1		7.1	0.0034	2088.2
Lateritic cube		1:4		6.4	0.0034	1882.4
		1:4		6.4	0.0034	1882.4
		1:4		6.55	0.0034	1926.5
Concrete interlocking block	200 × 230 × 125	1:3:1	WETTING	9	0.0058	1551.7
		1:3:1		8.5	0.0058	1465.5
Lateritic interlocking block		1:4		7.7	0.0058	1327.6
		1:4		6.9	0.0058	1189.7
		1:4		6.6	0.0058	1137.9

Area of sample (mm^2)	Crushing load (N)	Crushing strength (N/mm^2)	Ave. crushing strength (N/mm^2)
22500	110000	4.89	4.45
22500	92000	4.09	
22500	98000	4.36	
22500	30000	1.33	1.44
22500	30000	1.33	
22500	38000	1.69	
23000	177000	7.7	6.73
25000	144000	5.76	
25000	22000	0.88	1.54
25000	64000	3.00	
23000	17000	0.74	

3.5 Volume Computation of Materials used for Interlocking Block

Density of Portland cement = 1.44 tone/ m^3 = 1440 kg/ m^3

Thus, volume = mass / density

= 50 ÷ 1440 = 0.034722 m^3 (for 50kg cement bag)

Length of block, l = 200 mm

Width of block, w = 230 mm

Height of block, h = 125 mm

Total volume of block = l × w × h

= 200 x 230 × 125 = 5750000 mm^3

= 5.75×10^{-3} m^3

Table 13.0: Volume of Materials by Proportion for Lateritic Clay Interlocking Block

Item	Calculation	Result
Unit ratio	$5.75 \times 10^{-3} \div 5 = 1.15\times 10^{-3}$ m^3	1.15×10^{-3} m^3
Cement	$1.15\times 10^{-3} \times 1 = 1.15\times 10^{-3}$ m^3	1.15×10^{-3} m^3
Lateritic clay	$1.15\times 10^{-3} \times 4 = 4.60\times 10^{-3}$ m^3	4.60×10^{-3} m^3
Summation	$(1.15 + 4.60) \times 10^{-3} = 5.75 \times 10^{-3}$ m^3	5.75×10^{-3} m^3

From table 13.0 above, the volume for an interlocking block of lateritic clay is 4.60×10^{-3} m^3, with cement summing up to be 5.75×10^{-3} m^3**.**

Table 14.0: Volume for One Square Metre Wall (Lateritic Interlocking Block)

Item	Calculation	Result
Cement	$40 \times 1.15 \times 10^{-3} = 0.046$ m^3	0.046 m^3
Lateritic clay	$40 \times 4.60 \times 10^{-3} = 0.184$ m^3	0.184 m^3
Summation	0.046 + 0.184 = 0.230 m^3	0.230 m^3

Table 14.0 gives the volume for one square metre wall to be 0.230 m^3, obtained by summing the volume of cement and lateritic clay.

Table 15.0: Volume of Materials by Proportion for Concrete Interlocking Block

Item	Calculation	Result
Unit ratio	$5.75 \times 10^{-3} \div 5 = 1.15\times 10^{-3}$ m^3	1.15×10^{-3} m^3
Cement	$1.15\times 10^{-3} \times 1 = 1.15\times 10^{-3}$ m^3	1.15×10^{-3} m^3
River sand	$1.15\times 10^{-3} \times 3 = 3.45\times 10^{-3}$ m^3	3.45×10^{-3} m^3
Madube gravel	$1.15\times 10^{-3} \times 1 = 1.15\times 10^{-3}$ m^3	1.15×10^{-3} m^3
Summation	$(1.15 + 3.45 + 1.15) \times 10^{-3}$ $= 5.75 \times 10^{-3}$ m^3	5.75×10^{-3} m^3

Table 16.0: Volume for One Square Metre Wall (Concrete Interlocking Block)

Item	Calculation	Result
Cement	$32 \times 1.3125 \times 10^{-3} = 0.042\ m^3$	$0.042\ m^3$
River sand	$32 \times 3.9375 \times 10^{-3} = 0.126\ m^3$	$0.126\ m^3$
Madube gravel	$32 \times 1.3125 \times 10^{-3} = 0.042\ m^3$	$0.042\ m^3$
Summation	$(0.042 + 0.126 + 0.042) = 0.210\ m^3$	$0.210\ m^3$

3.6 Volume Computation of Materials used for Sand Screed Block

Length of block, l = 450 mm
Width of block, w = 225 mm
Height of block, h = 225 mm
Total volume of block = volume of block - volume of hollow

Table 17.0: Volume of Sand screed Block for One Square Metre

Item	Calculation	Result
Volume of solid block	$450 \times 225 \times 225 = 22,781,250\ mm^3$ $= 0.02278125\ m^3$	$0.02278125\ m^3$
Volume of hollow	$2(155 \times 130 \times 225) = 9,067,500\ mm^3$ $= 0.0090675\ m^3$	$0.0090675\ m^3$
Actual volume of block	$22,781,250 - 9,067,500 = 13,713,750\ mm^3$ $= 0.01371375\ m^3$	$0.01371375\ m^3$
For one square metre ($1m^2$)	$8 \times 0.01371375 = 0.10971\ m^3$	$0.10971\ m^3$

Table 18.0 Volume of Mortar for One Square Metre (Concrete Mortar)

Item	Calculation	Result
Volume + hollow	$25 \times 450 \times 225 = 2,531,250\ mm^3$ $= 0.00253125\ m^3$	$0.00253125\ m^3$
Volume of hollow	$2(155 \times 130 \times 25) = 1,007,500\ mm^3$ $= 0.0010075\ m^3$	$0.0010075\ m^3$
Actual volume of mortar (horizontally)	$0.00253125 - 0.0010075 = 0.0015275\ m^3$	$0.0015275\ m^3$
(vertically)	$50 \times 225 \times 225 = 2,531,250 mm^3$ $= 0.00253125 m^3$	$0.00253125 m^3$
Total volume of mortar	$0.0015275 + 0.00253125 = 0.004055\ m^3$	$0.004055\ m^3$
For one square metre ($1m^2$)	$8 \times 0.004055 = 0.03244\ m^3$	$0.03244\ m^3$

Volume of materials by proportion "Using a mix ratio of 1:3:1"

Table 19.0: Volume of Sand screed Hollow Block

Item	Calculation	Result
Unit ratio	$0.01371375 \div 5 = 2.74275 \times 10^{-3} m^3$	$2.74275 \times 10^{-3} m^3$
Cement	$2.74275 \times 10^{-3} \times 1 = 2.74275 \times 10^{-3} m^3$	$2.74275 \times 10^{-3} m^3$
River sand	$2.74275 \times 10^{-3} \times 3 = 8.22825 \times 10^{-3} m^3$	$8.22825 \times 10^{-3} m^3$
Madube gravel	$2.74275 \times 10^{-3} \times 1 = 2.74275 \times 10^{-3} m^3$	$2.74275 \times 10^{-3} m^3$
Summation	$(2.74275 + 8.22825 + 2.74275)$ $= 0.01371375\ m^3$	$0.01371375\ m^3$

Table 20.0: Volume of Mortar

Item	Calculation	Result
Unit ratio	$0.004055 \div 5 = 8.11 \times 10^{-4} m^3$	$8.11 \times 10^{-4} m^3$
Cement	$8.11 \times 10^{-4} \times 1 = 8.11 \times 10^{-4} m^3$	$8.11 \times 10^{-4} m^3$
River sand	$8.11 \times 10^{-4} \times 3 = 2.433 \times 10^{-3} m^3$	$2.433 \times 10^{-3} m^3$
Madube gravel	$8.11 \times 10^{-4} \times 1 = 8.11 \times 10^{-4} m^3$	$8.11 \times 10^{-4} m^3$
Summation	$8.11 \times 10^{-4} + 2.433 \times 10^{-3} + 8.11 \times 10^{-4}$ $= 0.004055\ m^3$	$0.004055\ m^3$

Table 21.0: Volume of Mortar and Sand screed Block for One Square Metre Wall

Item	Calculation	Result
Volume of block & mortar	0.10971 + 0.03244 = 0.14215 m^3	0.14215 m^3

3.7 COST ANALYSIS

The cost of an interlocking block depends on the proportion and type of constituent material. In other words, the grade of the mix design which affects the compressive strength influences the cost. The cost of some materials is listed below;

Cement (one bag or 50kg) = N2, 200
Lateritic clay tipper (15m^3) = N8, 500
River sand tipper (15m^3) = N12, 000
Madube gravel tipper (15m^3) = N17, 000

Table 22.0: Cost of Materials per Volume (Lateritic Clay Interlocking Block)

Item	Calculation	Result
Cement Lateritic clay	2, 200 ÷ 0.034722 = N63, 360 per m^3 8,500 ÷ 15 = N566.67 per m^3	N63, 360 m^{-3} N566.67 m^{-3}

Table 23.0: Cost of Materials for One Square Metre (Lateritic Clay Interlocking Block)

Item	Calculation	Result
Cement	63, 360 × 1.15 × 10^{-3} = N72.86	N72.86
Lateritic clay	566.67 × 4.60 × 10^{-3} = N2.61	N2.61
Summation	72.86 + 2.61 = N75.47 per block	N75.47
For one square metre (40 blocks)	40 × 75.47 = N3018.80	N3,018.80

From table 23.0 above, one square metre lateritic clay wall costs N3018.80 which is economical as it is influenced by the cost of lateritic clay material.

Table 24.0: Cost of Materials per Volume (Concrete Interlocking Block)

Item	Calculation	Result
Cement River sand Madube gravel	2, 200 ÷ 0.034722 = N63, 360m^{-3} 12,000 ÷ 15 = N800m^{-3} 17, 000 ÷ 15 = N1,133m^{-3}	N63, 360m^{-3} N800m^{-3} N1,133m^{-3}

Table 25.0: Cost of Materials for One Square Metre (Concrete Interlocking Block)

Item	Calculation	Result
Cement	63, 360 × 1.15 × 10^{-3} = N72.86	N72.86
River sand	800 × 3.45× 10^{-3} = N2.76	N2.76
Madube gravel	1,133 × 1.15 × 10^{-3} = N1.30	N1.30
Summation	72.86 + 2.76 + 1.30 = N76.92 per block	N76.92
For one square metre (40 blocks)	40 × 76.92 = N3,076.80	N3,076.80

From table 25.0 above, one square metre concrete interlocking block wall amounts to N3, 076.80 which are higher than cost of lateritic clay interlocking blocks, N3, 018.80. The variation will cumulatively affect gross construction cost. Therefore, it is more economical to use lateritic clay interlocking block.

Table 26.0: Cost of Materials for One Square Metre 9" Sand screed Block

Item	Calculation	Result
Cement	63, 360 × 3.55275 × 10^{-3} = N225.10	N225.10
River sand	800 × 1.066125 × 10^{-2} = N8.53	N8.53
Gravel	1,133 × 3.55375 × 10^{-3} = N4.03	N4.03
Summation	225.1 + 8.53 + 4.03 = N237.66 (per block)	N237.66
For 1m^2 wall	237.73 × 8 = 1, 901.8 ≈ N1,902	N1,902

3.8 Description of Moulding Machine

The manually operated dual mould interlocking block production machine was constructed of 40mm rectangular steel pipe, steel plate, welded electrically. The machine has long steel attached with two mould lids which is also used for compaction. Each of the mould has equal dimension of 200mm length, 230mm width, 125mm height respectively, and designed with 12mm projected and grooved parts. Palettes are placed inside the mould and each mould have different palette to adequately form the toe, middle and top block grooves and protrusions. The machine has ejector steel for ejecting the blocks.

3.9 Procedure for the Production of Interlocking Block

Aggregates such as lateritic clay or sand and gravel are mixed thoroughly with cement, and brought into semi-consistency with water. The proportion of cement aggregate ratio adopted was 1: 4. That is, one unit of cement to four units of lateritic clay or one unit of cement to three units of river sand to one unit of gravel. Palettes were fixed at the bottom of the dual mould. The mixture is placed into the mould and the interchangeable lid is covered with adequate compaction effort to produce interlocking block with high density and compressive strength. The hand ejector is lowered to eject the fresh stabilized lateritic clay or concrete interlocking blocks which is kept to set and harden. Prior to the placement of the mixture, the inner part of the mould with the palette is lubricated to ease the removal of the interlocking block. The blocks are allowed to dry under the sun, during which they gain strength and at the same time shrinkage takes place. They can then be neatly fixed into walls by the aid of the projected and depressed parts. The top, middle and toe blocks have different forms of projected and depressed parts achieved by the aid of palettes placed at the bottom of the mould and the mould lids. When produced by mechanical vibrating machine higher compaction and strength are achieved. The required quality also depends on material used and its availability.

IV. Results And Discussion

4.1 Results for Sieve Analysis

Table 27.0: Table for Sieve Analysis Graph

Sieve size (mm)		9.50	4.75	2.38	1.18	0.425	0.30	0.15	0.065
Cumulative Passing %	**Lateritic clay 'A'**	-	-	-	99.2	87.6	85.6	76.4	33.4
	Lateritic clay 'B'	-	-	98.8	96.8	86.0	84.0	75.2	36.0
	River sand	-	95.2	82.4	60.4	31.2	21.6	8.0	-
	Madube gravel	90.7	43.4	3.4	-	-	-	-	-

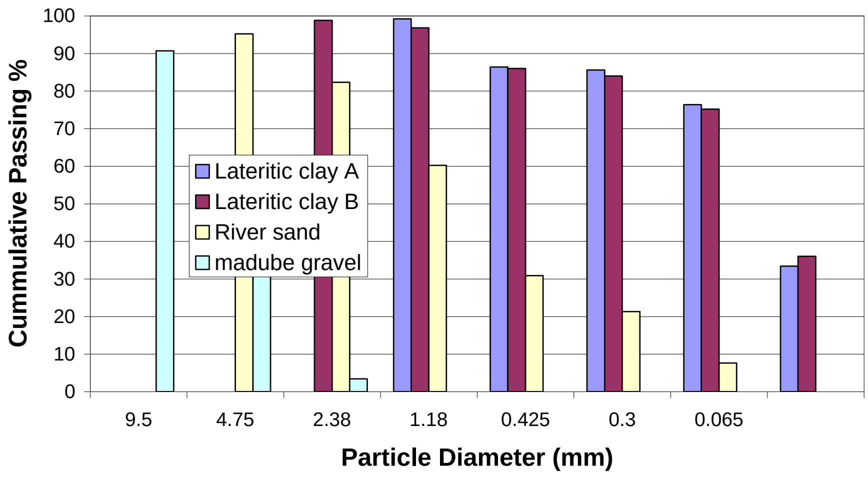


Fig. 1 Comparison of Various Sample Grain Size using Line Chart.

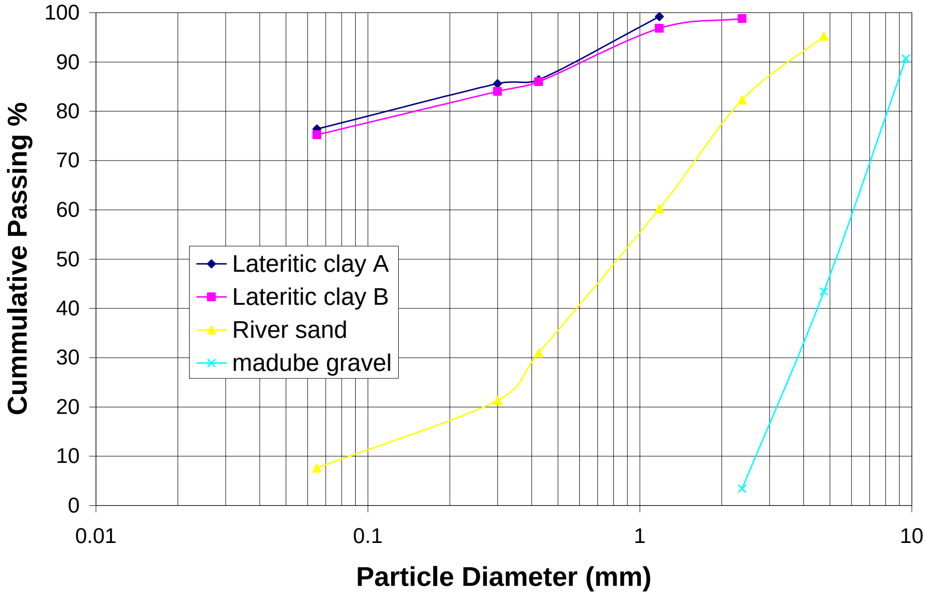


Fig 2 Comparison of Various Sample Grain Size using Line Chart.

Table 27.0 was used to plot the above graphs of figures 4.1 and 4.2 which show the cumulative percentage passing of the particle grain size distribution on the respective sieves. Particles size distribution of lateritic clay A and B, river sand and madube gravel were represented on both bar chart and line graph respectively. From the graph lateritic clay A and B have higher percentage passing sieves 1.18 to 0.15mm diameter aperture than river sand because it contains finer and less coarse than river sand. This can be seen clearly on the bar chart.

4.2 Results for Atterberg Limit

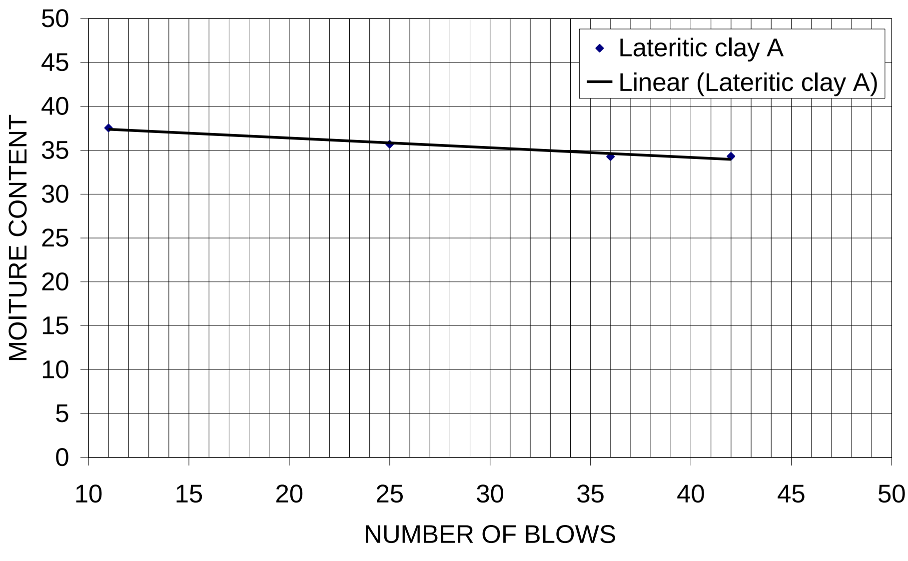


Fig. 3 Lateritic clay A

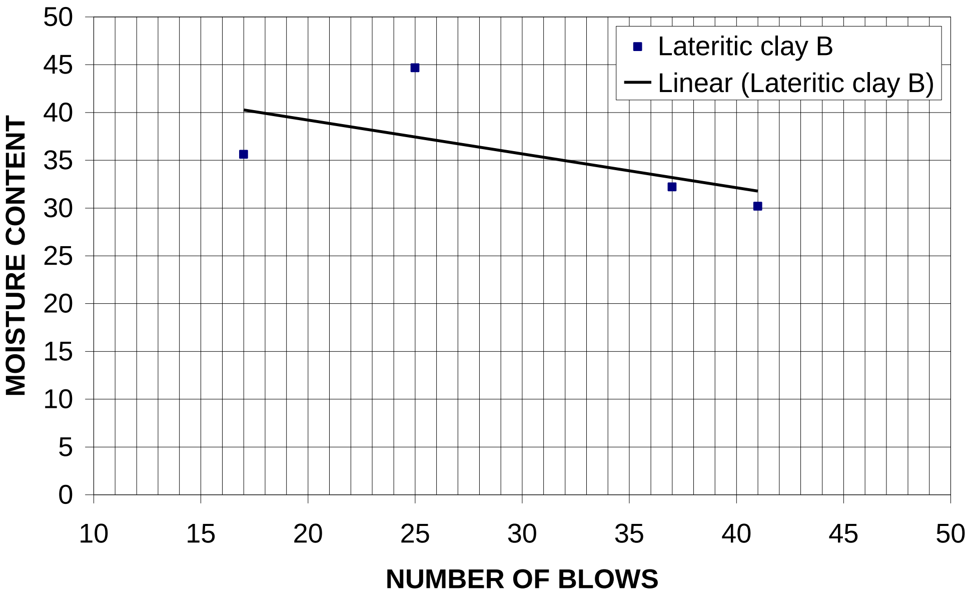


Fig. 4 Lateritic clay B

Table 28.0 Results for Atterberg Limit

Materials	Lateritic clay 'A'	Lateritic clay 'B'
Liquid limit	35.80	37.50
Plastic limit	20.22	21.95
Plasticity index	15.58	15.55
Shrinkage limit	7.14%	7.87%

The results on table 28.0 of the Atterberg limit reviews that the lateritic clay 'A' has liquid limit of 35.8, plastic limit of 20.22, plasticity index of 15.58 and shrinkage limit of 7.14%. More so, lateritic clay 'B' reviews that the soil has liquid limit of 37.5, plastic limit of 21.95, plasticity index of 15.55 and shrinkage limit of 7.87%.

4.3 Results for Compaction Effort

Table 29.0: Result for Compaction Effort

Item	kJ/m^3
Compaction Effort	3.687

Table 29.0 shows the compaction effort of a single drop of the lid which of course serve as the hammer. For subsequent compaction effort, the number of blows is multiplied to the unit compaction effort in the table above.

4.4 Results for Compressive Strength

Table 30.0: Results for Compressive Strength

Samples	Crushing Strength (N/mm^2)
Concrete cube	4.45
Lateritic cube	1.44
Concrete interlocking block	4.80
Lateritic interlocking block	1.42

4.5 Results for Volume of Lateritic Clay Interlocking Block Materials

Table 31.0: Volumetric Results for Interlocking Block (Lateritic Clay)

Item	Unit (m^3)
Cement	1.15×10^{-3}
Lateritic clay	4.60×10^{-3}
Interlocking block	5.75×10^{-3}
One square meter wall	0.230

Table 31.0 above shows that the volume of materials used for an interlocking block is $5.75 \times 10^{-3}m^3$ and the volume for one square meter wall is $0.230m^3$.

4.6 Results for Volume of Concrete Interlocking Block Materials

Table 32.0: Volumetric Results for Interlocking Block (Concrete)

Item	Unit (m^3)
Cement	1.15×10^{-3}
River sand	3.45×10^{-3}
Madube gravel	1.15×10^{-3}
Interlocking block	5.75×10^{-3}
Square meter	0.230

Table 32.0 shows that the volume of materials used for an interlocking block is $5.75 \times 10^{-3}m^3$ and the volume for one square meter wall is $0.230m^3$.

4.7 Results for Volume of Sand Screed Block Materials

Table 33.0: Volumetric Results for Sand screed Hollow Block

Item	Unit (m^3)
Cement	2.74275×10^{-3}
River sand	8.22825×10^{-3}
Madube gravel	2.74275×10^{-3}
Block	0.01371375
Square meter	0.14215

Table 34.0: Volumetric Results for Mortar

Item	Unit (m^3)
Cement	8.11×10^{-4}
River sand	2.433×10^{-3}
Madube gravel	8.11×10^{-4}
Mortar	0.004055
Square meter	0.03244

Table 35.0: Volumetric Results of Mortar and Sand screed Block for One Square Metre Wall

Item	Unit (m^3)
Volume of block and mortar	0.14215

Tables 33.0, 34.0 and 35.0 show that the volumes of materials which can be used for both sand screed block and mortar is $0.01371375m^3$ and $0.004055m^3$ respectively. And the volume of materials used for a square meter wall is $0.14215m^3$.

4.8 Results for Cost Analysis

Table 36.0: Cost of Lateritic Clay Interlocking Block

Item	Amount (N)
per block	75.43
For one square metre	3, 017.2

Table 37.0: Cost of Concrete Interlocking Block

Item	Amount (N)
per block	76.92
For one square metre	3, 076.80

From tables 36.0 and 37.0 above, one square metre concrete interlocking block wall amounts to N3, 076.80 which is higher than cost of lateritic clay interlocking block, N3, 018.80. The variation will cumulatively affect gross construction cost. Therefore, it is more economical to use lateritic clay interlocking block.

Table 38.0: Cost of Sand screed Block and Mortar

Item	Amount (N)
per block	237.73
For one square metre	1, 902

Due to the vertical hole in the sand screed blocks, table 38.0 above shows that the cost of one square metre wall is N1, 902, and of course the wall cannot resist the effect of impacts such as bullets and some other sharp objects.

V. Summary And Conclusion

The production of the interlocking blocks in this project was preceded by modelling of 250mm length, 210mm width and 125mm height interlocking toe, bottom and bottom blocks efficient production of the interlocking block in the laboratory using available local materials. The model as well as the interlocking blocks neatly key to each other in both horizontal and vertical directions. This production was achieved by manually operated dual interlocking block machine having interchangeable lids of ample compaction effort, a pedal and hand ejector. Two different pallets were used to form the grooves and protrusions. The laboratory tests facilitated the design and construction of the interlocking block with affordable compressive strength. The results were made in tabular and graphical representation.

Conclusively, a dual mould interlocking block machine with compaction effort (3.687 KJ/m^3) was effectively constructed for interlocking block production. The materials were sampled from kilometre 69 Maiduguri/damboa road and Bama road which was tested in the laboratory to ensure their properties for production of interlocking blocks. Therefore, the interlocking blocks attained ample compressive strength and can resist impact of bullets and other sharp objects using available local materials such as lateritic clay, river sand, Madube gravel, port-land cement and water which cannot be afforded by the hollow sandcrete blocks.

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