THE EFFECT OF VARYING RANGE OF SOIL GRAIN SIZES ON CASSAVA STARCH STABILIZED COMPRESSED EARTH

BY

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MSc/ENV.DES/41221/2004-05

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DEPARTMENT OF BUILDING,
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DECLARATION

I declare that the work in the project entitled THE OF EFFECT VARYING RANGE OF SOIL GRAIN SIZES ON CASSAVA STARCH STABILIZED COMPRESSED EARTH has been performed by me in the Department of Building, Faculty of Environmental Design Ahmadu Bello University Zaria, under the supervision of Prof M.M. Garda and Mal. Khalil I.M. The information derived from literature has been duly acknowledged in the text and list of references provided. No part of this project was previously presented for another degree at any university.

_____	_____	_____
Name Of Student	Signature	Date

CERTIFICATION

This Project entitled THE EFFECTS VARYING RANGE OF SOIL GRAIN SIZES ON CASSAVA STARCH STABILIZED COMPRESSED EARTH by Peter Ponjul Ramson meets the regulations governing the award of the degree of the MSc Construction Technology of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

_____ _____

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ABSTRACT

This study evaluated the strength and durability characteristics of cassava starch stabilized compressed earth bricks at 3 different grain size ranges. Laterite obtained locally from Zaria was sieved into 3 constituent grain sizes ranges of ≤ 2.36mm, ≤ 1.18mm and ≤ 600μm. Earth bricks of size 140mm × 140mm × 80mm were produced with earth brick production machine through the application of a pressure of $4N/mm^2$. The bricks were produced at 6 different stabilization levels with cassava starch as stabilizer for all the grain size combinations. The stabilization level are; 0%, 4%, 8%, 12%, 16% and 20%. Result shows that cassava starch stabilized bricks attained a maximum compressive strength of $1.83N/mm^2$ at 28 days strength gain. This is 10.9% higher than the NBRRI specified minimum strength of $1.65N/mm^2$ for compressed stabilized earth bricks. The study also reveals grain size ≤ 2.36mm and 20% stabilization as the overall best grain size combination and stabilization level respectively. Maximum water absorption of 13.23% was revealed at 28 days curing period while a good abrasion resistance accounting for 0.15% loss in weight was attained. The study therefore concluded that earth bricks produces with soil grain size ≤ 2.36mm and stabilized at 20% cassava starch content are of satisfactory strength and abrasion resistance and therefore recommended for use as interior walls and in areas of low exposure to moisture.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Earth as a building material is available everywhere. In developing countries, earth construction is economically the most efficient means to house the greatest number of people with the least demand of resources (Al-Sakkaf, 2009). Traditional earth construction materials such as adobe bricks suffer from moisture attack and cracks, thus the need to continuously maintain them in order to keep them in good condition. According to Adam and Agips (2001), traditional earth construction technology has undergone considerable developments that enhance earth's durability and quality as a construction material for low-cost buildings. Such methods include rammed earth and machine pressed compressed stabilized earth bricks. Stabilization of these earth bricks is achieved using various methods that often involve the use of a variety of stabilizers. Adam and Agip (2001) identified these stabilizers to include artificial ones such as Portland cement and lime and the natural ones such as agricultural waste amongst others.

Cassava starch which is the stabilizer in view in this research was recently evaluated for its suitability as stabilizer and found to improve some mechanical properties of selected soil types (Khalil 2005). Incidentally the abundance of the cassava crop in Nigeria is not in doubt. Phillips et al (2004) pointed out that Nigeria is the highest cassava producer in the world.

The effects of soil grain sizes in imparting changes in mechanical behavior of soils have also been pointed out by researchers like Wang, Lu and Shi. (2010), Rahardjo et al (2002) and many more.

This research work intends to evaluate the possibility of further improving the strength and durability characteristics of the cassava starch stabilized compressed earth bricks through the exploration of mechanical behavior of different grain size range of a selected soil type.

1.2 STATEMENT OF RESEARCH PROBLEM

Despite the diverse number of policies and programme adopted by the Nigerian Government, housing delivery has remained a major challenge leading to deficits in delivery. Oluwakiyesi (2011) puts the housing shortfall at between 16 and 18 million housing units. Ajanlekoko (2011) pointed out that the National housing programme launched by the Nigerian Government in1994 had a delivery target of 121,000 units to be distributed throughout the states of the Federation. Only 1,367 were completed and another 17,792 units were under construction. The National Rolling Plan (NRP) on the other hand, puts the housing requirement of Nigeria at a conservative annual estimate of between 500,000 and 600,000 thus needing an estimated 250 to 300 million Naira to make up for the shortfall. It can therefore be inferred that initiatives at enhancing housing delivery need not be limited to housing policies and programs of Government alone but should more importantly include reduction in overall construction cost particularly amongst the rural populace. Ajanlekoko (2001) asserted that the rapid up-swing in the prices of building materials in the last five years has further reduced the affordability for most Nigerians. Oresegun (2011) noted high cost of building materials and labour to be amongst major problems affecting housing delivery in Nigeria. Satprem (2009) recommended among other measures, a reduction in the amount of cement for brick making in other to enhance cost effectiveness.

Cement availability in Nigeria has recently been characterized by high cost, fluctuating price, scarcity and profiteering by cement manufacturers. This fact has been attested to in a Thisday news paper report of 24th April, 2011 captioned “amid scarcity cement producers post bumper profit”. The report states “indications emerged last week that the unabated shortage of cement products and its correspondent exorbitant price are raising the profitability of local manufacturers, which are alleged to have conspired to frustrate calls for higher importation as

a way of bridging the gap between demand and supply". Despite the cement challenge particularly in Nigeria, it still remains the main stabilizer in compressed earth brick production. This research therefore intends to consolidate on the gains in the cheaper and more readily available cassava starch stabilized compressed earth brick by evaluating the effects of grain sizes of soil (which in this case is laterite).

1.3 JUSTIFICATION

Compressed stabilized earth bricks have been noted to be probably the most cost effective alternative for solving the housing problems in Nigeria. However, cement still remains the main stabilizer in earth brick production with its attendant problems particularly in Nigeria. According to Adam and Agips (2001) Portland cement is amongst the most widely used and readily available stabilizer in developing countries. Satprem (2009) affirmed that compressed earth blocks are most times stabilized with cement or lime. Even the Nigerian Building and Road Research (NBRRI) Technological Innovation Catalogue considers only cement as stabilizer for Compressed Stabilized Earth Brick in its brick making technological innovation even though it (NBRRI), has established that cement content in compressed stabilized earth bricks above 5% is uneconomical (Agbede and Joel, 2008). There is therefore a need to search not only for cheaper and more environmentally friendly alternative stabilizers but also for optimization of their application as brick stabilizers. An analysis at the commencement of this study reveals that starch paste produced from 200g of dry cassava starch powder for stabilization of 140mm ×140mm × 80mm earth brick was sufficient for production of a minimum of 12 bricks at 5% stabilization. However 200g of cement for the production of same size of bricks at same stabilization level (5%) was sufficient for production of 5.2 bricks. Furthermore, equal amount of cassava starch is at least 4 times cheaper than cement.

The effect of soil grain sizes in imparting changes on mechanical behavior of soils was noted by various authors. According to Wang, et al. (2010) the mechanical properties can be obviously different even if there is a little difference in the grain size distributions of the undisturbed fine sand while the mechanical properties of the remoulded and the undisturbed fine sand are different even if the grain size distributions are the same. Verruijt (2010) classified soils according to their grain sizes and noted that grain size is a major factor in the different mechanical behaviour of the main types of soils i.e. sand, clay and peat while Rahardjo et al (2002) opined that the result of index and engineering properties of soils indicates that variation in index and engineering properties of soils are influenced largely by the pore-size distributions (which relates with grain sizes). These changes in mechanical behaviour as a result of changes in grain sizes may yield an optimum result in the application of cassava starch as stabilizer in compressed earth bricks.

1.4 AIM AND OBJECTIVES

1.4.1 Aim

The aim of this research work was to investigate the effect of varying soil grain sizes on stabilized compressed earth bricks using cassava starch as stabilizer.

1.4.2 Objectives

i. To establish the effects of varying soil grain sizes on durability of compressed stabilized earth bricks

ii. Establish the active chemical compounds in laterite and cassava starch

iii. To determine the chemical reactions of laterite and cassava starch

iii. Identify the best grain size range (within the scope of study) for stabilization with cassava starch

iv. Establish the effects of varying soil grain sizes on strength of starch stabilized compressed earth bricks

1.5 METHODOLOGY

The methodology adopted for this research was an extensive review of literature, publications, journals etc on soil stabilization as well as characteristics of the stabilizer under consideration i.e. cassava starch. Laboratory tests were carried out in conformity with already established procedures obtained from relevant literatures. Three sets of cube samples each of 140 X 140 X 80mm compressed stabilized earth bricks were cast, cured and tested at 7, 14, and 28 days respectively.

One set each of the test sample was prepared with soil of grain size passing sieve sizes 2.36mm, 1,18mm and 600μm respectively. Stabilization of sets of bricks was done at 0%, 4%, 8%, 12% 16% and 20%. Similar stabilization levels with different method of compaction (using the California Bear Ratio and Proctor mould) were established from literature.

1.6 SCOPE AND LIMITATIONS

1.6.1 Scope

Only chemical, physical and mechanical analyses were carried out on test samples. This research work was also carried out on single soil type (laterite) which was locally sourced from Biye Borough pit Zaria. As such no comparism was made with the performance of other soil types.

1.6.2 Limitations

1. Tests on stabilized bricks were confined to;

a. Compressive strength test

b. Abrasion resistance

c. Water absorption

2. Brick size was limited to 140mm×140mm×80mm obtainable from the press machine

3. Compressive pressure for brick molding was limited to $4N/mm^2$ applicable to the moulding machine used for brick production.

4. Only the NBRRI manual brick making machine was used. Not comparism was made with bricks molded with other brick making machines.

CHAPTER 2

LITERATURE REVIEW

2.1 SOIL DEFINITIONS

A number of definitions exist for the term soil depending on the person defining.

In the layman's mind, the soil is a very concrete thing, namely, the "dirt" on the surface of the earth.

To the soil scientist, or pedologist, the word "soil" conveys a somewhat different meaning, but no generally accepted definition exists (Jenny 1994). Hilgard (1914) defined soil as "the more or less loose and friable material in which, by means of their roots, plants may or do find a foothold and nourishment, as well as other conditions of growth." This is one of the many definitions that consider soil primarily as a means of plant production.

Ramann (1928) writes: "The soil is the upper weathering layer of the solid earth crust." This definition is scientific in the sense that no reference is made to crop production or to any other utilitarian motive.

Jopte (1936), a representative of the Russian school of soil science, objects to Ramann's formulation on the grounds that it does not distinguish between soil and loose rock material. According to Jopte, the soil is a natural body, differentiated into horizons of mineral and organic constituents, usually unconsolidated, of variable depth, which differs from the parent material below in morphology, physical properties and constitution, chemical properties and composition, and biological characteristics.

The Geologist regards soil as the material in the relatively thin surface zone within which roots occur and all the rest of the crust is grouped under the term “rock” irrespective of its hardness. To the Engineer, soil is the ungraded or uncemented deposits of mineral and/or organic particles or fragments covering a large portion of the earth crust (Tawfiq 2004).

It is problematic whether any definition of soil could be formulated to which everyone would agree. This research work however finds the definition by Ramann to be the most suitable working definition.

2.2 SOIL FORMATION

Hilgard (1914) defined soil formation as the transformation of rock into soil. The rock may be gneiss, limestone, shale, sand, loess, peat etc. To avoid too liberal an interpretation of the term "rock," soil scientists prefer to use the expression "parent"
material or "soil" material. The relationship between parent material, soil formation, and soil may be conveniently expressed as follows:

Parent material——————————> Soil.

Soil formation

Time is the variable factor through which the soil evolves from one state to another.

The above concept of soil formation is broader than that of a certain group of soil scientist who distinguish between *weathering* and *soil formation*. The Encarta English dictionary (2004) has defined soil as the disintegration of and decomposition of rocks and minerals by natural processes such as action of frost or percolating ground water. Weathering is considered as geologic and destructive while soil formation is regarded as pedological and creative. Thus weathering in this case is considered as only one of the many processes of soil formation (Hilgard 1914).

The parent materials exist in great variety. Each type may undergo a different weathering process, different weathering of soil itself at various stages of formation, different means of transportation, different manner of deposition of soil, history of loading, wetting and drying

and many other processes (Ujene 1999). This accounts for the existence of a great variety of soils.

Natural soils were noted by Spence and Cook (1993) to cover about 20 percent of the land surface. This makes them (soils) one of the most abundant construction material. Balami and Izam (1998) observed that soils are readily dug and moulded and understandably amongst the most ancient building material. These therefore underscore the importance of soil not only as foundation upon which structures are based but also in the production of building components. Walling units like mud blocks, burnt or compressed bricks and roofing elements like tiles and slates are some of the products of soils (Khalil 2005).

Khalil (2005) identified the existence of the following types of soils; sandy soils, clay soils, humus, laterite soils and gravelly. He noted that laterite offered the highest increase in compressive strength and best overall response to treatment with cassava starch. Olufemi (1988) analysed laterite derived from four basement complex rocks and sedimentary formations from southwest Nigeria, for their geotechnical properties, chemistry and mineralogy. He noted that granite gneiss derived and sedimentary laterite soils are good engineering material. These and more, are the reasons for limiting this research work to a study with laterite soil alone.

2.3 SOIL TYPES

There are different types of soils depending on a number of factors. These factors include the following; physical, chemical and biological interactions, weathering process, transportation, climate disposition, zone etc (Tawfiq 2004).

2.3.1 Humus

“These consist of the remains of plants and to a lesser extent, of animals, which have decomposed through the action of bacteria and other micro-organisms into a darkish,

armorphous mass. It is usually possible to pick out details of the vegetable structure in humus where the process of decay has not been completed. The humus content provides nitrogen and other elements such as phosphorus, calcium and potassium, which are broken down from decaying plant tissues by soil bacteria and made available in form, which plants can absorb through their roots. It also has the beneficial physical effect of improving the texture; on one hand it helps a sandy soil to retain while on the other hand it opens and aerates a clay soil" (Monkhouse 1975) in (Khalil 2005).

2.3.2 Clay Soil

"These soils consist of a large proportion of very fine mineral particles with individual grains less than 0.002mm in diameter. These particles are chemically extremely complex, but consist mainly of hydrated aluminium silicates. Clay contains little air, moreover, it can hold water, so forming a tenacious sticky mass, but when it dries out completely it forms a hard, concrete-like surface, seamed with numerous cracks," (Monkhouse 1975) in (Khalil, 2005). Susan (2005) in Khalil (2005) averred that clay soils tend to be more or less dark brown in colour and become sticky when wet. This soil hardens to something resembling concrete in dry weather. The clay does retain water and take a time to heat up in spring. This is why they are described as 'heavy' and 'cold'.

2.3.3 Sandy Soil

Sandy soils are fine grained silica base and retain very little clay. They are thus loose when dry and not at all sticky when wet, hence termed cohesion less soils", (Susan 2005) in (Khalil 2005). Monkhouse (1975) in Khalil (2005) opined that "sandy soil is a light soil which consists mainly of sand, that is, grains of quartz, with considerable air spaces between them.

The sand may be ‘coarse’ where the particle are between 0.2mm and 2.0mm in diameter, or ‘fine’ between 0.05mm and 0.2mm where the grains are just visible to the naked eye. These light soils allow water to drain through rapidly”.

2.3.4 Laterite Soil Type

The term ‘Laterite’, which is derived from the Latin word *later* meaning brick, was first used by Buchanan in 1807 for describing a red iron-rich material found in southern parts of India. Laterites are highly weathered soils which contain large, though extremely variable, proportions of iron and aluminium oxides, as well as quartz and other minerals. They are found in abundance in the tropics and subtropics, where they generally occur just below the surface of grasslands or forest clearings in regions with high rainfall. The soil colour can vary from red, brown, and violet to black, depending on the concentration of iron oxides (Adam and Agib 2001).

Selby (1971), defined laterite soils as soils that have an oxic zone: an altered subsurface horizon consisting of a mixture of hydrated oxides of iron or aluminium together with variable amounts of non-expanding lattice clays and accessory diluents, like quartz, that are highly insoluble. Buchanan called it laterite because it was frequently dug out of the ground while it was moist and soft and left in the sun to dry and harden to bricks.

Gidigasu (1977) opines that tropical weathering and laterization essentially involve chemical and physico-chemical alteration and/or transformation of primary rock-forming minerals into materials rich in clay minerals and laterite constituents (Iron, Aluminium, Tin and Manganese). He identified three major stages in laterization as follows:

1. physico-chemical breakdown of primary minerals and the release of constituent elements (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, etc);

2. laterization, which involves the leaching under appropriate drainage conditions of combined silica and bases and the relative accumulation, or enrichment from outside sources, of oxides and hydroxides of sesquioxide (mainly $A1_2O_3$, Fe_2O_3, and TiO_2);

3. dehydration or desiccation which involves partial or complete dehydration (sometimes involving hardening) of the sequioxide-rich materials and secondary minerals.

In the past, there has been much confusion in the engineering literature concerning what constitutes a laterite soil, with various writers adopting different chemical, geological, and pedological definitions. Gidigasu's (1977) suggested solution to this problem is to use a very broad and general definition that encompasses all of the tropically weathered, reddish-coloured soils. These may be residual or nonresidual, and may range from decomposed rock through clays, to sesquioxide-rich, indurated crusts. Therefore, the term laterite is considered to encompass all the above three stages of laterization process not limiting itself to any particular textural, compositional or morphological properties.

2.4 LATERITE FORMATION IN NIGERIA

Ikoyi (1997) observed that the location and distribution of laterite in Nigeria is associated with temperature and rainfall conditions that characterized the earth surface.

Nigeria falls within the tropics i.e. lying between latitude 4°N and 14°N. Therefore Nigeria has all necessary conditions like abundant rainfall, high temperature, good drainage and crystalline rock parent materials which aid the formation of laterite. The relief and temperature are higher in northern Nigeria than in the southern part. The reverse is however the case for rainfall and humidity. In the lowlands of the extreme south with annual rainfall of over $20cm^3$ and mangrove swamp forest vegetation where deltaic sedimentation or alluvial and recent soil deposits are generally encountered, leaching is the dominant process. Everything including Silica and clays is leached from the soil and carried away by ground

water except iron and aluminium, which form hydrated oxides. At high temperature, bacteria destroy the humus so that the groundwater is not acidic thereby resulting in the formation of laterite. The soil formations in other parts of the country are products of weathering that leach and form the laterite (Ajayi, 1985).

Adesunloye (1985) noted that laterite soil are both residual and transported and only about of the five characterized tropical residual soil profiles have been identified as relevant to laterite formation in Nigeria. Some of the groups include; Group A, which are residuals of granite origin coinciding principally with the basement complex which include newer and older basalt of the Jos Plateau; Group B, which represent residual soil of sedimentary origin of predominantly tertiary deposits, while Group C is considered to be of transported origin of early quartenary and later tertiary age. Badmus (2010) asserted that the most common materials used for construction are lateritic soils because they occur naturally with intense weathering (in the tropics) and there is lack of good quality crushed aggregate as well as economically attractive. Lateritic soils are found in the tropical environment, where there is an intense chemical weathering and leaching of soluble minerals (as is the case with Nigeria). Laterites are reddish brown well graded and sometimes extend to depth of several tens of metres. They are found almost everywhere in the tropics with wide applications in the construction industries. Earth has been one of the used in construction of houses in Nigeria from time immemorial and found to be efficient (Adakole 1992).

2.5 EFFECTS OF GRAIN SIZES ON MECHANICAL PROPERTIES

The effect or soil grain sizes in imparting changes in mechanical behavior of soils were noted by various authors. Wang, Lu and Shi (2010) evaluated the effects of grain size distribution and structure on mechanical behaviour of silty sand and concluded as follows;

“a. The mechanical properties can be obvious different even if there is a little difference in the grain size distributions of the undisturbed fine sand. The main reason may be the effects of structural characteristics.

b. The mechanical properties of the remoulded and the undisturbed fine sand are different even if the grain size distributions are the same. The main reason is the existence of the structural characteristics of the undisturbed sand while the remoulded sand loses its structural character.

c. The grain size distribution, especially the contents of sand and clay, affects the mechanical properties of mixed sand.

d. A kind of mixed sand which has the same mechanical properties as that of the undisturbed sand can be found”. Verruijt (2010) classified soils according to their grain sizes and noted grain sizes is a major factor in the different mechanical behaviour of the main types of soils i.e. sand, clay and peat while Rahardjo et al (2002) opined that the result of index and engineering properties of soils indicates that variation in index and engineering properties of soils are influenced largely by the pore-size distributions (which relates with grain sizes).

2.6 SOIL STABILIZATION

Modifying soil properties by adding another material to improve its durability is called soil stabilization (Adam and Agib 2001). Olaoye (2004) also defined soil stabilization as the alteration of any property of a soil in order to improve its engineering performance. Soil stabilization has been widely used since the 1920s mainly for road construction. Successful stabilization of soil results in one or more of the following;

a. increase in strength and cohesion of the soil

b. reduction in permeability of the soil

c. making of the soil water repellant

d. increase in the durability of soil or

e. reduction in shrinkage and expansion of the soil in dry and wet conditions

The art of soil stabilization is not new. Kulkarni noted that Indians have stabilized soils from pre-historic times up to 600 BC. These stabilized soils were used for constructing mud walls, for fabricating bricks, for applying a waterproof plaster to walls and sometimes for preparing statutes of gods and goddesses and also for applying waterproof plaster to these idols. Adam and Agib (2001) also observed that the concept of soil stabilization is not new since natural stabilizers such as natural oil and plant extracts, animal dung and crushed ant-hill material have been used for many centuries. They noted however that in recent times, more rigorous scientific rather than adhoc methods of soil stabilization have been introduced, developed mainly from early techniques devised mainly for stabilization of earth roads.

2.7 SOIL STABILIZERS

A number of stabilization methods have been identified by various authors. However some of the stabilization methods such as the chemical stabilization involve the use of a wide range of additives in order to achieve a desired result. Adam and Agib (2001) noted that stabilizers in use include manufactured ones such as Portland cement, lime, bitumen, gypsum, alkalis, sodium chloride, calcium chloride, polymers and the natural ones agricultural and industrial wastes. Other natural stabilizer earlier mentioned include natural oil and plant extracts, animal dung and crushed ant-hill materials, bird droppings and animal blood have been used for the manufacture of compressed stabilized earth building blocks. The waste materials

generally consist of nitrogenous organic compounds which help to bind together soil grains. Cassava starch has also been scientifically established by Khalil (2005) to impart stabilization characteristics to a wide range of soil types.

2.8 STABILIZATION TECHNIQUES

Various researchers have classified soil stabilization Techniques into a number of methods. For instance Spence and cook (1983) classified soil stabilization into three methods namely;

i. Stabilization by Mechanical compaction

ii. Stabilization by addition of binders and

iii. Stabilization by addition of water proof

Houben and Guiland (1994) on the other hand classified soil stabilization into;

i. Mechanical stabilization

ii. Physical stabilization and

iii. Chemical stabilization.

For the purpose of this research work however, a broader classification of soil stabilization techniques inferred by (Adam and Agib 2001), is adopted.

2.8.1 Mechanical stabilization

Adam and Agib (2001) noted that mechanical stabilization involves tamping or compacting the soil by using a heavy weight to bring about a reduction in the air void volume, thus leading to an increase in the density of the soil. The main effects of compaction on the soil

are to increase its strength and reduce its permeability. The degree of compaction possible, however, is affected greatly by the type of soil used, the moisture content during compaction and the compression effort applied. Best results can be obtained by mixing the correct proportions of sand and clay in a soil. More recent developments for roads and embankment construction have led to compacting soil with vibrating rollers and tampers. Tampers and block-making presses are also used for single storey constructions. The major drawback of mechanically compressed stabilized earth blocks is their lack of durability especially in places of moderate to high rainfall. Manual stabilisation or compaction methods vary from foot treading to hand tamping equipment, with compacting pressures varying between 0.05 to about 4MN/m^2. Mechanical equipment may achieve compacting pressures of several thousand MN/m^2. Olaoye (2004) averred that the mechanical compaction is the most economical means of soil stabilization.

2.8.2 Cement Stabilization

"Ordinary Portland cement hydrates when water is added; the reaction produces a cementitious gel that is independent of the soil. This gel is made up of calcium silicate hydrates; calcium aluminate hydrates and hydrated lime. The first two compounds form the main bulk of the cementitious gel, whereas the lime is deposited as a separate crystalline solid phase. The cementation process results in deposition between the soil particles of an insoluble binder capable of embedding soil particles in a matrix of cementitious gel. Penetration of the gel throughout the soil hydration process is dependent on time, temperature and cement type. The lime released during hydration of the cement reacts further with the clay fraction forming additional cementitious bonds.

Soil-cement mixes should be compacted immediately after mixing in order not to break down the newly created gel and therefore reduce strengthening. The basic function of cementation is to make the soil water-resistant by reducing swelling and increasing its compressive

strength. With respect to the general processes of cementation, penetration and binding mentioned above, many factors must be considered. Processes may also vary between different types of soils. Cement is considered a good stabiliser for granular soils but unsatisfactory for clays. Generally cement can be used with any soil type, but with clays it is uneconomical because more cement is required. The range of cement content needed for good stabilization is between 3% and 18% by weight according to soil type" (Adam and Agib 2001).

It has also been established that there is relationship between linear shrinkage and cement content need for stabilization. Table 2.1 shows that cement to soil ratio ranges between 5.56% and 8.33% for measured shrinkage variation of between 15mm to 60mm.

Table 2.1 – Relationship between cement to soil ratio and Shrinkage

Measured Shrinkage (mm)	**Cement to soil ratio**
Under 15	1:18 parts (5.56%)
15-30	1:16 parts (6.25%)
30-45	1:14 parts (7.14%)
45-60	1:12 parts (8.3%)

(Source: Adam and Agib 2001).

Adam and Agib also noted that for a given shrinkage, the cement to soil ratio is a function of compaction effort exerted. For example, a CINVA Ram machine exerts a compaction pressure of about 2MN/m^2, by increasing this pressure to about 10MN/m^2 the cement content can be reduced to between 4% and 6% for soil with shrinkage of up to 25mm. Over this shrinkage value, 6% to 8% cement would need to be used for effective stabilization.

2.8.3 Lime Stabilization

Adam and Agib (2001) further reported that by adding lime to the soil for stabilization, four basic reactions are believed to occur: cation exchange, flocculation and agglomeration, carbonation, and pozzolanic reactions. The pozzolanic reaction is believed to be the most important and it occurs between lime and certain clay minerals to form a variety of cementitious compounds which bind the soil particles together. Lime can also reduce the degree to which the clay absorbs water, and so can make the soil less sensitive to changes in moisture content and improve its workability. Lime is a suitable stabilizer for clay soils. Lime is more widely available than Portland cement in Sudan (and other developing countries) and is produced locally in traditional kilns. However, some improvements still need to be made in its production and processing.

The advantages that lime has over Portland cement are that it requires less fuel to manufacture and requires relatively simple equipment to make. It is therefore more suitable for village scale production and use.

It has been reported that when lime is used as a stabiliser instead of cement, the quantity needs to be doubled. However Adam (2001) shows that such doubling is not necessary if a sufficiently high compacting effort is applied on a high clay content soil. The reduction in the volume of air voids brings the lime and soil particles into closer contact and the stabilising reactions can take place more easily. Tests show that wet compressive strengths of between $3MN/m^2$ and $3.5MN/m^2$ may be achieved with compacting efforts in the range of 8 to $14MN/m^2$. Blocks made from Sudanese black cotton soils are tested using wide range of compaction pressures. A 6% lime content is used for stabilizing black cotton soil from Sudan with a silt and clay content of 58% and a linear shrinkage of 11%.

2.8.4 Bitumen Stabilization

Bitumen stabilization has been described by Ujene (1999) as a chemical method of soil stabilization. Adam and Agib (2001) identified two ways by which bitumen can stabilize soils. The first way is through a binding process that increases strength particularly in granular soils. Generally, small amounts of bitumen (2% to 6%) give the soil cohesion. When these percentages are exceeded the bitumen tends to act as a lubricant separating the particles and thus reducing the strength. The second way is when the bitumen acts as a water repellent. The two mechanisms usually occur together in any soil but to different degrees, depending on the type of soil. Soils suitable for bituminous stabilization are sandy soils. Clay need large amount for a good result. The main disadvantages of bituminous materials as stabilizers are;

i. they are not traditional building materials in most developing countries,

ii. they are expensive to import,

iii. cost of preparation (i.e. heating, storing and mixing) is high,

iv. heat can have adverse effect on their binding properties especially in hot countries.

2.8.5 Gypsum Stabilization

Gypsum is used in the early civilization for building mainly for plaster and mortar. It is a traditional material in the Mediterranean and Middle East countries. The advantage that gypsum has over Portland cement and lime is that it requires a low calcination temperature (about 1/7th of that needed for cement and 1/5th of that needed for lime).

Besides its agricultural and chemical uses, one of the main uses of gypsum is in the production of Portland cement where it retards the setting of the cement. Gypsum is a good stabiliser for sandy soils.

2.8.6 Pozzolana Stabilization

Pozzolanas are fine silica and alumina rich materials which when mixed with hydrated lime produce cementitious materials suitable for stabilisation and construction needs (Adam and Agib. 2001). In their natural state, pozzolans are found as volcanic ash or pumice. They can also be manufactured from finely ground recycle fired clay bricks and mudstone. They have been used extensively for building plaster and stabilizers with excellent results.

2.9 CASSAVA

Cassava (*Manihot esculenta*), also called manioc, tapioca or yuca, is one of the most important food crops in the humid tropics, being particularly suited to conditions of low nutrient availability and able to survive drought (Burrell, 2003). The plant grows to a height of 1 to 3 m and several roots may be found on each plant. Although cassava leaves are sometimes consumed, the major harvested organ is the tuber, which is actually a swollen root. The plant is propagated mostly from stem cuttings. A major limitation of cassava production is the rapid post harvest deterioration of its roots which usually prevents their storage in the fresh state for more than a few days (Okezie and Kosikowski, 1982). Cassava ranks very high among crops that convert the greatest amount of solar energy into soluble carbohydrates per unit of area. Among the starchy staples, cassava gives a carbohydrate production which is about 40% higher than rice and 25% more than maize, with the result that cassava is the cheapest source of calories for both human nutrition and animal feeding. A typical composition of the cassava root is moisture (70%), starch (24%), fibre (2%), protein (1%) and other substances including minerals (3%) (Tonukari, 2004). Compared to other crops, cassava excels under suboptimal conditions, offering the possibility of using marginal land to increase total agricultural production (Cock, 1982). Plant breeders, agronomists and recently molecular biologists have made substantial improvements in cassava yields during

the last two decades. While, genetic characterization and mapping has revealed some insights into the molecular nature of cassava (Tonukari et al.1997; Fregene et al. 2003).

2.9.1 Cassava Types

Khalil (2005) identified two main types of cassava; the sweet and the bitter types. The bitter varieties are found to contain prussic acid and in most varieties, a cyanide producing sugar derivative in varying amounts. The poisonous acid in cassava is extracted by different complex refining systems. Cassava is cut in pieces and soaked in water for one to two days to facilitate acid extraction depending on the variety. Other means are by grating, pressing and heating of the tuber.

2.9.2 Cassava Production in Nigeria

Phillips et al (2004) established in their work on cassava industrial revolution in Nigeria that Nigerian cassava production is by far the largest in the world; a third more than production in Brazil and almost double the production of Indonesia and Thailand. Cassava production in other African countries, the Democratic Republic of the Congo, Ghana, Madagascar, Mozambique, Tanzania and Uganda appears small in comparison to Nigeria's substantial output. This is illustrated in figure 2.1.

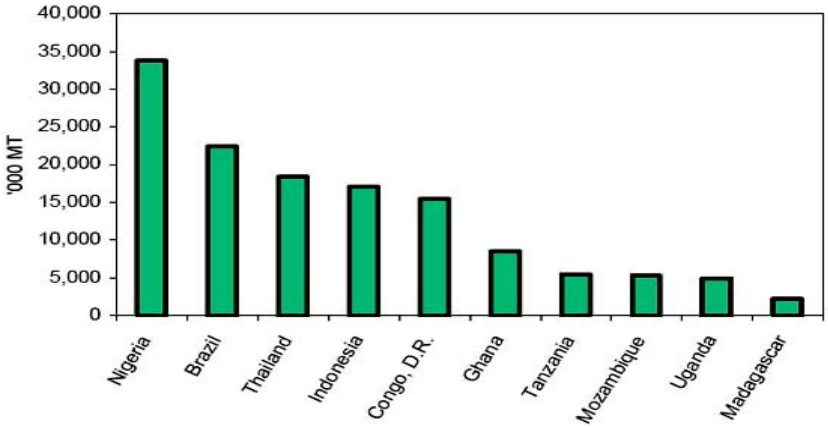


Fig 2.1 World Major Producers of Cassava. (Source; Phillips et al 2004)

According to Phillips and Taylor (2005), three sets of estimates exist for Nigerian cassava Production from 1996 to 2002.

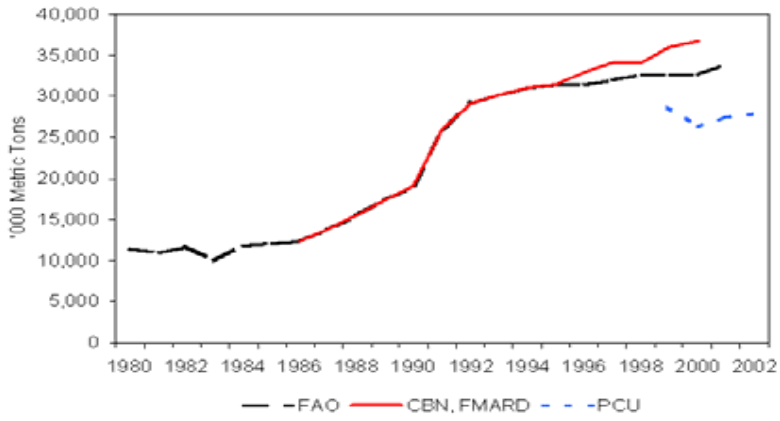


Fig 2.2 Cassava Industrial Revolution In Nigeria1980-2002 (Source: Phillips et al 2004)

The Food and Agriculture Organization of the United Nations (FAO) in Rome (FAO, 2004a) estimated 2002 cassava production in Nigeria to be approximately 34 million tonnes. The trend for cassava production reported by the Central Bank of Nigeria mirrored the FAO data until 1996 and thereafter rises to the highest estimate of production at 37 million tonnes in 2000 (FMANR, 1997; Central Bank of Nigeria).

The third series provided by the Project Coordinating Units (PCU, 2003) had the most conservative estimate of production at 28 million tonnes in 2002. PCU data collates state

level data provided by the Agriculture Development Project (ADP) offices in each state. Comparing the output of various crops in Nigeria, cassava production ranks first, followed by yam production at 27 million tonnes in 2002, sorghum at 7 million tonnes, millet at 6 million tonnes and rice at 5 million tonnes (FAO, 2004a). Expansion of cassava production has been relatively steady since 1980 with an additional push between the years 1988 to 1992 owing to the release of improved IITA varieties.

By zone, the North Central zone produced over 7 million tonnes of cassava a year (1999 to 2002). South South produces over 6 million tonnes a year while the South West and South East produces just less than 6 million tonnes a year. The North West and North East are small by comparison at 2 and 0.14 million tonnes respectively (Table 2-1).

Table 2.2 Cassava Production In Nigeria by Geopolitical Zones 2000-2002 (tonnes)

Region	2000	2001	2002
South West	4,993,380	5,663,614	5,883,805
South South	6,268,114	6,533,944	6,321,674
South East	5,384,130	5,542,412	5,846,310
North West	2,435,211	2,395,543	2,340,000
North Central	7,116,920	7,234,970	7,405,640
North East	165,344	141,533	140,620
Total	26,363,099	27,521,016	27,938,049

(Source: Project Coordinating Units FMANR, 2003)

On a per capita basis, North Central is the highest producing state at 0.72 tonnes/per person in 2002, followed by South East (0.56), South South (0.47), South West (0.34), North West

(0.10) and North East (0.01). National per capita production of cassava is 0.32 tonne/per person. Benue and Kogi state in the North Central Zone are the largest producers of cassava (IITA, 2004).

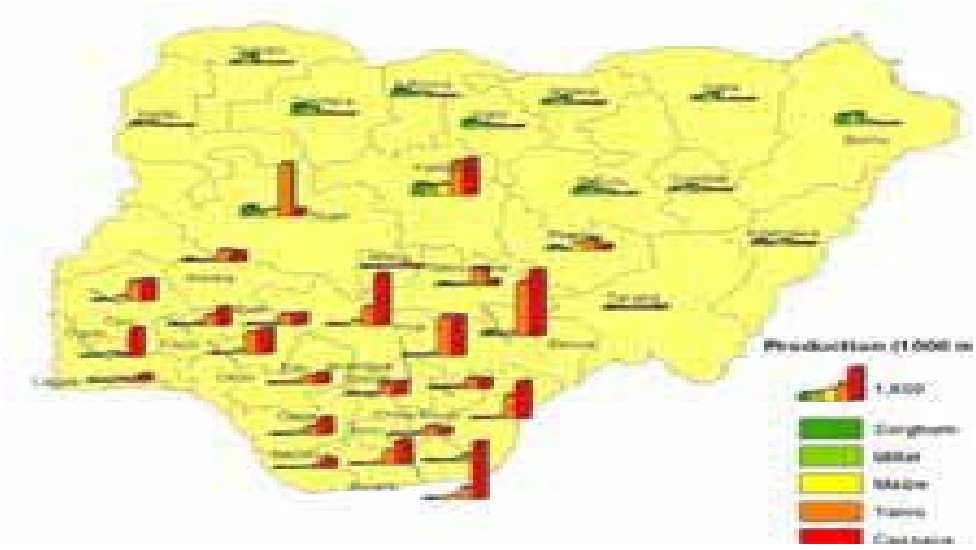


Figure 2.3 Crop Production in Nigeria by States In 2002 (Source; Phillips et al 2004)

2.9.3. Composition and Applications of Cassava Starch

The nutritive reserve of cassava is starch which is one of the most important products synthesized by plants that is consumed as food and used in industrial processes. Richard and Honeyman (1954) noted that starch occurs in all green plants; roots as in yams, potatoes, cassava and carrots; fruits as in mangoes; seeds as in cereals and grains such as maize, guinea corn, rice, wheat etc. He further noted that green plants synthesize starch naturally by the process of photosynthesis a process through which chloroplast containing chlorophyll (a mixture of colouring matter) cause carbon (iv) oxide, CO_2 inhaled from air by the leaves, and water, H_2O absorbed by root to react in the presence of sunlight to form glucose a monosaccharide at the same time oxygen is liberated into the atmosphere.

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

photosynthesis

Equation 1: Photosynthesis Process

Polymerization of this glucose eventually leads to formation of starch which is then stored. Mali, Sakanaka and Yamshita (2005), Famá, et al. (2005) asserted that starch is a polysaccharide composed by the amylose, a linear or sparsely branched polymer, and the amylopectin, a highly branched polymer.

The chemistry of locally supplied cassava was observed by Vicentini et al. (2005) to comprise of 14.9% moisture, 16% amylose, 0.21% soluble sugars, 0.23% ash, 0.39% fibre, 0.24% total nitrogen, 0.15% lipids.

Cassava starch has a variety of uses. Dextrin pre-gelled cassava starch are used for adhesive while starch and hydrolysates are used for pharmaceuticals and seasoning, (Kormawa and Akoroda, 2003). Oil companies were noted by Phillips et al (2004) to be interested in producing cassava starch for drilling mud. The starch was also observed to find application in the Textile for sizing and dying to increase brightness and weight of cloth (Tonukari, 2004). Tonukari further asserted that cassava starch is also an important raw material for powder in the cosmetics industries. In detergent soap manufacture, starch is used to get better recovery and to improve the shelf life of detergents. While in the rubber and foam industries, starch is employed for getting better foaming and color.

The construction industry is not an exception in the application of cassava starch. Cassava starch has several other numerous uses such as an additive in cement to improve the setting time, and it is used to improve the viscosity of drilling mud in oil wells. It is also used to seal the walls of bore holes and prevent fluid loss.

CHAPTER 3

MATERIALS AND METHOD

3.1 MATERIALS

The experiment carried out in this work was based on assessing the strength characteristics, durability and resistance of compressed earth bricks at different grain size ranges stabilized with cassava starch. The soil type in this experiment was laterite obtained from Biye Borough Pit Zaria. The laterite was reddish brown with violet pigmentation belonging to A-2-6 class using AASHTO soil classification system. The soil sample was sieved through the 5mm sieve and particles retained were pulverized and sieved again.

The starch was obtained from the Lafia in Nasarawa State, Nigeria. It was manually processed by rural dwellers within Lafia environs and sold at the Lafia market. It was obtained in its soluble state and air dried to be in powder form. The starch is disease, pest and draught resistant and low in cyanide content. The water used in the experiments was portable drinking water from tap deemed fit for human consumption. It was obtained from the Building Department taps.

Stabilization techniques, which involves mixing of soil with stabilizing agent in different proportions already in use as reviewed from past works was adopted. The experiment consist of the physical properties of the soil, stabilizer (starch) and the final mechanical tests on prepared specimens that measured the performance characteristics of the stabilized bricks at different levels of stabilization. Six levels of stabilization 0, 4, 8, 12, 16 and 20 percent starch paste content by weight were adopted as reviewed from literature. The experiment was carried out for grain sizes ranges passing sieve sizes 2.36mm, 1.18mm, and 600μm, respectively.

The experiments were conducted in the departmental laboratories of Building and Civil Engineering, Ahmadu Bello University, Zaria as well as the National Research Institute for

Chemical Technology (NARICT) Zaria. Tests were all carried out in conformity with relevant British standards.

3.2 BRICK PRODUCTION

Bricks of sizes 140mm×140mm×80mm were produced using NBRRI manual brick moulding machine. Compressive pressure applicable to the machine is 4N/mm^2. Trial brick samples were produced at 17% moisture content which was determined as the suitable moisture content for smooth production at 0% level of stabilization. The weight of earth for production of 1No brick was then determined. 54No bricks were produced for each mechanical test. This number was sufficient for 3 test samples per mechanical property for the 6 levels of stabilization and 3 curing periods.



Plate I: NBRRI Earth Brick Production Machine

3.3 CURING

Damp curing of the bricks was done by covering the bricks with plastic sheets for a period of 5 days. The plastic sheets were then removed and the bricks air dried at room temperature for the remaining of the 3 different period of curing i.e. 7days, 21days and 28days applicable per mechanical property.

3.4 CHEMICAL ANALYSES

Fourier Transform Infrared Spectrometer (FTRI) analysis was carried out on both the laterite and starch samples at the National Research Institute for Chemical Technology (NARICT), Zaria. The FTRI spectrometer is a laboratory equipment that uses spectroscopic technique to identify and study chemicals in a given substance. The aim of the FTRI analysis was to identify the active chemical compounds in the laterite and starch samples with a view to identify possible reactions that would take place between the two samples. Results of the FTRI analysis are presented on table 4.1

3.5 PHYSICAL PROPERTIES

3.5.1 Laterite Sample

Physical property tests were carried out on the laterite soil samples in conformity with relevant standards. Tests carried out are as follows;

1) Field settling test: was done in conformity with BS 812: 1975: Part 2.This test is significant in order to establish the quantity of silt in the soil, the cleanliness of the soil as well as the proportion of the different particle sizes. Excess quantity of silt and impurities adversely affect the quality of soil and can reduce the bond between soil particles and the stabilizer. Result of field settling test is given on table 4.2 and test procedure is at appendix A.

2) Specific gravity test: was carried out in accordance with BS 1377:1990. This test is relevant in order to measure the volume of the laterite sample excluding its pore space. This value indicates the gravity of the laterite sample without the need for crushing value test. Result of specific gravity test is given on table 4.2. Test procedure is at appendix C.

3) Moisture content test: this was carried out as specified in BS 1377:1990. It indicates the water absorption capacity of the laterite sample and may influence the bond between the stabilizer and the soil particle. The actual water absorption of the laterite sample has to be deducted from the total water required of the mix to obtain the effective mixing water which also controls compaction. Result of moisture content test is given on table 4.2 while procedure is at appendix D.

4) Sieve analysis: this was conducted in conformity to BS 410: 1976. This test is relevant to obtain the grain size distribution of the laterite sample and their relative percentages in the soil sample. This test indicates the classification of the soil. Result of sieve analysis is given on table 4.3. Test procedure is at appendix B.

5) Atterberg limit test: this was carried out in conformity with BS 1377:1990. This test is significant for indication of the soil classification and condition and it provides a relationship to structural properties such as strength, compressibility, permeability, swelling potential etc. Result of Atterberg limit test is presented on table 4.2 and test procedure is at appendix E.

6) Compaction characteristics test: this test was carried out in conformity with BS 1377:1990: Part 4:3.2. This test is a measure of the reduction in voids in the laterite sample and the resultant increase in unit weight. Results of the compaction characteristic test are presented in figures 4.2 (a-b). Test procedure is at appendix F.

3.5.2 Cassava Starch

Physical property tests carried out on cassava starch sample are as follows;

1) Paste consistency test: This test was carried out to establish the quantities of starch mixed into a paste using cold water and hot water that will give a standard consistence, paste clarity and uniform viscosity. Result of paste consistency test are presented table 4.4 and procedure is at appendix G.

2) Mix proportion test: this was also carried out in conformity with BS 1377: 1990: Part 4. The mix proportion test establishes the amount of laterite and starch at the different stabilization levels and the relationship with optimum water content required at the various levels. Results of the mix proportion test are presented on table 4.5 and test procedure is at appendix H.



Plate II: Specific Gravity Test



Plate III: Compaction Characteristic Test



Plate IV: Weighing Of Bricks

3.6 MECHANICAL PROPERTIES

1) Abrasion resistance test: this test is significant to establish the resistance of stabilized specimen to wear. This is because one of the applications of stabilization is in erosion and dust control Heebink and Hassett (2001). 54 brick specimens were used for 3 tests, 3 curing period and 6 stabilization levels. Abrasion test was carried out as established in Khalil (2005) as detailed in appendix I and the results are presented on table 4.6.

2) Water absorption tests: water test was done to determine the water absorption rate of stabilized specimens. The resistance to permeability is an important property of stabilization thus the significance of the test. 54 brick specimens were used as described in abrasion resistance test. Tests were carried out according to procedure established in Khalil (2005). This is detailed in appendix J. Results are presented on table 4.7.

3) Compressive strength test: This test was carried out in conformity with established literature; Khalil (2005) detailed in appendix K. An important property of stabilization is the strength development of stabilized specimen with age therefore the significance of this test. Similarly, 54 brick specimens were tested as in abrasion resistance test. Results of these tests are presented on figures 4.3 a-d.

CHAPTER 4

DATA PRESENTATION, ANALYSIS AND DISCUSSION

The results of the Fourier Transformed Infrared Spectrometer (FTRI) test are presented on table 4.1. The result show the active functional groups contained in the laterite and cassava starch use in this research. This is indicated by infrared spectra.

Table 4.1 FTRI Result of Active Functional Groups In Laterite And Starch

SAMPLE	FUNCTIONAL GROUPS DETECTED	IR SPECTRUM
Laterite	N —H	3651 cm^{-1}
	O —H	3386 cm^{-1}
	O —H	1627 cm^{-1}
Starch	N —H_{str}	3651 cm^{-1}
	C —H_{str}	2929.97 cm^{-1}
	C —H_{str}	1648 cm^{-1}
	C —H_{str}	1351 cm^{-1}
	C —H_{str}	1351 cm^{-1}
	C —H_{str}	1150 cm^{-1}

IR= Infrared.

4.1 CHEMICAL ANALYSES OF LATERITE AND STARCH

The results in table 4.1 revealed by FTRI analysis implies that the active elements in both the laterite and the starch samples are hydrogen (H), Carbon (C), Oxygen (O) and Nitrogen (N). This is indicated by the infrared spectra on table 4.1. Atoms of the functional groups in table 4.1 come together to form electrostatic Hydrogen bond with each other, in a network of bonds. Hydrogen bonding is a special type of intermolecular attraction between the hydrogen atom in a polar bond (particularly an H F, H O, H N bond) and an unshared electron pair on a nearby small electronegative ion or atom (usually an F, O or N atom in another molecule), (Brown et al 2006). For example, a hydrogen bond exists between the H atom in an HF molecule and the F atom of an adjacent HF molecule, F H---- F H (where the dots represent the hydrogen bond between the molecules. The hydrogen bonds account for the strength and durability characteristics of the stabilized bricks.

Mean values of all physical property tests carried out on cassava starch and laterite are presented on table 4.1. Mean values are taken for three tests carried out for each physical property. The results of sieve analysis is presented on table 4.3

Table 4.2: Mean Values of Physical Properties of Laterite and Cassava Starch

MATERIAL	TESTS					
	Silt Content (%)	Specific Gravity	Moisture Content (%)	Atterberg Limit		
				LL (%)	PL (%)	PI (%)
Cassava Starch	-	1.42	16.9	-	-	-
Laterite	12.8	2.05	17.03	37.38	25	12.38

Note: LL= Liquid Limit, PL= Plastic Limit, PI= Plasticity Index

Table 4.3: Sieve Analysis Result For Laterite

SIZE ANALYSIS							
Sieve Size	5mm	2.36mm	1.18mm	600µm	300µm	150µm	Pan
% Weight Retained	7.5	14	19.9	18.7	22.1	9.1	8.1

4.2 PHYSICAL PROPERTIES

4.2.1 Field Settling Test

Silt content was measured from the result of the field-settling test. The silt test of the laterite was carried out from the parent sample. The mean value was taken from three tests. The result indicates substantial silt content of 12.8% while clay content is 87.2%. Details of the results are presented at appendix K

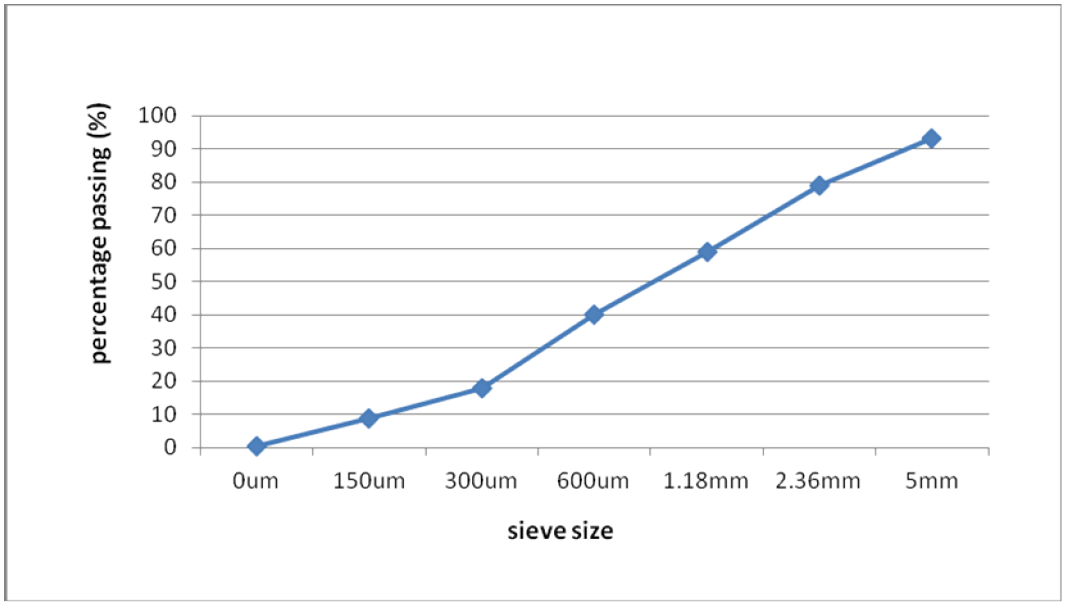


Figure: 4.1 Grain Size Distribution Curve

4.2.2 Grain Size Analysis

Parent sample of soil was sieved through 10mm sieve and the sieve analysis was carried out on the product. The result of sieve analysis shows that above 12% of laterite particles fall in the silt, clay region. Graph of the sieve analysis curve slopes gently indicating that the soil is non uniform in grain sizes and well graded as established by (Verruijt 2001). Figure 4.2 illustrates the distribution of grain sizes.

4.2.3 Specific Gravity

The specific gravity of the soil sample was determined using a Pycnometer bottle. Average specific gravity of 2.03, 1.97 and 1.86 were obtained for laterite of grain sizes ranges of 2.36mm, 1.18mm and 600µm respectively showing a reduction in specific gravity with reduction in grain sizes while 1.42 was recorded as average specific gravity of cassava starch. Details of specific gravity results are at appendix L. The specific gravity of the parent laterite sample had earlier been determined to be 2.05.

4.2.4 Moisture Content

The moisture content is used in determining added water in mixes to achieve maximum compaction at or near optimum moisture content (OMC). The moisture content test for the purpose of this research was carried out on the parent sample to establish the general adsorption characteristic of the soil. Moisture contents of 16.9% and 17.03% were determined for cassava starch and laterite samples respectively. Details of the results are presented in appendix M

4.2.5 Atterberg Limit

The results of Atterberg limit test is presented on table 4.2. Liquid and Plastic Limits of 37.38% and 25% respectively, were obtained giving a Plasticity Index was 12.38%. The Plasticity index value did not exceed the maximum of 35% stipulated in BS1377:1990 thus indicating good cohesion in the soil for adequate compaction for the enhancement of strength and durability characteristics. Details of the Atterberg limit test are at appendix N

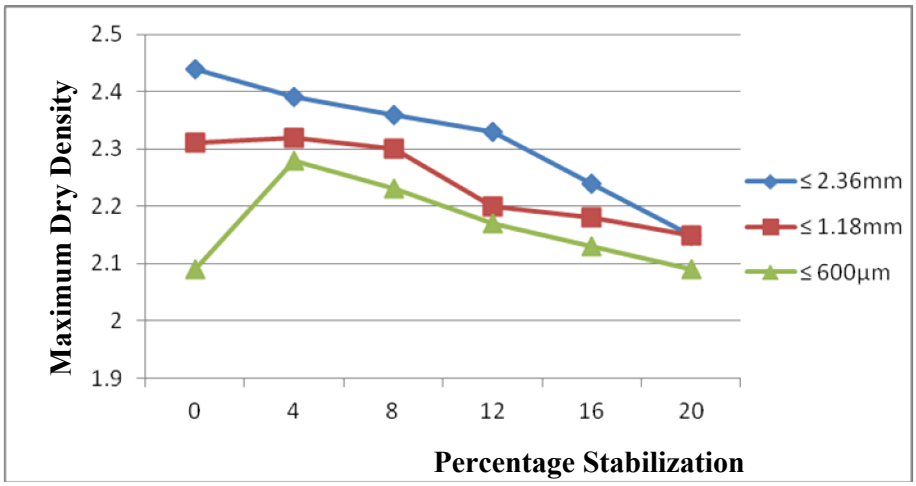


Figure 4.2a: Variation of MDD with Increase in Percentage Starch Stabilization

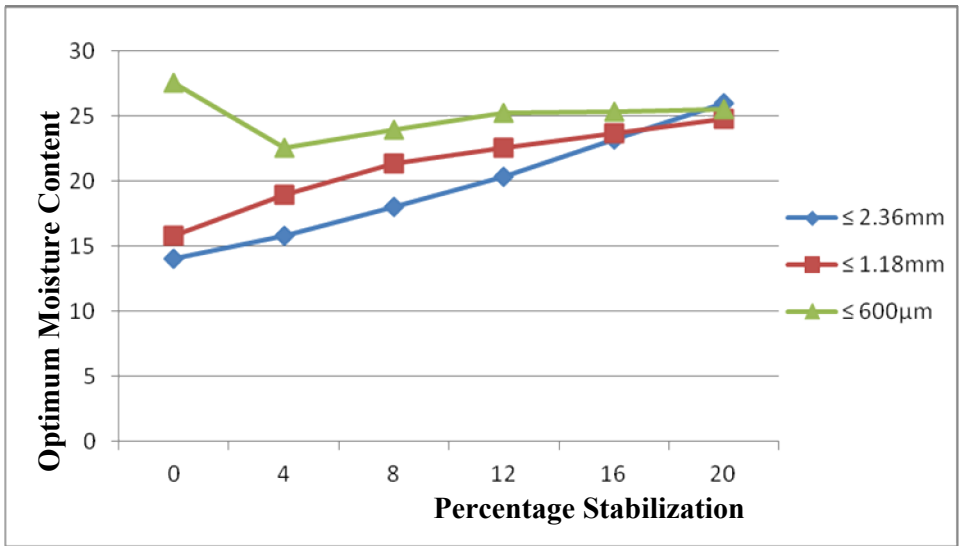


Figure 4.2b: Variation in OMC with Increase in Percentage Starch Stabilization

4.2.6 Compaction Characteristics

The laterite soil was compacted based on clause 3 of BS1377: 1990 at the different stabilization levels and grain size range. The result indicates a reduction in maximum dry density with increase in percentage stabilization for grain sizes ≤ 2.36mm and ≤1.18mm whilst a peak maximum dry density of 2.28 was established at 4% stabilization for grain size ≤ 600µm. Overall maximum dry density of 2.44 occurred at Optimum moisture content of 14.04% within grain size zone ≤ 2.36mm just as overall maximum moisture content of 27.5% occurred at 0% stabilization within grain size ≤ 600µm.

4.3 CASSAVA STARCH

Trial mixes were prepared to establish starch paste that is clear, of standard consistency, uniform viscosity and the results presented on table 4.4. Proportion of starch paste at each stabilization level in brick sample was also determined and results presented on table 4.5

Table: 4.4 Starch Paste Consistency

Test No.	1	2	3	4
Wp (g)	200	200	200	200
Wc (g)	100	200	240	240
Cm (g)	TS	LS	LS	LS
Wh (g)	600	600	800	1000
Ps	UTN	UTU	CTU	CVU

Where; Wp = weight of powder Wc = weight of cold water

%l = percentage loss in weight Wl = weight loss

UTN = unclear, thick and non-uniform paste TS = thick slurry

UTU = unclear, thick and uniform paste PS = paste

CTU = clear, thick and uniform Wh = weight of hot water

CVU = clear, viscous and uniform LS = light slurry

4.3.1 Starch Paste Consistency

Trial mixes were attempted in order to produce cassava starch paste. Cold water was used to prepare slurry; hot water was then added to the slurry which swelled up to form a paste. The quality of the paste produced depends on the quantity of the cold and hot water. Four mixes were prepared and was carried out using 200g of starch powder throughout by weight.

A consistent paste i.e. a clear, thick and uniform paste of standard viscosity was obtained using 20% cold water and 400% hot water by weight. (200g of starch powder mixed with 240g of cold water to form slurry and then 1000g of hot water at about 90^{o} c added to the slurry which produced the required paste of standard consistence). This gives a mix ratio of

1**:**1.2**:**5 of starch**:** cold water**:** hot water. Table: 4.3. The mix proportion at 20% cold water and 300% hot water was clear and uniform but not satisfactorily viscous.

Table 4.5: Proportion of Materials in Each Stabilization Level

STABILIZATION LEVELS (%)	**SAMPLE**		
L	**S_w (g)**	**P_w (g)**	**T_x (g)**
0	2500	0	2500
4	2400	100	2500
8	2300	200	2500
12	2200	300	2500
16	2100	400	2500
20	2000	500	2500

Note: $T_x = S_w + P_{w.}$ where S_w= weight of soil and P_w= weight of paste.

4.3.2 Mix Proportion

Trial mixes were also carried out to establish the proportion of cassava starch paste and laterite at each stabilization level of 0%, 4%, 8%, 12%, 16% and 20%. Optimum moisture content required for brick production at each stabilization level was also determined. Result of mix proportion test is presented on table 4.4

4.4 MECHANICAL PROPERTY TESTS

Mechanical properties tested are abrasion resistance, water absorption and compressive strength. Results of abrasion resistance and water absorption a presented on tables 4.6 and 4.7 respectively while compressive strength test results are show on figures 4.3a to 4.3d.

Table: 4.6 Abrasion Resistance at 28 Days Curing

GRAIN SIZE RANGE	PERCENTAGE WEIGHT LOSS TO ABRASION (%)					
	Stabilization Levels					
	0	4	8	12	16	20
≤ 2.36mm	4.59	3.45	3.38	3.30	1.83	0.15
≤ 1.18mm	7.74	5.81	4.81	4.76	2.5	0.23
≤ 600µm	14.23	11.18	4.63	4.28	3.76	0.29

4.4.1 Abrasion Resistance

The highest resistance of earth brick occurred at 20% level for all grain size zones. A loss in weight of 4g (0.15%) with depth of penetration of 0.1mm was the least obtained abrasion resistance result and applies to all grain size zones while the maximum loss in weight of 14.23% with depth of penetration of 25mm occurred at 0% level within grain size ≤ 600µm. This indicates that the more the starch contents the greater bonding of soil particles.

Table: 4.7 Water Absorption at 28 Days Curing

GRAIN SIZE RANGE	PERCENTAGE WEIGHT GAIN ON WATER ABSORPTION (%)					
	Stabilization Levels					
	0	4	8	12	16	20
≤ 2.36mm	DS	10.9	10.6	9.9	6.5	3.8

≤ 1.18mm	13.23	13.06	12.88	10.3	6.41	5.04
≤ 600µm	12.99	9.53	9.04	7.03	6.43	4.46

4.4.2 Water Absorption

This test was conducted on 54 specimens each for the 3 different grain sizes and 3 curing periods and 6 stabilization levels. It was done by taking the time taken by the control brick (0%) to reach its saturation point and all the remaining bricks were immersed for the same period of time. This procedure was adopted because laterite bricks can dissolve in water when immersed for 24 hours.

Result of the 28 day water absorption test at maximum strength gain presented on table 4.7shows that a water absorption of 13.23% which is above the 12% recommended by NBRRI, within grain size ≤ 1.18mm and while the sample completely dissolved at grain size ≤ 2.36mm. This indicates that the less the grain size, the more the water resistance at maximum strength. However a remarkable improvement was generally recorded at 20% stabilization for all grain size zones.

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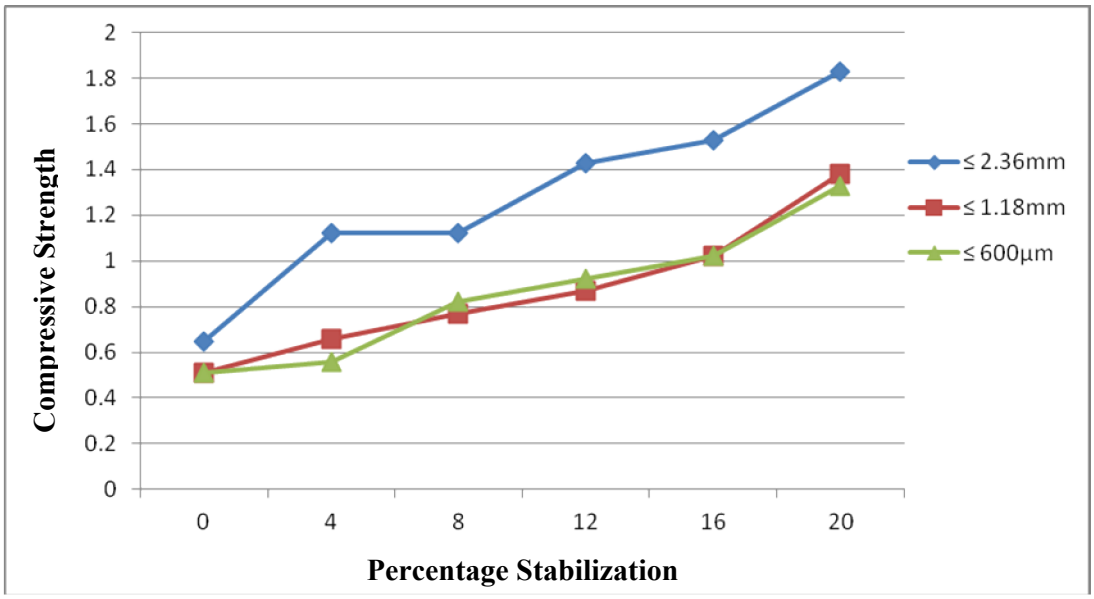


Figure: 4.3a Compressive Strength at 28days Curing

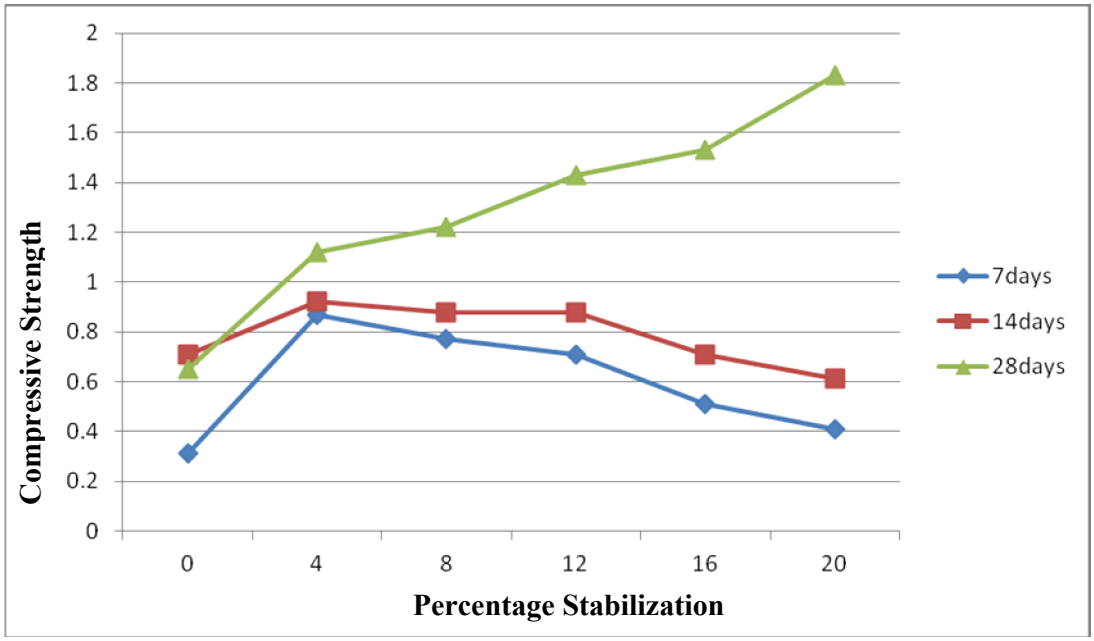


Figure: 4.3b Compressive Strength for ≤2.36mm

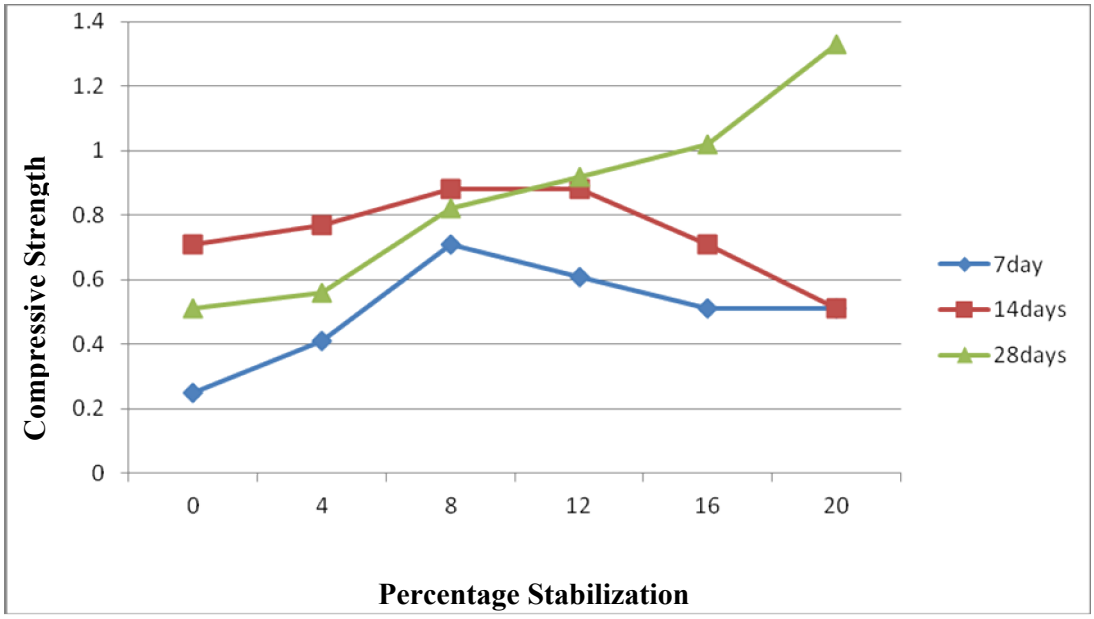


Figure: 4.3c Compressive Strength for ≤ 1.18mm

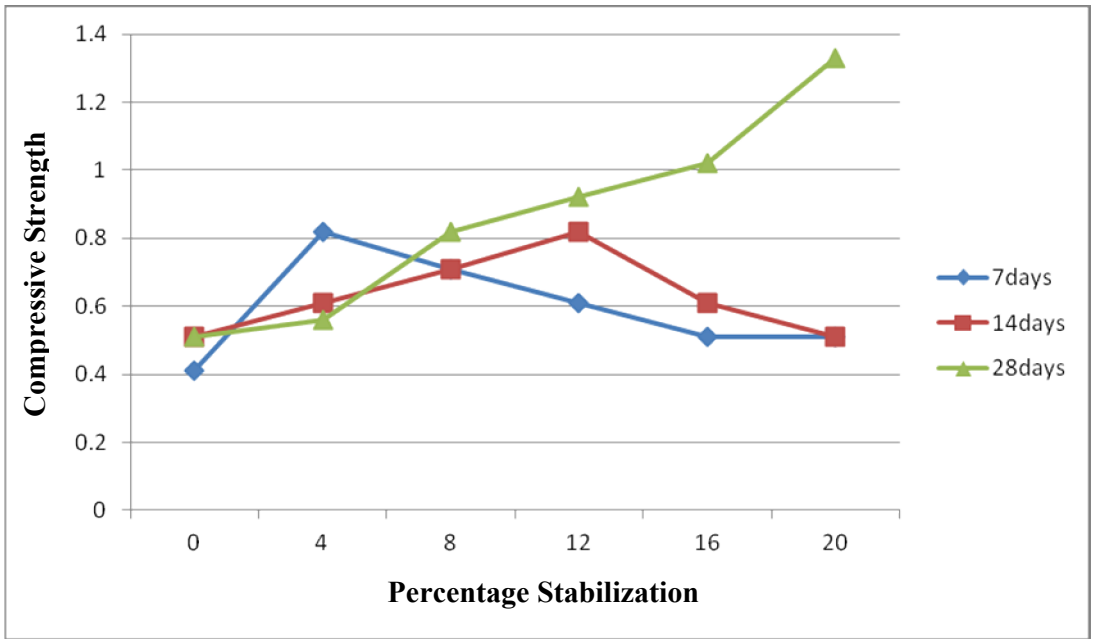


Figure: 4.3d Compressive Strength for ≤ 600µm

4.4.3 Compressive Strength

This test was conducted on 54 specimens of bricks each at 6 different stabilization levels and 3 curing ages for the three grain sizes under consideration. Results presented in figures 4.3 a-

d shows that the least strength of 0.25N/mm^2 occurred at 0% level within grain size zone ≤ 1.18mm while the highest strength of 1.83N/mm^2 occurred at 20% level and within grain size zone ≤ 2.36mm. Compressive strengths were generally higher at grain size ≤ 2.36mm. This indicates that better strength is attainable with a well graded (non-uniform) soil than with a poorly graded (uniform) soil.

As the starch content is increased, steady increase in stability occurred. At higher starch content, the rate of produced low strengths at 7 and 14 days but from 21 to 28 days the measure of compressive strength was higher than all other levels for all grain size range. See Appendix S.

CHAPTER 5

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 GENERAL SUMMARY

Three soil grain sizes (≤ 2.36mm, ≤ 1.18mm, ≤ 600μm) were sieved from a parent sample and analyzed for abrasion, water absorption and compressive strength and dry density at 6 levels of cassava starch stabilization. Tests were carried out through the production of bricks samples of sizes 140m×140mm×80mm produced with an earth brick molding machine exerting a molding pressure of $4N/mm^2$. The three soil grain sizes responded differently to treatment with cassava starch at varying levels of stabilization. Improvements were recorded in abrasion and compressive strength gain. However, rate of water absorption was only reduced substantially but not completely impeded.

5.2 SUMMARY OF FINDINGS

1. There was improvement in abrasion resistance for all grain sizes with best result attained at 20% starch content after 28 days curing. Maximum loss of weight in abrasion was 14.23% at 0% stabilization for ≤ 600μm grain sizes. Minimum weight loss in abrasion was 0.15% at 20% stabilization for ≤ 2.36mm grain size and with depth of penetration being less than 1mm.
2. Cassava starch slows down the rate of water absorption but can be soluble under prolonged exposure to water. A minimum water absorption rate of 3.8% was attained at 28 days curing and soil grain size of ≤ 2.36mm while the maximum water absorption led to outright dissolving of the sample at 28 days curing for 0% stabilization and ≤ 2.36mm soil grain size.

3. Compressive strength increased to a peak between 4-8% starch content at 7 days curing for all grain sizes but dropped to a minimum of 0.41N/mm^2 at 20% starch content, 0% stabilization and ≤ 2.36mm grain size. However a steady increase was recorded in strength with increase in starch content from 21 day curing period. A maximum of 1.83N/mm^2 was attained at 28 day curing for grain size ≤ 2.36mm and 20% stabilization.
4. A reduction in density of bricks was observed at 28 day curing period with increase in starch content for all grain sizes. A minimum density of 1339Kg/m^3 was obtained at 20% starch content and grain size ≤ 600μm while overall maximum density was1801 Kg/m^3 at 20% stabilization, grain size ≤ 2.36mm and at 7 days curing period.

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5. Best overall result in compressive strength, abrasion and water absorption was obtained at grain size ≤ 2.36mm and 20% cassava starch stabilization. This indicates that better strength characteristics are obtained with a grain size range that contains a combination of all grain sizes less than ≤ 2.36mm. NBRRI did not specify any particle distribution curve for soil to be used for brick production (Agbede and Joel 2008).
7. Compressive strength of cassava stabilized earth bricks of 1.83N/mm^2 at 28 days strength gain, 20% stabilization and grain sizes ≤ 2.36mm is above the 1.65N/mm^2 minimum specified by NBRRI thus suitable for use.
8. Increase in starch content for all grain sizes reduces the density of the bricks thus reducing the dead weight of the bricks.

9. Finer grain sizes are slower at absorbing water than larger grains. Grain size ≤ 600μm had the least water absorption of 12.99% at 0% stabilization and exhibited better resistant characteristics to water absorption.

5.3 CONCLUSIONS

1. Cassava starch was found to be suitable as stabilizer for compressed earth bricks having impart strength 10.9% higher than the NBRRI recommended minimum..

2 Remarkable improvement was also established in abrasion resistance. A mere 0.15% was recorded as minimum weight loss in abrasion.

3. Cassava starch stabilized earth bricks are more suitable for interior walls and in areas of low exposure to moisture. Least durability performance was in water absorption with some brick samples dissolving in water absorption even after 28 days curing

4. Soil sample with larger range of the different constituent grain size are more likely to give better strength and durability properties than the poorly graded soil samples

5.4 RECOMMENDATIONS

1. Further studies should be carried on other lateritic and clay soils for comparism purpose.
2. A comparism should be done with cassava starch from different sources as well as using different methods of application of the starch in brick production.

3. Cassava starch slows the rate of water absorption in earth brick but could be soluble on prolonged exposure to water; therefore further protection of walls from water should be made.
4. Reduction in density with increase in starch content reduces the dead load of cassava stabilized compressed earth bricks making it suitable for use as light weight curtain wall.
5. Earth bricks produced with cassava starch are recommended for use in interior walling units.

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APPENDICES

APPENDIX A

FIELD SETTLING TEST

Aim: Determination of the percentage of silt in the soil.

Materials: soil sample, water and sodium chloride.

Apparatus: Measuring Cylinder (250ml), stirrer, metric rule and weighing balance.

Procedure: this test was conducted according to BS 812: 1975: Part 2, which stipulated a maximum limit of silt in soil to be not more than 8%.

1% prepared salt solution (sodium chloride) was poured into the 250ml measuring cylinder to the 50ml mark was reached. The mixture was vigorously shaken and left to settle in the measuring cylinder for 3 hours.

The thickness of visible silt layer formed at the surface was measured and the depth of the sample excluding the silt layer was also measured.

The ratio of the depth of silt layer to that of sample in percentage obtained was compared to the 8% specified by BS 812: 1975: Part 2.

Significance: Excess quantity of silt and impurities adversely affect the quality of soils and might also reduce the bond between soil particles and stabilizer. Thus, it is important to ensure the cleanliness of the soil as well as the proportion of the different particle sizes which agreed general.

APPENDIX B

SIEVE ANALYSIS

Aim: To determine the grades of the soil samples and their zones

Materials: Soil sample

Apparatus: BS sieves of mesh sizes: 5mm, 2.36, 1.18, 600um, 300, 150 and 75; mechanical shaker and weighing balance.

Procedure: carried out according to BS 410: 1976

Sieve analysis involves passing a representative sample of the dry materials through a stack of nest of sieves in accordance with BS 410: 1976 with the largest mesh first. Sieving can be performed manually by shaking each sieve separately for at least two minutes or mechanically by the use of a sieve shaker for three to four minutes per stack of sieves.

Sieving was done manually and the weights of materials retained on each sieve and receiver was recorded.

Significance: This test is used to predict the size distribution and the relative percentages of the particles of each sample.

APPENDIX C

SPECIFIC GRAVITY

Aim: To determine the specific gravity of the soil and cassava starch powder

Material: All soil sample and water.

Apparatus: weighing balance, scoop, tray, stirrer, Pycnometer and measuring cylinder

Procedure: conducted in accordance with BS 1377: 1990, using the formula;

$Sg = [B - A]/ [D - A) - (C - B)]$ g/m^3, where A = Weight of Pycnometer, B = Weight of Pycnometer+Sample, C = Weight of Pycnometer+Sample+Water, D = Weight of Pycnometer+Water and Sg = Specific Gravity.

A Pycnometer (glass bottle with conical brass top of mass 525g) was used for this test. Some of the sample was placed in the bottle and weighed. Some water was added into the sample and stirred intimately to release entrapped air. The conical brass was tightly screwed and topped with water through the small opening at the top. The outside of the Pycnometer was wiped dry and weighed. The Pycnometer was emptied, rinsed, refilled with water and weighed after wiping dry again. The specific gravity of the soil was then determined.

Significance: this is the measure of the material volume excluding pores. A specific gravity test is important because it is dependent on the specific gravities of the individual constituent mineral elements and on the amount of voids present. This indicates the gravity of the material without the need for crushing value tests.

APPENDIX D

MOISTURE CONTENT

Aim: Determination of water absorption capacity of soil

Materials: Soil sample and water.

Apparatus: Beaker, weighing balance, oven and tray.

Procedure: as specified in BS 1377: 1990

A quantity of the sample was placed in a beaker of known weight and weighed. The beaker containing the sample was then flooded with water and kept for 24 hours. The soaked sample was the removed from water strained to remove surface water and then weighed. The sample was replaced into a crucible tray and put into an oven set at 105^{o}C and left for 24 hours. The sample was removed and allowed to cool off before weighing.

The ratio of decrease in mass of the dry sample expressed as a percentage is termed adsorption.

Significance: Moisture content may influence the bond between the additive and soil particles. The actual water absorption of soil has to be deducted from the total water required of the mix to obtain the effective mixing water, which control compaction.

APPENDIX E

ATTERBERG LIMITS

Aim: To determine the plastic limit, liquid limit and plasticity index of the laterite sample.

Material: Soil sample and water.

Apparatus: Cassagrande curve dish, (10cm in diameter and 3cm deep with smooth inner surface), grooving tool, glass plate, spatula, moisture content cans scoop, tray, No 200 sieve oven, balance and shrinkage gauge.

Procedure: This test was carried out according to BS 1377:1990,

(iii)Liquid limit; a sample of soil passing the No 200 sieve size (about 80g) was mixed with water to a thick consistency and evenly filled into the Cassagrande curved dish such that it was about 8mm deep to the center and gradually diminishing towards the edge of the dish. This was achieved by scraping the filled dish with a spatula. The paste was divided into two equal two equal parts by drawing grooving tool straight through the middle, thus making a v-shaped groove with a 2mm wide gap at the bottom.

The dish was fitted with a handle which when turned, provides the taping required to close the groove. A counter on top of this assembly indicates the number of taps. When the groove closed after 12 tapings more of the fine sample was added to the paste, mixed thoroughly and the process repeated. At each stage, part of the paste was fetched into a can for moisture content test. When the groove just closed at 25 tapings, the liquid limit was reached.

The ratio of weight of moisture to that of dry soil expressed as a percentage is termed liquid limit.

(ii) Plastic limit; about 5g of the same sample in (i) was mixed with water to make a malleable but not a sticky ball. This was rolled between the palm and glass plate into a thread

3mm in diameter until visible cracks appear on its surface. The thread was then broken into pieces of 10-15mm lengths and quickly placed into moisture content cans and placed in the oven for about 10 hour.

The ratio of the weight of water to that of the dry sample expressed as a percentage is termed plastic limit.

(iii) Shrinkage limit; the paste at the 25^{th} blow from (i) was fetched and placed into the shrinkage gauge (a semi cylindrical brass container). It was leveled smooth and tapped to remove bubbles. It was then placed into the oven, set at $105^{o}C$ for 24 hours.

The ratio of reduction in length to the original length expressed as a percentage is termed shrinkage limit.

NOTE: Cans are immediately closed on placing samples before weighing. When placing cans into oven, they are opened. On removing from oven, cans are quickly closed again in order to prevent moisture gain, allowed to cool off before final weighing.

Significance**:** This is important as it refers to those properties of soil that indicate the type, classification and condition of the soil, and provides a relationship to structural properties such as strength, compressibility, permeability, swelling potential and so on.

Result: Plastic limit and Liquid limit are on table 4.2

APPENDIX F

COMPACTION CHARACTERISTICS

Aim: to determine Maximum Dry Density (MDD) of soil type at all levels.

Materials: soil sample, starch paste and water.

Apparatus: CBR/proctor moulds, moisture content cans, weighing balance, 4.5kg/2.5kg rammers, trays, scoop and trowel.

Procedure: according to BS1377: 1990: Part 4:3.2,

The soil sample is mixed thoroughly with water in the required quantity in a metal tray using a trowel. The CBR/Proctor mould is rubbed with oil on the inside to prevent sample from sticking to the mould. The base is fixed and weight empty. The prepared sample is then placed into the mould in layers of approximately equal thickness; 5 layers for CBR mould and 3 layers for Proctor mould) using the 4.5kg and 2.5kg rammers for CBR and Proctor moulds respectively.

At the end of the compaction process, excess soil is removed by scraping the top of each mould with a metal scraper until the surface is leveled with the top of the mould. Any large particle protruding at the top is removed and the hole left is filled up with fresh part of the sample and tamped to produce a relatively smooth surface. The mould containing the compacted sample is then weighed and recorded. Part of the scraped sample is then placed into a can, weighed and placed into the oven for moisture content test.

Three specimens for each soil grain size zone to determine optimum moisture contents (OMCs) were compacted for the 0% level. Subsequently, 1 specimen each was compacted at the other levels making a total of 27 specimens prepared for this test.

Significance: compaction reduces voids in soils, packing closely together, the particles therefore controlling subsequent moisture changes, achieving a state of increased unit weight and hence, generally improves the strength characteristics of the soil.

APPENDIX G

PASTE CONSISTENCY

Aim: To determine amount of water for producing starch paste of standard consistency.

Materials: Cassava starch and water

Apparatus: Measuring cylinder (200ml), water heater, beakers (250ml) plastic tray, scoop, spatula and a bucket.

Procedure: Paste production involves mixing starch powder with an amount of cold water first. Hot water at about 90^0C is then added to the cold slurry to produce starch paste thus:

(1)-a 200g (powder) + 100g (cold water) = thick slurry

-b 600g (hot water) + thick slurry = non-uniform, whitish and very thick paste

(2)-a 200g (powder) + 200g (cold water) = light slurry

-b 600g (hot water) + light slurry = uniform, whitish and thick paste

(3)-a 200g (powder) + 240g (cold water) = light slurry

-b 800g (hot water) + light slurry = uniform, clear and thick paste.

(4)-a 200g (powder) + 240g (cold water) = light slurry

-b 1000g (hot water) + light slurry = uniform, clear, viscous paste.

Significance: This test is necessary in order to ascertain the quantity of cold and hot water required to produce cassava starch paste of standard consistence i.e. paste clarity and uniform viscosity.

APPENDIX H

MIX PROPORTION

Aim: to determine the proportion of materials in each specimen.

Materials: soil sample, starch paste and water.

Apparatus: measuring cylinder, weighing balance, scoop, trowel and tray.

Procedure: in accordance with BS1377: 1990: Part 4 as shown in table 3.2.

Significance: to determine suitable amount of water (OMC), which is soil dependent for maximum density in compaction related tests?

Calculations:

Proportion of starch paste by weight: Proportion of soil sample by weight:

$Pw = L\%$ of T_x $\qquad$ $Sw = T_x - L\%$ of T_x

$= T_xL/100$ $\qquad$ $= T_x\,[1-L/100]$

$= 0.01\,T_xL$ $\qquad$ $= T_x\,[1-0.01L]$

Where: P_w = weight of Paste $\qquad$ S_w = weight of soil

T_x = Total weight in a mould $\qquad$ L = level in percentage

x = 1 for CBR mould, x = 2 for proctor mould, [T_1 = 6000g, T_2 = 3000g].

APPENDIX I

ABRASION RESISTANCE

Aim: to evaluate the resistance of stabilized specimens to surface wear.

Materials: cylindrical specimens extruded from proctor mould.

Apparatus: weighing balance and wire brush.

Procedure: For this test 54 specimens were prepared, for 3 tests, 3 curing period and 6 stabilization period. Rectangular brick specimens produced from the NBRRI manual brick making machine were extruded and cured for up to 28 days. Each specimen is weighed before brushing its surface with a wire brush applying constant pressure. A total 3.6kg weight was attached to the wire brush and 60 strokes of the brush were applied to each brick. The specimen is re-weighed after brushing and the loss in weight is calculated by subtracting the new weight from the first. The result is the ratio in percentage of the loss in weight to the original weight. Depth of penetration of the wire brush is also measured by the use of straight edge graduated in millimeter and readable to 0.05mm.

Significance: “one of the applications of stabilization is in dust and erosion control,”

Heebink and Hassett (2001). This test is important in assessing the level of resistance of stabilized soil to surface wear, i.e. particle loss from surfaces of specimens.

APPENDIX J

WATER ABSORPTION

Aim: To determine the water absorption rate of stabilized specimens.

Material: Rectangular specimens (from compressed brick machine).

Apparatus: Water tank and weighing balance.

Procedure: specimens are prepared and cured for 7, 14, 21 and 28 days. All the specimens are weighed and then immersed in water. The average time taken for air bubbles (indicating water absorption) to stop proceeding from three samples was taken and used as approximate time for maximum water absorption. Specimens are removed after immersion and surface water is allowed to drain off before re-weighing. The increase in weight expressed as a percentage of the dry weight is termed the swelling characteristic or water absorption of the soil.

Significance: the resistance to permeability is another important property of stabilization. Thus, this test is important in determining the water absorption rate of the stabilized soil at the different levels.

APPENDIX K

COMPRESSIVE STRENGHT

Aim: To determine strength development of stabilized specimens with age

Material: rectangular specimens (from compressed brick machine).

Apparatus: universal crushing machine, and metal plates.

Procedure: 54 specimens, for 3, 3 curing period and 6 stabilization levels were used.

Specimens are weighed and placed centrally in the load frame of a universal crushing machine. Each specimen is placed on a 150mm×150mm square plate and a second plate of same dimension is placed on top of the specimens to ensure even distribution of load on the specimens. Loading is then applied at a constant rate of displacement. At failure, the maximum load causing it is recorded. The compressive strength of each specimen is then calculated with the load at failure expressed over the area of load application.

Significance: strength is one of the most important purposes of soil stabilization. Hence it is very important to ascertain the strength of the various soil types at the different levels and at different ages of curing in order to determine the effect of cassava starch on strength increase with age.

APPENDIX L

FIELD SETTLING TEST RESULTS

TEST	CONSTITUENT	DEPTH (mm)	% SILT
	Silt	11	
A	Clay	79	12.22
	Silt	13	
B	Clay	77	14.44
	Silt	10	
C	Clay	75	11.76
Average Silt Content (%)			12.8

APPENDIX M

LATERITE GRAIN SIZE ANALYSIS RESULTS

Sieve Size	Weight Retained (g)			Average Wt Retained (g)	Weight Passed (g)	% Wt Passed	% Wt Retained
	A	B	C				
5mm	72	78	76	75.33	924.7	93	7.5
2.36mm	147	146	127	140.00	784.7	79	14.0
1.18mm	227	192	177	198.67	586	59	19.9
600µm	187	188	188	186.67	399.3	40	18.7
300µm	166	257	240	211.00	178.3	18	22.1
150µm	110	61	103	91.33	87	9	9.1
Pan	86	74	82	80.67	6.3	0.6	8.1
TOTAL				**993.67**			**99.4**

APPENDIX N

SPECIFIC GRAVITY TEST RESULTS

Test	**Starch**		**Laterite ≤ 2.36mm**		**Laterite ≤ 1.18mm**		**Laterite ≤600µm**	
	1	2	1	2	1	2	1	2
A	824	824	824	824	824	824	824	824
B	963	964	1034	1043	995	999	982	970
C	2376	2376	2435	2425	2400	2436	2417	2393
D	2334	2335	2318	2328	2336	2332	2335	2336
Sg(g/m^3)	1.43	1.41	2.26	1.80	1.6	2.33	2.07	1.64
Sga(g/m^3)	1.42		2.03		1.97		1.86	

Where; A = Pycnometer C = Pycnometer + Sample + Water

B = Pycnometer + Sample D = Pycnometer + Water

Sg = Specific gravity Sga = Mean Specific gravity

APPENDIX O

MOISTURE CONTENT TEST RESULTS

Sample	**Cassava**	**Laterite**
1	19.6	18.46
2	14.4	17.24
3	16.9	15.38
Avm	**16.9**	**17.03**

Where: Avm = Average moisture content

APPENDIX P

ATTERBERG LIMIT TEST RESULTS

Liquid Limit Test	**Test A**	**Test B**	**Test C**	**Test D**	**Test E**	**Test F**
No of Blows	10	15	23	35	43	50
Container No	B13	Q45	A50	16	Q66	X41
Wt of Wet Soil + Cont. (g)	30.7	25.0	23.5	30.0	32.3	27.9
Wt of Dry Soil + Cont. (g)	26.2	21.2	20.2	25.9	27.4	24.2
Wt of Container (g)	15.1	11.7	10.7	14.4	14.1	13.9
Wt of Dry Soil (Wd) (g)	11.1	9.5	9.5	11.5	13.3	10.3
Wt of Moisture (Ww) (g)	4.5	3.8	3.3	4.1	4.9	3.7
Liquid Limit (%)	40.5	40.0	34.7	35.7	36.8	35.9
Average Liquid Limit (%)	**37.38**					

Plastic Limit Test	**Test A**	**Test B**	**Test C**
No of Blows			
Container No	14B	D3	X5
Wt of Wet Soil + Cont. (g)	12.2	12.8	14.5
Wt of Dry Soil + Cont. (g)	12.1	12.7	14.4
Wt of Container (g)	11.7	12.3	14.0
Wt of Dry Soil (Wd) (g)	0.4	0.4	0.4
Wt of Moisture (Ww) (g)	0.1	0.1	0.1
Plastic Limit (%)	25	25	25
Ave (%)	**25**		

APPENDIX Q

COMPACTION CHARACTERISTICS TEST RESULTS

Stabilization Levels (%)	Properties	Grain Sizes		
		≤ 2.36mm	≤1.18mm	≤ 600µm
0	MDD (g)	2.44	2.31	2.09
	MC (%)	14.04	15.8	27.5
4	MDD (g)	2.39	2.32	2.28
	MC (%)	15.80	18.94	22.5
8	MDD (g)	2.36	2.30	2.23
	MC (%)	18.06	21.35	23.89
12	MDD (g)	2.33	2.20	2.17
	MC (%)	20.32	22.5	25.27
16	MDD (g)	2.24	2.18	2.13
	MC (%)	23.16	23.65	25.36
20	MDD (g)	2.15	2.15	2.09
	MC (%)	26.00	24.8	25.54

MDD = Maximum dry density, MC = Moisture Content

APPENDIX R

COMPRESSIVE STRENGTH AND DENSITY AT 7 DAYS CURING

Starch Content (%)	**0**	**4**	**8**	**12**	**16**	**20**
≤ 2.36mm Grain Size						
Weight of Brick (g)	2371	2434	2510	2548	2592	2824
Density of Brick (Kg/m^3)	1512	1552	1601	1625	1653	1801
Load at Failure (KN)	6	17	15	14	10	8
Compressive Strength (N/mm^2)	**0.31**	**0.87**	**0.77**	**0.71**	**0.51**	**0.41**
≤ 1.18mm Grain Size						
Weight of Brick (g)	2352	2379	2415	2465	2510	2585
Density of Brick (Kg/m^3)	1500	1517	1540	1572	1601	1649
Load at Failure (KN)	5	8	14	12	10	10
Compressive Strength (N/mm^2)	**0.25**	**0.41**	**0.71**	**0.61**	**0.51**	**0.51**
≤ 600µm Grain Size						
Weight of Brick (g)	2368	2243	2296	2346	2380	2407
Density of Brick (Kg/m^3)	1510	1430	1464	1496	1517	1535
Load at Failure (KN)	8	16	14	12	10	10
Compressive Strength (N/mm^2)	**0.41**	**0.82**	**0.71**	**0.61**	**0.51**	**0.51**

APPENDIX S

COMPRESSIVE STRENGHT AND DENSITY AT 14 DAYS CURING

Starch Content (%)	**0**	**4**	**8**	**12**	**16**	**20**
			≤ 2.36mm Grain Size			
Weight of Brick (g)	2491	2453	2440	2434	2499	2564
Density of Brick (Kg/m^3)						
Load at Failure (KN)	14	18	17	17	14	12
Compressive Strength (N/mm^2)	**0.71**	**0.92**	**0.88**	**0.88**	**0.71**	**0.61**
			≤ 1.18mm Grain Size			
Weight of Brick (g)	2365	2325	2296	2252	2196	2069
Density of Brick (Kg/m^3)	1508	1483	1464	1436	1400	1320
Load at Failure (KN)	14	15	17	17	14	10
Compressive Strength (N/mm^2)	**0.71**	**0.77**	**0.88**	**0.88**	**0.71**	**0.51**
			≤ 600µm Grain Size			
Weight of Brick (g)	2280	2203	2168	2140	2105	2069
Density of Brick (Kg/m^3)	1454	1405	1383	1365	1342	1320
Load at Failure (KN)	10	12	14	16	12	10
Compressive Strength (N/mm^2)	**0.51**	**0.61**	**0.71**	**0.82**	**0.61**	**0.51**

APPENDIX T

COMPRESSIVE STRENGHT AND DENSITY AT 28 DAYS CURING

Starch Content (%)	**0**	**4**	**8**	**12**	**16**	**20**
			≤ 2.36mm Grain Size			
Weight of Brick (g)	2557	2572	2586	2486	2385	2384
Density of Brick (Kg/m^3)	1631	1640	1649	1585	1521	1520
Load at Failure (KN)	12	22	24	28	30	36
Compressive Strength (N/mm^2)	**0.65**	**1.12**	**1.22**	**1.43**	**1.53**	**1.83**
			≤ 1.18mm Grain Size			
Weight of Brick (g)	2342	2292	2242	2174	2105	2100
Density of Brick (Kg/m^3)	1494	1462	1430	1386	1342	1339
Load at Failure (KN)	10	13	15	17	20	27
Compressive Strength (N/mm^2)	**0.51**	**0.66**	**0.77**	**0.87**	**1.02**	**1.38**
			≤ 600µm Grain Size			
Weight of Brick (g)	2249	2229	2174	2130	2085	2049
Density of Brick (Kg/m^3)	1434	1422	1386	1358	1330	1307
Load at Failure (KN)	10	11	16	18	20	26
Compressive Strength (N/mm^2)	**0.51**	**0.56**	**0.82**	**0.92**	**1.02**	**1.33**

APPENDIX U

COMPRESSIVE STRENGHT OF BRICKS (N/MM^2) WITH INCREASE IN CURING

Stabilization Levels (%)	Duration Of Curing (Days)		
	7	**14**	**28**
	≤2.36mm		
0	0.31	0.71	0.65
4	0.87	0.92	1.12
8	0.77	0.88	1.22
12	0.71	0.88	1.43
16	0.51	0.71	1.53
20	0.41	0.61	1.83
	≤1.18mm		
0	0.25	0.71	0.51
4	0.41	0.77	0.66
8	0.71	0.88	0.77
12	0.61	0.88	0.87
16	0.51	0.71	1.02
20	0.51	0.51	1.38
	≤600µm		
0	0.41	0.51	0.51
4	0.82	0.61	0.56
8	0.71	0.7	0.82
12	0.61	0.82	0.92
16	0.51	0.61	1.02
20	0.51	0.51	1.33

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