SCILCRETE AS A CONSTRUCTION MATERIAL FOR LOW COST HOUSING

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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.

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THESIS APPROVAL

We hereby recommend that the thesis prepared by IR. VALENTINE EZIEFULE EZETAH entitled "Soilcrete as a construction material for Low Cost Housing" be accepted in partial fulfilment of the requirements for the award of Master of Engineering (in Civil Engineering) of Ahmadu Bello University, Zaria.

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DEDICATION

Dedicated to Tomorrow's

NIGERIA.

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ABSTRACT

A soil sample which was identified as a weak material for stabilization with coment was used in testing the load carrying capacity of soilcrote specimens and the various affects on it. The stress-strain deformation pattern of soilcrote was also studied in addition to the effect of height-diameter ratio on the compressive strength of soilcrete cylinders. The soilcrete specimens were produced at action pressure similar to that for hand operated soilcrete block moulding machines.

The results present some knowledge of soilcrete as a building material, and these suggest that hand rated machines are likely to produce soilcrete blocks suitable for low cost housing.

A total of 197 cubes, 79 cylinders and 24 hollow blocks were tested.

CONTENTS

		Page
Title Page		i
Thesis Declaration		ii
Thesis Approval		iii
Dedication		iv
Acknowledgement		v
Abstract		va
Table of Contents		vi
List of Figures		vii
List of Plates		viii
Preface		ix
CHAPTER ONE	Introduction	1
CHAPTER TWO	Literature Review ...	6
CHAPTER THREE	Tests Performed ...	26
3.1	Production of Test Specimens	26
3.2	Tests Performed ...	28
CHAPTER FOUR	Results and Discussions ...	36
CHAPTER FIVE	Conclusions and Recommendations	
APPENDICES	... ...	68
REFERENCES	... ...	86

LIST OF FIGURES

FIG:		PAGE:
4.3.1	14 days compressive strength of cement cubes vs water content	39
4.3.2	14 days compressive strength of 8% cement cubes vs compaction pressure of various water content.	41
4.5.1	28 days compressive strength vs air drying Period (as percentage of 28)	44
4.5.2	Compressive strength vs Period of curring (as a Percentage of 14)	45
4.7	Compressive strength vs height/diameter ratio of soilcrete cylinders.	48a
4.8	The stress strain graph of various soilcrete cylinder specimens.	52a
4.9.1	Compressive strength of 8% cement cubes vs compaction Pressure for different ages.	58
4.9.2	Compressive strength Developement with time of 8% cement cubes, of various compaction Pressures.	59
4.9.3	28 day compressive strength vs compaction Pressure for different cement contents.	60
4.9.4	Strength developement with time for 0% cement cubes.	61
4.9.5	14 days compressive strength vs compaction Pressure for various cement contents.	62

LIST OF PLATES

PLATE:		PAGE:
1	Picture showing the different types of Specimens used in the experiments	5
2.	Picture showing the CEABU Machine used in Moulding the hollow blocks	35

PREFACE

Soilcrete is a material not yet universally accepted for construction of low-cost houses in developing countries. Although much is known about soil-cement for highway construction, this knowledge cannot be entirely applied to soilcrete for low-cost housing because of the difference in their uses and applications, and also a major difference exists in their methods of compaction which is an important factor affecting the compressive strength of soilcrete. Therefore there is the need to study the physical properties of soilcrete as it relates to housing requirements. Compressive strength is of main importance to this study because of its singular importance to walling units (of which soilcrete is mainly used as) and because of the ease in assessing compressive strenth by crushing.

There are no existing standards in Nigeria for the practice of soilcrete, this work is seen as a step towards Nigerian standards and specifications for soilcrete, bearing in mind our perculiar circumstances. The Chief of Staff Supreme Headquarters, Major General Tunde Idiagbon puts it right when he said - "Planners, Policy-makers and Housing Authorities should realise that our increasingly over-populated towns and cities can never achieve tolerable environmental conditions if they insist on rigid housing standards designed for wealthier industrial societies which include housing codes and regulations utterly remote from our social economic realities" (29).

CHAPTER 1

INTRODUCTION

Housing is man's most important need, next to food. This explains the governmental slogan of "housing for all in the year 2000". In terms of the qualitative housing needs, the estimates of housing needs and demands in Nigerian Urban Centres are very staggering. A study (31) puts the figures of needs in Nigerian urban centres at between 3.2 to 3.7 million housing units between 1980 to 1990. These figures do not include housing needs created by replacement of old ones estimated at 13,000 per annum. On the whole, Nigeria is expected to add about 13 million new dwelling units to the existing housing stock before the end of this decade. As only about 30% of Nigerians live in the urban areas (32), the addition of the housing needs in the rural areas, for the attainment of the goal - "Housing for all in the year 200 0" will simply be staggering. Since the cost of building materials constitute about seventy percent of the cost of a building (30), it is therefore implicitly necessary that new building materials that are cheap and locally available must have to be developed for the construction of low cost houses in the urban and rural areas.

Socilcrete is a mixture of soil, cement and water compacted to give a solid mass which takes the shape of

mould. Soilcrete is used for the construction of low cost houses in the developing countries. An impediement to Nigerian housing problem (in addition to lack of foreign exchange to import building materials) is high cost of building materials. Ideally building materials for low cost houses should be produced from locally available raw materials which must be abundantly available. Materials such as burnt clay bricks which are popular construction materials are high energy-intensive and expensive. The advantage of soilcrete is that it is a low energy material. Soilcrete could be produced at the project site which includes rural villages thus reducing transportation costs. Another advantage of soilcrete as a construction material is the addition of value to soil, by increased usage.

The use of any building material depends much on the local codes and specifications for the material in question. The codes and specifications in turn depend on the continous knowledge of the material. This work intends therefore to be part of the continous knowledge of soilcrete as a construction material.

A number of tests were carried out on soilcrete to investigate its performance by the ability to withstand load. The effect of compaction pressure on the compressive strength of soilcrete was studied. The aim was to study the behaviour of soilcrete hollow blocks (400 x 150mm with depth between 160-150mm) that will be produced with

the non power operated machines developed for soilcrete block-production which are very suitable for low cost and rural housing schemes, with a compaction pressure of about $4N/mm^2$(10). The compressive strengths of three shapes of specimens; the cube, cylinder and full size block were also studied. Cylinders with varying height-diameter ratios were crushed to investigate the effect of height-diameter ratio on the compressive strength of soilcrete specimens. The deformation of soilcrete when under stress was studied for different compaction pressures, to assess the effect of compaction pressure on the deformation pattern of soilcrete.

Finally, a number of terms need be explained as used within the context of this text.

Compressive Strength

The compressive strength of a soilcrete specimen is the maximum compressive stress the specimen is capable of developing before failure. This is the ratio of the maximum axial load the specimen can carry, to the original surface area of the specimen before deformation.

Wet and Dry Compressive Strengths

The wet compressive strength of a specimen 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 wet.

The dry compressive strength of a soilcrete specimen is the maximum stress the specimen is capable of developing before failure without immersion in water prior to testing. This means the specimen is tested dry.

Water Content

The water content of a soilcrete mix is the mass of water in the soilcrete as a percentage of the total mass of soil and cement.

Cement Content

The cement content of a soilcrete mix is the mass of cement in the mix as a percentage of the total mass of soil and cement put together, but excluding water. That means that a soilcrete mix of 8% cement content is made up of 8kg of cement and 92kg of soil per 100kg of the dry soilcrete. So also for every 100kg of 12% cement content mix, there are 12kg of cement and 88kg of soil. These represent the following proportions in volume ratios:-

(a) 8% cement content equivalent to (approx) 1:15 cement: soil

(b) 10% cement content equivalent to (approx) 1:11½ cement:soil

(c) 12% cement content equivalent to (approx) 1:9½ cement:soil

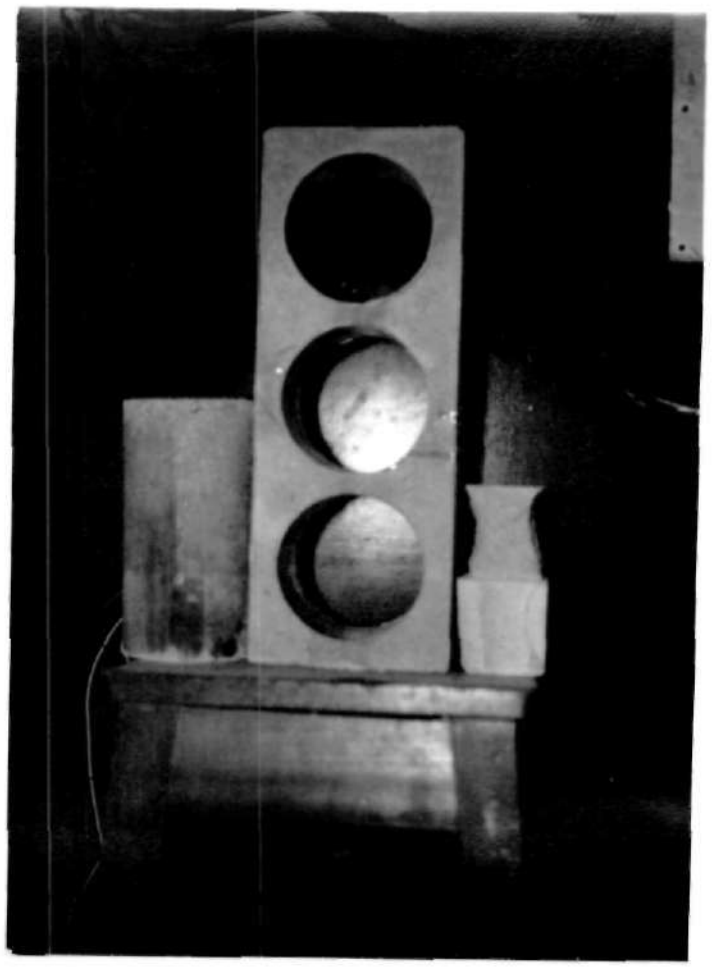
The calculations are based on cement having a specific gravity of 3.1 and soil a specific gravity of 2.4.

Compaction Pressure

Soilcrete elements are produced by "pressing" the wet soilcrete mixes into a compact mass. The amount of press applied to a soilcrete specimen is measured in terms of the compaction pressure. Thus the compaction pressure is the amount of pressure applied on the soilcrete element to compact it.

Calculation of Compressive Strength

The gross cross sectional area of the hollow blocks was used in the calculation of the compressive strength.



Picture showing the different types of Specimens used in the experiments.

CHAPTER 2

LITERATURE REVIEW

Soilcrete is one of the new building materials for construction of houses and its quality depends mainly on soil. Everything cannot be said to be known about soilcrete for the construction of low cost houses in the tropical zones. Standard specifications and codes do not, meanwhile, exist in Nigeria for soilcrete practice. Much is however known about a similar material; soil-cement for highway construction. Most researches carried out on soil-cement presently are on soil stabilization, aimed at knowing more about this highway construction material. These researches and other specifications on soil-cement and cement-related materials have been a guide to this research. These are briefly reviewed.

Laterites

Laterite is the most commonly stabilized soil for construction. Red clay is otherwise known as laterite. The red colour (according to whether it is associated with little or much water) is given to the soil by iron oxide present in it. In laterite, silica tends to be washed away while alumina (aluminium sesquioxide) and iron oxide tend to remain near the surface being relatively insoluble in water unless humus is present (12). Thus a soil with humus tend to be more lateritic.

Laterites are widely distributed throughout tropical and subtropical regions of Africa, South America, Central America, Australia, India and South-East Asia. The word laterite was derived from latin word later which means brick (11). Nanda (13) contends that there is much confusion about laterite. He reports that some people have defined laterite from its morphology, others on the basis of chemical composition, while still others thought to recognise laterite with colour. For engineering purposes, Nixon and Skipp cited on 13 define laterite as those ferruginous and alumino-ferruginous materials having vesicular concretionary appearance which cap a soil profile of either in situ development over a parent rock or similar material. Their colour range from ochre through red, brown or violet. One point agreed by all definitions of laterite is its association with the red colour derived as a result of the iron oxide present in it.

Current Researches

Herzog(9) on the use of additives in the stablization of poorly reacting soils with cement says the poor response of such materials is due to the presence of active organic matter. He found the most active organic matter as that containing the hydroxyl group able to combine with mix. He found calcium chloride effective in sands and ineffective in heavy clays, while ferric chloride was effective in clay. In another investigation (8).

Herzog found that the addition of 0.75% calcium chloride to cement stabilized soils of 8% and 10% cement content gave an increase in the crushing strengths from 3.9N/mm^2 and 5.2N/mm^2 to 5.7N/mm^2 & 7.6 respectively, that is an average of about fourty-seven percent increase in strength.

Dumbleton (6) in his investigations 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 require a strength of at least 1.7N/mm^2 at seven days to show an indication of proper hardening of the cement. He observed that the mixture of lime and cement for stabilizing clay gave the highest strength values. The effect of immersion in water on the compressive strength of clay soils stabilized with hydrated lime is a constant loss of strength for any particular clay and is independent of age. He observed that the soaked strength increased with age. He points out that hydration of cement is independent of the soil and that this is the primary source of strength for the cement-stabilized soils. There is the effect of soil type on the strength of stabilized soil. This effect is mechanical - particle size distribution; and chemical - due to compounds present like organic matter which affect the hydration of cement. But in the case of lime there is no case of hydration to form cementitious compounds. It is 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 more calcium ions are supplied to the mix (6).

In his investigations on the compressive strength of hollow blocks, Ejeh (7) tested soilcrete hollow blocks produced by Occidental Construction Company Zaria. The company is situated in Kakoyi area of Zaria, where there is abundance of laterite. The Company uses the block moulding machine made by Tecmor, Brazil. Blocks tested for crushing strength gave average compressive strength per gross area (dry) of $4.4N/mm^2$ for blocks of 10% cement content and $2.5N/mm^2$ for 8% cement content. Ejeh reports that the hollow blocks produced by the Company were of dimensions 400 x 150mm cross section, with varying heights due to varying amount of material fed into the block mould and unsteady compression pressure. The company produces blocks of 8% cement content for market sales. In his tests carried out with 8% cement content hollow blocks, Ejeh observed that the block strengths are affected by the contact layer while testing for strength. He made other number of observations which include that:-

(a) The ratio of wet strength to dry strength of soilcrete hollow blocks were of two types; the first is the constant wet strength ratio in which the average value is 65%. The second ratio being the minimum wet strength-dry strength ratio with an average value of 42%. This minimum wet-dry strength ratio is got after one day's immersion in water prior to testing for compressive strength while the strength

ratio increases with the increase in the number of days of immersion in water prior to testing for strength, to the constant wet-dry strength ratio.

(b) The wet-dry strength ratio for 8%, 10% and 12% cement content hollow blocks are 42%, 38 and 45% respectively.

Ejeh also investigated the curing methods for soilcrete hollow blocks and recommends that for standard tests and quality control, the immersion in water method is more conducive to laboratory atmosphere since spraying is uneven and the quality of water used cannot be said.

He concludes his research findings by recommending among other things that:-

(1) Soilcrete hollow blocks will fully develop their compressive strength after curing by spraying with water and covering with water proof materials for a week.

(2) For purposes of laboratory tests, the immersion period of 24 hours in water prior to testing for wet compressive strength should be adopted for soilcrete hollow blocks. Since this immersion period gives the minimum wet compressive strength it therefore presents the worst conditions likened to a (house) site flooded for 24 hours during the rainy season and the lowest strength of the walling units is envisaged.

(3) Soft boards should be adopted as the contact layer for the compressive strength test for soilcrete hollow blocks.

(4) The 12% cement content soilcrete blocks after 12 days

immersion in water prior to testing have an average wet compressive strength of 3.0N/mm^2 with the lowest individual strength of 2.3N/mm^2 which satisfy the requirements of 2.76N/mm^2 imposed by B.S 3028 on type B sandcrete blocks. (5) The compressive strength in relation to the compaction pressure should be investigated.

Finally he reports that a minimum compressive strength of 1.4N/mm^2 has been recommended by several building authorities throughout the world for stabilized soil blocks.

Working on the characteristics of the optimal water-cement ratios of some local clays, Aderibigbe (3) et al crushed three cylinders at a time of the ages of 3, 7, 14 and 28 days. They made a number of observations as follows.

(1) The ratio of compressive strength measured from cylinder specimen range from 0.21-0.4 of cube strength which was considered low (with an average of 0.33) compared to 0.54 for periwinkle concrete and 0.75 for gravel concrete.

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

(3) The density of laterite-cement mixes were found to be between 1288-2229kg/ m^3. The report was concluded by saying that:-

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

(b) The optimum water/cement ratio increases linearly with increasing laterite-cement ratio.

Also regarding the water-cement ratio of a mix, Dutron (5) et al found that maximum compressive strengths of stabilized laterites were obtained at optimum moisture contents or slightly less.

In his research findings presented at the 7th Biennial Conference of West African Science Association (1) Professor Adepegba made a number of observations and findings as follows:-

(1) He 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 contain little or no stones and more redish than the rock laterite. In general, the soft laterite come out of the pit pulverized and all particles can pass through B.S. sieve number 7.

(2) The factors which affect the strength of a mix are (a) cement content; (2) particle size; (c) type of soil; (d) uniformity of mix; (e) airing period and curing conditions.

(3) Between 0 and 22% cement content, latercrete is superior to sandcrete structurally.

(4) Since soil-cements are best used as blocks, the water content must be right to enable immediate demoulding.

(5) The mean optimum moisture content was 17%. For all mixes, the optimum moisture content of the soft laterite remains approximately constant, for increasing cement

content. This is because particles of about same size with cement form 95% of soft laterite. The optimum moisture content for soft laterite is about the plastic limit.

(6) Soft laterite gave higher strength values than rock laterites.

(7) 9% latercrete (1 cement:12 laterite) is better than the present use of 1:6 for first class sandcrete jobs.

(8) The elastic modulus of late crete is about half that of sandcrete. This means that latercrete will have higher deformation before failure.

In a paper presented at the conference on material testing research and control, Cleszkiewicz (15) et al reported that the compressive strength of hollow blocks is taken as the ultimate failure axial load divided by the gross cross-sectional area (including hollow). The actual stresses in the tested hollow blocks are from 133-300% of the assumed minimum stresses. It was also reported that soft board sheets are the most suitable contact layers for all assessment of soilcrete compressive strength, and that 90% of the 28 day strength is developed within the first week and the other ten percent within the next three weeks.

Uzomaka (27) on methods of testing some physical properties of sandcrete, observes that capping of the bed faces of sandcrete blocks as suggested by Nigerian Standard Organization draft code on the practice of sandcrete gives

rise to a misconception of the actual load bearing area of the block. He also observes that capping increases the strength of the block because the mortar provides greater area for load distribution and has a stiffening effect by filling up the interstices of the block. Capped or uncapped, it is the solid area of the block that transmits and sustains the load. Thus he gives the compressive strength of a sandcrete hollow block as $Us = \frac{P}{BL-2ab}$

where P = the ultimate failure axial load

B,L = the width and length of block respectively

a,b = width and length of the cavities (two).

This agrees with Cleszkiewicz et al and makes a distinction between compressive strength of hollow blocks and solid blocks.

Lunt (10) investigated the use of stabilized soil blocks for low cost housing. He reports that soil is mankinds oldest building material and traditional methods of soil construction such as rammed earth, wattle and duab, and adobe are still commonly used in many regions of the world. He reports that soils suitable for stabilization are widely distributed about the world, they are far from universal. A soil which has been compacted properly will be stronger and more durable than when poorly compacted. The optimum moisture content which gives maximum soil density can be determined by a standard laboratory procedure. These tests he contends 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. Lunt studied two Ghanaian soils stabilized with hydrated lime. Blocks used in the investigations were of dimensions 290 x 140 x 90mm. These soils stabilized with hydrated lime were compacted at pressures of 4, 8 and 16MN/m^2. It was observed that the strength of these soils improved from 1.05 MN/m^2 to 3.55 MN/m^2 for the Fumesua soil. The Kumasi soil has 9 percent gravel, 35% sand and 56% silt and clay, while the Fumesua soil was 1.5% gravel, 39.5% sand and 49% silt and clay. He observed that all blocks produced at or above 8 MN/m^2 gave strengths which exceeded the minimum recommended design value of 1.4 MN/m^2. The soil blocks compacted at higher pressures also exceeded the minimum strength of 2.8 MN/m^2 which is specified by BS 2028. On the durability of the stabilized soil, he reports that with CINVA-RAM blocks and those made at 4MN/m^2 pressure, some surface damage occured after spraying them with water for six hours. He continues that a soil wall must possess adequate strength to satisfy load bearing requirements. In most climates the wall will be wet at various times, so it is important that the wet compressive strength should be determined. He reports that the wet strength of a stabilized soil wall will be only one-third of its dry strength. He contends that although small test specimens could be used to economise materials, full-sized blocks should be tested in building projects of importance.

Soils for Stabilization

Any (24) soil can be stabilized if sufficient amount of cement is added, but the cement content required to achieve a given stability must normally be increased as the silt and clay content increases. This means it may not be economically possible to stabilize with cement certain soils such as heavy clays. American experience (24) indicates that sandy and gravelly soils with about 10-35% silt and clay have the most favourable characteristics for cement stabilization. Experience in Britain is that soils with liquid limit greater than 45 and plastic index over 20, cannot be economically stabilized with cement. Cla (23) reports that soils with liquid limit less than fourty and clay content up to about 20% are suitable for stabilization. The table below he reports serves as a guide to selection of soils for stabilization.

Type of Location Physical Properties	For Permanent Urban Buildings	For Rural Housing with Low Rainfall
Clay content	between 5-20%	between 5-30%
Sand content	33% minimum	40% minimum
Liquid limit	40% maximum	50% maximum
Plastic index	between 2.5-22%	2.5-30%
Optimum moisture content	between 10-14%	between 7-16%

Adepegba (1) reports that according to highway research board a good soil for economic stabilization with cement should be within these particle sizes:

passing ASTM sieve No 4 (4.76mm) 50%

passing ASTM sieve No 40 (0-42mm) 15-100%

passing ASTM sieve No 200 (0.074mm) 50%

In addition the liquid limit should be less than 40, and the pastic index not greater than 18.

In the stabilization of soils, any type of cement could be used (34). American recommendation as to amout of cement required to stabilize soils shows that the least amout 3-5% of cement by weight is required by A-1-9 soils, the percentage increasing to 9-15% for A-6 soils and 10-16% for A-7 soils which require the highest amount of cement content for stabilization.

Shape Factor in Concrete Testing

A brief mention of the influence of size and shape of specimen in the testing of concrete for compressive strength is considered necessary as soilcrete tests are guided by concrete test specifications.

The test specimen for concrete according to BS 1881 must be a 150mm cube except if the maximum aggregate size does not exceed 3/4", a 4 inches oube may be used. The standard size of compression test specimen under ASTM designation C192-57 is a cylinder having a diameter of 6 inches and a length of 12 inches.

One of the difficulties of testing concrete for ultimate strength is that the value of the crushing strength is dependent on the shape of the specimen (19). The friction between the specimen and the crushing surfaces of the testing machine restrains the specimen at either end and causes an apparent increase in strength. With a prism which is the usual shape of test specimens in Europe, the ratio of the length to breadth is invariably unity, but if cylinders are used any ratio of length to diameter can be adopted (19). The effect of this ratio on the crushing strength is given in graph form. The effect of the length-diameter ratio is smaller for ratios of 2 and above, than for ratios under 2, therefore this is probably the best ratio to choose (19). It also seems that the choice of the standard ratio of 2 is suitable not only because the end effect is largely eliminated and a zone of uniaxial compression exists within the specimen, but also because a slight departure from this ratio does not seriously affect the measured value of strength (28). This end effect decreases more rapidly the more homogeneous the material; it is thus less noticable in mortars and probably also light weight aggregate concrete (28). BS 1881 gives a correction factor to be adopted for compressive strength of cores drilled from hardened concrete so as to obtain the equivalent strength of cylindrrical specimen with height-diameter ratio of two. This correction factor is presented in form of a line equation; $CF = 0.89 + 0.11r$ where CF is the correction factor, r is the height-diameter ratio in excess of one and 0.89 is the constant for a

height-diameter ratio of one (19). It shows that there is little difference between the compressive strength of a cube and that of a cylinder with height-diameter ratio of unity (28). Although BS 1881 and ASTM C42-68, both give correction factors for height-diameter ratios, it has been found that correction depends on the level of strength of concrete. High strength concrete is less affected by variations in the proportions of the specimen and such a concrete is less influenced by the shape of the specimen (23). The influence of height-diameter ratio on the conversion factor is of practical significance in the case of low strength concrete when cores with height-diameter ratios less than 2 are tested, there is the tendency to over-estimate the strength that would be obtained with a ratio of 2 and it is the case of low strength concrete (or suspected of having too low a strength) that a correct estimate of strength is particularly important (28). It has been found that with light weight aggregate concrete the value of the ratio of a standard cylinder to a cylinder of height-diameter ratio of unity is between 95-97% (28). BS 1881 states that the strength of a cylinder is equal to four-fifths of the strength of a cube, but experiments have shown that there is no unique relation between the strength of the specimens of the two shapes. The ratio cylinder strength/cube strength depends primarily on the level of strength of the concrete and is higher, the higher the strength of concrete.

Strain Gauges(2)

The stress-strain relation of soilcrete as studied in this text were with strain gauges. Therefore strain gauges need be mentioned briefly. The relationship between the state of stress in a material and the surface strain has been known for many years although there is no precise information on the first uses of strain measuring devices.

The resistance strain gauge is the simplest in concept and least expensive. The relationship between the resistance change and the change in strain in a resistance strain gauge is called the gauge factor. The major features of ideal strain gauge include among others:-

(1) small size and mass, and low stiffness.
(2) suitability for static and dynamic measurements.
(3) freedom from temperature effects and other environmental conditions.
(4) low cost.

A number of factors affect the selection of strain gauges for measurements, these are briefly discussed.

(1) Single strain gauges are used when the loads are calibrated and the stresses are in one direction or uniaxial.

(2) The type of load determines the type of gauge e.g linear gauges for tensile and compressive loads and torque gauges for torsional load.

(3) If the direction of the principal strains is unknown, 3 gauges are used and the principal strain located by resolution of forces.

(4) Size of specimen determines the maximum size of gauge to be used.

(5) If expected strains are low (100×10^{-6}) the largest gauge and highest wattage is used.

(6) For static loads high stability of gauges is required while for dynamic loads a high output is more important.

(7) Small stress concentrations require the use of small gauges.

(8) Temperature at which tests are to be carried out also influence the selection of suitable foil.

Installation and Applications

In using adhessive for strain gauges' bonding, a number of fundamental precautions are necessary.

(a) The surface of the specimen must be well prepared and made free from dust to ensure good contact between the gauge and the specimen surface.

(b) The layer of adhessive applied should be as thin as possible.

(c) Adhessives must be mixed correctly.

(d) The gauges must be well protected from short curcuiting.

Soil block making process and Machines(10)

Concrete block machines are normally unsuitable for making stabilized soil blocks. This unsuitability of concrete block machines has led over the past years to a number

of simple press being developed. Lunt (10) in his paper describes some of the known presses which are being used for housing construction in the third world.

There are two main types of presses - (a) constant press and (b) constant volume. With the constant volume type, the ram moves a fixed distance. Reducing the amount of soil fed into the constant pressure machine will produce a smaller block, but with the constant press type, less soil will cause under-compaction and give a block of low density. In both cases therefore the amoung of soil fed into the machine is important and should be controlled with care. Although it is doubtful whether manually operated presses can produce compaction pressures higher than $4MP/m^2$, they are still popular throughout the developing countries because of their cheapness, simplicity and mobility. Lower driven presses although capable of producing denser blocks at higher outputs are likely to be more expensive as it may be difficult to obtain spare parts as readily as for the simpler machines.

There are about seven machines developed to date for the production of soilcrete blocks. They are discussed here.

Cinva Ram

This is hand operated originally designed by Inter-American Housing and Planning Centre (CINVA) in Bogota Colombia. They are now manufactured in several countries

under license from the IDEC Housing Corporation in New York U.S.A. This utilizes a lever system to a press a piston on the mixed material. It is capable of producing 300 blocks and more daily.

Tek Block (10)

This was designed by University of Science and Technology Kumasi Ghana. It equally utilizes a lever system like in the CINVA Ram, but the lever arm is made of wood instead of the 3-piece metal arm of the Cinva ram. It produces 290 x 215 x 140mm blocks and output is between 200-400/day depending on the number and skill of the workmen.

Landcrete

This South-African made landcrete press; is hand operated and can produce blocks of various sizes. It is reported that this press may no longer be available as all references to it are found only in old literature.

Ellson

This is produced by Ellson Pty South africa. It is manually operated press which is claimed to produce very dense blocks because of its high lever ratio of 500-1. One particular Ellson model - the Universal Press is claimed to produce about 1000 blocks daily at compaction pressure of about 7MN/m^2 with two men operating the levers.

Superter

A range of hyraulically powered soil-cement brick press is being manufactured in Brazil. One version has a

4 block mould producing a brick size of either 230 x 110 x 50 or 200 x 100 x 50 with an output of 20,000 bricks per 8 hour day. It is powered by a 5HP electric motor.

Latorex

A Danish Firm Drostholm products has developed a plant system for the high speed production of lime-stabilized laterite blocks. It is designed for a wide range of soils. It produces 230 x 110 x 55mm bricks at a capacity of 12,000 bricks/8 hour day. The press operate at high pressures. The bricks can be steam-cured and are claimed to have a compressive strength of between 15 and 40MN/m^2.

CELBU (26)

A machine for the production of soilcrete hollow blocks was developed by the Civil Engineering Department of Ahmadu Bello University, Zaria. It allows the variation of pressure and hollow formers. It produces blocks of dimensions 400 x 150 x 150mm. The press is provided by a frysonet machine and the applied load read from the machine. One block is produced at a time.

CHAPTER 3

TESTS PERFORMED

3.1 Production of Test Specimens

The soil for the production of the test specimens for this research was dug out from a site at a depth of about 300mm after scraping away top soil. The soil was dried and sieved to pass through British Standard Sieve No. 7. Sieving of the soil makes the cement-soil mixtures thorough and uniform. In all the various tests carried out, three types of specimens were used. The specimens are (1) 70.7mm cubes (2) 103mm cylinders (3) full size hollow blocks 400 x 150 x (150-160). The water content range for the production of soilcrete was earlier determined.

The first type of specimen produced were the cubes. Too less water could not allow the material to be moulded, while too much water caused the material to flow when some compacting "press" was applied. Moulding of soilcrete specimen required the application of compacting press, it means that for the cubes, the required 70.7mm height could not be achieved in one compression but in two stages. The cubes are left in the mould for one day before demoulding and consequent curing, by immersion in water and air drying.

The cylindrical specimens were produced using the same machine (the universal testing machine) as in the case of the cubes. Adaptations were made to fit the production

of these specimens by the machine. A cylindrical mould of internal diameter of 103mm was filled with soilcrete mix and a slight manual "pre-compression" was done to create space for additional material to be added so that compression was achieved in one stage. Except specimens for testing of variation of strength with height/diameter ratio, where deliberate attempt was made to vary the heights of the cylindrical specimens by varying the amount of material put into the mould, in all other specimens conscious effort was made to mould equal amounts of material which kept the cylinder heights ranging from 195 to 208mm. The specimens are demoulded immediately after casting by pushing out of the mould.

CEBU machine was used in the production of some hollow blocks. The mould is filled with material and given some manual "pre-compression" and then filled. Compaction is done at one stage. The blocks are demoulded immediately after by pushing it out of the mould.

The major difficulty in the production of soilcrete test specimens lies on its demoulding. As was earlier mentioned, cubes were demoulded one day after casting.

The cylinders and full size blocks were demoulded immediately by pushing them out of their moulds. This no doubt induced some strains on the fresh specimens and consequent dislodgement of a good "foundation" for build-up of compressive strength. Also in addition, the immediate demoulding caused some "rebound" in the specimens; having been subjected to high compaction and release. These two factors account for the appearance of cracks on the cylinders and blocks. These craks appear immediately after demoulding, increasing to the maximum in a space of time of about thirty minutes.

For the reasons above, an attempt was made to mould some blocks without demoulding by pushing. This could not be achieved because it required a special mould with all the four sides collapsible which could not be made available at the time of this research. Another major problem in the production of soilcrete blocks is high reinforcement requirement of the steel moulds as the compaction pressure increases.

3,2 Tests Carried Out

3.2.1 Identification and Calssification of Soil

The soil sample was dug from the new Faculty of Engineering building site. Tests were carried out to identify and classify the soil according to BS 1377 - *methods of tests for soil classification and compaction.* These tests were specifically made:-

(a) The specific gravity of the soil was determined using the specific gravity bottles.

(b) The sieve analysis of the soil was determined by the wet method in addition to a sedimentation test as most part of the soil passed through sieve No. 200.

(c) The maximum dry density and the optimum moisture content of the soil was determined, using the standard proctor method.

(d) The Atterberg's limits were determined and all the results are presented in chapter 4.

3.2.2 Determination of Water Content Range

A number of cubes were moulded at different water contents and it was observed that at water content of about 16% a compaction pressure of $2N/mm^2$ could not be exceeded, as the material flows out of the mould when pressed. Also moulding was not good at water content of 8% and less. Therefore 3% and 16% were assumed two extremes of water range. A compaction pressure of $4N/mm^2$ could not be exceeded without damage to the moulds. Therefore a compaction pressure of $4N/mm^2$ was adopted in moulding fifteen cubes without cement (0% cement) within a water content range of 10-15%. The cubes were crushed after 14 days and the results of the test are given in table 4.3.1 and discussed in 4.3.1.

3.2.3 Method of Curing

Following a previous research by Ejeh (7) the method of curing of the specimens to get the highest strength was

studied. Thirty cubes were moulded with cement content of 10% at a water content of 14% and compaction pressure of $4N/mm^2$. All the samples were demoulded after one day and subjected to different curing conditions.

For the twenty-eight day strength investigations, three samples were crushed after complete immersion for 13 days and air dried for 14 days. Three were crushed after immersion in water for twenty days and air dried for seven days. Three others were crushed after immersion in water for twenty-four days and air dried for three days. While the last three were crushed after twenty-six days in water and air dried for one day. In all, the cubes were crushed at an age of twenty-eight days.

For the 14 days strength, three cubes were crushed after six days immersion in water and seven days air drying. Three were crushed after ten days immersion in water and three days air drying while three others were crushed after twelve days in water and one day air drying. All the samples were crushed at the age of 14 days.

The seven days strength was also investigated. Six cubes were crushed. Three were crushed after three days immersion in water and three days air drying, while the other three were crushed after five days immersion and one day air drying.

It should be noted that the curing method being investigated above is for cubes stabilized with cement.

The curing method for no-cement cubes need not be investigated as immersion in water dissolves the cubes. Therefore the curing of all specimens without cement was simply by air-drying. The results of the curing tests are discussed and presented in chapter 4.

3.2.4 Durability

Six cubes with a cement content of 8% were moulded at a compaction pressure of $4N/mm^2$ and a water content of 14% were subjected to water spray. A shower of water with a pressure head of about 2.5m was allowed to spray water on the cubes with the face of the cubes 200mm from the shower face. The spray was continuous for six hours. This is similar to the quick tests carried out by Lunt (19) and Bedi et al (33).

3.2.5 Uniformity of Mix and Moulding Process

The uniformity of the soilcrete mixes were apparent. First a thorough (or complete) mixing of the soild and cement is apparent through the uniformity of the colour. Initially the colour of the soil is different from that of the cement but a good mixing produces a uniform colour. Also soil being a cohesive material forms pallets when water is added. A good mix ensures that the pallets are broken into tiny uniform sizes. But to test emperically the uniformity of the mixes ten cubes of 8% cement content and water content of 14% were moulded and crushed after 14 days for compressive strength. The results are discussed in chapter 4.

3.2.6 Wet/Dry Compressive Strength Ratio

Cubes of 8% cement content and 14% water content were crushed after one days immersion in water prior to testing for crushing strength while three others were crushed dry. Six other cubes were crushed at 28 days; three were crushed dry while the other three were crushed after one day's immersion in water prior to testing.

Six cylindrical soilcrete specimens of 8% cement content were crushed, three dry and the other three after one day's immersion in water prior to testing for compressive strength.

Six cylinders of 12% cement content and full size blocks (400 x 150 x 150) of 8% and 12% cement contents were also subjected to wet and dry tests. The results of wet/dry compressive strength tests are presented and discussed in chapter 4.

3.2.7 Shape Factor on Compressive Strength

Cylindrical soilcrete specimens of 8% cement content were moulded at a water content of 14%. The cylinders were produced in different height/diameter ratios. All specimens were tested for compressive strength after 14 days of moulding, by crushing. The aim of the test being to determine the variation of strength with height/diameter ratio of the cylinders.

Also to study the effect of the shape of the specimen on the compressive strength, cubes and full size hollow blocks of 8% cement content compacted at a pressure of $4N/mm^2$ and water content of 14% were crushed after 14 days of moulding. The aim being to compare the compressive

strengths of cube-cylinder-hollow block of same mix and compaction pressure. The results of this test are presented and discussed in chapter 4.

3.2.8 Stress-Strain Tests

In the deformation tests, the standard method for testing of concrete (BS 1881) was adopted as a guideline. The TML PL 10 and TML PC 10 strain gauges with gauge factors 2.08 and 2.11 respectively were used to record the strains in the specimens while the stresses were applied by the universal dension testing machine. For these test 8% and 12% cement content cylinders were used. The 8% cement content specimens were compacted at pressures of 1 to 4N/mm^2, while the 12% cement cylinder were compacted at a pressure of 4N/mm^2. All the specimens were of water content of 14% and were all cured by complete immersion in water for six days and air drying for seven days. The specimens were subjected to stresses while recording the strains. The aim of the tests is to study the deformation of the soilcrete specimens with respect to different compaction pressures and cement content. These results are presented and discussed in chapter 4.

3.2.9 Compressive Strength Tests

First fifteen cubes of zero cement content and 14% water content were crushed after 1, 3, 7, 14 and 28 days for compressive strength development. For all the

compressive test specimens, a water content of 14% was selected and used.

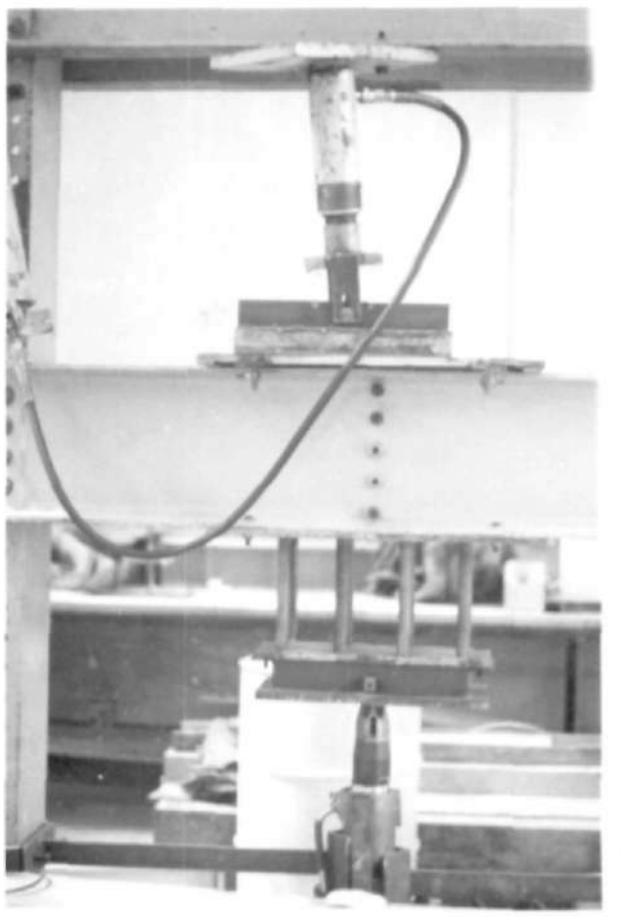
Fourty-eight cubes of 8% cement content were moulded at varying compaction pressures of 1, 2, 3, 4N/mm^2. These were crushed in the universal tension testing machine after 3, 7, 14 and 28 days of moulding. The cement content of the cubes were increased to 10% and 12% respectively, compacted at various compaction pressures of 1, 2, 3 and 4N/mm^2. These cubes were also crushed after 28 days. The aim of all the cube tests above being to investigate the variation of strength of the cubes with compaction pressure and cement content. Also to study the strength development with time of soilcrete specimens.

Cylindrical specimens of 8%, 10% and 12% cement content were moulded at varying compaction pressures of 1-4N/mm^2. The specimens were crushed after 14 and 28 days of moulding.

Hollow blocks of size 400 x 150 x 150 and cement contents of 8% and 12% compacted at pressure of 4N/mm^2 were moulded using the CERAU machine (a machine developed in the Department of Civil Engineering, A.B.U., Zaria, for the production of soilcrete hollow blocks) and these were crushed after 14 days. These hollow blocks were cured by water spray while covered with bag material to prevent loss of water by evaporation and aid even distribution of the water sprayed on the blocks. The aim of this method of curing is to subject the blocks to worst condition in

addition to attaining real industrial conditions. These blocks were crushed for compressive strength; eighteen were crushed for wet compressive strength.

The results of strength tests are presented in chapter 4.



Picture showing the CEABU Machine used in Moulding the hollow blocks.

CHAPTER 4

RESULTS AND DISCUSSION OF RESULTS

4.1 Identification and Classification of Soil

The colour of the soil is light brown changing to reddish brown on addition of water. This suggests some link with lateritic soils but very far from a typical laterite which is usually red as the case of Kokeyi laterite deposit (7). The sieve analysis shows the constitution of the soil as follows:-

Percentage finer than BS No. 7 - 99.75

Percentage finer than BS No. 200 -79.50

Percentage sand - 20

Percentage silt - 60

Percentage clay - 20

The atterbergs limits of the soil are

(a) Liquid limit - 34%

(b) Plastic limit - 14%

(c) Plastic index - 20%

(d) Optimum moisture content - 16%

(e) Maximum dry density - 1836kg/m^3

Specific gravity = 2.4

Group Index = 8

The AASHO classification of the soil is A-6 soil. This agrees with an earlier report (7) that most laterites in Zaria are A-6 group. This soil specimen will ordinarily

be described as a silty soil.

From the table suggested by Professor Ola (22) the minimum sand content required for a soil suitable for stabilization with cement is 33% and also Professor Adepegba (1) reports that a soil for economic stabilization with cement, less than 50% should pass sieve No. 200. It would therefore be appreciated that from the two suggestions above of soils suitable for economic stabilization with cement, this soil sample would be regarded a poor material, and may be a waste also.

4.2 Durability

Lunt (10) subjected blocks stabilized with lime and compacted at about $4N/mm^2$, to water spray and found scratches on the blocks. But for the cubes tested, there were no signs of any water spray or errosion on them and this did not encourage any further research on durability by water spray. One point is however certain, there is improved durability performance over mud only which would be washed-off when subjected to the same water spray.

4.3 Water Content Range

The table (table 4.3.1) shows the variation of compressive strength for plain soil samples with different water contents. Plotting a graph of strength against water content in plain soil samples (see graph No. 4.3.1) gives a curve which becomes flat at 14% which is just 2% away from the optimum water content.

Table 4.3.1: The average compressive strengths of 0% cubes at various water contents, compacted at a pressure of $4N/mm^2$ and crushed after 28 days.

Water Content	Compressive Strength
10%	$3.4N/mm^2$
12%	$4.9N/mm^2$
13%	$5.1N/mm^2$
14%	$5.2N/mm^2$
15%	$5.1N/mm^2$

Table 4.3.2: The average dry compressive strengths 6% cement soilcrete cubes of different water contents and compaction pressure

Compaction Pressure	Compressive Strength		
	Water Contents = 14%	Water Contents 12%	Water Contents 10%
$1N/mm^2$	$3.4N/mm^2$	$3.3N/mm^2$	$3.3N/mm^2$
$2N/mm^2$	$6.5N/mm^2$	$6.2N/mm^2$	$5.7N/mm^2$
$3N/mm^2$	$7.5N/mm^2$	$8.2N/mm^2$	$7.1N/mm^2$
$4N/mm^2$	$8.3N/mm^2$	$8.3N/mm^2$	$7.3N/mm^2$

FIG. 4.3.1: 14 days compressive strength of no-cement cubes Vs water content

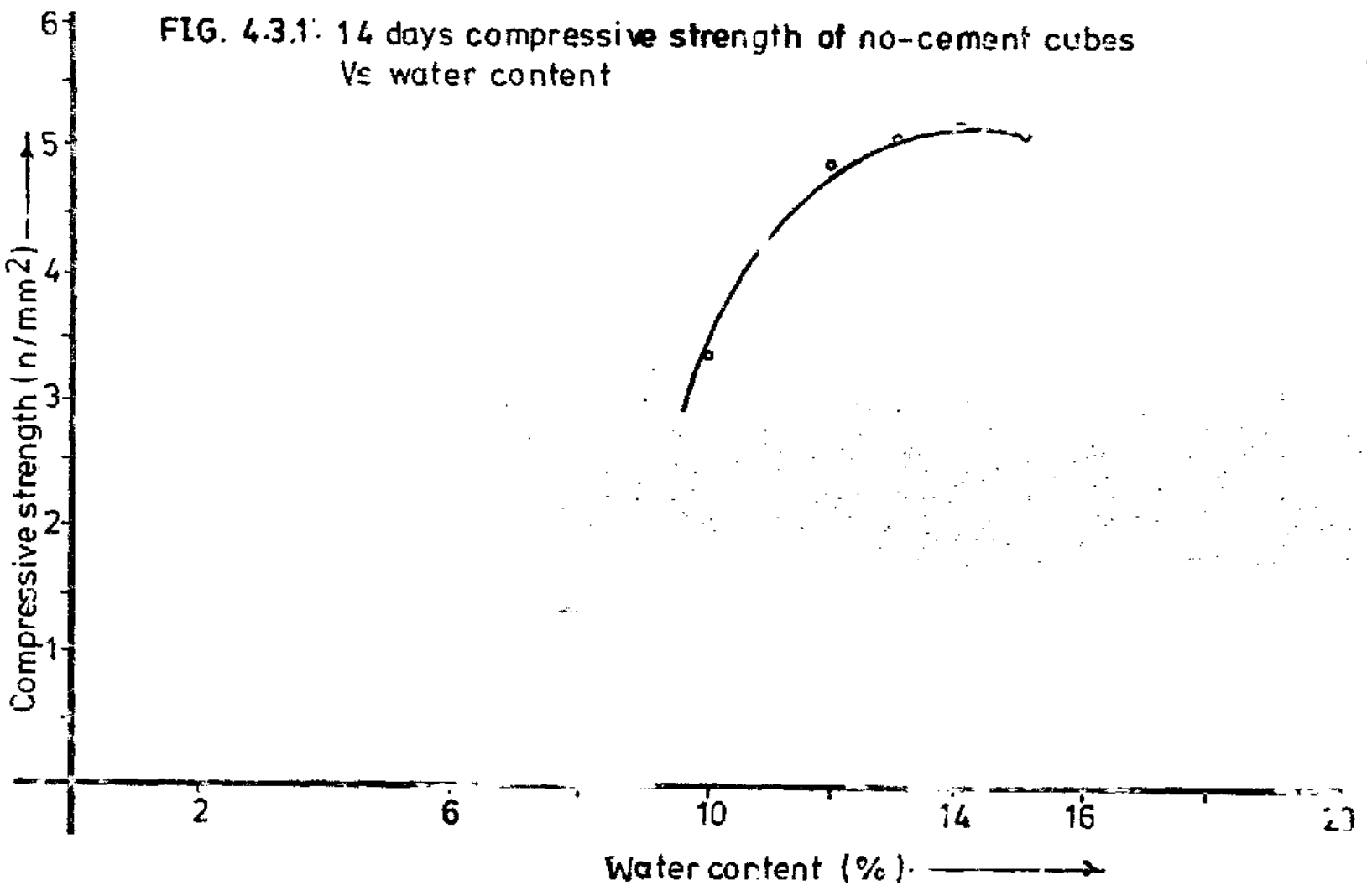


Table 4.3.2 gives the variation of strength with compaction pressure for different water contents of 8% cement content soilcrete. The strength of cubes was plotted against compaction pressure (see Fig. 4.3.2) for different water contents. The result confirms the strength was higher for 14% water content.

4.4 Uniformity of Mix

As was earlier said in this text, the uniformity of mix is visually apparent. However the results of the tests of the ten cubes show that the cubes have a mean strength of 8.1N/mm^2 and a standard deviation of 0.49. This limited results of the strength dispersions of the specimens are presented in table 4.4. Included in the table are results from an earlier study (7) of industrial soilcrete hollow block production. The results show that the soilcrete cubes (3% cement content compacted at a pressure of 4N/mm^2 and water content of 14%) have the same coefficient. (The coefficient of variation is equal to standard deviation/mean)of variation of 6% with the hollow blocks of same cement content and compaction pressure.

Although the results are limited, a low value of 6% coefficient of variation indicates a fairly uniform and constant mixing, of the soilcrete specimens. It will be observed from the table 4.4 that the industrially produced blocks have a higher coefficient of variation, which suggests greater dispersion of the strengths.

4.5 Curing Tests

Table 4.5 gives the results of the curing tests. The specimens for these tests were 10% cement cubes compacted at a pressure of $4N/mm^2$ and water content of 14%. The 28 day strength-curing test is plotted against the number of days of air drying (after complete immersion in water) expressed as a percentage of 28 days in graph (Fig. 4.5). In Fig. 4.5.1 the same was done for 14 days curing test. It should be noted that for 28 day strength, the period (number of days) of immersion in water of the specimen, plus the period of air drying plus one day (after which the specimen is cured in water) will sum up to 28 days. So also for 14 days curing, one day plus immersion period and air drying period sum up to 14 days.

The results show that for 28 days strength the highest strength was achieved with 25% air drying (seven days air drying) while for 14 days strength the highest strength was achieved for 50% air drying (7 days air drying). For each case, a projection of the curve to 100% air drying indicates a low strength. This means that the specimen in question cured by 100% air drying was not immersed in water at all and that explains the recorded low strength.

Table 4.4: Table showing the average compressive strengths, standard deviation and fractional standard deviation of a number of soilcrete specimens.

	Average C/strength	Standard deviation	**Coeficient of variation in percentages
(8% cement) soilcrete cubes	8.1	0.49	6%
(8% cement) hollow blocks	1.4	0.09	6%
(12%) cement hollow blocks	2.1	0.16	8%
*(8% cement) hollow blocks	2.0	0.30	15%
*(12% cment) hollow blocks	2.5	0.67	27%

*Dry compressive strengths and standard deviation results of an earlier research (7).

** Coefficient of variation =

Table 4.5: The average dry compressive strength of 12 percent cement soilcrete cubes subjected to different curing conditions

Age	Compressive Strength. No. of days of air drying before crushing			
	14 days	7 days	3 days	1 day
28 days	7.0N/mm^2	9.6N/mm^2	6.6N/mm^2	4.9N/mm^2
14 days	1.8N/mm^2	9.1N/mm^2	5.8N/mm^2	4.6N/mm^2
7 days	-	-	5.6N/mm^2	4.5N/mm^2

FIG. 4.5.1: 28 days compressive strength Vs air drying period

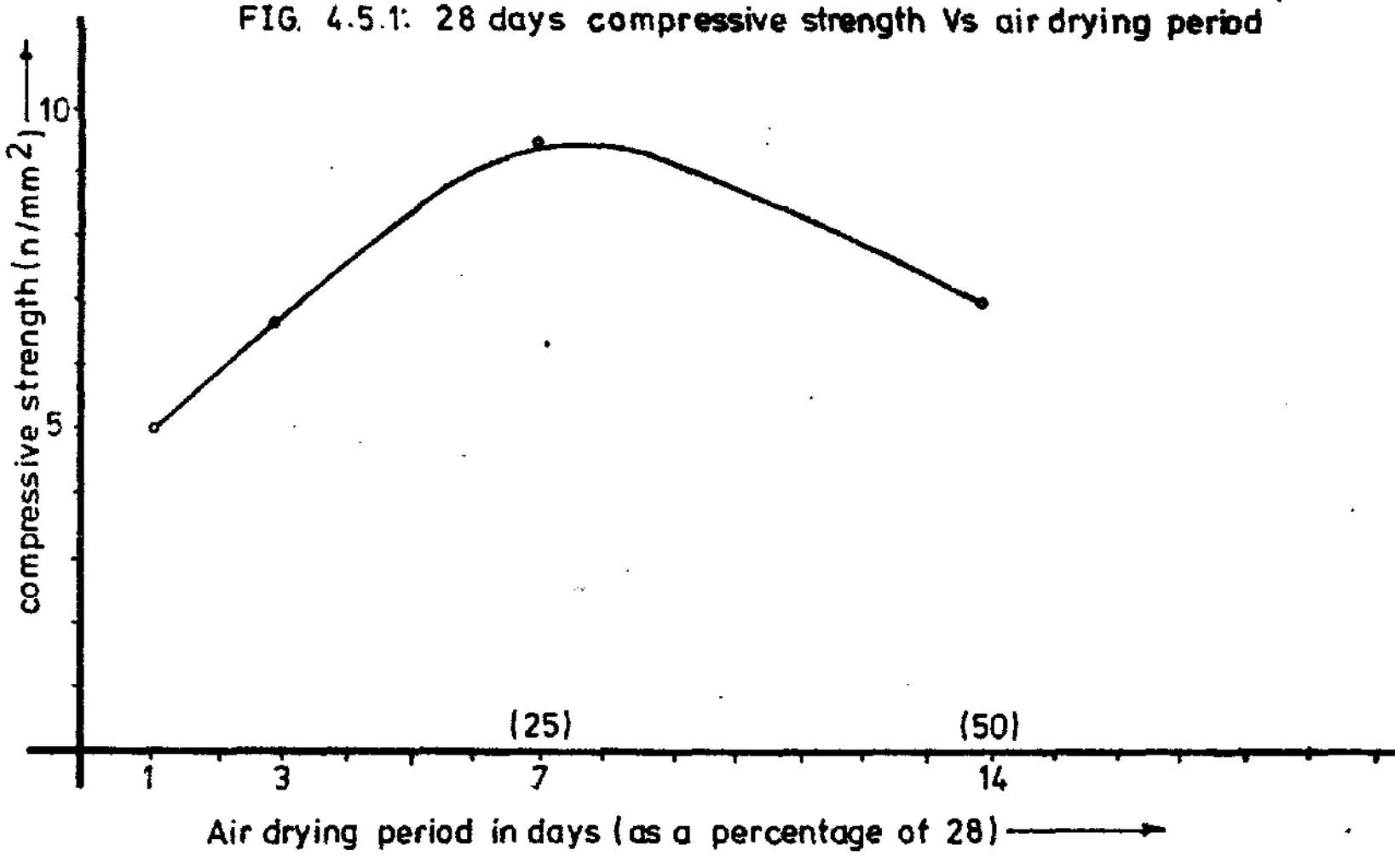
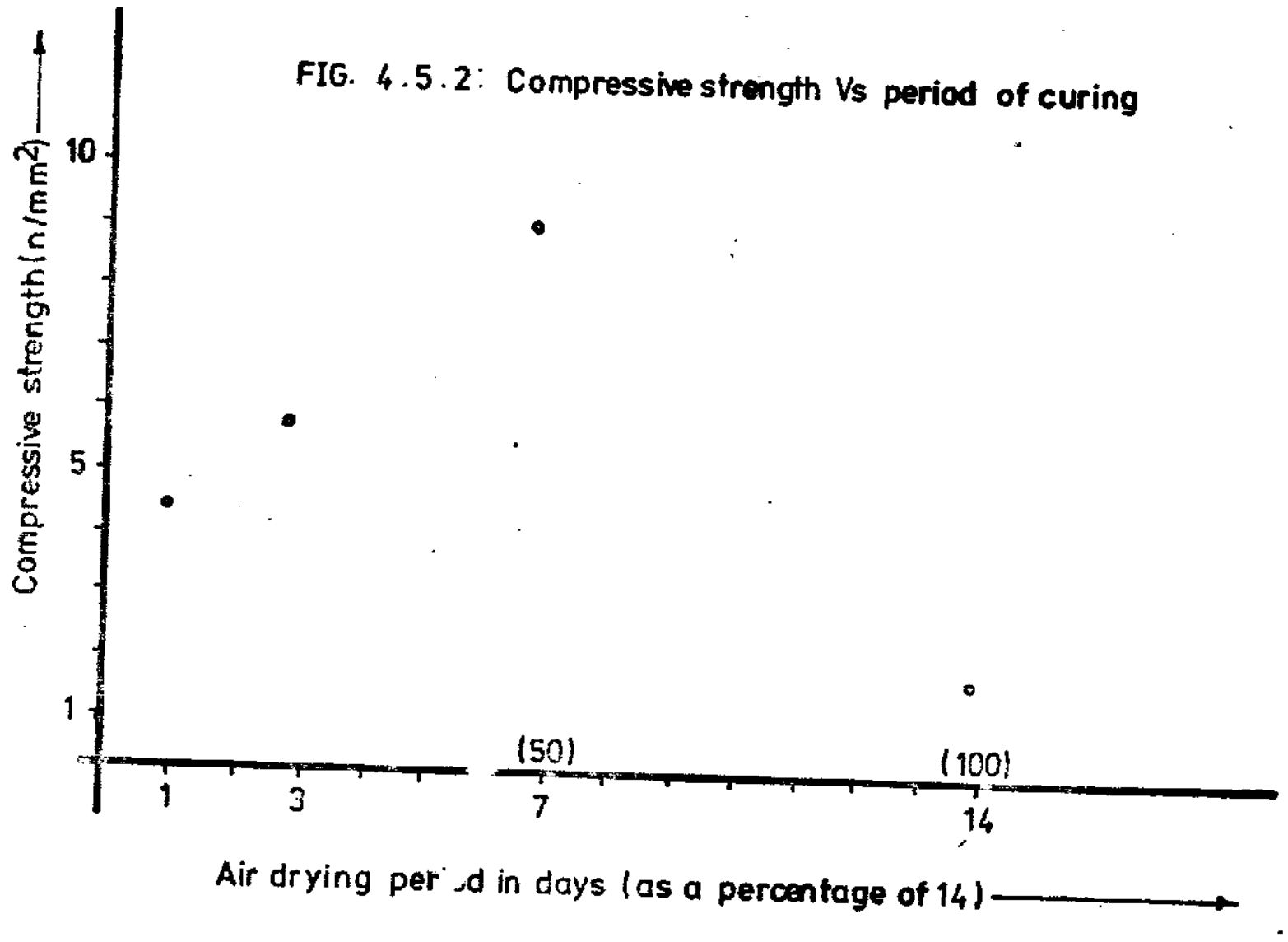


FIG. 4.5.2: Compressive strength Vs period of curing



4.6 Wet-Dry Compressive Strength Tests

The average values of the wet compressive strength and the dry compressive strengths of the different specimens are presented in table 4.6. The high ratio of wet/dry compressive strength recorded for 8% cement cylinders was attributed to low maturity of these cylinders at the time of test (November 1984 with a minimum temperature of 11^{oc} unlike other specimens tested with a minimum temperature record of 19^{oc}).

The results indicate that the wet/dry compressive strength ratio did not vary with the shape of specimen. This is to say that the wet/dry strength ratio of all the soilcrete specimens tested; cubes, cyliners and hollow blocks seem to rotate around the average value of 0.40. This result seems to agree with an earlier research result (7) which puts the ratio at about 0.42 (or 42%).

Nigerian building and Road Research Institute (30) (NBRRI) suggested as part of design precautions for the use of soilcrete blocks in low cost housing as part of improving on its performance that-

1. Improvement on the quality of the blocks is necessary.
2. Large overhang of roof to cut-off rains and protect walls should be provided.
3. Apply protective treatments to walls up to half a meter above the ground level.

Table 4.6: The average wet and dry compressive strengths of different soilcrete specimens

Type of Specimen	Wet Compressive Strength	Dry Compressive Strength	Wet/Dry Strength Ratio.
1. 8% cement soilcrete cubes compacted at pressure of $4N/mm^2$ and crushed after 28 days	$3.6N/mm^2$	$9.0N/mm^2$	0.40
2. 8% cement cubes compacted at $4N/mm^2$ and crushed after 14 days	$3.5N/mm^2$	$8.8N/mm^2$	0.40
3. 8% cement cubes compacted at $3N/mm^2$ and crushed after 14 days	$3.5N/mm^2$	$8.5N/mm^2$	0.41
4. 12% cement cubes compacted at $4N/mm^2$ and crushed after 28 days	$5.0N/mm^2$	$13.3N/mm^2$	0.38
5. 12% cement cylinders compacted at $4N/mm^2$ and crushed after 14 days (h/d = 2)	$1.4N/mm^2$	$3.7N/mm^2$	0.38
6. 8% cement cylinders compacted at $4N/mm^2$ and crushed after 14 days (h/d = 2)	$0.7N/mm^2$	$1.3N/mm^2$	0.54
7. 8% cement hollow blocks compacted at $4N/mm^2$ and crushed after 14 days	$1.4N/mm^2$	$3.4N/mm^2$	0.40
8. 12% cement hollow blocks compacted at $4N/mm^2$ and crushed after 14 day.	$2.1N/mm^2$	$5.3N/mm^2$	0.40

Oguara (31) suggests in addition that foundation up to D.P.C. level should be constructed with cement blocks. This practice is already in use in Sri Lanka (10). The reason for the advancement of the use of wet compressive strength (7) being a case where a house is overflooded with water. It seems therefore that precautionary desigus could take care of the effect of water on soilcrete. A soilcrete walling unit in a low cost housing unit is not likely to be subjected to much load. Also, in Nigeria, low cost houses do not exceed one storey; usually bungalows with walls serving as partitions. In Nigeria, it is expected that the effect of rain on walls is not likely to be the same for the North and South. Considering also that wet strength of a soilcrete walling unit is lesser than 50% of the dry strength, the use of the wet compressive strength of soilcrete should be specific or more meticulous.

4.7 Shape Factor on Compressive Strength of Soilcrete Specimens.

Table 4.7 presents the variation of compressive strength of soilcrete cylinder with height/diameter ratios. This is plotted in Fig. 4.7. The curve is similar to that for concrete cylinders. Also table 4.9.1 gives the average compressive strength of different specimens.

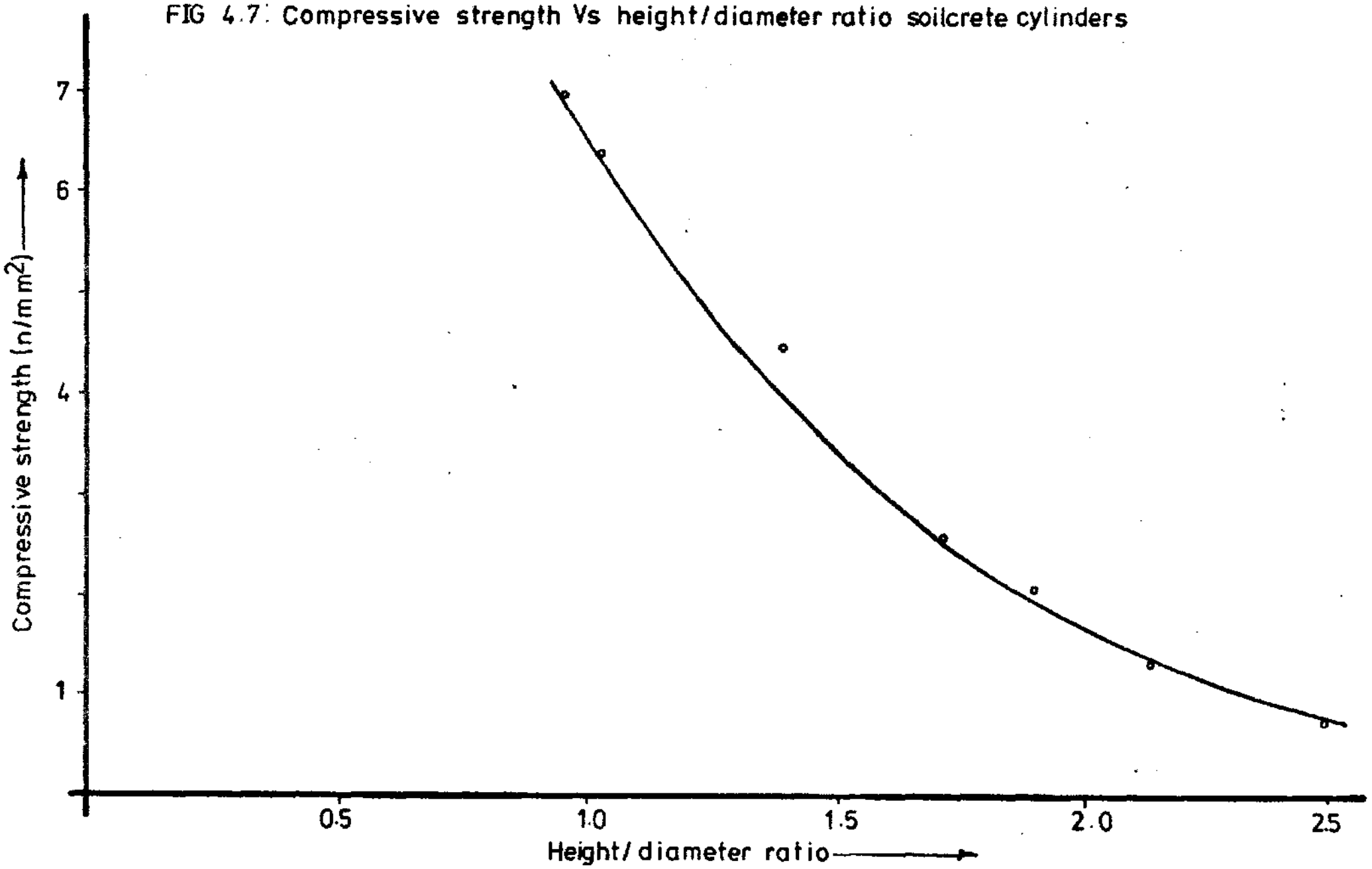
From Fig. 4.7 the average strength of a soilcrete cylinder of 8% cement content compacted at 4N/mm^2

Table 4.7: The average compressive strength of 8% soilcrete cylinders with varying height/diameter ratio.

	Height/Diameter Ratio	Average Dry C/Strength*
1.	0.95	7.0N/mm^2*
2.	1.02	6.4N/mm^2
3.	1.39	4.5N/mm^2
4.	1.71	2.6N/mm^2
5.	1.90	2.1N/mm^2
6.	2.13	1.4N/mm^2
7.	2.49	0.8N/mm^2

*Average of three specimens.

FIG 4.7: Compressive strength Vs height/diameter ratio soilcrete cylinders



pressure and water content 14%, with a height/diameter ratio of one is 6-8N/mm^2. This value is about 75% of the average strength for cubes which is 8-8N/mm^2. The explanation for this wide variation lies in the demoulding method of the cylinder specimens which causes strains in the fresh soilcrete cylinder specimens. The ratio of compressive strength of cylinders with height/diameter ratio of two, to cubes' strength is about 26%. This result is also consistent with an earlier research (3) which puts the range of the ratio, at between 0.25 and 0.41.

As the compressive strength of same mix and compaction pressure of hollow blocks is 3.4N/mm^2 and considering that the cylinder and block specimens are demoulded in the same way, from Fig. 4.7 the cylinder with same compressive strength (of the blocks) of 3.4N/mm^2 is that with a height/diameter ratio of 1.5. It therefore appears that the soilcrete cylinder with a height/diameter ratio of 1.5 is a better specimen for the assessment of strength properties of hollow blocks.

4.8 Stress-Strain (Deformation) Tests

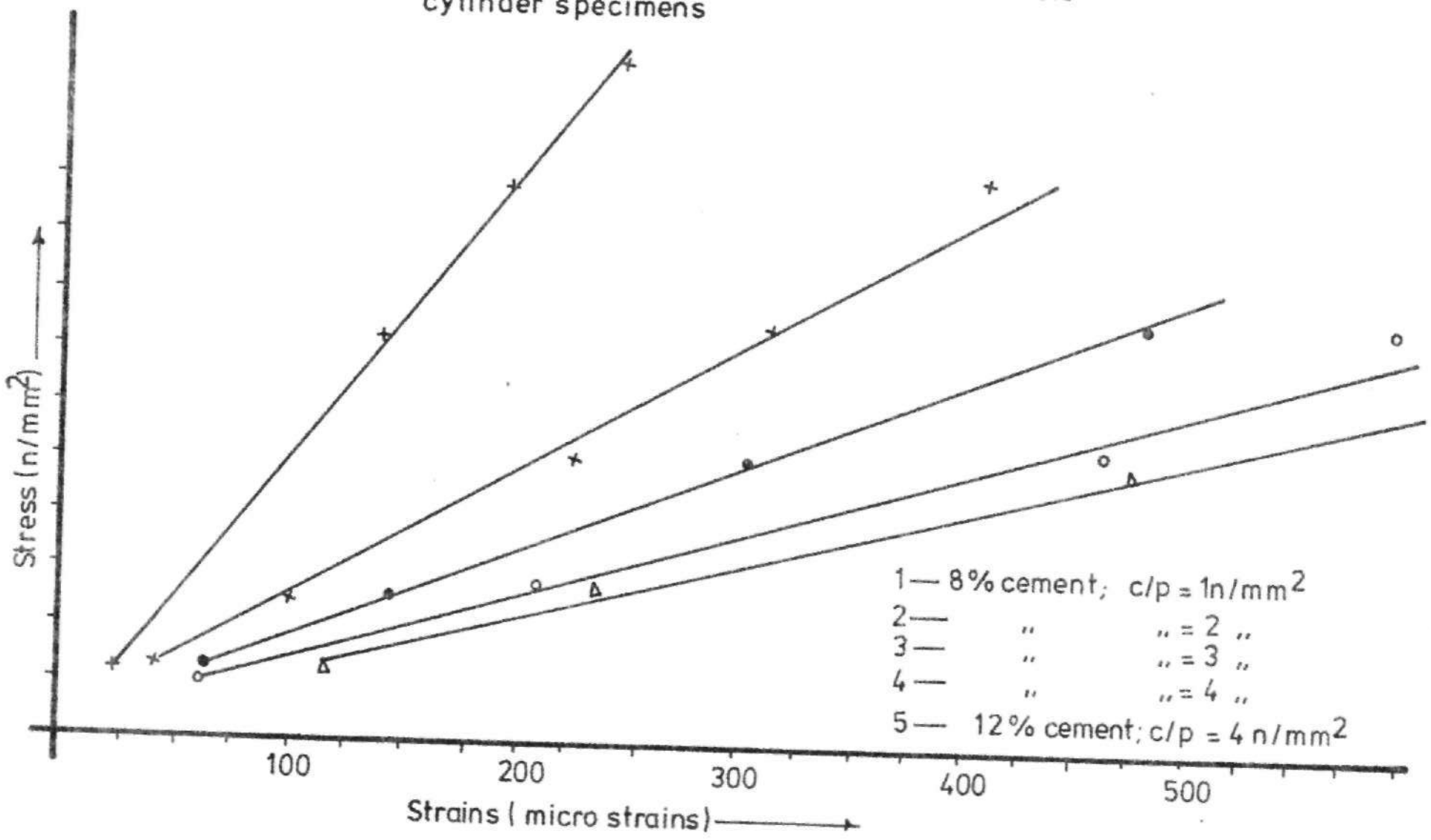
The results of the stress-strain tests are presented in table 4.8.1, and these are plotted in graph number (Fig. 4.8). The results show that the soilcrete cylinders exhibited some amount of elasticity

Table 4.3.1: The average strain values in micro strains of soilcrete cylinder specimens compacted at different pressures.

		Stress in N/mm^2					
		0.12	0.24	0.48	0.72	0.98	1.20
8% Cement Cylinders	*C/P = 1N/mm^2	115	235	485			
	C/P = 2N/mm^2	60	210	430	600		
	C/P = 3N/mm^2	65	145	305	485	650	
	C/P = 4N/mm^2	40	100	225	312	410	
12% Cement Cylinders	C/P = 4N/mm^2	25	53	90	140	195	250

*C/P - Compaction Pressure.

FIG. 4.8 The stress - strain graph of various soilcrete cylinder specimens



at the level of stresses tested. This is because on release the strain gauge meter reading returns to near the initial reading, before the addition of stress.

The results tend to follow a pattern; the modulus of elasticity of the specimens increased as the compaction pressure increases for a given cement mix.

With a modulus of elasticity of about 5000N/mm^2, for the 12% cement content compacted at 4N/mm^2, the results tend to agree with an earlier result (1) which puts the initial tangent modulus of 12.5% cement content laterite at about 4,667N/mm^2.

4.9 Compressive Strength Tests

The results of compressive strength tests are presented in tables 4.9.1, 4.9.2, 4.9.3, 4.9.4 and 4.9.5. The results are also plotted graphically in graphs numbers Fig. 4.9.1, 4.9.2, 4.9.3, 4.9.4 and 4.9.5. Figures 4.9.2 and 4.9.4 show the compressive strength variation with time of various soilcrete cubes compacted at different pressures. The results show that 0% cement mix, about 93% of the 28 day strength is developed in seven days (see Fig. 4.9.4). For 8% cement cubes compacted at pressures of 1, 2, 3 and 4N/mm^2, about 85, 97, 93 and 96% of the twenty eight day strength is developed in 14 days respectively. The cubes were cured by immersion in water for six days after demoulding, and air dried for seven days. The percentage of the 28 day strength developed after 14 days did not seem to vary considerably or in a particular manner with the compaction pressure.

Table 4.9.1: The average compressive strength of various types of soilcrete specimens crushed at the age of 14 days.

	Specimen type and Mix	Dry Compressive Strength	Wet Compressive Strength
1.	8% cement soilcrete cubes compacted at $4N/mm^2$	$8.8N/mm^2$	$3.5N/mm^2$
2.	8% cement soilcrete cylinders (h/d = 2) compatted at $4N/mm^2$	$2.1N/mm^2$	$0.8N/mm^2$
3.	8% cement soilcrete hollow blocks compacted at $4N/mm^2$	$3.4N/mm^2$	$1.4N/mm^2$
4.	12% cement soilcrete cubes compacted at $4N/mm^2$	$11.8N/mm^2$	$4.8N/mm^2$
5.	12% cement soilcrete cylinders (h/d = 2) compacted at $4N/mm^2$	$3.7N/mm^2$	$1.4N/mm^2$
6.	12% cement soilcrete hollow blocks compacted at $4N/mm^2$	$5.3N/mm^2$	$2.1N/mm^2$

Table 4.9.2: The average dry compressive Strengths of 3% cement soilcrete cubes crushed at different ages.
Curing was by immersion in water and air drying.

Compaction Pressure	Age = 3 days	Age = 7 days	Age = 14 days	Age = 28 days
$1N/mm^2$	$1.0N/mm^2$	$1.7N/mm^2$	$3.4N/mm^2$	$4.0N/mm^2$
$2N/mm^2$	$1.6N/mm^2$	$4.6N/mm^2$	$6.5N/mm^2$	$6.5N/mm^2$
$3N/mm^2$	$1.5N/mm^2$	$4.7N/mm^2$	$8.5N/mm^2$	$8.6N/mm^2$
$4N/mm^2$	$2.1N/mm^2$	$7.5N/mm^2$	$8.8N/mm^2$	$9.2N/mm^2$

Table 4.9.3: The average dry compressive strengths of 8, 10 and 12% cement content soilcrete cubes crushed after 14 and 28 days respectively. Curing was by immersion in water and air drying.

Compaction Pressure	8% Cement Age = 28 days	10% Cement Age = 14 days	10% Cement Age = 28 days	12% Cement Age = 28 days
$1N/mm^2$	$4.0N/mm^2$	$3.6N/mm^2$	$3.6N/mm^2$	$3.7N/mm^2$
$2N/mm^2$	$6.5N/mm^2$	$7.1N/mm^2$	$7.3N/mm^2$	$7.8N/mm^2$
$3N/mm^2$	$8.6N/mm^2$	$9.1N/mm^2$	$9.2N/mm^2$	$11.1N/mm^2$
$4N/mm^2$	$9.2N/mm^2$	$9.5N/mm^2$	$9.3N/mm^2$	$13.3N/mm^2$

Table 4.9.4: The average dry compressive strength of no-cement cubes compacted at $4N/mm^2$ pressure, at different ages.

Water content = 14%

Age of Cube	Average dry Compressive Strength
1 day	$1.5N/mm^2$
3 days	$3.0N/mm^2$
7 days	$5.1N/mm^2$
14 days	$5.4N/mm^2$
28 days	$5.5N/mm^2$

Table 4.9.5: The average dry Compressive Strength of no-cement cubes at different compaction pressures.
Water content = 14% Age = 14 days.

Compaction Pressure	Dry Compressive Strength
$1N/mm^2$	$1.2N/mm^2$
$2N/mm^2$	$2.8N/mm^2$
$3N/mm^2$	$4.0N/mm^2$
$4N/mm^2$	$5.2N/mm^2$

FIG. 4.9.1: Compressive strength of 8 % cement cubes Vs compaction pressure for different ages

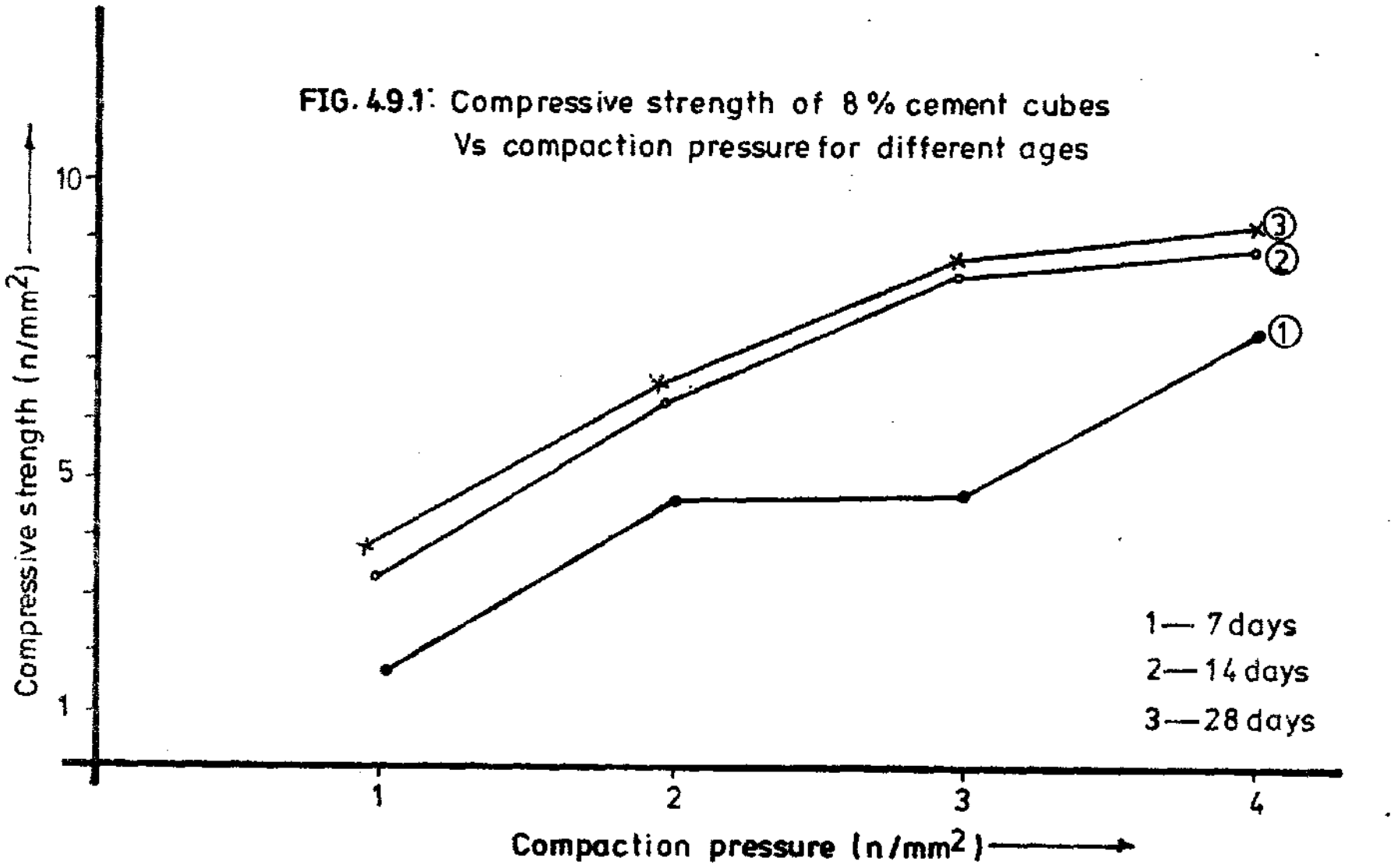


FIG. 4.9.2: Compressive strength development with time of 8% cement cubes, of various compaction pressure

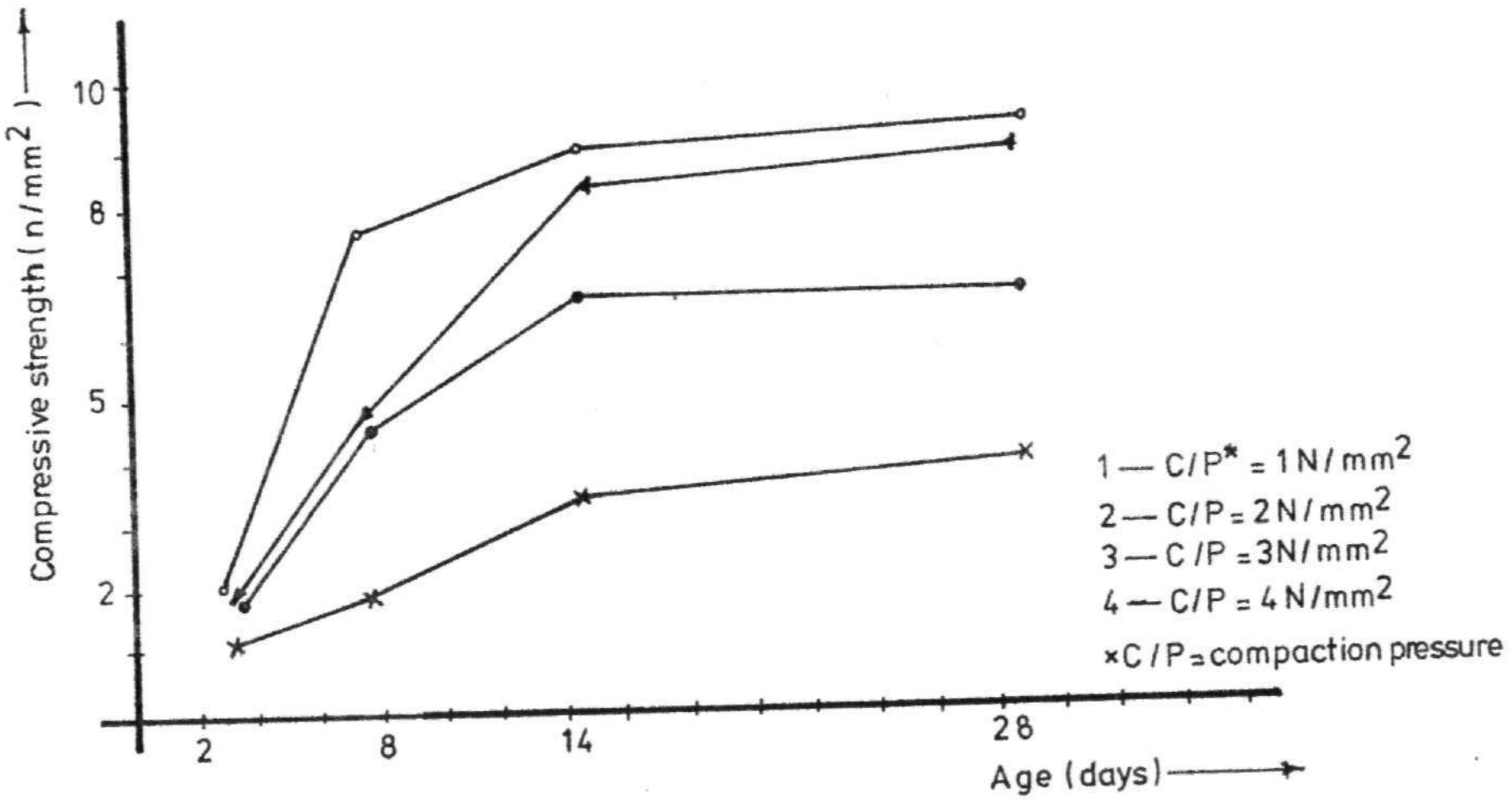


FIG. 4.9.3: 28 days compressive strength Vs compaction pressure for different cement contents.

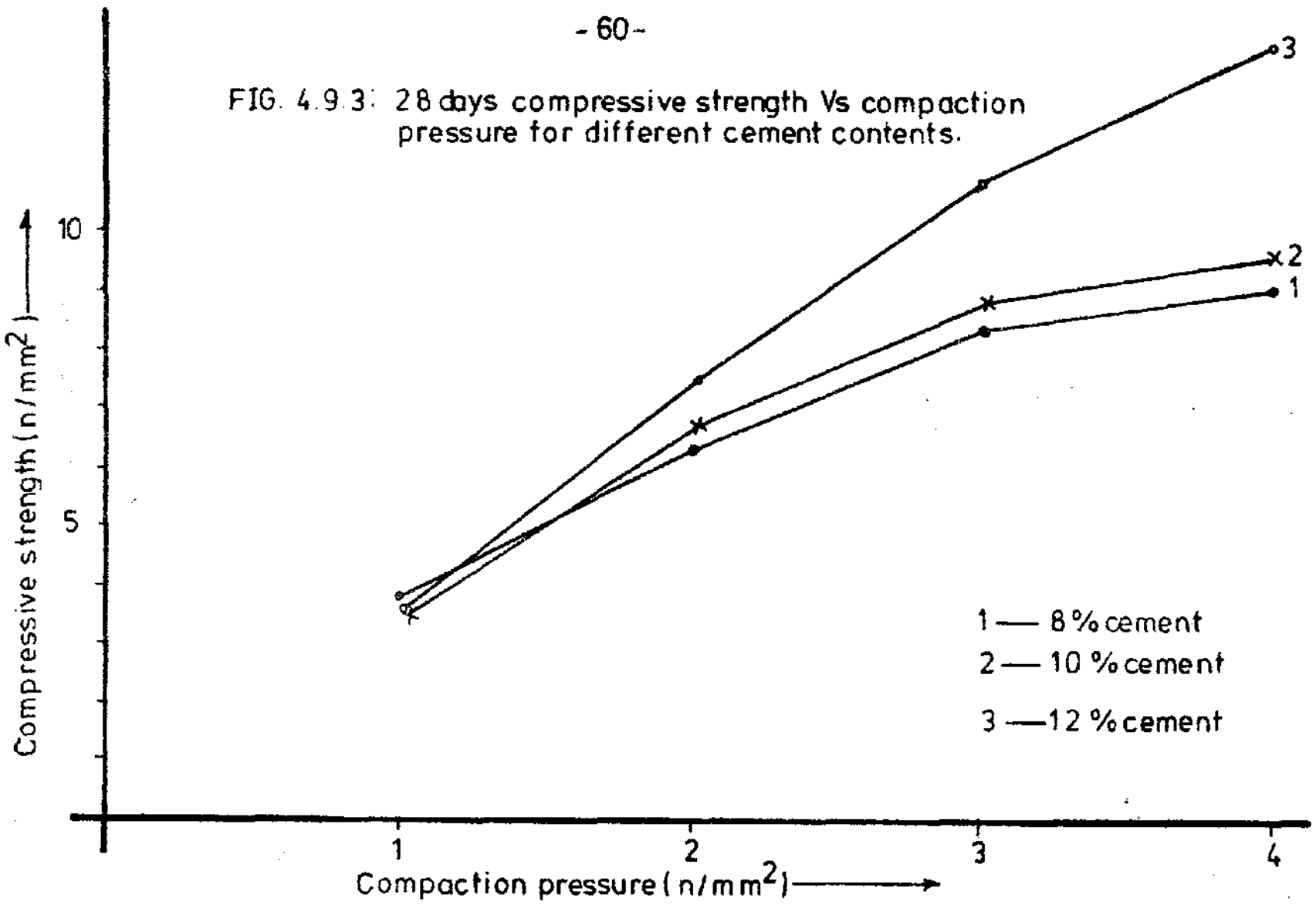


FIG. 4.9.4: Strength development with time for 0% cement cubes

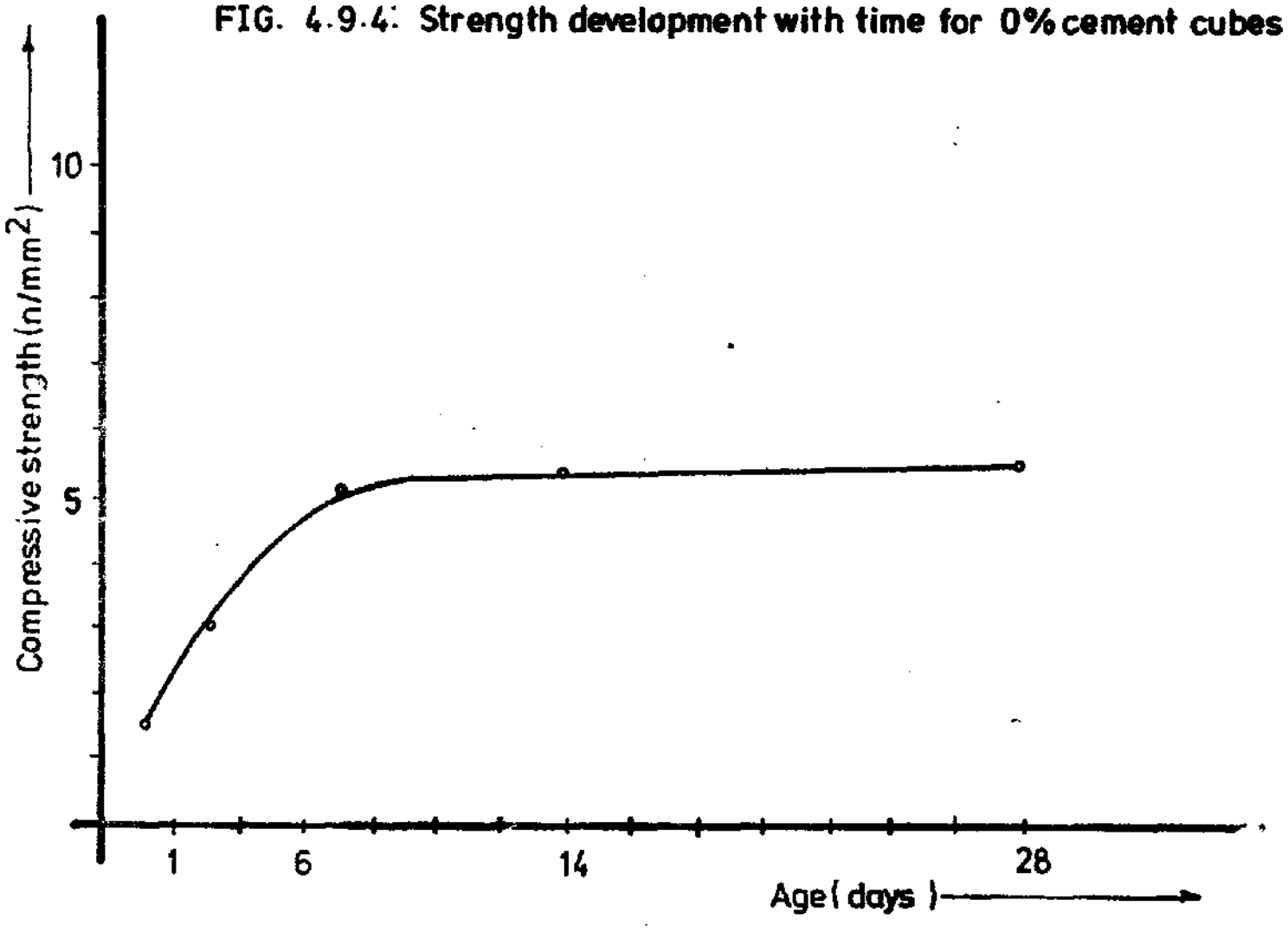


FIG. 4.9.5: 14 days compressive strength Vs compaction pressure for various cement contents

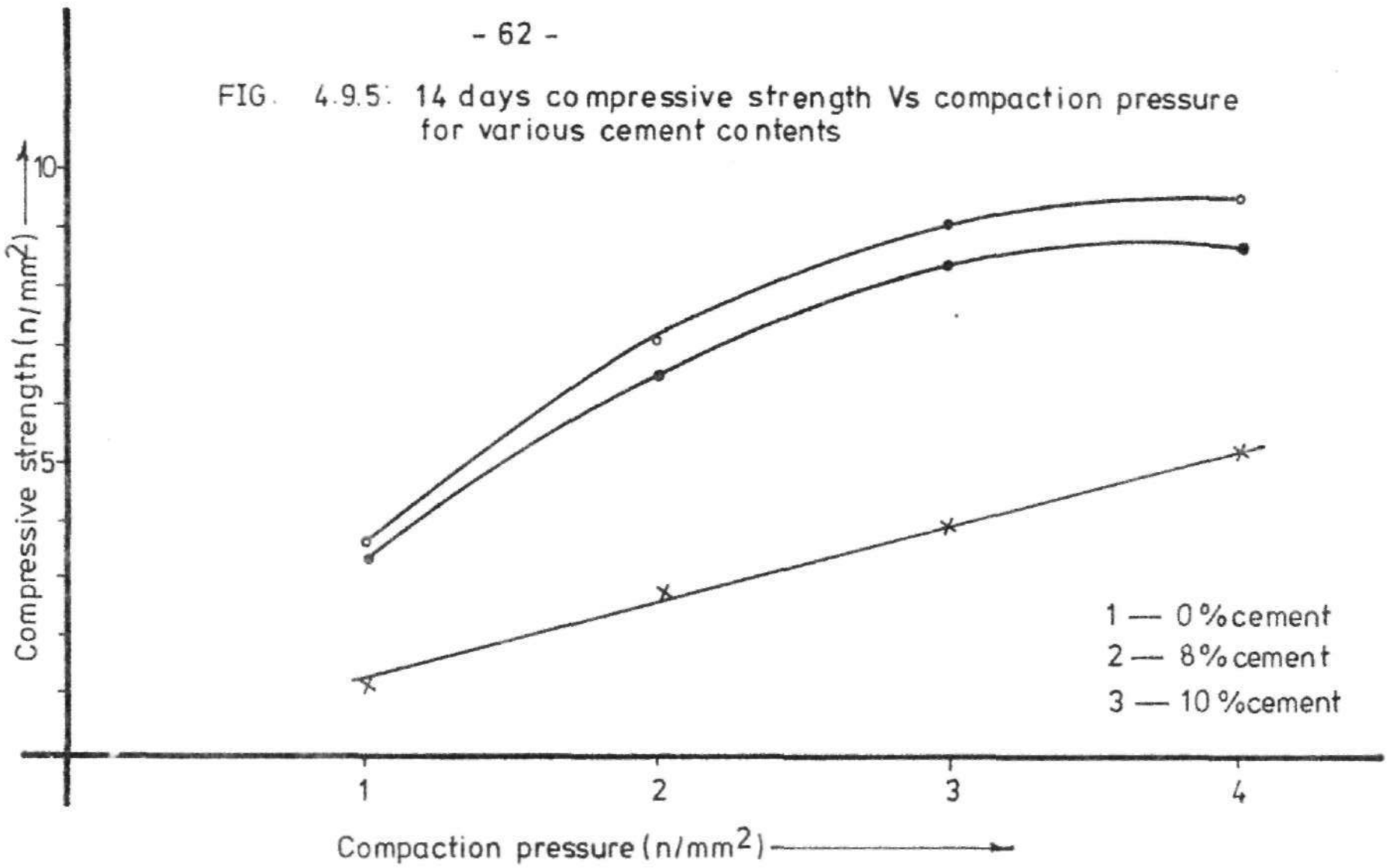


Table 4.9.1 presents the average compressive strength of various types of soilcrete specimens crushed after 14 days. The results show that the 8% cement content hollow blocks of size 400 x 150 x 150 have an average compressive strength (dry) of 3.4N/mm^2 and an average wet compressive strength of 1.4N/mm^2. The suggested (10) minimum compressive strength of 1.4.N/mm^2 is satisfied by 8% cement content hollow blocks compacted at a pressure of 4N/mm^2 at a water content of 14%. This suggests that hand-operated machines with a compaction pressure of 4N/mm^2 may produce soilcrete hollow blocks of 8% cement content satisfying the required minimum compressive strength. However, the lowest strength requirement of 1.7N/mm^2 for sandcrete hollow blocks by Federal Ministry of Works Lagos (7) is not satisfied. The 12% cement content hollow blocks compacted at a pressure of 4N/mm^2 with an average dry compressive strength of 5.3N/mm^2 and an average wet strength of 2.1N/mm^2 satisfy the Federal Ministry of Works requirement of 2.1N/mm^2. It need be noted that the Federal Ministry of Works did not specify water immersion condition prior to testing for strength.

From Fig. 4.9.3 which is the graph of strength variation with compaction pressure for different cement contents, it indicates that there is increase in the

strength of the soilcrete specimens with increased cement content for any given compaction pressure. This is consistent with other research results (1). The graph also shows that a compressive strength value obtained with 12% cement content at a compaction pressure of $2N/mm^2$ (for example) could also be obtained with 8% cement content but compaction pressure of about $2.5N/mm^2$. This implies that when specifying the compressive strength of a soilcrete specimen, the cement content alone is not enough unless specified with the compaction pressure.

Also from Fig. 4.9.3 which is the graph of compressive strength variation with compaction pressure for different cement concents. The results suggest that for non-cement cubes (0% cement), the compressive strength variation with compaction pressure is linear; this means that the compressive strength of the cubes within the ages tested, is directly proportional to the compaction pressure. For the 8% and 10% cement contents, the variation of strength with compaction pressure is curvilenear, showing that although there was increase in strength for increasing compaction pressure, this is not linearly dependent. This suggests that within the tested ages, the primary source of strength of the no-cement cubes is the compaction.

5.1 Conclusions

The tests and analysis of results presented in chapter 4 were made to enable some basic conclusions to be drawn. These conclusions are based more on comparisons than on analysis of the limited number of test results.

(1) The best water content for moulding of soilcrete is two percent lower than the optimum water content which in the case of tested samples is 16%.

(2) For no cement soil specimens, about ninety percent of its twenty-eight day strength is developed in seven days.

(3) For 8%, 10% and 12% cement soilcrete about ninety percent of the twenty-eight day strength is developed in 14 days.

(4) The ratio of the wet compressive strength to dry compressive strength of soilcrete specimens is about fourty percent.

(5) The method of demoulding soilcrete specimen affects its compressive strength.

(6) Soilcrete cylinder compressive strengths are very sensitive to variation in height/diameter ratio.

(7) The suitable height/diameter ratio of soilcrete cylinders for the assessment of strength properties is 1.5.

(8) 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.

(9) There is the need for detailed specifications for soilcrete hollow blocks on the basis of their increasing use as bearing walls and partitions.

(10) The higher compaction pressure of soilcrete the higher the compressive strength.

(11) For purposes of testing soilcrete specimens, the minimum age of 14 days should be adopted; six days complete immersion in water a day after moulding, and seven days air drying.

(12) For the purposes of specifying soilcrete specimens, the cement content alone is not enough unless specified with the compaction pressure.

5.2 Suggestions for futher research

(1) Research is necessary on the development of compatible soil-cement plaster material for the protection of soilcrete blocks from weather effects.

(2) Research should be carried out to determine the relation between the failure load of soilcrete wall and the compressive strength of the walling units.

(3) The effect of compaction pressure on the wet/dry compressive strength needs some more tests.

(4) The effect of different cement contents and different compaction pressures on the variation of compressive strength with respect to the height/diameter ratio of soilcrete cylinders should be studied.

APPENDIX I

Compressive Strength of Soilcrete Cubes Compacted at various Pressures.

Identification Number	Age	Remarks/ Cement Content	Compaction Pressure (N/mm^2)	Failure Load KN	Compressive Strength (N/mm^2)
1-1	3	8	1	6.0	1.2
-2	3	8	1	4.0	0.8
-3	3		1	5.5	1.1
2-1	3	8%	2	8.0	1.6
-2	3	Cement	2	7.5	1.5
-3	3	Content	2	7.8	1.6
3-1	3	Cubes	3	9.0	1.8
-2	3	Water	3	9.8	2.0
-3	3	Content	3	8.5	1.7
4-1	3	= 14%	4	10.5	2.1
-2	3		4	10.8	2.2
-3	3		4	10.5	2.1
-4	3		4	8.4	1.7
-5	3		4	11.9	2.4
-6	3		4	10.9	2.2
5-1	7		1	11.5	2.3
2	7		1	9.6	1.9
3	7		1	5.1	1.0
6-1	7		2	27.5	5.5
2	7		2	16.8	3.3
3	7		2	25.7	5.1

Appendix I cont'd.

Identification Number	Age	Remarks/ Cement Content	Compaction Pressure (N/mm^2)	Failure Load KN	Compressive Strength (N/mm^2)
7-1	7		3	16.6	3.3
2	7		3	28.0	5.5
3	7		3	16.7	3.3
8-1	7		4	41.1	8.2
2	7		4	36.1	7.2
3	7		4	35.0	7.0
9-1	14		1	16.6	3.3
-2	14		1	17.8	3.5
-3	14		1	17.1	3.4
10-1	14		2	33.9	6.8
-2	14		2	32.1	6.4
-3	14		2	31.5	6.3
11-1	14		3	41.5	8.2
-2	14		3	44	8.8
-3	14		3	41.4	8.2
12-1	14		4	42.6	8.5
-2	14		4	43.6	8.7
-3	14		4	45.9	9.2
13-1	14	8%	1	16.1	3.2
-2	14	Cement	1	17.1	3.6
-3	14	Content	1	15.6	3.1
14-1	14	Cubes	2	33.7	6.7
-2	14	Width	2	34.1	6.8
-3	14	Water	2	34.4	6.9

Appendix I cont'd.

Identification Number	Age	Remarks/ Cement Content	Compaction Pressure (N/mm^2)	Failure Load KN	Compressive Strength (N/mm^2)
15-1	14	Content	3	41.5	8.3
-2	14	Of 12%	3	40.3	8.1
-3	14		3	40.3	8.1
16-1	14		4	39.6	7.9
-2	14		4	42.7	8.6
-3	14		4	41.9	8.4
-4	14		4	41.5	8.3
17-1	14	8%	1	15.6	3.1
-2	14	Cement	1	18.0	3.6
-3	14	Cubes	1	16.5	3.3
18-1	14	Width	2	28.7	5.8
-2	14	Water	2	28	5.6
-3	14	Content	2	28.9	5.8
19-1	14	= 10%	3	35.0	7.0
-2	14		3	34.5	6.9
-3	14		3	36.5	7.3
20-1	14		4	41.3	8.3
-2	14		4	32.5	6.5
-3	14		4	41.0	8.2
21-1	28	12% Cement	4	68.0	13.6
-2	28	Content;	4	66.4	13.3
3		Water/C = 14%	4	64.5	12.9

Appendix I contd

Identification Number	Age	Remarks/ Cement Content	Compaction Pressure (N/mm^2)	Failure Load KN	Compressive (N/mm^2)
22-1	28	8% Cement	1	19.5	3.9
-2	28	Content	1	20.5	4.1
-3	28	Cubes	1	20.4	4.1
23-1	28	Water Content	2	32.5	6.5
-2	28	= 14%	2	32.3	6.5
-3	28		2	32.3	6.4
24-1	28		3	31.8	8.8
-2	28		3	44	8.7
-3	28		3	43.4	8.5
25-1	28		4	42.5	9.4
-2	28		4	46.5	9.2
-3	28		4	45.7	8.9
26-1	28	10% Cement	1	19.5	3.9
-2	28	Content	1	18	3.6
-3	28	Cubes	1	17	3.4
27-1	28	Water	2	39.9	7.8
-2	28	Content = 14%	2	39.0	7.8
-3	28		2	31.1	7.8
28-1	28		3	45.6	9.1
-2	28		3	46.4	9.3
-3	28		3	45.5	9.1
29-1	28		4	49.0	9.8
-2	28		4	48.5	9.8
-3	28		4	50.0	10.0

Appendix I cont'd

Identification Number	Age	Remarks/ Cement Content	Compaction Pressure (N/mm^2)	Failure Load KN	Compressive (N/mm^2)
30-1	28	12%	1	18.5	3.7
-2	28	Cement	1	20.0	4.0
-3	28	Content	1	17.6	3.5
31-1	28	Cubes	2	40.0	8.0
-2	28	12	2	37.5	7.5
-3	28	12%	2	39.0	7.8
32-1	28	Cement	3	54.9	11.0
-2	28	Content	3	54.9	11.0
-3	28	Cubes	3	56	11.2
13-1	14		1	17.9	3.6
-2	14	10%	1	17.8	3.6
-3	14	Cement	1	18.3	3.7
34-1	14	Content	2	34.0	6.8
-2	14	Cubes;	2	36.8	7.3
-3	14	Water	2	33.5	6.7
35-1	14	Content	3	45.0	9.0
-2	14	= 14%	3	46.4	9.3
-3	14		3	44.5	8.9
36-1	14		4	47.1	9.4
-2	14		4	47	9.4
-3	14		4	47.9	9.6

APPENDIX II

Dry Compressive Strength of 3% Cement Soilcrete Cylinders Compacted at Pressure of $_4N/mm^2$; Age = 14 days

Identification Number	Height (mm)	Height/ Diameter	Failure Load (KN)	C/Strength (N/mm^2)	Remarks
HD-1	93	0.95	50.6	7.3	
" 2	99	0.95	50.2	7.0	
" 3	96	0.99	55	6.6	
" 4	105	1.08	53.4	6.4	
" 5	105	1.08	54.9	6.6	
" 6	105	1.08	52.4	6.3	
" 7	143	1.39	37.9	4.6	
" 8	145	1.40	37.7	4.5	
" 9	143	1.39	36.4	4.4	
" 10	176	1.71	21.7	2.6	
" 11	176	1.71	19.3	2.3	
" 12	176	1.71	25.0	3.0	
" 13	196	1.90	17.2	2.1	
"14	195	1.90	20.2	2.4	
" 15	195	1.90	15.1	1.8	
" 16	219	2.13	10.4	1.3	
" 17	219	2.13	14.1	1.1	
" 18	219	2.13	10.5	1.3	
" 19	256	2.49	6.7	0.8	
" 20	257	2.49	7.3	0.9	
" 21	258	2.50	6.1	0.7	

Appendix II cont'd.

Identification Number	Height (mm)	Height/ Diameter	Failure Load (KN)	C/Strength (N/mm^2)	Remarks
R-22	155	1.5	29.2	3.5	
R-23	154	1.5	30.8	3.7	
R-24	152	1.5	30.8	3.7	
R-25	156	1.5	28.4	3.4	
R-26	158	1.5	28.0	3.4	
R-27	158	1.5	26.4	3.2	
R-28	154	1.5	26.	3.1	
R-29	156	1.5	30.7	3.7	
R-30	159	1.5	23.6	3.2	
R-31	156	1.5	29.9	3.6	

APPENDIX III

Compressive Strength of 10% Cement Cubes under different curring conditions.

Identification Number	Age	Failure Load (KN)	Compressive Strength N/mm^2	Remarks
C-11		28.1	5.6	3 days air drying,
C-12	7 days	28.0	5.6	3 days immersed
C-13		27.8	5.6	in water
C-21		21.5	4.3	5 days immersion
C-22	7 days	22.1	4.4	and one day
C-23		23.7	4.7	air drying.
C-31		23.0	4.6	12 days immersion
C-32	14 days	21.7	4.4	in water and one
C-33		24.6	4.9	day air drying.
C-41		28.2	5.7	10 days immersion
C-42	14 days	29.1	5.8	in water and 3 days
C-43		29.3	5.9	air drying.
C-51		45.4	9.1	5 days immersion
C-52	14 days	44.7	8.9	in water and 7 days
C-53		46.3	9.3	air drying.
C-61		8.8	1.8	No immersion in
C-62	14 days	8.8	1.8	water of 14 days
C-63		9.0	1.3	air drying
C-71		24.5	4.9	26 days immersion
C-72	28 days	24.6	4.9	in water and 1 day
C-73		24.2	4.9	air drying.

Appendix iii continued

Identification Number	Age	Failure Load (KN)	Compressive Strength N/mm^2	Remarks
C-81		32.6	6.5	24 days immersion
C-82	28 days	32.6	6.5	in water & 3 days
C-83		33.7	6.7	air drying.
C-91		49.0	9.8	20 days immersion
C-92	28 days	48.7	9.7	in water and 7 days
C-93		46.2	9.3	air drying.
C-101		35.5	7.1	13 days immersion
C-102	28 days	35.0	7.0	in water and 14 days
C-103		35.0	7.0	air drying.

APPENDIX IV

Compressive Strength of No-Cement Cubes Compacted at various pressures and water contents, crushed at different ages.

Age	Water Content	Failure Load(KN)	C/P	Compressive Strength
14 days	10	17.0	$4N/mm^2$	3.4
"	10	16.7	4 "	3.4
"	10	17.1	4 "	3.4
"	12	24.6	4 "	4.9
"	12	25.1	4 "	5.0
"	12	24.1	4 "	4.8
"	13	25	4 "	5.0
"	13	25.7	4 "	5.2
"	13	25.8	4 "	5.2
"	14	26.0	4 "	5.2
"	14	26.1	4 "	5.2
"	14	26.1	4 "	5.2
"	15	26.2	4 "	5.2
"	15	26.0	4 "	5.2
"	15	24.7	4 "	5.0
1 day	14	6.9	4 "	1.4
"	14	7.0	4 "	1.4
"	14	8.4	4 "	1.7
3 days	14	14.5	4 "	2.9
"	14	15.5	4 "	3.1
"	14	15.4	4 "	3.1
7 days	14	25.5	4 "	5.1
"	14	23.3	4 "	4.8
"	14	25.8	4 "	5.2

Appendix iv cont'd.

Age	Water Content	Failure Load (KN)	C/P (N/mm^2)	Compressive Strength
28 days	14	27.5	4	5.5
"	14	27.3	4	5.5
"	14	27.3	4	5.5
14 days	14	6.0	1	1.2
"	14	6.4	1	1.3
"	14	5.9	1	1.2
"	14	13.7	2	2.8
"	14	13.4	2	2.7
"	14	13.8	2	2.8

APPENDIX V

Compressive Strength of Hollow Blocks Produced at a Compaction Pressure of $_4 N/mm^2$ and Crushed after 14 days.

Identification Number	Weight (Kg)	Failure Load (KN)	Height (mm)	Compressive Strength (N/mm^2)	Remarks
38-1	10.0	84.0	160	1.4	8% Cement
38-2	10.4	85.0	165	1.4	hollow bl
-3	10.2	80.2	162	1.3	blocks
-4	10.1	84.8	160	1.4	crushed
-5	10.1	80.0	160	1.3	after one
-6	10.3	89.7	163	1.5	days
-7	9.9	85.6	158	1.4	immersion
-8	10.0	80.1	158	1.3	in water
-9	10.1	90.5	160	1.5	prior to testing.
10	9.7	206.8	158	3.4	8% Cement hollow blocks crushed dry.
11	9.8	204.0	160	3.4	
12	9.9	201.0	160	3.4	
B12-1	9.9	120.2	157	2.0	12% Cement blocks crushed after one days immersion in water prior to testing.
-2	10.1	114.3	160	219	
-3	10.2	138.0	162	2.3	
-4	10.2	144	162	2.4	
-5	10.2	120	160	2.0	
-6	10.0	132	160	2.2	
-7	10.0	120.6	160	2.0	
-8	10.0	130.5	158	2.2	
-9	10.3	126	165	2.1	

Appendix v cont'd.

Identification Number	Weight (Kg)	Failure Load (KN)	Height (mm)	Compressive Strength (N/mm^2)	Remarks
-10	8.8	326	160	5.4	12% Cement hollow blocks crushed dry.
-11	8.9	309	160	5.1	
-12	8.9	335	160	5.6	

APPENDIX VI

Wet Compressive Strengths of different Soilcrete Specimens

Identification Number	Failure Load (KN)	Compressive Strength N/mm^2	Remarks
W-251	18.1	3.6	8% Cement cubes compacted
25.2	17.7	3.5	at $4N/mm^2$ crushed after
25.3	18.5	3.7	28 days.
W-121	17.5	3.5	8% cement cubes compacted
-122	17.6	3.5	at $4N/mm^2$ crushed after
-123	17.4	3.5	14 days.
W-211	25.0	5.0	12% cement cubes compacted
-212	26.6	5.3	at $4N/mm^2$ crushed after
-213	23.0	4.6	28 days.
W-Cy-1	11.7	1.4	12% cement cylinders compacted
-2	11.8	1.4	at $4N/mm^2$ crushed after
-3	11.8	1.4	14 days.
W-Cy-7	6.0	0.7	8% cement cylinders compacted
-8	6.3	0.8	at 4N/mm crushed after 14
-9	5.3	0.6	days (height/diameter ratio
			= 2)
WCY-151	17.3	3.5	8% cement cubes compacted at
152	17.6	3.5	$3N/mm^2$ crushed after 14 days.
153	17.2	3.4	
WCY-10	6.9	0.8	8% cement cylinders compacted
WCY-11	6.3	0.8	at $4N/mm^2$ crushed after 14
WCY-12	7.10	0.9	days (height/diameter
			ratio = 2)

APPENDIX VII

Dry Compressive Strength of Cylinder Specimens with various cement contents (height/diameter ratio = 2

Identification Number	Compaction Pressure (N/mm^2)	Cement Content (%)	Failure Load (KN)	Dry Compressive Srength (N/mm^2)	Age (days)
Cy-1	4	12	30.3	3.7	14
-2	4	12	30.3	3.7	14
-3	4	12	30.4	3.7	14
4	4	10	21.6	2.6	14
5	4	10	21.3	2.6	14
6	4	10	21.6	2.6	14
7	4	8	11.7	1.4	14
8	4	8	10.0	1.2	14
9	4	8	11.2	1.4	14
10	4	8	17.8	2.1	14
11	4	8	19.1	2.3	14
12	4	8	16.2	2.0	14
13	4	0	10.8	1.3	7
14	4	0	10.7	1.3	7
15	4	0	11.6	1.4	7
16	4	0	11.7	1.4	28
17	4	0	11.7	1.4	28
18	4	0	12.5	1.5	28

APPENDIX VIII

Strains (Micro Strain) at different stress values of different soilcrete cylinders (hight/diameter ratio = 2)

	Inial reading	Stress 0.12	0.24	0.48	0.72	0.98	1.20	Release
8% Cement Mix Compacted at Pressure of $1N/mm^2$	1293	1270	1255					12900
	14830	14723	14602	14350				14081
	5950	5930	5865	5730				5920
8% Cement Mix Compacted at Pressure of $2N/mm^2$	7120	7080	7050	6750				7100
	7052	6992	6842	6572	6452			7011
	7000	6920	6650	6190				6730
8% Cement Mix Compacted at Pressure of $3N/mm^2$	13930	13960	13920	13820	13690	13560		13920
	14830	14765	14685	14525	14345	14180		14770
	15230	15120	15000	14780	14550	14350		14820
8% Cement Mix Compacted at Pressure of $4N/mm^2$	15040	15010	14770	14870	14770	14670		15015
	14830	14790	14730	14605	14518	14518		14800
	13920	13870	13790	13640	13585	13470		13805
12% Cement Mix Compacted at Pressure of $4N/mm^2$	12720	12700	12680	12650	12590	12510	12440	12670
	15900	15875	15848	14810	14760	14705	14650	15860
	13370	13340	13305	13260	13220	13190	13150	13340

APPENDIX IX

Dry Compressive Strength of Ten 8% cement cubes compacted at a pressure of $4N/mm^2$.

Identification Number	Failure Load (KN)	Compressive Strength (N/mm^2)	Remarks
U-1	43.3	8.3	Average strength
U-2	40.0	8.2	= $8.1N/mm^2$.
U-3	37.0	7.6	
U-4	39.0	8.0	
U-5	39.8	8.1	Standard Deviation
U-6	37.6	7.7	= 0.49
U-7	39.0	8.0	
U-8	36.0	7.4	
U-9	43.4	8.9	
U-10	39.0	8.0	

APPENDIX X

Dry Compressive Strength of Ten Cylinder of Cement content 8%; compacted at $4N/mm^2$ and crushed after 14 days.

Identification Number	Weight of Cylinder (gm)	Failure Load (KN)	Compressive Strength (N/mm^2)	Remarks
R-22	2525	29.2	3.5	Average
R-23	2533	30.8	3.7	Strength
R-24	2485	30.8	3.7	= $3.5N/mm^2$
R-25	2537	28.4	3.4	
R-26	2550	28	3.4	
R-27	2515	26.4	3.2	Standard
R-28	2531	26	3.1	Deviation
R-29	2547	30.7	3.7	= 0.23
R-30	2556	23.6	3.2	
R-31	2537	29.9	3.6	

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