THE USE OF RICE HUSK ASH AS A STABILIZING AGENT FOR LATERITIC SOILS IN THE MANUFACTURE OF BLOCKS FOR LOW COST HOUSING

BY

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NOVEMBER, 1989

DECLARATION

I hereby declare that this thesis has been composed by myself and that it is a record of my own research work. It has not been accepted in any previous publication for a higher degree.

All quotations are distinguished by quotation marks and the sources of information are specifically acknowledged by means of references.

ABDUL-RASHEED, ALIMI
NOVEMBER, 1989

CERTIFICATION

This Thesis entitled"The Use of Rice Husk Ash as a Stabilizing Agent for Lateritic Soils in the Manufacture of Blocks for Low Cost Housing" by Mr. Abdul-Rasheed Alimi meets the regulations governing the award of degree of Master of Science (Civil Engineering Construction Materials) of Ahmadu Bello University, Zaria, Nigeria, and is approved for its contribution to knowledge and literary presentation.

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This research project is dedicated to those who uphold and believe in justice.

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ABSTRACT

This thesis describes an investigation of the use of rice husk ash, in combination with cement and lime, as a stabilizing agent for lateritic soils in the manufacture of blocks for low cost housing. The effect of the rice husk ash on cement and lime stabilized soils were studied. In order to improve the strength and effect of moisture on the early strength of lime and rice husk ash cementitious mix (RHA cement), small amounts of cement were added to the mix anu three optimum mixes-were used for the manufacture of blocks. Evaluation of the masonry units indicated that rice husk could constitute up to 60% of the total stabilizer content in soil stabilization, and the mixes are found to be potentially suitable for the production of blocks for low cost housing.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDIX

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CHAPTER 1: INTRODUCTION

1.1 Background

The need for cheap local materials for the construction industry of any country cannot be over-emphasized if housing and building development programmes are to be sustained. Nowadays, it is no more news to hear that housing and building development programmes are being stalled in developing countries because of lack of building and construction materials. With the introduction of structural adjustment programme (SAP) in Nigeria, there has been a drastic increase in the cost of the conventional building materials. Since most of these building materials are either imported as finished products or secondary raw materials, their costs have risen very high under SAP. This may be attributed to the falling exchange rate of our currency. Under this situation, the United Nation's goal - Shelter for all by the year 2000 - would not be realised because the average and low income earners cannot afford houses of their own.

Ideally, construction materials should be developed from low- cost traditional building

materials, agro-industrial wastes or by-products which are abundantly available. The development of locally manufactured materials is advantageous from the point of view of increasing manufacturing activity and reducing the need for imported materials. Consequently, the cost of the manufactured building materials will be at affordable prices since most of these raw materials could probably be obtained at merely the cost of transportation. On the other hand, the importation of goods into developing countries is generally undesirable as it reduces foreign reserves.

Rice is cultivated in many parts of this country (Porteres, 1980), and rice husk is therefore abundantly available. Rice husk is a waste material obtained from the threshing of rice and it constitutes about one-fifth of the weight of the havested crop (Plate I). However, although some millions of tonnes are available annually in the rice mills, only a small amount of this is used as animal feed, fuel, glazing material, poultry and livestock bedding. The remaining tonnage is largely burnt as a means of disposal, a process which pollutes the air and may cause serious lung diseases, such as silicosis. After the burning, an ash which is approximately a fifth of husk weight is formed but the disposal of the ash itself presents a problem. An advantageous alternative to the undesired dumping

PLATE I: Rice Husk Dump at Sheda, Federal Capital Territory, Abuja.

or burning would be that of making a useful product out of it.

Cook (1980) has indicated that the chemical constituents of rice husk and rice husk ash (RHA) make these materials useful in building construction. It is generally believed that when rice husk is burnt, the ash formed has a high silica content, together with a little carbon. If the burning conditions are suitable, say between a controlled temperature of 450 - 800°C, the structure of the silica is finely divided and amorphous, in which conditions it can undergo a chemical reaction with lime, to form a stable compound-calcium silicate. This compound has cementitious properties and the cement is usually referred to as RHA cement. A review of world-wide small scale production of RHA cement for low cost housing has been made (Smith, 1984b).

Recently, the government has put more emphasis on the development of rural areas of this country and there is therefore a considerable increase in the use of cement these areas for housing, well-linnings, sewage

systems, road drainages and so on. In particular, there is an urgent need for the construction of low cost houses preferrably from indigenous material to cater for the housing needs of the rural dwellers. Lateritic soil blocks have long been used as a domestic masonry unit in low cost housing and the rural areas and considerable investigations have already been made to improve upon them (e.g. Ejeh, 1982; and Ezetah, 1985). This study is to investigate the use of RHA in the stabilization of lateritic soil blocks for low cost housing and rural buildings.

1.2 The Need for Study

Concrete and cement-based products are widely used in developing countries for building and construction works but shortage in the production of cement exists in many of these countries. In some countries, cement has to be imported at the cost of foreign reserves if building construction programmes are to be maintained or in order to keep pace with the ever-increasing demand. The capital and running costs in the local production of conventional cement however are high, and the cement is not cheap.

In Nigeria, it is reported that among others, gypsum-a major material for the production of cement is scarce and this has contributed to the soaring costs in local production of cement (Anonymous, 1989). In addition, cement manufacture is generally centralized and the costs of packaging and transport add substantially to the cost of conventional cement. Shortages prevail in many places, especially those remote from the points of production, and the large demand often give rise to a black market in the commodity, which therefore further increases cost, often to several times more than the officially quoted price. An alternative cement to ordinary portland cement (OPC) is therefore worthwhile.

In contrast, the cost for the production RHA cement is low. As mentioned earlier, rice husk is largely wasted and also lime from limestone or industrial limewastes should be cheap. Lime may be produced on a rural industry basis in simple kilns in regions where limestone is available (Ellis, 1974). A comprehensive book on small scale lime production has been published (Wingate, 1984). In a study of RHA cement in the Indian sub-continent, Smith (1984a) showed that the cost of RHA cement was 45% of that of an equal weight

of OPC. Although, it was reported that for equal strengths in the finished building work, more RHA cement would be used, but even so, then the price would be only 70% of that if OPC were used. Also, on the basis of pilot plant studies undertaken in Pakistan, India and Malaysia, it was estimated that the capital cost per tonne of annual capacity was approximately US$20 whereas for conventional cement it is around US$100-120 (Cook, 1980).

From the foregoing, it is apparent that RHA cement would require less capital investment than that required in the manufacture of OPC and that RHA cement might be made on a scale and in conditions more suitable to the rural areas of this country where more and improved housing is particularly needed, and low capital cost production methods are appropriate.

1.3 Objectives of Study

The objectives of this study is two-fold, namely:

(i) to determine suitable mix proportions of lime, RHA and OPC, consistent with adequate strength and low cost,

and

(ii) the evaluation of lateritic soil blocks made with the mixes determined from part (i).

1.4 Definition of Terms

1.4.1 Cement

Cement of interest is the one for making concrete and mortars and which has the property of setting and hardened under water by virtue of chemical reaction with it. It is therefore the hydraulic cement.

Hydraulic cements consists mainly of silicates and aluminates of lime, and can be classified broadly as natural cements, portland cements and high-alumina cements.

Portland cement may be described as any cement obtained by intimately mixing together calcareous and argillaceous, or other silica-, alumina-, and iron oxide-bearing materials, burning them at a clinkering temperature (about 1,400^{o}C), and grinding the resulting clinker. This is the definition of BSI(1978a) which stipulates also that no materials other than gypsum and water may be added after burning. The different Portland cements include the ordinary Portland, rapid hardening Portland, extra rapid hardening Portland, ultra high early strength Portland, low heat Portland, sulphate resisting Portland, Portland Blast-furnace, while Portland, Portland-Pozzolana and modified cements.

Ordinary Portland cement (OPC) is by far the most common cement in use and admirably suitable for use in normal concrete construction when there is no exposure to sulphates in the soil or in ground water.

1.4.2 Cement/RHA Content

The cement-RHA content of a soil-cement-RHA mix is the sum of the masses of cement and RHA in the mix expressed as a percentage of the sum of the masses of soil, cement and RHA, but excluding mass of water.

1.4.3 Compaction Pressure

Soil specimens are produced by "pressing" the wet soil mixes into a compact mass. The amount of force applied to a soil specimen is measured in terms of compaction pressure. Thus, compaction pressure is the amount of pressure applied on the soil specimen to compact or mould it. The commonly used unit of compaction pressure is N/mm^2 or MPa. Mechanical compaction of a soil has the sole a effect of increasing density of the soil, thereby increasing the strength. Optimum compaction is achieved at optimum moisture content (OMC) which can be determined by the compaction test. Strengths of stabilized soil blocks is believed to improve with increase in stabilizer content and compaction pressure, hence specifying blocks with the stabilizer content only without the corresponding information on compaction pressure has a little meaning.

1.4.4 Compressive Strength

The compressive strength of a soil specimen is the maximum compressive stress the specimen is capable of developing before failure. This is the ratio of the ultimate axial load to the original cross-section area of the specimen before failure.

Comparison of Strengths of Cubes and Cylinders:

It has been mentioned that the restraining effect of the platens of the testing machine extend over the entire height of a cube but leaves unaffected a part of a test cylinder (Neville 1981). It was therefore stated that the strengths of cubes and cylinders made from the same concrete differ from one another. According to British Standards Institution (BSI 1970a), the strength of a cylinder is equal to four-fifths of the strength of a cube, but experiments have shown that there is no simple relation between the strengths of the specimens of the two shapes. Also, it is reported that the ratio cylinder-strength/cube-strength depends primarily on the level on strength of the concrete, and is higher for higher strengths of concrete. The ratio also varies with the type of soil. For example, Aderibigbe et al (1983) observed that the ratio of compressive strength measured from a clay cylinder specimens range from 0.21 - 0.40 of cube strength which was considered low (with an average of 0.33) compared to 0.54 for periwinkle concrete and 0.78 for gravel concrete.

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Wet Compressive Strength: The wet compressive strength of a soil is the maximum stress the specimen is capable of developing before failure when the specimen is immersed in water for a specified period prior to testing. This means the specimen is tested in a wet condition. Ejeh (1982) reported that 24 hours immersion period in water prior to testing gives the minimum wet compressive strength and it presents the worst condition similar to a site (house) flooded for 24 hours during the rainy season and in which the lowest strength of the walling units is expected.

Dry Compressive Strength: The dry compressive strength of a soil specimen is the maximum stress the specimen is capable of developing before failure when the specimen is allowed to dry out for a specified period in the laboratory atmosphere before testing. In this investigation, the 28-day compressive strength was obtained after 21-days laboratory air-drying.

1.4.5 Durability

Durability of a soil material is its ability to withstand the conditions for which it has been designed without deterioration, over a period of years.

The major cause affecting the durability of a soil material is weathering. Weathering agents such as wind and rain quickly erode the soil material thereby causing damage or failure to the soil structure. Durability for a soil block can be predicted from an erosion test and, to a little extent, the wet compressive strength of the block (Sperling, 1962). Durability of soil material is generally known to improved through soil stabilization.

1.4.6 Lateritic Soils

These are highly weathered soils which occur abundantly in the tropical and sub-tropical regions of Africa, South America, Central America, Australia, India and South East Asia. They are rich in iron and alluminium oxides which are responsible for the often reddish, brownish and yellowish colour of the soil. The oxides also contribute to the strength properties of the soil.

Lateritic soil is good for block or brickmaking due its suitable properties and composition. Hence, it is the most commonly stabilized soil for blockmaking. The stabilizing effect of soil-cement is brought about by an immediate flocculation of the soil particles, which is

associated with a substitution of exchangeable cations by calcium ions. This reaction enables soil to become friable and readily processed when wet. It is followed by a slower pozzolanic action in the presence of moisture, whereby cementitious bonds are formed through a combination of the lime with fine siliceous and alumninous material that is present in the soil.

1.4.7 Pozzolana

Neville (1981) defined pozzolana as a natural or artificial material containing silica in a reactive form. The author reported a more formal definition of American Standards of Testing and Materials (ASTM) specification C618-78 which describes pozzolana as a siliceous or siliceous and aluminous material which is itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide (slaked lime) at ordinary temperatures to form compounds possessing cementitious properties. As mentioned in the definition, it is essential that pozzolana be in a finely divided state as it is only then that silica can combine with calcium hydroxide (liberated by the hydrating portland cement) in the presence of water to form

stable calcium silicates. Among such materials are vulcanic ash and pumice, industrial wastes such as pulverised fuel ash from coal-fired electricity generating power stations, and clay after calcining to approximately 700°C. Rice husks burnt at 450°C have been found by Cook et al (1976) to produce a pozzolana conforming to the requirements of the earlier ASTM standard C618-72. In considering pozzolanas in general it should be noted that the silica has to be amorphous, as crystalline silica has very low reactivity.

Malquori (1960) suggested that the pozzolanic activity of any material containing reactive silica can be determined by adding calcium oxide to the pozzolana with water free from carbon dioxide and measuring the alkalinity and calcium oxide content after a specified reaction time. Cook et al (1977) reported that investigation carried out by Damer indicated that RHA can be classed as a pozzolana on the basis of its reactivity measured in the above manner and that it conforms to the requirements of an ASTM C618 Class N pozzolana.

For an assessment of pozzolanic activity with cement, Neville (1981) explained the ASTM standard C618-78 which prescribes the measurement of a pozzolanic activity. This is established by the determination of strength of mixtures with a specified replacement of cement by pozzolana. There is also a pozzolanic activity index with lime, which determines the total activity of a pozzolana. According to BSI (1970b), pozzolanicity is assessed by comparing the quantity of Ca $(OH)_2$ present in liquid phase in contact with the hydrated pozzolanic cement with the quantity of $Ca(OH)_2$ capable of saturating a medium of the same alkalinity. The underlying principle is that the pozzolanic activity consists of fixing of $Ca(OH)_2$ by the pozzolana so that the lower the resulting quantity of $Ca(OH)_2$ the higher the pozzolanicity.

Malquori (1960) also indicated that pozzolanas containing a high proportion of silica, while combining readily with lime, produced hardened materials with poor mechanical strength. However, Cook et al (1977) found that as the percentage of an additive (sodium aluminate) in the mix was increased, the strength at 7, 28 and 90 days also increased.

The reaction between lime and pozzolanic materials is generally slow. As with most chemical reactions, however, the pozzolanic reaction rate may vary with temperature: in temperate climate strength development of RHA would be slow, but in tropics the rate would be more favourable for use in building and construction works.

1.4.8 RHA Content

The RHA content is the mass of RHA mixed with OPC expressed as a percentage of the sum of masses of RHA and OPC.

1.4.9 RHA Cement Content

The RHA cement content of a soil - RHA cement mix is the mass of RHA cement in the mix expressed as a percentage of the sum of the masses of RHA cement and soil, but excluding mass of water.

1.4.10 Lime/RHA Ratio

The lime/ RHA ratio is the masses of lime and RHA in a mix expressed as a ratio. Thus, a lime / RHA ratio of 1:2 is made up of one part of lime and two parts of RHA (by weight).

1.4.11 Moisture Content

The moisture content of a stabilized soil mix is the mass of water in the mix expressed as a percentage of the sum of the masses of soil and the stabilizers.

Optimum Moisture Content (OMC): The increase in the dry density of a given soil produced by compaction depends mainly on the moisture content of the soil and the amount of compaction applied. With a given amount of compaction there exists for each soil a moisture content termed the optimum moisture content at which the maximum dry density occurs for the given amount of compaction. The addition of either cement or lime will normally result in a change in the maximum dry density (MDD) and the OMC of a compacted material. In blockmaking, it is preferable to keep the moisture content of the stabilized soil near the optimum moisture content for the block machine in use.

1.5 Scope of Experimental Investigation

Preliminary tests were carried out to determine the chemical composition, fineness and specific gravity of RHA used in the investigation.

In addition, the influence of RHA on the physical properties of OPC and lime was studied.

Similarly, tests were carried out for the selection, identification and classification of the lateritic soil used in the investigation.

1.5.1 Compressive Strength Tests for Stabilized Soils

Three mix types were used in this part of the investigation. The first consists of OPC, RHA and lateritic soil. Sperling (1962) found that in the manufacture of soil - cement blocks in the Cinva-Ram machine, adequate stabilization of a lateritic soil obtained from a borrow pit at Accra was obtained by addition of 6% cement. The resulting block had good durability and load bearing capacity. With less cement the blocks had poorer durability and load bearing capacity, the latter tending to decrease on weathering. However, Ejeh (1982) found that in manufacturing soil - cement (soilcrete) blocks in Tecmor machine, adequate stabilization of lateritic soil obtained from Kakeyi in Zaria was obtained at 8% cement content. Results from the tests show that properly manufactured soilcrete blocks fully satisfy the strength requirements

imposed by Nigerian Code of Practice. Test was therefore carried out on the soil-cement-RHA mixes with three different cement/RHA contents of 8, 10 and 12%. It is known that up to 60% of RHA (by weight) can be incorporated in a mortar to produce units that will, in general, satisfy the requirements for non-load bearing masonry (Cook et al, 1977). RHA contents varying 0 to 80% were however used to study the influence of RHA on the compressive strength of a soilcrete mix. Ezetah (1985) reported that hand-operated machines developed for the production of soilcrete blocks with a compaction pressure of not less than $4N/mm^2$ may produce 8% cement blocks suitable for low cost housing. Compaction pressure of $4N/mm^2$ was therefore applied and a total of 72 test cubes (nominal dimensions of 100 x 100 x 100 - mm) were moulded at the OMC in a Universal Testing Machine (UTM). The cubes were demoulded immediately and covered with polythene sheet for 1 day, cured by complete immersion in water for 6 days and were then allowed to dry out for 21 days in the laboratory atmosphere. The cubes were tested on 7 and 28 days for compressive strength.

The second type of mix consists of lime-RHA mix (RHA cement) and lateritic soil. Test was carried out on soil - RHA cement mixes with 8, 10

and 12% RHA cement contents. Mixes were selected on economic grounds and to give adequate strength. Smith (1984b) reported that commonly 1:2 lime/RHA ratio is used to manufacture RHA cement, although lime/RHA ratios of 1:1.5, 1:2.25, 1:2.5 and 1:3 are being used at several locations. For each of the above RHA cement contents, three lime/RHA ratios of 1:1.5, 1:2 and 1:2.5 were used and three control mixes containing lateritic soil and 8%, 10% and 12% lime (by weight of lime and soil) were produced. Lunt (1980) studied two Ghanian soils stabilized with hydrated lime. It was observed that all blocks produced at $8N/mm^2$ or above gave strength which exceeded the minimum recommended design value of $1.4N/mm^2$. However, the soil blocks compacted at the higher pressures exceeded the minimum strength of $2.8N/mm^2$ specified by BSI (1968). On the durability of the stabilized soil, it was reported that some surface damage occurred in Cinva-Ram blocks and those made at $4N/mm^2$ pressure, after spraying them with water for 6 hours. Masoud et al (1970) have already demonstrated the suitability of lime-RHA bricks manufactured in an autoclave but this is certainly expensive and hence cannot be of general application for low-cost and rural buildings. But it is known that the effect of immersion in water on compressive strength of clay

soils stabilized with hydrated lime is a constant loss of strength for any particular clay and is independent of age (Dubleton, 1962). Also from a trial test, curing of lime or RHA cement-stabilized soil specimens under water was found to be unsuitable since the specimens disintegrated in water. However, this investigation still considered simple curing techniques for the production of stabilized soil specimens of adequate strength. In this test, a compaction pressure of $8N/mm^2$ was applied and a total of 72 cubes (nominal dimensions of 100 x 100 x 100-mm) were moulded at the OMC in a UTM. The cubes were demoulded immediately and curing consists of wrapping in polythene sheet for 7 days and then allowed to dry out for 21 days in the laboratory atmosphere. The cubes were tested on 7 and 28 days for compressive strength.

The third type of mix consists of RHA cement, OPC and lateritic soil. As mentioned earlier, the reaction between lime and pozzolanic materials is generally slow, hence stabilizing the soil specimens with RHA cement as in above test resulted in slow strength development relative to the OPC - stabilized soil specimens. But Dumbleton (1962) found that mixture of lime and OPC gave

higher strength values when used for stabilizing clay soil. Also mentioned is that lime or RHA cement - stabilized soil specimens did not withstand water curing while cement or cement/RHA-stabilized specimens, except 80% RHA content specimens, used in this investigation suitably cured in water. Accordingly, it is decided that some amount of OPC be added to the soil - RHA cement mix in an attempt to improve strength in the mix and to enhance adequate strength of the material even when saturated with moisture. Test was carried out on three mixes selected to conform as closely as possible with the soil-RHA-cement mixes which gave optimum strengths. OPC of 10%, 20% and 30% (by weight of RHA cement) were added to each of the cementitious mixtures to verify its effect on the strength development in the soil - RHA cement mixes. For each mix, compaction pressure of 4 or 8N/mm^2 was applied and a total of 54 cubes specimens (nominal dimensions of 100 x 100 x 100-mm) were moulded at the OMC in a UTM. The cubes were demoulded immediately after moulding and curing consists of spraying with water and wrapping with polythene sheet for 7 days, and then allowed to dry out for 21 days in the laboratory atmosphere. The cubes were tested on 7 and 28 days for compressive strength.

1.5.2 Evaluation of Masonry Units

Three mixes were selected from the compressive strength tests programme on the basis of adequate strength and minimum amount of OPC. OPC is relatively expensive, and unlike RHA cement which is cheap. From the point of view of providing a low cost unit it is considered desirable to choose mixes containing the greatest amount of RHA cement (and therefore least amount of OPC) compactible with adequate strength.

The compressive strength tests so far carried out used test cubes which are small, so as to economize materials, yet for a building project of any importance it is necessary to determine the compressive strength of a full-sized block. Thus, for each mix 36 full-sized blocks (230 x 110 x 85mm) were manufactured at the OMC in a Torsa block making machine (See Plate II). The blocks were demoulded immediately after moulding and curing consists of spraying with water and wrapping in polythene sheet of 7 days and then allowed to dry out for 21 days in the laboratory atmosphere. In conjunction with the masonry units, six - 100mm cubes and cylinders (height/diameter (h/d) ratio = 1.5) were cast. Ezetah (1985) found h/d ratio of 1.5 to be more suitable for assessing strength properties of soilcrete cylinders.

PLATE II: Torsa Blockmaking Machine used for the Manufacture of Lateritic Soil Blocks

Evaluation of the units was carried out to assess conformity with the existing specifications, standards and code of practice on soil and sand non-load bearing blocks. Tests for the evaluation included compressive strength, resistance to erosion and dimensional change due to moisture movement.

1.6 Significance of Study

Lateritic soil has been, and still is used as one of the commonest and cheapest materials for blockmaking in the rural areas of this country, but since wind and rain cause quick erosion, the material would have to be improved by soil stabilization.

The practice of soil stabilization is however a complex one. For example cement stabilization is suitable for granular soils but inefficient in predominantly one sized sands. Single-sized sands require high cement contents to achieve the required strength because of their high void content. Certain clay soils are uneconomic to stabilize due to the difficulty of pulverizing the soil and the high amount of OPC required. In such case, lime may be used, either alone, or when mixed with OPC. However, some soils cannot be stabilized with lime if they contain too little clay. In fact, clay components are required in soils that will react with lime. Furthermore, the presence of organic matter and sulphates especially in arid and semi-arid regions

would retard OPC or lime reaction in soil stabilization. This complexity is however minimised since a British Standard test (BSI, 1975) exists which can be used to identify soil materials suitable for stabilization.

On the contrary, Mehta (1975) reported that when laboratory tests were carried out on the RHA cements containing only from 15 to 20% lime they were found to be acid-resistant whereas concrete floors made from OPC (contains about 65% lime) do not show long-term durability in the food and chemical industries where acidic conditions prevail. Cook (1980) also reported that RHA cement has a superior resistance to arid environments.

As a pozzolana, RHA has been found useful as part-replacement for OPC in concrete and mortar works. When mixed with OPC, results have been reported where 70% of the cement was replaced without a significant loss in strength (Cook, 1980). It is clear that RHA is an excellent pozzolana when produced under control conditions. As such, it can give superior durability properties to concrete made with OPC.

From the discussion made on soil stabilization, it is apparent that the capability of either OPC or lime in meeting the requirements of the wide range of uses to which it is put has not been fully realised and the full benefit of the amount of stabilizer added obtained. But RHA cement or OPC mixed RHA has been successfully used in concretes and mortars as an economic alternative, it might therefore be possible to produce low cost lateritic soil blocks of adequate strength and durability from RHA. Since limited investigations exist in this area, the study will somewhat poineer a search for the true position.

CHAPTER 2: LITERATURE REVIEW

2.1 Soil Stabilization

In rural areas of most developing countries the use of the soil blocks has gained favour because the material is usually available locally in abundance and only moderate effort is involved in collecting sufficient to build a passable shelter. Few tools are required and repairs are easily made and with little skill. However, its use has to be abandoned in favour of other building materials in some areas because of the failure of soil walls to withstand the weather.

Soil is one of mankind's oldest building materials and that traditional methods of using soil for constructions such as rammed earth, wattle and duab, and adobe are still common in many regions of the world. But, not all soils can be adequately used for building construction due to their inherent properties.

In situations where only unsuitable soils are available for construction and generally because of the susceptibility of soil walls to damage by heavy

rains and winds, there is the need to improve the strength and durability of the soil material by the process of soil stabilization. Soil stabilization is commonly recognised as the improvement of the natural materials by the addition of a small proportion, usually less than 10%, of a stabilizing agent. The improvements which can result from stabilization include the following:

(i) increase in strength
(ii) increased resistance to the effects of water
(iii) drying of wet soils
(iv) volumetric stability
(v) improved workability
(vi) improved durability

A well stabilized soil block should therefore resist the effect of prolonged exposure to the weather, should have adequate mechanical strength even when saturated with moisture, and should not exhibit excessive dimensional changes on wetting and drying.

Soil stabilization can be achieved by use of conventional and unconventional stabilizers.

Unconventional stabilizers are natural fibrous and cementitious materials such as agro-industrial wastes, animal wastes and various vegetable extracts.

Conventional stabilizers are cementitious materials such as portland cement, hydraulic lime, lime-pozzolana mixes, and so on. These stabilizers cement soil particles or clusters of particles to form a solid matrix when dried. Although the conventional stabilizers are comparatively expensive they have so far proved to be more reliable than other stabilizers. Better strength and durability are obtained from the stabilized soils when compacted before drying. Lunt (1980) reported that a soil which had been compacted properly was stronger and more durable than when poorly compacted. The OMC which gives maximum soil density can be determined from a standard laboratory procedure. It is contended that these tests are designed for use with stabilized soils which would be compacted in dams, embankments and roads and so they are not necessarily valid for building purposes. Nonetheless, they can be used as a guide for preliminary work. Current research efforts geared at establishing criteria for the optimum use and application of cement and lime in soil

stabilization to achieve optimum strength and durability would be reviewed in the subsequent sections.

The third type of stabilizers are industrial materials such as bitumen, asphalt and certain resins which generally act as waterproofing agents for soils. Bitumen has been found to be particularly suitable for stabilizing cohensionless sands which would otherwise give rise to problems if stabilized with cement (Harris et al, 1983; Marais and Freeme, 1977).

It is pertinent to mention that stabilizers should be added in the correct amounts. Too little or too much of such unconventional stabilizers will lead to blocks of highly reduced strength and quality; whereas too much of conventional stabilizers will lead to wastage without an appreciable and significant increase above the optimum strength attained.

2.2 Current Researches

2.2.1 Cement - Stabilized Soils

In cement stabilization improvement in the soil properties is a result of the characteristic bonding of soil particles due to hydration of cement and usually leads to a rapid development in tensile and compressive strength of the stabilized material after compaction.

Materials containing organic matter cannot be stabilized with cement because it inhibits the setting of the cement paste. Herzog (1960a) investigated the use of additives in the stabilization of poorly reacting soils with cement. It was indicated that the poor response of such soils is due to the presence of active organic matter. It was seen that the most active organic matter is that containing the hydroxyl group capable of combining with the mix. It was also seen that calcium chloride was effective in sands but ineffective in heavy clays, while ferric chloride was effective in clays. In another study, Herzog (1960b) found that the addition of 0.75% calcium chloride to cement-stabilized soils of 8% and 10% cement content increased the crushing strengths from 3.9N/mm^2 and 5.2N/mm^2 to 5.7N/mm^2 and 7.6N/mm^2 respectively, that is, an average

increase of about 47% in strength.

Study by Dutron and Cloes (1961) shows that maximum compressive strengths of stabilized laterites were obtained at OMC or slightly less.

Dumbleton (1962) observed that natural soils have strengths of between 0 and 0.2N/mm^2 and when soils are stabilized with cement it is usual to expect a strength of at least 1.7N/mm^2 at 7 days to show an indication of proper hardening of the cement. It was also observed that the soaked strength increased with age. It was indicated that hydration of cement is independent of the soil and the reaction is primarily the source of strength for cement-stabilized soils. However, the researcher conceded that there is the effect of soil type on the strength of the stabilized soil. This effect is due to the particle size distribution of the soil and the presence of any organic matter which affects hydration of cement. It was believed that the active-organic matter in soils interferes with hydration of cement by combining with the calcium ions of the cement. To eliminate this effect, it was suggested that more calcium ions should be introduced into the mix.

Ibrahim (1972) considered the application of accelerated curing technique in respect of cement-stabilized soils and it was clear that accelerated

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curing technique can be applied to soil-cement mixtures. The result however shows that the relationship between normal 7-day strength and the accelerated strength is not unique but varies from soil to soil.

Adepegba studied the structural properties of cement-stabilized laterite (latercrete) and that of cement-stabilized sand (sandcrete). It was indicated that some of the important properties affecting the strength of cement-stabilized soils include cement content, particle size of soil, type of soil, uniformity of mix, airing period and curing condition. In another study, Adepegba (1975) attempted to replace sand in the normal concrete by laterite fines, which was referred to as laterized concrete (latercrete). It was found that between 0 and 22% cement content, latercrete is superior to sandcrete structurally. And that 9% latercrete (1 cement: 12 laterite) is better than the present use of 1:6 for first class sandcrete jobs. However, the elastic modulus was found to be about half that of sandcrete.

Investigating the characteristics of the optimal water-content ratios of some local clay soils stabilized with cement, Aderibigbe et al (1983) made the following observations:

1. For Alawusa laterite (48% clay) 80% of its 28-day strength is developed in 14 days, while it is 40% in 3 days.

2. The density of laterite-cement mixes were between 1288-2239kg/m^3.

The researchers concluded that:

1. There exists optimum water/cement ratio for a given mix

2. The optimum water/cement ratio increases linearly with increasing laterite-cement ratio.

Ejeh (1982) investigated the compressive strength of hollow blocks produced by Occidental Construction Company (O.C.C) in Zaria, Nigeria. The company uses laterite from Kakeyi village near Zaria and a Brazilian block-making machine manufactured by Tecmor. O.C.C. produces hollow blocks with 8% cement content mostly for market purposes and the 10% and 12% cement content on demand. The hollow blocks are 400 x 150-mm in cross-section with a nominal height of 150-mm. Water content of about 7.5% was used in moulding the blocks. Compaction pressure used, apart from being unsteady, was not specified. The

following observations were made from the study:

1. The 8% and 10% cement soil-cement (soilcrete) blocks gave an average dry compressive strength of 2.5N/mm^2 and 4.4 N/mm^2 respectively. The 12% cement soilcrete blocks gave an average wet compressive strength of 3.0N/mm^2 after 12 days immersion in water prior to test. It is seen that the latter result satisfies the requirements of 2.76N/mm^2 imposed by British Standards Institution (1953) on non-load bearing sandcrete blocks. Also, the Federal Ministry of Works and Housing (FMWH) of Nigeria recommendation is an average minimum strength of 2.10N/mm^2 while a minimum compressive strength of about 1.4N/mm^2 is specified by several building authorities worldwide.

2. The soilcrete hollow blocks have an average wet/dry compressive strength ratio of 0.65.

3. The soilcrete hollow blocks have a minimum wet/dry compressive strength ratio of 0.42.

Ejeh (1982) also investigated the curing methods for soilcrete hollow blocks and it was recommended that for standard tests and quality control, the immersion in water method is more

appropriate to laboratory work since spraying may be uneven and also the quality of water used may be doubtful. However, soilcrete hollow blocks from the study fully develop its dry compressive strength after curing by spraying with water and covering with water-proof materials for 7 days.

When the blocks were tested between different packing materials by the same researcher, the results show that the highest compressive strength was obtained when the blocks were tested between soft boards of 10mm thick layers. It was therefore recommended that soft boards be adopted as the contact layers for the compressive strength test for soilcrete hollow blocks. Oleszkiewicz et al (1983) confirmed that soft board sheets are the most suitable contact layers for all assessment of soilcrete compressive strength. It was seen from this study that 90% of the 28-day strength of a soilcrete hollow block is developed within the first week and the 10% within the next 3 weeks.

Ezetah (1985) studied the use of soilcrete as a construction material for low cost housing. He conducted tests on 70.7mm cubes, 103mm cylinders and 400 x 150 x (150 - 160) full size hollow blocks. The followings were deduced from the study:-

1. The best water content for moulding of soilcrete is 2% lower than the OMC of the soil.

2. For 8%, 10% and 12% cement soilcrete about 90% of the 28-day strength is developed in 14 days while for no cement (unstabilized) soil specimens, about 90% of its 28 day strength is developed in 7 days.

3. The ratio of the wet compressive strength to dry compressive strength of soilcrete specimens is about 0.4. This is in agreement with the result obtained by Ejeh (1982).

4. Soilcrete cylinder compressive strength are very sensitive to variation in h/d ratio. The compressive strengths of cylinders with h/d ratios of 1 and 2 were about 75% and 26% of the cube's strength respectively.

5. Higher compaction pressures give higher compressive strengths to the soilcrete material.

6. For the purposes of testing soilcrete specimens, the minimum age of 14 days should be adopted, 6 days complete immersion in water a day after moulding, and 7 days air-drying.

2.2.2 Lime-Stabilized Soils

In lime stabilization improvement in the soil properties is a result of the flocculation of the clay particles in the material and gives a consequent reduction in the plasticity index (PI) and increase in bearing capacity. It is usually characterised by an increase in the plastic limit (PL) of the soil. However, as mentioned earlier strength development is normally slower than with cement unless rapid reacting minerals are present for example amorphous silica. Like in cement stabilization organic compounds including decomposed organic material and sugar interfere with the formation of cementitious compounds in lime stabilization.

Bassey (1953) found that the wet/dry strength ratio for sand-lime bricks ranges from 0.6 to 0.75. It was also found that sand bricks are practically saturated after soaking in water for 24 hours which is the standard time for soaking for the wet

compressive strength. In another study, Bassey (1954) reported that strength of dry sand-lime bricks and concrete bricks is 30 to 50% higher than when saturated. The two types of bricks differ in that respect from clay bricks which do not vary much in strength between the two extremes. In the compressive strength test, 12 bricks were usually tested after soaking in water for 24 hours. The uniformity of such results was calculated as the average of the lowest seven values (or the lowest 60% of the sample if other than 12 bricks were tested), expressed as a percentage of the average of the whole sample.

As mentioned earlier, Lunt (1980) carried out laboratory studies on two Ghanaian soils with lime as the stabilizing material at the Building Research Establishment in England. The results also show improvements in strengths of Kumasi and Fumesua soil blocks which increased from 1.05N/mm^2 to 3.55N/mm^2 and 0.70N/mm^2 to 3.05N/mm^2 respectively as the compaction pressure was increased. The Kumasi soil has 9% gravel, 35% sand and 56% silt and clay while the Fumesua soil is 1.5% gravel, 39.5% sand and 49% silt and clay. It was apparent that improved performance can therefore be achieved by increasing the compaction pressure although the degree of improvement diminishes as the pressure

increased. The studies show the relationship between lime content and block strength over the range of fabrication pressures most likely to be achieved with an inexpensive block-making press. This work demonstrates that blocks made from lime-stabilized soils can have sufficient strength and durability for use in low-cost housing in tropical countries.

After increasing the curing temperature to 95°C, the Kumasi soil compacted at 8N/mm^2 and 16N/mm^2 gave strengths of 4.85N/mm^2 and 5.45N/mm^2 while in the case of Fumesua soil, strengths of 4.45N/mm^2 and 4.60N/mm^2 were recorded. The effect of temperature on the strength producing reactions between lime and the soils virtually eliminated the main draw back of lime stabilization which is its relatively slow strength development. Also, from the study it was deduced that the wet strength of a stabilized soil wall is only one-third of its dry strength.

2.3 The Potential of RHA Cement as an Alternative Cementitious Material in Soil Stabilization.

One of the earlier references to the potential benefits of using RHA for making a cement in United States of America was published by Hough and

Barr(1956). The authors referred back to the successful making of building blocks, using RHA mix with cement as early as 1923.

In Thailand, Lazaro and Moh (1970) produced small test cylinders which were pressed from mixtures of clay, RHA and lime. Optimum proportions of lime to RHA were found at about 1:2.

Shah et al (1970) reported that a production plant was set up in the Pakistan Punjab using a husk incerator made from an oil drum. It was claimed that more than 4% carbon in the ash resulted in a loss of strength.

In 1971, Mehta mentioned RHA as one of the material which could react with lime. Later, Mehta (1975) developed a large scale plant producing ash for mixing with OPC. He found that amorphous ash was better than the crystalline form for reaction with lime. It was claimed that the cementing material obtained from the blends of RHA with OPC was capable of producing mortars and concrete with 28 day compressive strengths of over 8000 psi ($55N/mm^2$).

In another American experience, Cady and Groney (1976) burnt husk in piles to a maximum temperature of $800^{o}C$ and the strengths of mortar cubes varied from 2 to $8N/mm^2$.

There has been more RHA research in India than elsewhere, and commercial applications have started and also in progress. Dass and Malnotra (1977) and the Central Building Research Institute (CBRI, 1979) reported that waste lime sludge from sugar refining has been investigated in North India. Rolled into balls in admixture with husks, dried in the sun, then fired in a simple trench, without the need for extra fuel, this material can be ground to a fine powder for sale as a cemntitious pozzolanic cement. Mortar strength of 5N/mm^2 have been obtained. At the same institute higher grade lime has been used with RHA. Without fine grinding only 0.4 N/mm^2 mortars were obtained, but when intergrounded together, 20N/mm^2 was obtained. Another research by CBRI (1977) and Rehsi (1979) showed that equal proprtions of husk and clay, rolled into balls, sun dried, fired, ground and mixed with lime gave a type of masonry cement, mortar strength of 4 to 7N/mm^2 being obtained. In Nepal, Shrestha (1979) researched into a process using husk and lime sludge rolled into balls, and produced strengths up to 9N/mm^2. Mohammed (1979) reported that a Malaysian entrepreneur produced RHA cement in a pilot plant, using husk burnt in piles and mixed with lime. Mortar strengths of 9N/mm^2 were obtained but the mix contained some unspecified additives. In

another Malaysian research, Ong (1979) reported that an experiemental work carried out at an institute showed that open-air burning of husk did not give a satisfactory ash.

In another Indian experience, Aggarwal (1980) found that high compressive strength mortars and concretes can be developed using an additive of high alumina content. 500°C was a suitable husk ignition temperature, though 700°C was used in this case. Quite high carbon contents were tolerable. Cement Research Institute of India (1980) also found that ash from parboiling rice was up to 95 per cent crystalline and therefore unsatisfactory. They developed an openwork brick incinerator with metal mosquito netting inside to retain the husk. A ratio 1:2 of lime to RHA gave mortar with 28-day strengths of $4N/mm^2$. Commercial plants use this technology. Masood and Mehrotra (1981) found that intermixing of ash and lime was not so effect as intergrinding.

An Australian research by Cook and Suwanvitaya (1982) indicated that although maximum strengths of about $8N/mm^2$ were achieved with a low propertion of lime to RHA (many workers use 1:2) the lime may be leached out and this could seriously

impair the long-term performance, so 1:1 mixes have been proposed instead. This Australian work also indicates that considerable content of carbon does not adversely affect the strength though there may be some retardation of setting. For this research, husks were burnt in an electric furnace in which optimum conditions of 600^{o}C for 35 minutes were discovered. Mortar cubes made with the RHA and lime did not increase in strength after 28days, unlike other pozzolanas, perhaps due to the high reactivity of this RHA.

2.4 Evaluating Soils for Blockmaking

Most of the information and recommendations exist mainly for the evaluation of a soil for blockmaking when cement is used as the stabilizing agent. Middleton (1952) simply recommended that the PL should lie between 10-25% preferably 12-20%. Rosenak (1957) also recommended that the liquid limit (LL) of a soil should be less than 45% for satisfactory stabilization with 5% cement. Webb et al (1958) after examining 40 soils produced more detailed recommendations which can be summarized as follows:-

Particles smaller than	
5 μ m (clay)	20% maximum preferably 10% maximum
LL	50% maximum preferably 30% maximum
PI	20% maximum preferably 10% maximum
LS	6% maximum preferably 4% maximum
(Modified A.S.T.M. D559-57)	
Loss after 20 cycles	10% sandy soil 7% clay soil

Fitzmaurice (1958) also gave very detailed recommendations, the most important of which are as follows:

	For permanent Urban Building	For Rural Building
Sand content (SC)	33% minimum	40% minimum
Clay content (CC)	5-20%	5-30%
PI	2.5-22%	2.5-30%
LL	40 maximum	50 maximum

Adepegba found that there are basically two types of laterites in Nigeria - the rock laterite and the soft laterite. The

difference is in the particle size and colour. The soft laterite contains little or no stones and are more reddish than the rock laterite. In general, the soft laterite comes out of the pit pulverised and all particles can pass through British Standard (BS) sieve No. 7. He reported that soft laterite gave higher strength values than rock laterites.

Research has been carried out to investigate brick/block production based on stabilized soils at the Department of Civil Engineering, Ahmadu Bello University, (ABU), Zaria (1982). The most important recommendations given are produced below:

	For permanent Urban Building	For Rural Housing with Low Rainfall
CC	5-20%	5-30%
SC	33% minimum	40% minimum
LL	40% maximum	50% maximum
PI	2.5-22%	2.5-30%
OMC	10 - 14%	7-16%

These recommendations agreed with the ones given by Fitzmaurice (1958).

These recommendations may serve as a useful guide to the selection of soils for stabilized blocks although results of other investigations have questioned their value. For example, Sperling (1962)

mentioned that the Department of Town Planning, Accra examined 150 soils from many sites in Ghana. On the assumption that the results of the A.S.T.M. Wet-Dry Erosion Test give a satisfactory indication of the amount of cement required to achieve satisfactory stabilization, it was seen that the particle size distribution, LL, PI and LS results do not give reliable indications of the amount of cement required to stabilize a given soil. Also, unreliable indications were obtained with a field shrinkage test proposed by Alcock (1956).

Some tests were carried out at the West African Building Research Institute (W.A.B.R.I.) to study the effect of soil composition on durability and other properties of soil-cement blocks. From the results, Sperling (1962) concluded that the suitability of a soil for the production of soil cement blocks cannot be satisfactorily predicted either from particle size analysis or the results of other laboratory index tests carried out on a sample of the soil. It was recommended that the satisfactory method of testing the soil is to make soil-cement blocks from it and examine their quality. To assess the results, it was also recommended that the qualities required of a soil-cement block must be defined satisfactorily.

CHAPTER 3: EXPERIMENTAL PROCEDURE

3.1: Materials

3.1.1.: Lateritic Soil

Lateritic soil samples were obtained from four sites, namely, Bomo, Kudingi, Wusasa and Shika areas in Zaria. Laboratory results of index properties and classification of the samples are listed in Table 3.1.1. The Kudingi lateritic soil was selected as the most suitable soil for blockmaking on the basis of its plasticity and grading properties.

Supplies of the lateritic soil were obtained from a local borrow pit at Kudingi area. The soil index properties were determined in accordance with the tests of BSI (1975b). The summary of the test methods used is given below:

a) The specific gravity of the soil was determined using the specific gravity bottle and distilled water .

b) The Atterberg Limits and indices were obtained as follows:

1. The LL of the soil was determined using a LL device and a grooving tool.
2. The PL of the soil was determined by rolling the soil sample on a glass

TABLE 3.1.1 Index Properties and Classification of Soils

Sample	Percent Passing					LL %	PL %	AASHO[2] Classification	Casagrande (Unified) Classification
	3/16" (4.75mm) BSS[1]	No 7 (2.36mm) BSS[1]	No 36 (425μm) BSS[1]	No 200 (75μm) BSS[1]	2μ				
Bomo	100	98.3	60.7	45.6	5.6	37.4	17.1	A-6	SC
Kudingi	100	94.4	88.3	76.1	10.0	29.7	16.7	A-6	CL
Wusasa	100	96.6	69.6	57.6	2.5	43.2	17.5	A-7	CL
Shika	100	94.9	69.3	61.9	2,1	48.3	24.4	A-7-5	CL

[1]BSS - British Standards Sieve

[2]AASHO - American Association of State Highway Officials

plate until a 3.175-mm diameter shows sign of crumbling.

3. The LS was determined using a LS device. The LS device is a metal mould measuring 140x10x10-mm. The mould was filled with soil having a moisture content equivalent to LL and was then placed in oven at 105°C until no further shrinkage was produced.
4. The particle size distribution was carried out using the combined sieve and hydrometer analysis.
5. The MDD and OMC were determined from the "Standard Proctor" compaction test.

The results of the index and classification properties of the Kudingi lateritic soil are presented in section 4.1.1 of Chapter 4.

3.1.2 Cement

The cement used in the study is the Ashaka Cem brand, a local OPC manufactured by the Ashaka Cement Company Limited, Bauchi, Nigeria. Supplies of the cement were obtained from a local dealer in Zaria. The relevant properties were determined in accordance with the tests of BSI (1978b) and the specific gravity of the

cement, determined using the specific gravity bottle and water-free kerosene, are presented in section 4.1.2 of chapter 4.

3.1.3 Lime

The lime used in the study is the Limbux brand, a British hydrated lime (slaked lime) with 74% CaO neutralizing value. The manufacturer is the Imperial Chemical Industries PLC, Mono Division, Lime Group, Buxton, Derbyshire-Great Britain. Supplies of the hydrated lime were obtained from an old stock of the lime belonging to the Jabi Dam Water Works in the Federal Capital Territory (FCT), Abuja. The result of relevant properties obtained by improvising the tests of BSI (1978b) and the specific gravity is presented in section 4.1.3 of chapter 4.

3.1.4 Rice Husk Ash (RHA)

Rice husks used were collected from a local rice mill at Sheda village in FCT, Abuja (see Plate III).

PLATE III: A Rice Mill at Sheda Village in the Federal Capital Teritory, Abuja, with some bags of Rice Husk awaiting to be Disposed of.

The rice husks were air-dried and the RHA was produced by burning the husks to a maximum temperature of 800°C. The husks were initially stored in clay containers and the containers were then arranged into a large brick kiln situated at the Ceramic Section in the Department of Industrial Design, A.B.U. Zaria (see Plate IV). Combustion at this temperature was obtained by simply igniting the husks with domestic cooking gas. While the husks were burning, the temperature within the middle sections of the kiln was continously monitored by a parometer (See Plate V). The maximum temperature was attained in about 4 hours. The burning was discontinued at this temperature and the kiln and its contents were allowed to cool. The colour of RHA produced varied from dark-grey to black giving an indication of high carbon content in the ash.

The ash was grounded in an electric ball mill (See Plate VI). About 20kg of the RHA was fed into the mill, which already contained about 20kg of river pebbles, and the grinding time of the ash was about 4 hours. The chemical composition carried out in the Chemical Engineering Department A.B.U. Zaria, specific gravity and finesss (determined by combined sieve and hydrometer

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PLATE IV: Brick kiln used for the Burning of Rice Husks

PLATE V: Parometer used for Monitoring of the Brick Kiln Temperature

PLATE VI: Electric Ball-Mill used for the Grinding of Rice Husk Ash

analysis) are presented in section 4.1.4 of chapter 4.

3.2 Preliminary Tests to Investigate the Effect of RHA on Physical Properties of the Cement and Lime

3.2.1 Setting Time Tests

Six mix types were used to determine the effect of RHA on the setting time of OPC and hydrated lime. Mixes with 0, 15, 30, 45, 60 and 75% RHA (by weight of OPC or the lime) were produced. Tests with OPC and hydrated lime pastes were carried using the Vicat apparatus in accordance with BSI (1978b). The results of the tests are presented in section 4.2 of chapter 4.

3.2.2 Soundness Tests

For each of the mix types used in the setting time tests, the corresponding soundness test specimens were cast. The soundness test is used as a check on expansion by late hydration after setting. The soundness of OPC and hydrated lime pastes were determined using the Le Chatelier apparatus in accordance with the tests of BSI (1978b). The results of the tests are presented in section 4.2 of chapter 4.

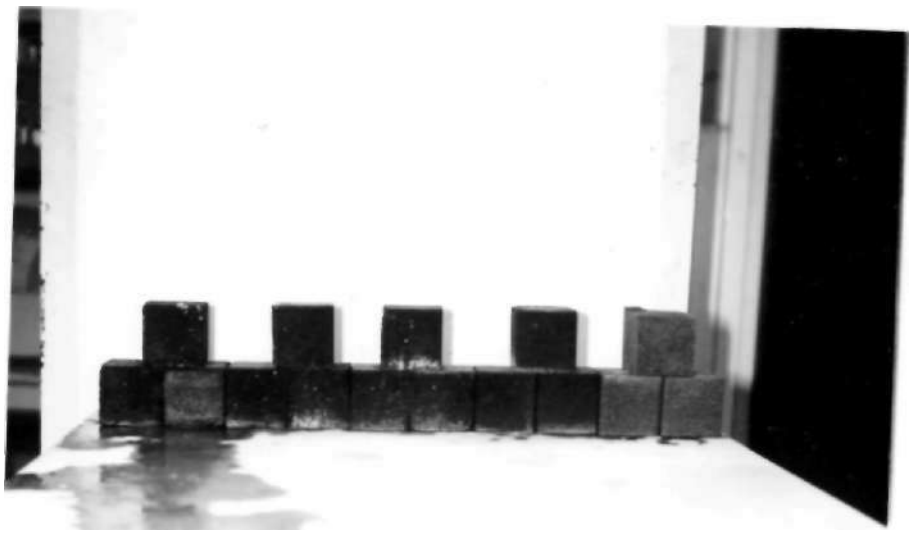

PLATE VII: OPC and OPC/RHA Mortar Cubes

3.2.3 Compressive Strength Tests

Compressive Strength Test for OPC/RHA Mortar: Six mix types were used to determine the effect of RHA on the compressive strength of OPC mortar cubes (See Plate VII). Mix with 0, 15, 45, 60 and 75% RHA (by weight of OPC) and a local river sand (thoroughly washed, dried, passed through BSS No 14 (1.18mm) and retained on BSS No 25 (600μm) were cast. The water/OPC+RHA ratio of each of the OPC/RHA mix was determined from the mass of water required to give a nominal slump equal to that of the OPC control mix. The test was carried out in accordance with BSI (1978b) and the result is presented in section 4.2 of chapter 4.

Compressive Strength Test for RHA Cement Mortar: Five mix proportions of the lime and RHA, with different lime/RHA ratio of 1:1, 1:1.5, 1:2, 1:2.5 and 1:3 were used for making the RHA cement mortar cubes. For each mix proportion, a mortar of 1:3 ratio of RHA cement-sand mix was cast. The sand is a local river sand (thoroughly washed, dried, passed through BSS 1.18mm and retained on BS 600μm). The

sixth mix which is a control mix, consists of hydrated lime and the sand. The water/lime + RHA ratio used for the RHA cement test mortar was determined from the mass of water required to give a nominal slump equal to that of the hydrated lime control mix. The test was carried out in accordance with BSI (1978b) and the result is presented in section 4.2.3 of chapter 4.

3.3 Production of Test Specimens

3.3.1 Determination of OMC

The OMC of the cubes and cylinders were determined in UTM while that of the blocks were determined in TBM.

OMC of Cubes and Cylinders: The test cube was used to determine the OMC of the two test specimens. The cube was moulded at different moisture contents for all the selected cement-soil and cement/RHA-soil mixes, starting from a moisture content lower than the OMC determined from the "standard Proctor" compaction test, at increasing intervals of 2% moisture content. The cube was moulded at a compaction pressure of $4N/mm^2$ in UTM and the cube produced was weighed and carefully inspected for any deffects or cracks. A representative sample of the material was obtained for moisture content

determination. It was observed, that the weight of the cube increased continuously with increase in moisture content until the OMC of the mix was reached. Hereafter, the weight of the cube decreased continuously with further increase in moisture content, and the cube produced had some minor cracks on them. With still further increases in moisture content the cracks became larger and subsequently the material flowed out of the mould during moulding. The optimum moisture contents determined for mixes in the UTM were used in moulding the OPC-soil and OPC/RHA-soil specimens as shown in Table 4.3.1 of chapter 4.

The same procedure was used for lime - soil and RHA cement-soil mixes but the compaction pressure was now increased to $8N/mm^2$, which is the suitable minimum compaction pressure for lime-stabilized blocks as indicated by Lunt (1980). Results of the OMC tests were used in moulding lime-soil and RHA cement-soil specimens as shown in Table 4.3.2.

OMC of Blocks: The blocks were also moulded at different moisture contents, for all the three selected mixes used for blockmaking, starting from a moisture content higher than the OMC of 16% determined from the "Standard Proctor" compaction test. This was so because compact

blocks could not be produced in the TBM at the OMC of 16% or less. Three blocks were moulded in the machine each with a moisture content increase of 2%. The blocks produced were also weighed and inspected for any deffects or cracks. A representative sample of the material was obtained for moisture content determination. It was also observed that the weights of the blocks increased continuously with increase in moisture content until the OMC of the mix was reached. Afterwards, the weights of the blocks decreased continuously with further increases in moisture content, and also the blocks had cracks on them. In addition, the extraction of blocks from the moulds became increasingly difficult. The optimum moisture contents determined for the mixes in the TBM were used in moulding the blocks and are shown in Table 4.5.1 of chapter 4.

3.3.2 Moulding of Test Specimens

Air-dried soil of known moisture content was sieved through BS sieve 3/8" (9.5mm). The soil and the stabilizers with sufficient water (to bring the moisture content of the mix to the optimal value) were thoroughly mixed by

hand until the mix appeared uniform in colour and consistence. After mixing the 100-mm test cubes were moulded in the UTM. The cube mould with adaptations to fit on the machine was used for the production of the specimens (see Plate VIII). The inner sides of the mould and the base plate were initially cleaned with water to ensure easy demoulding of the cube specimens. For each selected compaction pressure, the mould was fed with pre-determined quantity (volume) of the mix to ensure the production of uniform-sized specimens (See Plate IX). The machine was also used in demoulding the specimens after moulding has been completed.

The same procedure was used in the production of the cylinders but the cylindrical mould used instead.

The blocks were maufactured in the TBM at the OMC of mixes. The machine is a manually operated press, which may be operated by one man. The compaction pressure at which the blocks were moulded is not known since the blockmaking machine has no means of measuring the pressure. It can however be guessed that the machine operates at a low pressure, say below $4N/mm^2$. After the soil material has been

PLATE VIII: Production of Soil Cubes in the Universal Testing Machine

PLATE IX: Stabilized Soil Cubes

PLATE VIII: Production of Soil Cubes in the Universal Testing Machine

fed into the moulds, the excess was scraped and the blocks were moulded by pressing the tube of the machine lever. The moulds cover was opened and the three manufactured blocks were extracted (See Plate X).

3.3.3 Curing of Test Specimens

The specimens made from OPC, OPC/RHA or OPC/RHA cement were moist cured for 7 days and then dried out in laboratory atmosphere for 21 days. Sperling (1962) and Ejeh (1982) reported that 7 days moist curing is ample and that little improvement can be obtained by prolonging the curing period. On the drying period, Sperling (1962) also explained that during this period most of the shrinkage takes place, thus reducing the consequent cracking which would take place if the damp blocks are built directly into a wall.

The specimens made from lime or RHA cement-soil mixes were covered with polytehene sheet for 7 days soon after moulding to minimize loss of water in order to avoid the adverse effects of premature drying on strength development.

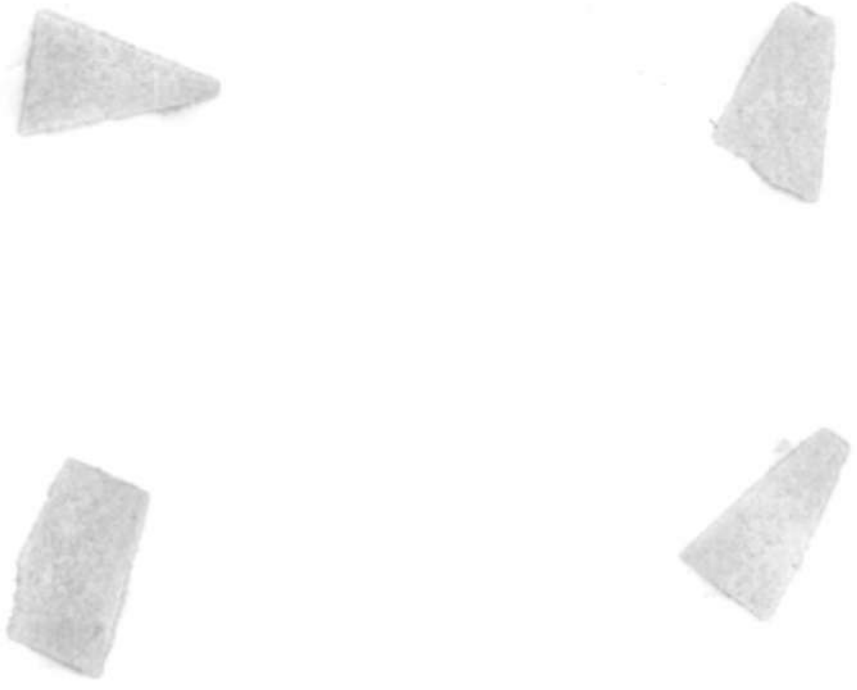

PLATE X: Stabilized Soil Cylinders and Blocks

The average ambient temperature within the laboratory at the time of this study was about 26°C.

3.4 Compressive Strength Tests for Stabilized Soils

Compression tests of cubes and cylinders were conducted on the as-cast faces and the average of three determinations was obtained. The test cubes were not tested at right angles to the as-cast positions as in concrete test cubes. These cubes were unlike concrete cubes in which, due to bleeding, the properties of different layers (as-cast) are not the same. In the blocks, the compression tests were conducted on the largest faces of the dry and wet blocks, the latter having been soaked beforehand for 24 hours. The blocks were compressed between sheets of soft boards. An average of 12 determinations was obtained for the block compressive strength.

Loading was applied uniformly and increased continuously at a rate of approximately 15 MN/m^2 in accordance with BSI (1970a) until no greater load was sustained by the specimens. Results of compressive strength tests are presented in sections 4.3.1, 4.3.2, 4.3.3 and 4.5.1 of chapter 4.

3.5 Erosion Tests for Blocks

Two methods were used for determining resistance to erosion of the blocks. The first which is W.A.B.R.I method, was carried out on three blocks after curing and drying have been completed. Sperling (1961) indicated that the W.A.B.R.I. erosion test is suitable for predicting the durability of a soil-cement block and it can also be used for control during manufacture. Sperling (1962) also indicated that the test, which is a simple field test, is more effective than the A.S.T.M. erosion test. The procedure for W.A.B.R.I. erosion test has been described in the Appendix.

The second which is a water spray test, similar to the quick tests carried out by Lunt (1980) and Bedi and Chandra (1983) was carried out on three blocks after curing and drying have been completed. The procedure used in this study is that a shower of water with a pressure head of about 2.5m was sprayed on the largest faces of the blocks for 6 hours. A block is said to be durable if no damage occurred on the faces.

Results from the two erosions tests are presented in section 4.5.2 of chapter 4.

3.6 Dimensional Changes in Blocks

The extent of the dimensional changes produced on drying and on wetting the blocks was measured by means of a vernier calipers for the length, breadth and height. The shrinkage recorded was the difference in the measurements between those of the block 24 hours after manufacture and those after 28 days which include 7 days moist curing and 21 days air drying. The expansion on wetting was obtained by immersing this air-dried block in water for 24 hours. An average of three determinations was obtained for the two tests.

CHAPTER 4 PRESENTATION AND DISCUSSION OF RESULTS

4.1: Properties of Materials

4.1.1: Kudingi Lateritic Soil

From careful examination, the Kudingi lateritic soil may be described as a light-brown, sandy or silty clay laterite with some fine roots. The list of some important soil index properties determined is given below:

1.	Specific gravity	2.55
2.	Atterberg Limits and indices:	
	a. Natural moisture content	10.1%
	b. LL	29.7%
	c. PL	13.0%
	d. PI	16.7%
	e. LS	5.7%
3.	Particle size distribution:	
	a. Percent finer than BS Sieve No 7	94.4
	b. Percent finer than BS sieve No 36	88.3
	c. Percent finer than BS sieve No 200	76.1
	d. Percentage of gravel	4.0
	e. Percentage of sand	56.0
	f. Percentage of silt	30.0
	g. Percentage of clay	10.0

h) Effective size (D10) 0.002mm

i) Coefficient of uniformity (C_u) 14.8

j) Coefficient of curvature (C_c) 6.2

4. "Standard Proctor" compaction test:

a. MDD 1898.2kg/m^3

b. OMC 16%

The soil may be grouped as a fine-grained soil in accordance with the definition given by BSI(**1975b**) since the soil contains not less than 90% passing a 2mm BS test sieve. The Cu of the soil is greater than 6, hence the soil may additionally be described as broadly-graded.

The soil classification is made under the following systems:

1. American Association of State

Highway Officials (AASHO) system - A-6
The soil class under this classification system agrees with the results of Department of Civil Engineering, A.B.U. Zaria (1982), Ejeh (1982) and Ezetah (1985) which indicated that most laterites in Zaria area are in A-6 group. However, samples of lateritic soils from Wusasa and Shika borrow pits of Zaria were found to be in the A-7 group.

2. Unified Soil (Casagrande) System -CL

The soil group under the Unified Soil classification system makes it suitable for cement and/or lime stabilization as indicated by Yoder and Witczak (1975).

4.1.2: Cement:

The relevant properties of the cement used in the study are given in Table 4.1.2 below:

Table 4.1.2: Properties of Cement used

Type	:	Nigerian OPC
Consistence	:	28.5%
Initial setting time	:	1hr. 28mins.
Final setting time	:	2hr 26mins
Soundness	:	2.0mm
Specific gravity	:	3.14
Temperature of test	:	26^{o}C
Mortar cube strength	:	

Age (days)	Compressive strength (N/mm^2)
3	15.5
7	23.8

It can be seen that properties of the cement used comply with the requirements of BSI (1978a).

4.1.3 Lime

The relevant properties of the lime a used in the stucy are given in Table 4.1.3 below:

Table 4.1.3: Properties of Lime used

Type	: British hydrated lime
Initial setting time	: 13hr 00mins
Final setting time	: 26hr 58mins
Soundness	: 1.5mm
Specific gravity	: 2.74
Temperature of test	: 26^{o}C

Mortar cube strength:

Age (days)	Compressive Strength N/mm^2
7	0.50
28	1.00

4.1.4 Rice Husk Ash (RHA)

The typical chemical compositior of the RHA with the specific gravity and fineness of the RHA used in the investigation is shown in Table 4.1.4.

Table 4.1.4 Chemical Composition and Physical Properties of RHA used

Constituent	Percentage
SiO_2	66.590
Al_2O_3	0.810
Fe_2O_3	0.690
CaO	0.102
MgO	0.884
Na_2O	0.630
K_2O	1.570
Carbon	27.160
Ignition Loss at 1000°C	0.006
Fineness-calculated as the mass proportion of the RHA retained on BS test sieve No 300 (53μm)	105m^2/kg
Specific gravity	1.53

It can be seen from the table that the ash is composed essentially of silica (although lesser percentage when compared to the silica content of the ashes used by Cook et al, 1977; and Cook, 1980) with small amounts of other oxides. The specific gravity of the ash is also lower than value of 2.35 obtained by Cook et al (1977). However, the Al_2O_3 content is

higher. These differences in the ash composition may be due to the method of production of the ash, but this can generally be due to the inherent differences in the materials from different locations. The second reason is confirmed by differences in composition of the ashes used in the researches mentioned above.

The carbon content of the ash is quite high. This was noticeable from the dark-grey to black colour of the ash. The temperature of combination as recorded by the parometer is generally considered to be adequate, hence the large quantity of carbon trapped in the ash containers may have been due to limited access of oxygen during the burning.

The fineness of the RHA agree with the requirements of between 100-200 m^2/kg (Blaine fineness) suggested by Cook (1980).

The ignition loss is also small and within the acceptable limits.

4.2 Effect of RHA on Physical Properties of Cement and Lime

4.2.1 Setting Time Tests

The results of the setting time tests for the OPC-RHA mixes are presented in Table 4.2.1.1. The effect of OPC replacement by RHA on initial-and final-setting time is shown in Fig. 4.2.1.1. It can be observed that the effect of RHA content on the initial setting time is considerable while its effect on the final setting time is little. The initial setting time of the control mix decreased from 1hr 28min to 29min when the OPC was replaced by 75% RHA while the final setting time of the control mix and the OPC-RHA mixes was about 3hr. Initial setting time may be defined as the time for the concrete to be properly laid and finished and so that disturbance of one batch when placing the subsequent batch does not matter. To comply with the minimum time of 45min prescribed by BSI (198a), only about 40% OPC should therefore be replaced by RHA.

Table 4.2.1.1: Setting Time and Soundness of OPC/RHA Pastes

Mix Proportion OPC+RHA:Sand	Consistence %	Initial Setting time hr : min.	Final Setting time hr : min	Soundness* mm
1 + 0 : 3	28.5	1 : 28	2 ; 46	2.0
0.85+ 0.15 : 3	35.5	1 : 08	3 : 06	0.5
0.70 + 0.30: 3	41.0	0 : 54	3 : 12	0.5
0.55 + 0.45: 3	54.0	0 : 43	3 : 12	0.5
0.40 + 0.60: 3	63.5	0 : 33	3 : 00	0.5
0.25 + 0.75: 3	74.0	0 : 29	2 : 48	0.5

*Average of two determinations

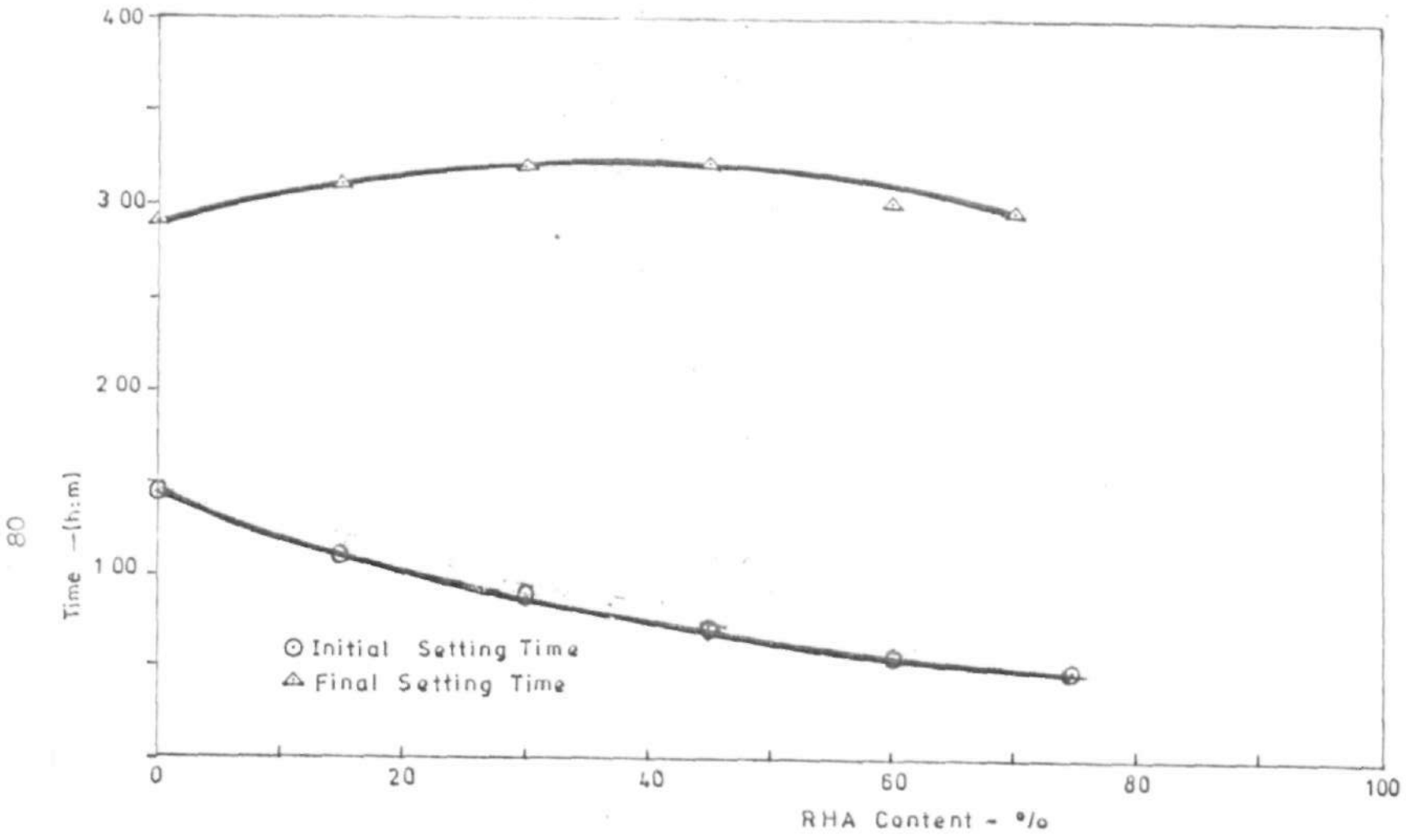

Fig. 4.2.1.1 Initial and Final Setting Time of OPC/RHA Paste.

There is also the effect of RHA on the standard consistence of the cementitious pastes which varied from 28.5% for the control mix to 74% for the mix 75% RHA content.

The results of the setting time tests for the lime-RHA mixes are presented in Table 4.2.1.2. The effect of RHA on the initial- and final-setting time of the lime is shown in Fig. 4.2.1.2. The initial-and final-setting time of the lime-RHA pastes show that there is a continous decrease from the control mix to that containing 75% RHA. It can however be observed that at about 60% RHA content (about 1:2 lime/RHA ratio) there is a little effect of RHA on the setting time. Above this RHA content, the initial setting time is long but adequate. The final setting time may be defined as the minimum delay before shuttering can be removed. To comply with the maximum time of 10hr prescribed by BSI (1978a), a minimum lime/RHA ratio of 2 should therefore be used in making the RHA cement. The result is in agreement with the suggestion of Cook (1980) that only 20%-30% by weight of hydrated lime needs to be mixed

TABLE 4.2.1.2 Setting Time and Soundness of Lime/RHA (RHA Cement) Pastes

Mix Proportion Lime + RHA: Sand	Consistence %	Initial Setting Time hr : min	Final Setting Time hr. : min	Soundness* mm
1 + 0 : 3	64.5	13 : 00	26 : 58	1.5
0.85+0.15:3	77.5	8 : 48	19 : 00	1.0
0.70+0.30:3	72.0	5 : 30	14 : 00	0.5
0.55+0.45:3	67.0	3 : 48	11 : 24	0.5
0.40 + 0.60: 3	62.0	2 : 40	10 : 00	0.5
0.25 + 0.75:3	57.0	2 : 24	9 : 36	0.5

*Average of two determinations

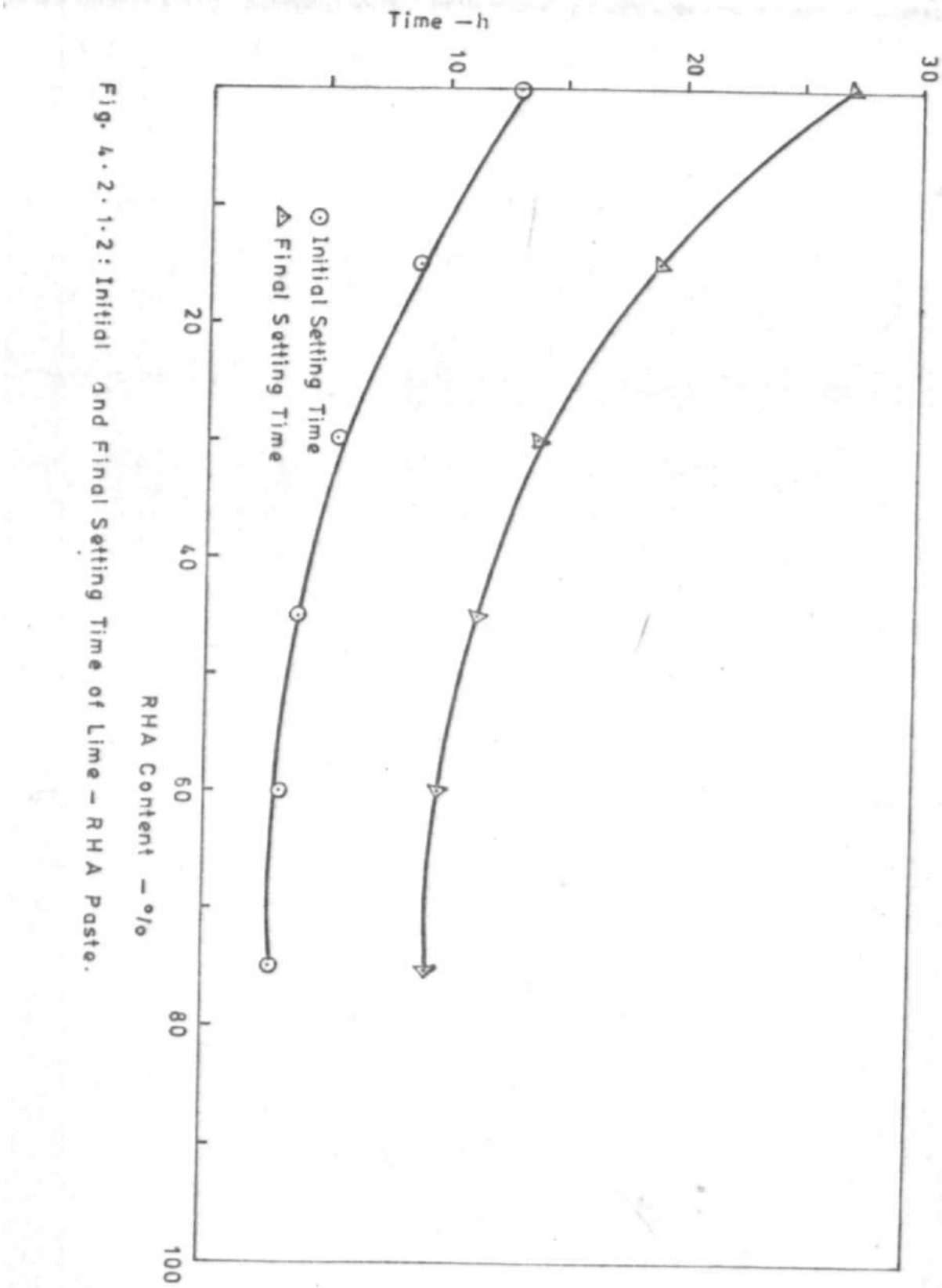

Fig. 4·2·1·2: Initial and Final Setting Time of Lime – RHA Paste.

with RHA to produce a suitable cement.

4.2.2 Soundness Tests

The results of the soundness of OPC/RHA and lime/RHA pastes determined by Le Chatelier test are shown in Tables 4.2.2.1 and 4.2.2.2 respectively. The results show that the two types of cementitious mixtures were entirely satisfactory since they complied with the requirement of BSI(1978a).

4.2.3 Compressive Strength Tests

Compressive Strength of OPC/RHA Mortar Cubes: The results of compressive strength of OPC/RHA mortar cubes are shown in Table 4.2.3.1. It can be observed that the compressive strength increased with age for all the mixes. This is an indication that a pozzolanic reaction occured between OPC and RHA over the 28-day test period. It can also be observed that when the cubes were cured continuously under water at about the normal curing temperature of 26^{o}C, direct replacement of OPC by RHA will produce mortars with lower strength. However, the limited results indicate that upto 45% replacement of OPC can occur without significant loss in 28-day strength.

Table 4.2.3.1: Compressive Strength of OPC/RHA Mortar Cubes Continuously moist cured

Mix Proportion OPC: RHA: Sand	Water/OPC+RHA	Age at test			
		7 days		28 days	
		Saturated Density* kg/m^3	Compressive Strength** N/mm^2	Saturated Density* kg/m^3	Compressive Strength** N/mm^2
(1+0) : 3	0.40	2048	23.80	2091	24.94
(0.85+0.15):3	0.50	1964	19.35	2022	23.60
(0.70+0.30):3	0.58	1899	16.43	1971	23.79
(0.55+0.45):3	0.78	1871	10.51	1852	17.19
(0.40+0.60):3	0.89	1771	7.68	1775	11.98
(0.25+0.75):3	1.04	1724	1.84	1730	3.22

*Average of three determinations

** Average of three determinations

Compressive Strength of Lime/RHA Mortar Cubes:

The results of compressive strength of Lime/RHA mortar cubes, cured by covering the specimens with wet sack for 7 days only and then stored in laboratory atmosphere, are shown in Table 4.2.3.2. The lime-sand mortar cube which is the control specimen was only air-dried, since it disintegrated when wet-cured. The 28-day compressive strength of the lime-sand cube is very low, probably due to the effect of curing, so it can not be of further interest. The compressive strength of the lime/RHA specimens compared favourably with some of the published strength results earlier reviewed. It is even expected that when the ash is of high quality (amorphous ash with lower carbon content) is intergrounded (not intermixing, as in this test) with good quality hydrated lime, then higher strength results would be obtained. Secondly, addition of reactive alumina into the mix is expected to improve both the early and later strength characteristic of the lime/RHA cementitious mix. Finally, it is also expected that an elevated temperature curing in form of hot water curing would improve the initial strength gain in the mixes. The 28-day compressive strength of the lime/RHA mortar cubes varied from 3.44

Table 4.2.3.2 Compressive Strength of Lime/RHA Cement Mortar Cubes moist Cured for 7 days

Mix Proportion Lime:RHA:Sand	Water/Lime+RHA	Age at test			
		7 days		28 days	
		Saturated Density* kg/m^3	Compressive Strength** N/mm^2	Air-dried Density** kg/m3	Compressive Strength** N/mm^2
1 : 0 : 3	0.65	1280 +	0.50 ++	1302 +	1.00 ++
1 : 1.0 : 3	0.67	1905	3.02	1618	3.44
1 : 1.5:3	0.68	1863	4.43	1641	4.86
1 : 2.0:3	0.68	1858	3.50	1641	5.48
1:2.2:5	0.73	1881	4.90	1570	6.58
1 : 3.0: 3	0.74	1858	4.65	1613	6.38

* Average of three determination
** Average of three determinations
\+ Air-dried density
++ Dry Compressive Strength

to 6.58N/mm^2 with the 1:2.5 Lime/RHA ratio (i.e about 25.0% lime content) giving the highest strength. This result is based on limited investigation and therefore further detailed investigation is necessary. The compressive strength of the specimens also increased over the 28-day test period indicating a pozzolanic reaction between lime and the RHA.

4.3 Compressive Strength of Stabilized Soils

4.3.1 Compressive Strength of OPC/RHA - Stabilized Soils

The results of 7- and 28-day compressive strength of the OPC/RHA - stabilized soil are presented in Tables 4.3.1.1 and 4.3.1.2 respectively. The effect of RHA on the compressive strength of the soil-OPC mix is shown in Figs. 4.3.1.1 and 4.3.1.2. It can be observed that the compressive strength decreased, although at varying degrees for the three mixes, as the RHA content increased. Nevertheless, there is an advantage in using RHA as a supplement stabilizing

Table 4.3.1.1: 7-day Compressive Strength for OPC/RHA-Stabilized Soil Cubes Compacted at 4N/mm^2

Mix No	OPC/RHA Content %	RHA Content %	Moisture content % Required	Actual	Saturated Density** kg/m^3	Compressive Strength** N/mm^2
1	8	0	14	13.4	2330	1.63
		10	16	15.8	2300	1.48
		20	16	15.6	2274	1.30
		30	16	15.5	2246	1.16
		40	16	14.9	2218	1.00
2	10	0	14	13.4	2248	2.29
		15	16	15.9	2248	1.99
		30	16	16.1	2237	1.63
		45	16	16.2	2168	1.26
		60	16	15.3	2099	0.93
3	12	0	14	13.4	2166	2.93
		20	16	15.7	2125	2.36
		40	16	15.6	2074	1.77
		60	16	15.1	2044	1.15
		80	17	16.5	1934	0.43

*Average of two determinations
** Average of three determinations

Table 4.3.1.2: 28-day Compressive Strength for OPC/RHA-Stabilized Soil Cubes Compacted at $4N/mm^2$

Mix No	OPC/RHA Content %	RHA Content	Moisture Content %		Air-dried Density**	Compressive Strength**
			Required	Actual*	kg/m^3	N/mm^2
1	8	0	14	13.1	1978	5.57
		10	16	15.8	1955	5.00
		30	16	15.6	1951	4.30
		40	16	14.9	1883	3.50
II	10	0	14	13.4	1908	7.94
		15	16	15.9	1904	6.75
		30	16	16.1	1899	5.60
		45	16	16.2	1840	4.40
		60	16	15.3	1782	3.30
III	12	0	14	13.4	1839	10.30
		20	16	15.7	1860	8.20
		40	16	15.6	1761	6.13
		60	16	15.1	1701	4.30
		80	17	16.5	1642	1.80

*Average of two determinations

**Average of three determinations

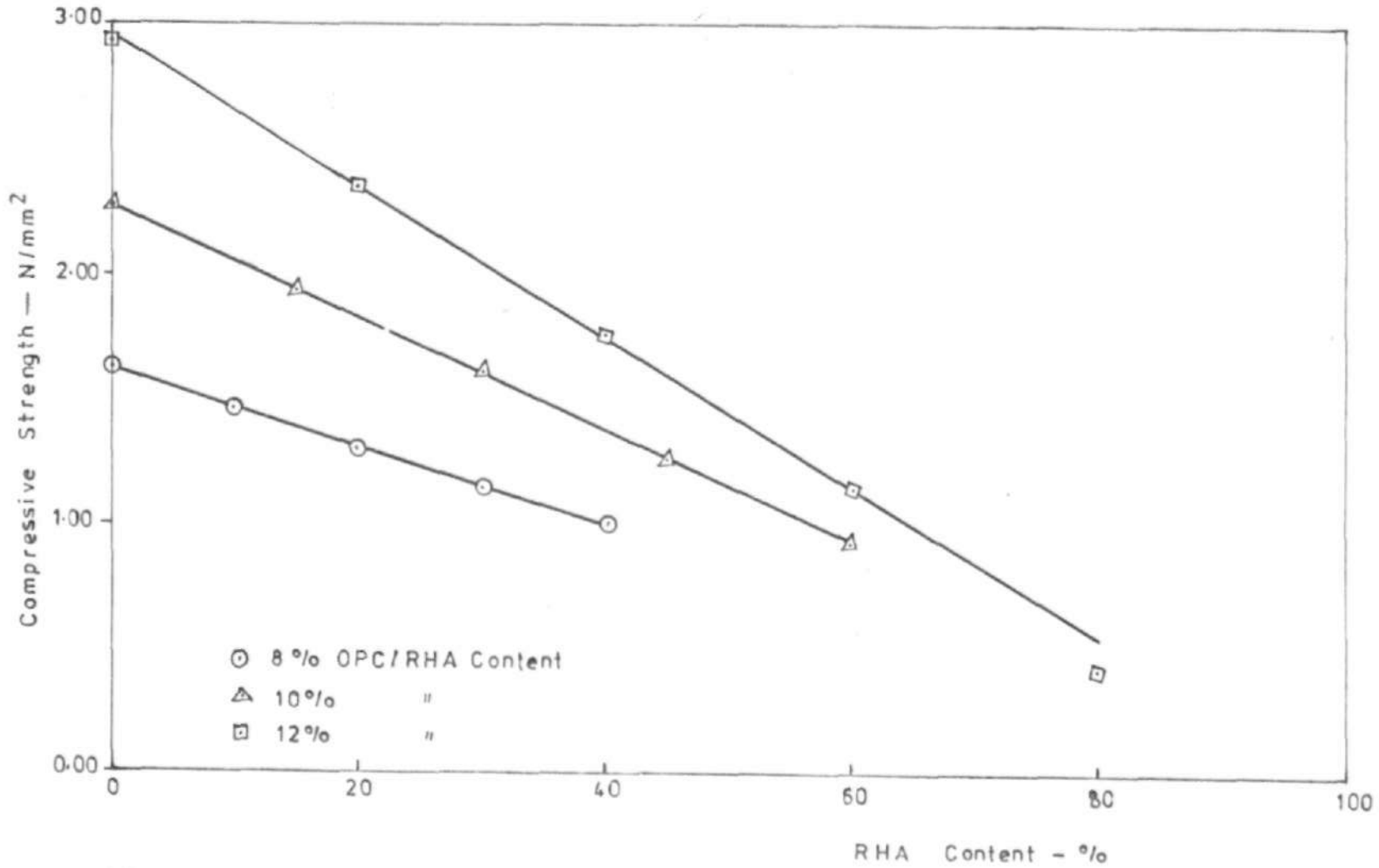

Fig. 4·3·1·1 7-day Compressive Strength for OPC / RHA – Stabilized Soil Cubes Compacted at 4 N/mm²

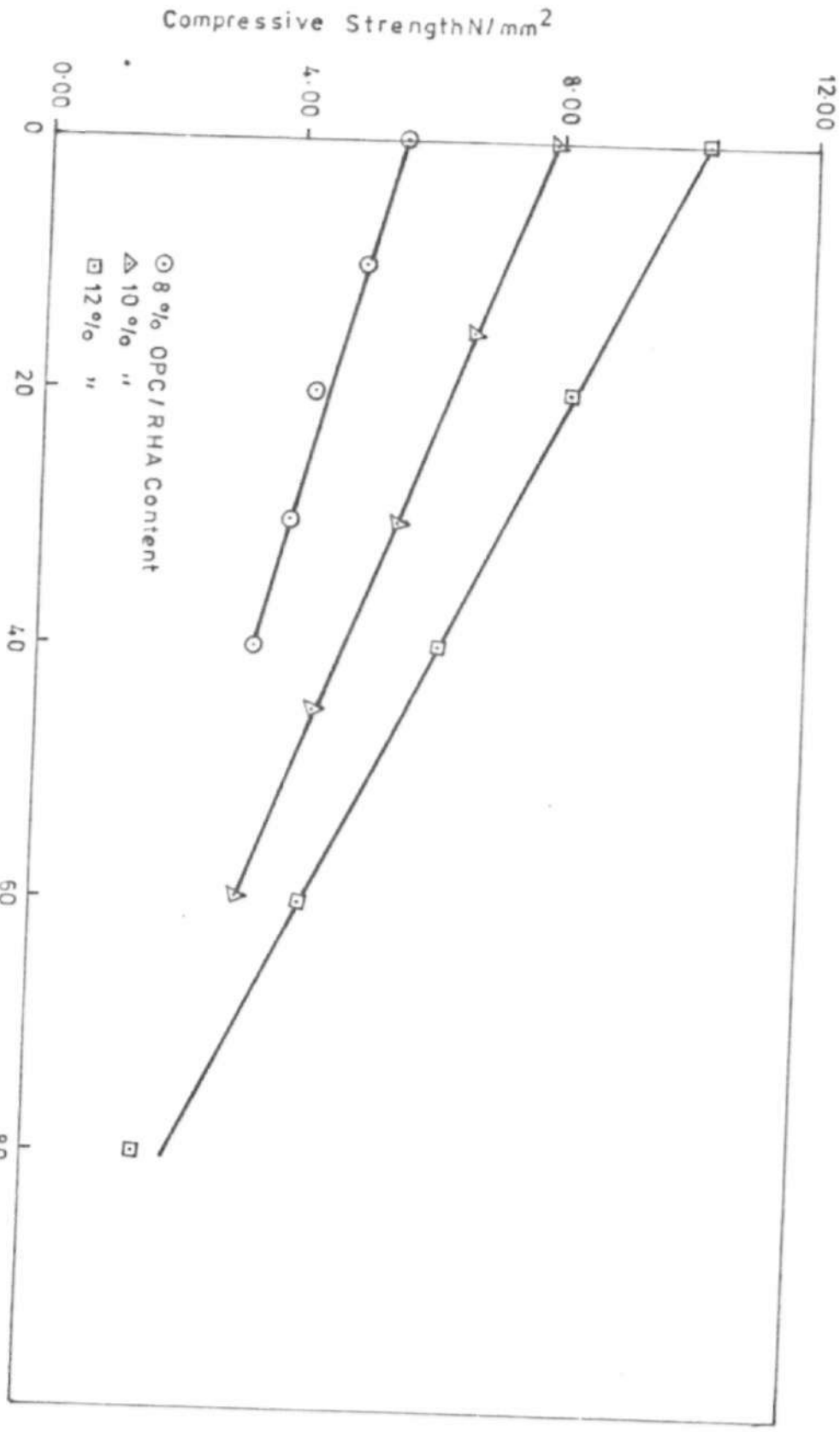

Fig. 4·3·1·2 28-day Compressive Strength for OPC / RHA - Stabilized Soil Cubes Compacted at 4 N / mm2

agent in the OPC-lateritic soil mix. For instance, the 10% replacement in 8% OPC/RHA content mix and 40% replacement in 12% OPC/RHA content mix contain equal quantity (mass) of OPC (with different masses of RHA) but the 28-day compressive strength of the 12% OPC/RHA is about 23% greater. Similarly, a 40% replacement by RHA in the 8% OPC/RHA content mix has equal mass of OPC as the 60% replacement by RHA in the 12% OPC/RHA content mix but a strength difference of about 23% also exist between the latter and former mixes. It is apparent therefore that improved strength can be achieved by increasing the RHA in a mix while the OPC content remains constant.

The rate of gain of strength over the 28-day test period indicates the occurrence of the pozzolanic reaction in the mix. The strength gain in all the OPC/RHA mixes were about the same with an average of the 29% of the 28-day strength developing in 7 days. It is probable that this strength ratio is primarily influenced by the moisture condition of the soil specimen since the ratio remained constant for all the various mixes. The 7-day strength test was carried out immediately after curing

the specimens under water for 7 days has been completed while the 28-day was determined after further allowing them to dry out for 21 days.

The 7-day saturated density of the mix ranges from 1934 to 2330 kg/m^3 while the 28-day air-dried density is from 1642 to 1978 kg/m^3. The trend is that the density of a mix decreases as the RHA content increases. The reduction in density of the stabilized soil material, however, would be advantageous in constructions where self-weight represents a very large proportion of the total load on the structure.

4.3.2: Compressive Strength of RHA Cement-Stabilized Soils

The results of 7- and 28-day compressive strength of the RHA cement-stabilized soil are presented in Tables 4.3.2.1 and 4.3.2.2 respectively. The results show that although the RHA cement mixes were compacted at 8N/mm^2, the compressive strengths of the cubes were lower than that of OPC/RHA-stabilized cubes which were compacted at 4N/mm^2. It is therefore apparent that OPC/RHA stabilization is more effective than RHA cement (Lime/RHA) stabilization. The rate of gain of strength over the 28-day test period also indicates the

TABLE 4.3.2.1: 7-day Compressive Strength for RHA-Cement-Stabilized Soil Cubes Compacted at 8N/mm^2

Mix No.	RHA Cement Content %	Lime/RHA Ratio	Moisture Content Required %	Moisture Content Actual*	Moist Density** kg/m^3	Compressive Strength** N/mm^2
I	8	1:0	14	12.8	1997	1.33
		1:1.5	16	15.5	1900	1.52
		1:2.0	17	16.9	1895	1.55
		1:2.5	18	18.1	1884	1.59
II	10	1:0	14	13.4	1942	1.50
		1:1.5	16	15.2	1848	1.57
		1:2.0	17	16.3	1843	1.62
		1:2.5	18	17.2	18832	1.63
III	12	1:0	14	14.2	1903	1.33
		1:1.5	16	14.9	1811	1.72
		1:2.0	17	16.6	1806	1.78
		1:2.5	18	17.8	1795	1.82

*Average of two deerminations
**Average of three determinations

TABLE 4.3.2.2: 28-day Compressive Strength for RHA Cement-Stabilized Soil Cubes Compacted at 8N/mm^2

Mix No.	RHA Cement Content %	Lime/RHA Ratio	Moisture content % Required	Actual*	Air-dried Density** kg/m^3	Compressive Strength*** N/mm^2
I	8	1:0	14	12.8	1805	3.12
		1:1.5	16	15.5	1665	3.61
		1.2.0	17	16.9	1659	3.72
		1:2.5	18	18.1	1652	3.77
II	10	1:0	14	13.4	1786	3.22
		1:1.5	16	15.2	1648	3.73
		1:2.0	17	16.3	1642	3.84
		1:2.5	18	17.2	1635	3.89
III	12	1:0	14	14.2	1780	3.58
		1:1.5	16	14.9	1642	4.15
		1:2.0	17	16.6	1636	4.27
		1:2.5	18	17.8	1629	4.33

*Average of two determinations

**Average of three determinations

***Average of three determinations

occurence of the pozzolanic reaction in the mix. Pozzolanas containing a high proportion of silica, while combining readily with lime, are known to produce hardened materials with poor mechanical strength (Malquori, 1960).

The ratio of the 7-day compressive strength to the 28-day compressive strength is about 42% for both the RHA cement-soil mix and the corresponding control mix (contains only hydrated lime and the soil). This ratio is greater than that of OPC/RHA and its control mix (contains only OPC and the soil) which is 20%. This high early strength in the RHA cement mixes, except only when rapid reacting minerals such as amorphous silica was in the RHA, may be due to the reducing effect of the moisture condition of OPC-stabilized soil specimen on its compressive strength. This is because it is generally believed that strength producing reactions in OPC mix are faster than that of hydrated lime. The 7-day compressive strength test of the RHA cement-stabilized soil specimens was made on moist specimens while that of OPC/RHA was on wet specimens. Hence the 28-day strength (i.e. after sufficient time should have been allowed for pozzolanic

activity to be develored) is more suitable for assessing the strength of blocks made from stabilized soil mix.

Unlike in the OPC/RHA- soil mix, the results show that the compressive strength of RHA cement--soil mix progressively increased as the RHA content of the mix increased. Thus, the mix with 1:2.5 lime/RHA ratio (has the largest RHA content) produced greater strength values than the 1:2 and 1:1.5 ratios.

The density of the RHA cement-soil mixes was between 1995-1997 kg/m^3 at 7 days and between 1629-1805kg/m^3 at 28 days. This is however lower than that of the OPC/RHA soil mixes.

4.3.3: The Effect of OPC on Compressive Strength of RHA Cement-Stabilized Soils

From Tables 4.3.2.1 and 4.3.2.2, it can be seen that there are no significant diferences between the compressive strengths of the various mixes used. The effect of OPC on the mixes that gave average strength results (i.e. 10% RHA cement content) is studied and the results are presented in Tables 4.3.3.1 and 4.3.3.2. The results in Tables 4.3.3.2 indicated that addition of 10%, 20% and 30% (by weight of RHA cement) into the mixes increased the 28-day compressive strengths of the mixes with about 26%, 50% and 61% respectively. It can also be seen that addition of 20 and 30% OPC to the RHA cement-soil mixes and compacting the test specimens at $4N/mm^2$ gave 28-day strength results comparing favourably with the results of the equivalent mixes (without OPC) but compacted at $8N/mm^2$. It is therefore apparent that the addition of OPC into RHA cement-soil mixes significantly improved the strength. It is also apparent that the mixes containing adequate OPC would be suitable for block manufacture in a simple low-pressure block-making machine such as the Torsa or Cinva Ram.

313

Table 4.3.3.1: Compressive Strength for 10% OPC/RHA Cement content-Stabilized Soil Cubes Compacted at 4N/mm^2

Line: RHA Ratio	OPC[1] Content %	Moisture Content % Required	Actual*	Age at Test			
				7 days		28 days	
				Wet density** kg/m^3	Compressive strength ** N/mm^2	Dry Density** kg/m^3	Compressive Strength** N/mm^2
1:1.5	10	17	16.2	2048	0.68	1790	2.56
	20	17	16.8	2019	0.78	1721	3.69
	30	17	17.1	2092	0.88	1967	4.35
1:2.0	10	18	17.5	1995	0.73	1760	2.63
	20	18	17.9	1967	0.85	1698	3.80
	30	18	17.3	2037	0.95	1717	4.43
1:2.5	10	19	18.7	2036	0.74	1745	2.73
	20	19	18.9	2007	0.86	1713	3.92
	30	19	19.2	2078	0.97	1776	4.58

1 By weight of RHA cement

* Average of two determinations

** Average of three determinations

Table 4.3.3.2: Compressive Strength for 10% OPC/RHA Cement Content Stabilized Soil Cubes Compacted at 8N/mm^2

Lime: RHA Ratio	OPC content[1] %	Moisture content %		Age at Test			
		Required	Actual*	7 days		28days	
				Wet Density** kg/m^3	Compressive Strength** N/mm^2	Dry Density** kg/m^3	Compressive Strength** N/mm^2
1:1.5	10	16	14.8	2020	1.00	1782	4.44
	20	16	15.6	2040	1.15	1762	5.80
	30	16	16.1	2067	1.20	1740	5.93
1:2.0	10	17	16.3	1968	1.03	1758	4.80
	20	17	16.3	1987	1.27	1738	5.63
	30	17	16.9	2013	1.33	1760	6.10
1:2.5	10	18	17.5	2008	1.04	1743	5.25
	20	18	17.3	2027	1.30	1723	5.86
	30	18	17.9	2054	1.35	1701	6.45

1 By weight of RHA cement

* Average of two determinations

** Average of three determinations

4.4 Evaluation of Masonry Units

4.4.1 Compressive Strength of Stabilized Soil Blocks

The results of compressive strength evaluation is shown in Table 4.4.1. It has been observed that there are as yet no specifications for stabilized soil blocks in Nigeria. However, the results, when compared to the recommendations of the Federal Ministry of Works, (FMW, 1979) Nigeria on sandcrete blocks, indicate that only the 28-day dry compressive strength can conform to the strength requirements of the sandcrete blocks. The wet compressive strength which is found to be the lowest strength expected from the masonry unit (Ejeh, 1982) does not conform with the minimum strength requirements of the above body or that of BSI (1968). The cube and the cylinder strengths are however significant because they exceeded the generally accepted minimum strength of 1.4N/mm^2. It was noted, during the course of investigation,that increasing the cement content of the mixes would progressively increase strength. It is therefore apparent that higher OPC content, above what was used in this study, and perhaps even a more effective blockmaking machine is required for the units to conform to the requirements of sandcrete or concrete blocks

Table 4.4.1: Compressive Strength of Stabilized Soil Blocks

Mix No	Lime: RHA Ratio	OPC content[1] %	Moisture content used for Moulding blocks % Required	Actual*	28-day Compressive Strength N/mm^2					
					Wet			Dry		
					Cube**	Cylinder**	Block***	Cube**	Cylinder**	Blo
1	1:1.5	20	23	22.5	1.58	1.74	1.05	5.80	6.32	3.7
2	1:2	20	24.5	23.9	1.58	1.76	1.06	5.83	6.39	3.8
3	1:2.5	20	26	25.8	1.62	1.77	1.09	5.86	6.47	3.9

1 By weight of RHA cement
* Average of two determinations
** Average of three determinations
*** Average of 12 determinations

as specified by the above bodies. The blocks made from the mixes would hence be suitable for use in low cost housing and rural buildings in this country.

4.4.2 Erosion

The results of erosion tests conducted on the stabilized blocks are shown in Table 4.4.2. The results indicate that in the W.A.B.R.I. erosion test, the block withstood the test and the average loss obtained for each of the mixes is well below the tentatively recommended maximum loss of 42 gms.

In the case of the spray test, the blocks were not eroded on their surfaces and therefore were considered to be durable.

4.4.3 Dimensional Changes in Blocks

The results of the dimensional changes which occured in the stabilized soil blocks are shown in Table 4.4.3. The results indicate that the drying shrinkage and wetting expansion of the blocks are comparable to the results obtained elsewhere (Sperling, 1962) and therefore the mixes are dimensionally stable.

Table 4.4.2: Erosion Tests for Stabilized Soil Blocks

Mix No.	Lime: RHA ratio	OPC[1] content %	Moisture Content used for Moulding Blocks Required	Actual*	W.A.B.R.I. Erosion Test Loss** gms	Water Spray Test
1	1:1.5	20	23	22.5	6.0	Durable
2	1:2	20	24.5	23.9	5.0	Durable
3	1:2.5	20	26	25.8	4.5	Durable

[1] By weight of RHA cement

*Average of two determination

** Average of three determinations

Table 4.4.3 Dimensional Changes in Stabilized Soil Blocks

Mix No	Lime: RHA Ratio	OPC content[1] %	Moisture Content used for Moulding Blocks Required	Actual*	Shrinkage** %	Expansion on wetting** %	Moisture Absorption on Wetting** %
1	1:1.5	20	23	22.5	0.07	0.29	16.1
2	1:2	20	24.5	23.9	0.09	0.28	14.9
3	1:2.5	20	26	25.8	0.10	0.25	13.6

1 By weight of RHA cement

** Average of two determinations

** Average of three determinations

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1: Conclusions

From the results of this investigation, the following conclusions can be made:

1. Up to about 23% increase in strength can be achieved by increasing the RHA content in the OPC-lateritic soil mix while the OPC is kept constant in the mix.

2. An average of only about 29% of 28-day compressive strength of the OPC/RHA soil mix is developed at 7 days when the mix specimens are cured under water for 7 days.

3. The 7-day saturated densities of OPC/RHA soil mix used range from 1934-2330kg/m^3 while the 28-day air-dried density is from 1642-1978kg/m^3.

5. It is apparent that OPC/RHA mix is more effective than RHA cement in soil stabilization.

6. An average of only 42% of the 28-day compressive strength of the RHA cement-lateritic soil mix is developed at 7 days when the mix specimens are cured under polythene sheet for 7 days.

7. The optimum lime/RHA ratio for use in RHA cement-stabilized soils is 1:2.5.

8. The densities of the RHA cement-soil were between 1995-1997kg/m^3 at 7 days and between 1629-1805kg/m^3 at 28 days.

9. The addition of 30% OPC (by weight) into the RHA cement-soil mix can increase the strength by 61% and this strength favourably compared with the strength of 8% OPC-lateritic soil mix.

10. An average of only 22.5% of the 28-day compressive strength of the OPC-RHA cement-lateritic soil mix is developed at 7days when the mix specimens are subjected to water spray curing for 7 days.

11. The densities of OPC-RHA cement-lateritic soil mixes lie between 1967-2092kg/m^3 at

7 days and 1698-1967kg/m^3 at 28 days.

12. An increase in wet compressive strength (to a minimum of 2.25N/mm^2) is required before the mixes (containing up to 60% of the RHA by weight) used in this study, can conform with the requirements of BSI (1968) and FMW (1969) on precast sandcrete or concrete blocks. It is probable that this strength increase could most economically be achieved by increasing the OPC content of the mix and perhaps using a more effective blockmaking press.

5.2 Recommendations

From the results of this investigation, the following recommendations can be made on this area of study;

1. The results from this investigation is based on limited number of tests and test period. It is necessary to obtain results from a more detailed test programme which is to be carried out over a longer test period of up to, say, 90days.

2. The effect of soil composition, curing method and method of production of RHA in relation to

the quality of the ash on the strength and other properties of mixes used should be investigated.

3. The need to determine the strength and durability of RHA-based stabilized soil blocks in the field. This should involve the building of a free standing test wall.

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APPENDIX

W.A.B.R.I. EROSION TEST

The procedure for the W.A.B.R.I. block erosion test is described below:

1. After curing has been completed, immerse the block in water for further 24 hours.

2. Place the block in a clean receptacle, large enough to allow the block lie on its largest face. Fill the receptacle with clean water until it just covers the block.

3. Scrub the upper face of the block longitudinally for three minutes by drawing a loaded brush, held parallel to the length of the block back and fore at a rate of approximately one stroke. If a suitable watch or timer is not available, 180 strokes can be counted. Care must be taken not to press on the brush when moving it back and fore, not to allow it to travel so far that it projects over the edge of the block, and to avoid going too near the edge. The brush is a flat household scrubbing brush of the dimension 63.5mm by 158.75mm in cross-section and 38.1mm thick (i.e. a windmill brand 858 "Briton" brush). The brush is loaded centrally by a weight of 30N which is fixed

securely to it.

4. After scrubbing, remove the block, allow the water suspension in the receptacle to stand for ten minutes and decant the suspension.

5. Wash the eroded soil material into an evaporating dish and place in the oven to dry.

6. When dry, collect and weigh the residual soil.

7. Discard brush after 20 tests.

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