INVESTIGATION INTO THE POSSIBLE USE OF POWDERED BURNT BRICK (PBB) AND ORDINARY PORTLAND CEMENT (OPC) ADMIXTURE FOR SANDCRETE BLOCKS PRODUCTION

BY

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DEDICATION

To the Almighty God for sustaining me and His abundant Grace that saw me through,

AND

To my Parents

Rev. (Rtd) & Mrs. DUTSE BUNGWON

I dedicate this work.

ACKNOWLEDGEMENT

No project of this magnitude is complete without incurring a variety of debts. I am therefore obliged to register my deep appreciation to my supervisors, **Dr. A.A. Hussein** and Mr.I K Zubairu who provided the needed guidance, encouragement and supervision at all stages of this work, their tight schedule notwithstanding. Their thoroughness and insistence on scholarliness not only helped this work but has greatly aroused and broadened my academic interests.

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Time and space will not allow me to pen down all that contributed in one way or the other toward the completion of this work, to all, I say THANK YOU.

Lastly, but most importantly to God, I owe all. May the knowledge acquired be used to honour you.

ABSTRACT

The thesis is essentially a comparative investigation between using Ordinary Portland Cement (OPC) and an admixture (blended cement of Portland cement (OPC) and Powdered Burnt Brick (PBB). It was directed at ascertaining the suitability or otherwise of the blended cement for use in the production of sandcrete blocks as OPC is used.

Three sets of trial mixes of varied composition were produced to determine parameters like optimum water/cement ratio, optimum percentage replacement by weight of the OPC by the PBB It was also used to determine the effect of varying the aggregates/cement ratio. A number of other tests carried out to ascertain properties *of* specimens produced are as follows.

Compressive strength determined for various ages ranging between 3 days and 90 days were found to be generally high. For instance the 28th day strength of specimens for a mix of 1:6 gave a strength of not less than 87% of the 0% replacement when the OPC was replaced by 20% PBB.

Split tensile strength, obtained varied between 8 - 11% of the compressive strength of the same mix ratio at 28 days Mixes with the PEJB have higher tensile values than those without.

The setting time test revealed that mixes with 0% replacement have bigger initial setting times than those with 10% and 20% replacement But the former have smaller - final setting time than the latter.

Since the optimum percentage replacement of the OPC by the PBB is only 20, the cost saving might be small but other advantages like low heat of hydration, high tensile strengths, pride of an additional local material that can be used abound.

It was observed that mortar mixes with 20% replacement of OPC by PBB mixes developed strengths that compared favourably with the mortar mixes with 0%replacement. The application of the former in mortars was also recommended in line with the present use of the later.

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LIST OF SYMBOLS AND ABBREVIATIONS

B	=	Bulk Density of Powdered Burnt Brick.
$\hat{x}$	=	mean strength of specimens.
BS	=	British Standard
ASTM	=	American Society of Testing Materials.
PBB	=	Powdered Burnt Brick.
OPC	=	Ordinary Portland Cement.
SD	=	Standard Deviation.
Sx	=	Mean square error / standard error.
n	=	number of samples.
X	=	Individual strength values of each sample.
K	=	Probability factor.
E	=	Accuracy of measurement.
□	=	Reliability of measurement.
t□	=	value of reliability for n-l
A	=	Cross - sectional area.
W	=	Load.
f	=	Applied stress
P	=	splitting load.
ii	=	Pi = 22/7
l	=	length of cylinder.
d	=	Diameter of cylinder.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Shelter remains man's second most important need even when he is not aware of it so (National Housing Policy, Feb., 1991). The prevailing economic situation makes meeting this need for all quite difficult especially in the near future as cost of building materials keep soaring. This situation is forcing the Government, corporate bodies and individuals to explore, among other things, possible local building materials that can be used either as they occur or to be improved upon before usage. In general, local building materials are often readily available as against most of the conventional types in use. Where the former are found to be suitable, there could be a considerable cost saving. These efforts have led to the findings that our locally produced Rice Husk Ash (RHA) and Pulverised Fuel Ash (PFA) work effectively in conjunction with ordinary portland cement (OPC) as blended cement (pozzolanic cement) (Alimi, 1989, Audu, 1992 respectively).Many other local materials have been ascertained suitable for construction purposes like Palm kernel shells as aggregates (Nuhu-Koko, 1988), Periwinkle Shells as lightweights aggregates (Bukata, 1989).

With the abundance of clay all over our country, a topic such as above becomes very relevant. The many clay product factories all over Nigeria with much waste of the burnt products, as it is often the case in these factories, even makes a study of this sort imperative. Though Powdered Burnt Bricks (PBB) has been in use in countries like India and Italy, it is necessary to ascertain that the Nigerian type can be used and its degree of suitability in meeting standard requirements. Where it has been found suitable, it is being used in conjunction with OPC to form blended cement. If found to be suitable it will no doubt reduce cost due to its abundance and add to the alternatives available thereby reducing the pressure on cement.

The later accounts for a substantial chunk of any construction cost as much of it has to be used despite its high and increasing cost(Ananymous,89). It will also enable clay product manufacturers earn money from their waste.

Essentially, this research work investigated the suitability of locally produced PBB for use with OPC for sandcrete block production and its compressive strength, split tensile strength and setting time values were compared with the standard values.

1.2 Aim of Research

The research work was aimed at investigating the suitability of powdered burnt brick (PBB) obtained from the Kaduna Brick Factory as a pozzolan for the production of sandcrete blocks when used as a blended cement.

1.3 Objectives

The objectives of this research work were as follows:-

(i) to investigate the suitability of burnt clay (brick) as a pozzolan.

(ii) to identify an optimum replacement percentage of the cement (OPC) by the pozzolan (PBB) for mortar.

(iii) to determine effects of the pozzolan on the properties of mortar both in its fresh and hardened stages.

(iv) to determine the effect of the pozzolan on the setting time of the blended cement.

1.4 Justification of the Research

A number of countries have worked on burnt clays as a pozzolan but results obtained cannot be universally applied in countries other than the one in which such a research might have been carried out.

This is because variations abound in the composition of the clays from different climatic conditions and sometimes even within the same climatic regions there could be variations. It is likely, therefore, that results to be obtained will not be the same with those already obtained in other countries. This uncertainty justifies the research.

The need to know for certain the performance of the burnt clays found in Nigeria cannot be over-emphasised. This is particularly true since generalisation in scientific works can be very dangerous or lead to wastage as the case might be.

Obtaining suitable results from this research works might imply cost saving on binding material and less pressure on OPC, moreso that clay is in abundance in Nigeria.

1.5 Scope and Limitations

All tests carried out were limited to physical tests to determine physical properties of the powdered burnt bricks, the mortar mixes and specimens made from the various mixes. Chemical tests on the powder were not carried out due to cost, non availability of necessary equipment and time factor.

Specimens were tested for a maximum period of 90 days. The long period was to enable a proper assessment of properties to be carried out as pozzolans generally perform better with age. Specimens to be used shall be of standard size cubes of 70mm x 70mm x70mm (Orchard, 1962). Few full size sandcrete blocks(230mmx 230mmx 450mm) were made to correlate results with those obtained from cubes.

All burnt bricks used were obtained from the Kaduna Clay Product Factory, Kaduna, along Kachia Road,Nigeria.

1.6 Methodology

In conducting this research, relevant literature on the subject matter were reviewed. Burnt bricks were crushed into powder of required fineness using a mechanical machine. A number of tests were carried out on the powder like fineness, specific gravity, bulk density and setting time.

Trial tests were conducted to determine optimum values of water/cement ratio, percentage replacement of OPC by the PBB and effect(s) of size distribution variation on strength. Using the results of the trial tests specimens were made and their properties investigated. Specimens made with 100% OPC (0% replacement) as binding material were used as reference samples or basis of comparison.

Tests carried out on fresh and hardened mortar of various mixes include slump test, compressive strength and split tensile tests. Ages of compressive tests were 3, 7, 14, 28 and 90 days while that of the tensile test was 28 days.

All tests were carried out under normal room temperature in the laboratory of the Department of Building, Ahmadu Bello University, Zaria. Specimens were covered with wet sacks for the first 24hours. There after the specimens were demoulded and cured in a tank kept in the laboratory up to the time appropriate test were carried out on the them.

Results obtained were analysed and conclusions and recommendations drawn appropriately.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Background

Over the years, a lot of materials of various forms have been thought of and many tried for construction purposes. In the early times the method of trial and error was used to test their suitability or otherwise. Now, however, scientific methods are being used. These are found to give more reliable results at lesser cost and risk. Through these processes, a lot of materials have been ascertained suitable for construction though to varying degrees. A number of these materials can be used directly for construction as naturally as they occur like timber, grasses, stones. Others have to be processed or have their individual parts held together by another material. Others still are used to hold others together like mineral or non-mineral binding agents, adhesives, nails. Sometimes it is a combination of the different processes and types as appropriate. This work shall be looking more into the last category.

Mineral binding agents are fine powders that are capable of producing a plastic pasty mass on mixing with water and passing into a stone when exposed to physical and chemical action, (Komar, 1973). This property makes mineral binders very suitable for the preparation of mortars and concrete.

The use of binding materials is very old. One of the first binders that was put into use by man is unburnt clay. As early as 3000 BC, stronger binders had been obtained artificially by burning some substances. Gypsum and lime were among the first in this group. Much later stronger and water resistant binders were obtained by adding crushed burnt brick to air-setting lime.

The walls of Sophiysky Cathedral in Kiev, Russia, were laid on lime with addition of crushed burnt brick in the 11th century. Other mineral binders that followed were hydraulic lime, Roman cement and Portland cement among others, (Komar, 1973).

Though quite a number of mineral binders have been found, very few are being effectively used today in the construction industry. This could be attributed to the low availability of some, leading to high cost of finished products. For others their effectiveness is low so that with better substitutes around sometimes at about the same cost, they are abandoned or hardly used.

Some materials sometimes used as binding materials in themselves, they possess no binding ability but they do when they are combined with other materials especially lime. These materials are called **POZZOLANS.** Examples of these materials include fly ash, diatomite, powdered burnt brick (clay), blastfurnace slag. The availability of these materials varies from place to place, so do their quality which determines their effectiveness or reactivity. In general, though the reactivity of pozzolan is on the low side, other advantages they possess encourage their usage especially where they occur in abundance. This research is focussed on pozzolan with particular emphasis on powdered burnt brick (PBB).

Mineral binders are classified into Air-setting and hydraulic-setting varieties. The former are substances that pass into a stone state gaining or retaining mechanical strength in the air only e.g. gypsum, magnesium binding materials. The hydraulic-setting are substances that pass into the stone state not only in the air but also in water e.g. Portland cement, Pozzolanic binding materials.

Hydraulic binding materials consist mainly of silicates and aluminates of lime and can be classified broadly as natural cements, Portland cements and high-alumina cements.

2.2 Pozzolans

Pozzolans were defined by the American Society of Testing Materials (ASTM) specification C 618 -78 as:

> "materials that have siliceous or siliceous-aluminous contents which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties."

The name pozzolan is derived from the name of a town Pozzuoli in Italy where Mount Vesuvius is located. It was from this mountain that Volcanic ash was found and used by the Romans for the construction of their structures (Waddell, 1962). Volcanic ash is usually referred to as the first natural or simply original pozzolan to be used for construction. The most commonly used, however, is the fly ash probably due to its availability.

A number of materials have been tested and found to be suitable as pozzolans though their effectiveness varies from one material to the other. The variation is due to various reasons as shall be seen later. Most of the materials are bye-products of agricultural and industrial processes. They are often produced in large quantities constituting a waste problem if they remain un-used. This aspect alone would justify increased use of these materials even if there were no other benefits.

Whenever pozzolans are used in concrete or mortar, as it is often the case, they are either for partial replacement or as an addition to the cement. When pozzolans are to be used for partial replacement for cement, the pozzolan and the cement are batched separately before mixing with other ingredients in the mixer.

The binding property the pozzolans acquires when mixed with cement is as result of a chemical reaction of the amorphous silica and/or alumina content of the pozzolan and calcium hydroxide. The latter is a product of the hydration of cement which if not reduced could lead to fast deterioration of the concrete or mortar when exposed to injurious chemicals.

2.2.1 Classification of Pozzolans

Different types of pozzolans exist and of these there could be varieties. For a better and easier understanding, pozzolans have been classified into groups. The basis of this classification is often occurrence. They are classified into natural and artificial pozzolans.

Natural pozzolans are those used as they occur naturally except that they are ground to at least cement fineness. They are further subdivided into volcanic and sedimentary pozzolans. Artificial pozzolans, on the other hand, are often industrial or agricultural processes bye-products. Some are burnt or calcined at high temperatures to bring them to their active stage. (Table 2.1).

In general, pozzolans, whether natural or artificial are usually ground to their amorphous form as the crystalline type especially the active silica in the pozzolan has low activity. Alumina and iron, if present in the admixture, like silica are also active, **(OCHARD, 1962),** though their reactions are said to be very complex.

Table 2.1: Classification of Pozzolans

NATURAL POZZOLANS		ARTIFICIAL POZZOLANS
VOLCANIC	SEDIMENTARY	
Volcanic ash	Diatomites	Granulated blast-furnace slag
Pumice	*Tripoli*	*Fly Ash*
Trasses	Opoka	Rice Husk
Vitrophyres	Shales	Burnt Clays

Source: Concrete Technology and Practice by **W.H. Taylor.** (1977)

2.2.2 Chemical Compositions of Pozzolans

The composition varies from one pozzolan to the other and even with the same type of pozzolans but obtained from different locations. Sometimes, still, variation could occur with pozzolans obtained from the same location but produced at different times or conditions. In general, composition of pozzolans depends on the raw/parent material from which it is produced, the location of the material and the conditions under which it is produced.

The major constituents of any pozzolan are silicon dioxide (SO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3). These together often constitute at least 70% of the pozzolan as stated by the ASTM requirements. It is believed that most of the major characteristic properties of pozzolans are determined by these major constituents. It has also been discovered that these three are all active in the chemical reaction with the calcium hydroxide to form the cementitious compounds. In addition, the iron gives most pozzolans the grey or brown colour. In a typical American pozzolanic cement, these major constituents of the pozzolan account for only 25 - 45% averagely, **(Orchard, 1962)**. Other constituents of typical pozzolans include small quantities of calcium oxide, magnesium oxide (Table 2.3).

Table 2.2: Physical Requirements for Pozzolans according to the American Society for Testing Materials (ASTM) C618 - 78.

PROPERTY	Standard Requirement in Percentage (%)
Drying Shrinkage (Maximum percentage)	0.15
Water Requirement (Maximum percentage of Control)	115.00
Loss of Ignition (Maximum percentage)	12,00
Increase in Drying Shrinkage of Portland Pozzolanic Cement Mortar bars at 28 days (Maximum percentage)	0.03
Water Soluble Fraction (Maximum percentage)	10.00
Fineness: amount retained when wet sieved	
i) No. 300 Sieve (Maximum percentage)	2.00
ii) No. 200 Sieve (Maximum percentage)	30.00
Pozzolanic Activity Index + Portland Cement at 28 days (Minimum percentage of Control)	75.00

Table 2.3: Chemical composition for Pozzolans according to the American Society for Testing Materials (ASTM) C681 - 78.

CONSTITUENTS	Standard Requirement in Percentage (%)
SiO_2 + Al_2O_2 + Fe_2O_3 (Min. percentage)	70.00
Magnesium Oxide (MgO) Maximum percentage)	5.00
Loss of Ignition (Maximum percentage)	12.00

2.3 Properties of Pozzolans and their cement.

The action and properties of pozzolans differ widely and their efficacy in any particular circumstance can be determined only be careful tests, (**Orchard, 1962**).

A pozzolanic cement or blended cement as sometimes called, is a hydraulic cementing material obtained by combining fine grinding of clinker (cement) and an active mineral admixture (pozzolan) or by thoroughly mixing the same materials having been separately ground, (**Taylor, 1977**). Generally, the quantity of the admixtures added is usually between 15 - 40% by weight of the cement. The admixture - to - clinker ratio depends on the activity of the former and the mineralogical composition of the latter. Taylor (1977) discovered that the greater the activity of the admixture, the greater its capacity to bind the calcium oxide hydrate but the lower its amount in the pozzolanic cement and vice versa.

Properties of pozzolans include among others the following:

2.3.1 Fineness

The BS12:1978 gives the minimum specific surface area of pozzolans as 2500 sq.cm/g which is quite close to that of ordinary Portland cement of 2250 sq.cm/g. Powdered burnt clay called sukhi in India, gotten from Amritsar was found to have a specific surface area of

3246 sq.cm/g **(Uppal et al, 1964)**. Using the less accurate method, fineness retained on the 90-Um (No. 170 ASTM) test sieve is determined and the maximum residue is limited to 10% by weight.

This property is important because fineness enhances the reactivity of pozzolans. It has been found that the amorphous pozzolans are more reactive than the crystalline.

This is so because, the finer the pozzolan, the greater the area available for reaction and hence the higher the strength of the mixture, **(Uppal et al, 1964)**.

2.3.2 Hydration

It is a chemical reaction between the cementitious material and water. It is preceded by the setting of the cement. The latter is the disappearance of plasticity or stiffening of cement paste which begins when water is added to the cement. Setting time depends on the cement type and environmental factors. A pozzolanic cement with fly ash as the admixture from BOKARO in India was found to have initial setting time of 188 min. and final setting time of 293 minutes **(Rehsi & Garg, 1963)**.

Pozzolanic cements are characterised by smaller strength gain during the early periods of hardening as compared to ordinary Portland cement. There are two stages in the hardening of pozzolanic cements. First, there is the hydration of the portland cement minerals. The second is the interaction of the active mineral admixture (pozzolan) with the calcium oxide hydrate released during the hardening of the Portland cement. Hydration takes long. For pozzolanic cement, 90 days is usually used to assess its working strength since considerable increase occurs beyond 28 days used for portland cement **(Mather, 1956)**.

Relatively, only small amount of heat of hydration is usually released and at a low rate during the setting and hardening of pozzolanic cement **(Taylor, 1977)**. This makes it very suitable for use in mass concrete works since large internal stresses will not be developed. It is therefore, very good for use in the tropics where high temperature abound such that the net effect of heat is not detrimental to the concrete or mortar.

The admixture (pozzolan) expands as a result of the heat of hydration making the concrete/mortar denser. This implies that pozzolanic cements have a lower permeability compared to ordinary portland cement. This property makes them very good for water retaining structures **(Taylor, 1977)**.

2.3.3 Activity of Pozzolans

The basic characteristic property of pozzolans influencing usage is their activity. It is the degree to which the pozzolan is active to react with lime (calcium oxide) in forming the binding compounds. The chief constituent of pozzolan is silica and it was previously believed to be the only component that goes into reaction with lime. However, from recent investigation it has been found that aluminium and iron oxide if present in the pozzolan also take part in the chemical reaction which are known to be complex **(Orchard, 1979)**.

Pozzolanic activity is described by the amount of calcium oxide (Ca0) absorbed from the mix/g of the admixture (pozzolan) during 30 days **(Taylor, 1977)**. BS4550: part 2: 1970 has it that, 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. This means that pozzolanic activity consists of the fixing of $Ca(OH)_2$ by the pozzolan so that the lower the resulting quantity of $Ca(OH)_2$ the higher the pozzolanicity.

The American Society of Testing Materials (ASTM) standard C618-78 prescribes the measurement of pozzolanicity index. It is determined by assessing the strength of mixtures with a specified replacement of cement by the pozzolan.

Pozzolanicity is still imperfectly understood. However, the chemical composition of the pozzolan and its specific surface influence is considerable (Neville, 1981).

With respect to the first method of measuring pozzolanicity, it is said that pozzolans like Tripoli and diatomite have an activity as high as 150, trass 60, pumice, tiff and volcanic ash 50 and naturally burnt clay rocks as low as 30 (Taylor, 1977). Up till now, no definite relationship has been found between the activity of pozzolans and the resulting strengths, nor with other properties of hardened concrete or mortar made from the cement.

A mineral admixture is considered active if the setting time of a paste prepared from the admixture and air slaked lime does not exceed seven days after mixing and if paste becomes water resistant not later than three days after the setting. The rate of reaction of any mix depends on the chemical composition, pore structure and fineness of the pozzolan.

2.3.4 **Economy**

Since most pozzolans are by-products of agricultural and industrial processes found in large quantities, they are usually gotten at little or no cost, moreso, that they often constitute a waste problem for the owners. The major sources of cost are the burning for those pozzolans that must be calcined and the grinding to required fineness.

It has been found that the use of pozzolanic cement is cheaper than wholly using portland cement such that the usage of pozzolan is often justified by economic consideration e.g. Gipps and Britton estimated that £50,000 was saved by using a local pozzolan in concrete for the **koon-boo-loomba dam** in Australia **(Orchard, 1962)**.

2.3.5 Water Requirement

The water requirement of pozzolanic cement of dense and solid admixtures like trasses and tuffs is almost the same as that of Portland cement. However, it increases considerably when soft and porous admixtures like diatomites and tripoli are used. For this reason, the required mobility of a concrete mix using pozzolanic cement is provided by an appropriate addition of water. This action in turn calls for a greater consumption of cement so that the strength of the concrete is not reduced **(Taylor, 1977)**.

2.3.6 Strengths

Using any of the strength tests - mortar or concrete tests - it has been established that compressive strengths of pozzolanic cements are lower than those of portland cements of the same clinker at early ages. At later ages, however, the gap reduces considerably. This is due to the hydration of the pozzolann which takes longer time utilising one of the products of the hydration of the clinker cement e.g. Lea (1970) found that a pozzolanic cement of 40% burnt clay powder and 60% Ordinary Portland Cement (OPC) used for concrete gives 68% of the strength of unsubstituted portland at 28 days. At 180 days, the strength was 82% while after one year the strength was about 95%.

As would be expected, the strength at whatever age depends on the percentage replacement of cement with the pozzolan, the type of pozzolan and the mineralogical composition of the pozzolan among others.

Tensile strength of pozzolanic cement unlike the compressive strength, is higher than that of portland cement at longer ages e.g. using the same mix as above, Lea (1970) found that the tensile strength art 28 days was 92% of the unsubstituted.

The American Society of Testing Materials standard C595-79 limits the pozzolan content to between 15 and 40% of the weight of the Portland-pozzolan cement. If 90 days strength, rather than 28 days strength is the mix design criterion, replacement levels in excess of the 40% limit or at worst on the high side of the limit will satisfactorily be obtainable.

2.3.7 Others

Pozzolanic cements show good resistance to sulphate attack and some other destructive agents when compared to portland cement. Other advantages attributed to pozzolanic cement include improvement of workability of mixes, reduction of bleeding and segregation, resistance to freezing and thawing. All these are higher when compared to Portland cement. It is often argued, though, that the advantages gained from most of these are relatively very small.

2.4 Pozzolanic Reaction

In order to understand pozzolanic reaction it necessary to look at the hydration of portland cement.

2.4.1 Hydration of Portland cement

The process by which cement sets and hardens by taking up water in complex chemical reaction is called hydration. This process starts immediately after the cement comes in contact with water and this is continuous for months or even years though at a decreasing rate with age. The rate of this chemical reaction increases with increase in fineness of the cement.

Portland cement is made up of about four main compounds that may react with water with the most active being Tricalcium silicate ($3CaO.SiO_2$) often abbreviated as C_3S

. Cement compounds react with water in two ways.

First, by a direct addition of some water molecules, this is the true reaction of hydration. The second is hydrolysis, which is an alkaline reaction giving off hydroxyl irons (OH^-). The two reactions are not usually differentiated but are just called hydration.

The hydration of C_3S is as below:

$$2Ca_3O.SiO_5 + 6H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2 \quad \text{.....2.1}$$

The products of hydration as can be seen above, are calcium silicate (tobermorite) of lower basicity and lime in the form of calcium hydroxide. The former has a binding ability but the latter which is in the form of free lime is undesirable and even detrimental to the concrete or mortar. The free lime if left hardens by combining with carbon dioxide very slowly to form calcium carbonate. This product has expansion tendencies. In so doing it causes cracks and failure of the mortar/concrete **(Neville, 1981).**

$$Ca(OH)_2 + CO_2 \text{ ------> } CaCO_3 + H_2O \quad \text{.....2.2}$$

The second compound of Portland cement, bicalcium silicate (C_2S) also hydrate like C_3S but with less lime liberated as can be seen in the equation below:

$$2C_2S + 4H_2O \text{ ---> } 3CaO.3SiO_2.3H_2O + Ca(OH)_2 \quad \text{.....2.3}$$

While Tricalcium aluminate (C A) hydrates without taking up nor releasing lime, Tricalcium aluminoferrite hydrates to take in little of the lime released by the first two compounds .

2.4.2 Pozzolanic Effect on Ordinary Portland Cement Hydration

When a pozzolan is added into the mix, another chemical reaction apart from the hydration of the portland cement clinker minerals takes place. This reaction is the interaction of the active mineral admixture, which is normally silica from the pozzolan, with calcium oxide hydrate which is released during the hydration of the portland cement. At the same time, the calcium hydroxide is bound into calcium silicate sometime called calcium hydrosilicate, as shown by the equation below:

$$Ca(OH)_2 + SiO_2 + (n\text{-}l)\ H_2O \text{ -----> } CaO.SiO_2\ .nH_2O \quad \text{.....2.4}$$

This hydration product, just like that of portland cement, also sets and hardens. In addition, it helps the mortar/concrete to acquire greater water-resisting property than with only portland cement. This happens so because this hydration product fills pores of the mortar/concrete.

This reaction between lime and silica helps to reduce or even removes completely the lime in the concrete/mortar after a complete hydration. This takes months or even years.

Since the lime-silica reaction uses a product of hydration of the portland cement, this explains the slower strength gain during initial period of hardening of the pozzolanic cement compared to Portland cement.

2.5 Some Pozzolans in Use

Quite a number of materials are in use as pozzolans having been found suitable. Below are a few especially those that are readily available and had been widely used or are today being widely in use.

2.5.1 Volcanic Ash

It is said to be the first natural pozzolan to be used for construction purposes. It was first used in Italy found at Mount Vesuvius close to a town called Pozzouli. The name pozzolan is actually derived from the name of the town as has been observed.

Volcanic ash is a product of volcanic eruptions. The glassy material formed as a result of violent eruptions, though similar in composition to the material of less violent eruption, is found to be more reactive with lime.

Occurrence of volcanic ash is restricted as it is found only in places of active volcanic eruptions. It is either found as fine grained ashes or as large particles or tuff (solidified volcanic ash). The latter has to be ground before usage as a pozzolan.

2.5.2 Fly Ash

Fly ash also called Pulverised Fuel Ash (PFA) is an artificial pozzolan produced by burning powdered coal It is usually the residue of the combustion collected by either mechanical or electrostatic separators from the flue gases of power plants.

In many countries where coal is still a major source of energy, the most common artificial pozzolan is the fly ash, **(Neville, 1972)**. Fly ash in the finely divided state is generally finer than ordinary portland cement. The American Society of Testing Materials (ASTM)

standard ASTM C618 -78 requires not less than 2800 sq.cm/g of specific surface for fly ash with specific gravity to lie between 1.85 - 2.25. Its particles are spherical which is an advantage from the water point of view requirement.

Composition and properties of fly ash vary widely from plant to plant and sometimes even in the same plant from hour to hour production. In general, composition depends on the type of fuel burnt and the variation of load on the boiler. Major constituents are silica, iron oxide, calcium oxide with varying amounts of carbon and aluminium oxide. Any good fly ash should have a high chemical composition consistency, high specific surface area, low percentage of unburnt carbon and alkali. Some type of fly ash, like that found from Neyyeli, contain free lime to the extent of about 25% . Since pozzolans usually combine with free lime to form stable calcium silicates in the presence of water, it follows that this type of fly ash does act as a pozzolan and in addition possesses some cementitious properties by itself without cement being added to it.

2.5.3 Blastfurnace Slag

It is an artificial pozzolan. It is a non-metalic product obtained in the molten state simultaneously with pig iron during the process of reduction of iron ore in a blastfurnace. The main constituents of blastfurnace slag include lime, silica and alumina which are same with those that make up portland cement only that proportions vary. Its chemical composition and properties vary widely depending on nature of ore, composition of limestone flux and the kind of iron being made. The molten slag is usually cooled in a cold water tank after which the clinker is broken into small particles to give granulated blastfurnace slag. In this condition, it is inert and can be transported and stored in heaps. Storage could even be in wet conditions without any special precautions. Before usage as a pozzolan, this is ground very fine. The wet grinding is usually employed. It is believed to give finer product with much smaller power consumption (Ochard ,1962) The dry process has many inherent problems like difficulty in sieving.

The ground slag normally has specific surface of at least 3000 sq.cm/g. About 30% or more portland cement can be replaced using blastfurnace slag without adverse effects on strength and other properties.

Because of the similarities in their composition, the properties of pozzolanic cements made with blastfurnace as the admixture are very similar to those of ordinary portland cement.

2.5.4 Rice Husk Ash (RHA)

It is gotten by burning rice husk, an agricultural by-product. The burning removes the organic matter leaving a silica rich ash. Rice husk produces a high quantity of ash, about 20% by weight of the husk. The ash has a high silica content, sometimes up to 95% by weight.

The temperature and duration of burning are of paramount importance because it is the amorphous silica not the crystalline that possesses high pozzolanic properties. The burning temperature is always below 700 C as temperature above this leads to crystallization of the silica making it less active. The colour of the ash is dark grey to white, depending on the residual carbon in it. Carbon has no negative effect if it is less than 10% of the ash. To improve reactivity of the ash, it is ground in mill for about one hour or more if it is suspected to contain crystalline silica. It has been found that about 30% of Portland cement in mortar and concrete can be replaced by rice husk ash or mixed with 30 - 50% of hydrated lime to be used like cement in mortars rendering and mass concrete **(Alimi, 1989)**. A major disadvantage, however, of using rice husk ash is its increase of shrinkage which increases with increased percentage replacement.

2.5.5 Burnt Clays/Bricks

Clay is an earthen mineral mass or fragmentary rock capable of mixing with water and forming a plastic viscous mass. On drying, it retains the shape it was given and after burning

acquires the strength of a stone **(Chong, 1977)**. Clay results from the weathering (mechanical and chemical disintegration) of igneous rocks, shales and clayey limestone. This implies that clay composition is quite variable depending on nature of the parent rock and on the previous history of the deposit.

Clays are composed of grains of various sizes. These include 5-0.14mm called sand fractions, 0.14 - 0.005mm called dust fractions and less than 0.005mm as clay fractions. The proportions of these fractions determine to a large extent the plasticity of the clay mass. The great the percentage of the clayey particles, the higher its plasticity and cohesiveness. Clay is found almost everywhere on the face of the earth at varying depths in the earth crust. It occurs in large quantities but of varying suitability due to differences in composition.

Classification of Clays

Clays are often classified into two types based on origin and resistance to temperature.

Classification by origin: clays are divided into -

(a) Residual Clays - they are of primary deposits but are generally contaminated by particles of rocks from which they are formed.

(b) Transported or Sedimentary Clays - they are more despersé and free from large particles of mother rock.

Classification by resistance to high temperature: clays are divided into:-

(i) Refractory clays - these feature high refractoriness not below 1580°c. They are distinguished by high content of alumina (40% and above) and low content of impurities (e.g. $FeSO_4$ should not exceed 3%) that lowers the refractoriness. They are highly desperse (60-80% are less than 0.005mm) and very plastic.

(ii) High melting clays: these have refractoriness between 1350 - 1580°c and contain small amounts of impurities such as quartz and felspar. It is used mainly for facing

brick, floor, tiles etc. They are made up of particles of size ranging between 0.01mm - 0mm and 0.005mm -0. They hardly have up to 50% of particles with less than 0.001mm size. Sometimes only 6 - 10% of the particles are less than 0.001mm.

(iii) Low Melting Clays - their refractiveness is below 1350°c and they are more varied in composition as they contain sand, limestone, iron oxide, mica and organic substances.

Sometimes, clays are classified on the basis of plasticity. In effect therefore, clays are divided into the following:-

(a) **High Plasticity Clays** - these have a water requirement of over 28% and air shrinkage from 10 to 15%.

(b) **Medium Plasticity Clays** - they have a water requirement of 20 - 28% and air shrinkage of 7 to 10%.

(c) **Low Plasticity Clays** - they have a water requirement of less than 20% and air shrinkage of 5 to 7%.

Calcining of Clays

Clays have a characteristic property of turning into a stone mass in the process of calcining (burning). Burning of clays is often done when it is to be used for clay blocks or other ceramic articles. Also, clay is sometimes burnt principally to convert the inert silica it contains into a reactive form in order to use clay as a pozzolanic material.

Calcining of clays passes through a number of stages depending on what the clay is to be used for. In general, the stages include preparation, moulding, drying and burning. If the clay is to be used only as a pozzolanic material, then the first and second stages are unnecessary.

The clay is dug from the source using mechanical means mostly, sometimes the manual method is employed. The dug material is then transported to the calcining centre.

The preparation involves the removal of stones and other undesirable elements that might be found in the clay and mixing it by itself or with other clay(s) as might be required to obtain homogeneity. It also involves the tampering of the clay by adding water and kneading it to bring it to the required consistency. All these are done by the help of special machines designed for this purposes.

Moulding is only done if clay is to be used for the production of block or other ceramic articles. Hand or machine moulding is used to mould clay into shape and size. The machine moulding is generally more economical except where special shapes are required **(Adams, 1974)**.

The machine moulding also has an advantage of conveniently using relatively stiff clay with the lower moisture content thereby reducing shrinkage of the element during the drying and burning processes.

The clay having been molded appropriately is then dried at about 100oc. Drying this way is to eliminate water of plasticity (mechanically mixed or entrapped water) thereby making the clay rigid though brittle. This helps to reduce distortion and cracking of the elements during firing resulting from the pressure of the water vapour going off **(Taylor, 1973, Chong, 1977)**. Drying also makes the clay items light and porous which is advantageous. Drying often takes about three to four days.

The burning of clays and their products is done by subjecting them to intense heat through the use of any of the following three methods, namely: the car tunnel kiln, the Hoffman kiln and the clamps methods. Fuel used for firing is usually gas and sometimes coal or wood. When fired, the clay structure alters completely with a hard, rigid material forming. Firing causes localised melting or sintering of the clay as easy-fusing clay components melt, spread out and envelope particles that are still solid. On cooling the moulten mass solidies and cement the particles **(Taylor, 1973; Komar, 1973)**. This partial melting of clay minerals and the action of surface tension of the moulten mass brings the particles closer together and so cause a reduction of its volume. This phenomenon is usually known as the fine shrinkage.

At temperatures between 100 - 700oC, clay minerals loose their water of crystallization thereby losing plasticity. At higher temperature, say up to 900oC, the clay acquires properties of hydraulic admixtures. This is essentially when the silica and other elements like alumina and iron which have been in their inert stages are converted to their reactive state. At this stage also, iron compounds are oxidized to ferric oxide from ferrous and carbonaceous impurities are burnt out.

The colour of burnt clays depend solely on the content of iron oxides which more often than not give the burnt clays and their products a red colour. This holds when there is excess oxygen inside the kiln, but a dark brown or even black colour results when there is no enough oxygen. Direct firing of clays and their products takes about two days. Clay products that are underfired in terms of temperature and/or time are liable not to be durable especially if used externally and in exposed situations **(Adams, 1974)**. Cooling of fired clay products is done gradually to prevent setting high internal and surface stresses that cause cracks.

Before using burnt mass clay or its products as a pozzolanic material the mass clay or products are first broken into small pieces. These small pieces are then ground into fine powder having a minimum specific surface area of 2500 sq.cm/g as applicable to pozzolans. Grinding could either be manually or mechanically done, but where large quantity is required the latter is used. The grinding, just like for cement clinkers, is done in laboratory ball mills or other suitable machines like mortar mixer.

The major problem as with any other dry process is the difficulty of sieving since sizes are usually very small. Size is often below 90micron, being generally smaller (finer) than that of ordinary portland cement. Storage is generally easy with no special precautions required. Burnt clay is stored both in open and under shade in all seasons. In general, it is not stored in its powder form but as broken or unbroken pieces of the mass clay or of their products. This is because in this state the clay is inert like the broken pieces of blasfurnace clay. Therefore, the storage of burnt clay masses or product is neither costly nor risky.

Properties of Powdered Brick

A number of properties are associated with burnt clays which are affected greatly by the presence of impurities. Thus, a high content of free silica not bound by aluminium oxide (Al_2O_3) in the clay compounds reduces the binding properties of clays, increases the porosity of the burnt clays and products as well as lowers their strength.

Burnt clays are usually ground very fine. Fineness is often higher than that of ordinary portland cement e.g. while the specific surface area of ordinary portland cement is given as 2250 sq.cm/g minimum (BS 12: 1978) a sample of powdered burnt clay from Amritsar was said to have a specific surface of 3246 sq.cm/g **(Uppal et al, 1964)**. Showing an appreciable difference. Even the rapid hardening portland cement has a specific surface of 3250 sq.cm/g, jut tallying with that of the sample in India as stated above. With either the pozzolan or cement, the higher the fineness the more reactive it becomes.

In general, powdered burnt clay is lighter than ordinary Portland cement from physical handling. The specific gravity of Portland cement often lies between 3.1 - 3.2. But a sample of powdered burnt clay from Amritsar in India was discovered to have a specific gravity of 2.48 which is lower than that of ordinary portland cement. This agrees with the result of physical handling stated above. The lower the specific gravity the higher the water requirement and the lighter the material. Because powdered burnt clay is lighter, higher volumes of it are usually used than the volume of the portland cement it is replacing.

All clays contain iron compounds, though to varying degrees of concentration. On heating with an oxidizing flame, therefore, clays turn red. The colouring material is often ferric oxide. The intensity of the colour depends on the concentration of the compounds of iron.

The higher the concentration the deeper the intensity of the colour. If there occurs any clay without iron compounds, on heating in an oxidizing flame, it will turn white. Also, when there is no enough oxygen during the burning process the clay turns dark brown or black as stated earlier.

The chemical composition of clay whether in its burnt or unburnt stage is basically the same since burning just removes water of plasticity and crystallization. Other little changes are the conversion of ferrous to ferric compounds and burning out of carbonaceous impurities which are often small in quantity.

Burnt for powdered burnt clay, the composition of two typical clays can be seen below:

Table 2.4: Composition of two typical clays

Chemical Constituent		PROPORTION -Percentage by weight	
		Powdered Bricks - 1	Powdered Brick - 2
Primary	Silicon oxide	60.20	50.52
	Aluminium oxide	17.72	38.35
	Iron oxide	7.58	2.35
Secondary	Tin oxide	1.25	1.35
	Calcium oxide	2.68	0.75
	Iron oxide	2.50	0.91
Tertiary	Potassium oxide	3.20	0.78
	Sodium oxide	1.03	0.52
	Sulphur trioxide	2.53	0.40
	Loss of Ignition	1.29	4.03

Source: Adapted from Properties of Materials **(Orchard, 1962)**.

Powdered burnt clay just like any other pozzolan does not have any binding ability when put into water under whatever condition since it does not react with water. At this stage, it does not even have any physical binding ability having lost its plasticity during burning.

Properties of powdered burnt clay pozzolanic cement

The properties of burnt clay pozzolanic cement or products made from it vary depending on the mineralogical composition of the clay and the temperature of curing. In general, clay with amorphous silica and high alumina contents is the best. In a country like Britain, the influence of temperature is nil at 0°c but is considerable at 18°c.

With careful proportioning, strength developed by pozzolanic cement of clay is the same with that where only the portland cement is used of the same mix. This is possible because the powdered burnt clay contains some particles that are finer than the portland cement. So, because of the larger specific surface area, the finer particles of the powdered burnt clay fills voids in the aggregates in a better way. Thus, the strength lost by the mix through replacement of the cement is compensated for, to some extent, by the greater compactness of the mass. At early ages, the replacement of portland cement by the pozzolan of clay results in a decrease in the compressive strength. But the difference reduces or even disappears at ages of 3 months or more when compared with those where no replacement is done. Another very important point as regards the use of burnt clay is that tensile strength of the pozzolanic cement concrete/mortar is always higher than strengths of unsubstituted Portland cement. In his experiment with burnt clay, Lea (1970) found that with 40% replacement of portland cement by burnt clay, the tensile strength at 28 days was 92% of the unsubstituted one. At 180 days the strength was 102%.

Other desirable properties to be derived from the use of powdered burnt as a pozzolan as compared to ordinary portland cement only include:-

(a) Low heat of hydration, often similar to that of low heat Portland cement. It is low in terms of total heat evolved and temperature attained. This is a big asset in mass concreting as it reduces high thermal stresses occurring. This helps to reduce cracks developing. This is the chief advantage of any pozzolanic cement **(Neville, 1981)**.

(b) Higher resistance to chemicals - In general, it has high resistance to sulphate attack and to some other destructive agents. This is so because, the pozzolanic reaction leaves less lime to be leached out and also reduces the permeability of the mass.

This prevents other elements from being absorbed into it let alone to attack it. Also, since less lime exist, the destructive expansion caused by alkali-reactive aggregates is greatly reduced.

(c) Improves permeability of the mass due to the greater compactness of the mass as a result of the finer particles of the clay pozzolanic cement. This makes it very good for water retaining structures.

(d) Reduction in cost. Since the pozzolan due to its ready availability is often cheaper than the cement, a mixture of the two will mean a reduction in cost for the portland cement e.g. A corps of Engineers are said to have saved $5m (Five million Dollars) between 1940 - 1950 by the reduction permitted in cement content of some 19 x 10 cu m of concrete it placed **(Mather, 1956)**.

(e) Burnt clay pozzolanic cement increases water requirement for some mix. This results in increased drying shrinkage and resultant cracking. Others are improvement of workability especially in concrete works, reduction in volume changes and higher durability. Gains in these areas are usually small.

Use of Clays

Clay is commercially important as a raw material because it occurs naturally and in abundance almost everywhere. It is one of the first construction materials to be used by early man but due to its low strength and other poor properties, its usage did not gain much ground, moreso that other materials of better quality were discovered.

Man discovered that burnt clay acquired more strength than the unburnt, so, where higher strength was required, clay was burnt sometimes to as high as 1500°c in order to convert the clay products into hard durable materials of fixed shapes **(Adams, 1974)**. Initially clays were basically used for only bricks, mortars and for plastering wall made from such bricks. Now, however, clay products are numerous especially of the calcined (burnt) type. They are of different shapes, sizes, types and colour to fit strength, aesthetic and other requirements. Products of clay include bricks for wallings, tiles for flooring/cladding, sanitary

wares, electrical insulators etc.

It was also discovered that the powder of burnt clay products acts as a pozzolan. Burnt clay as a pozzolan has long been known to the Romans, Indians and the Egyptians. The Romans utilised ground burnt brick and tiles as substitute for naturally occurring pozzolans because of their non-availability. The crushed brick and tiles were also used as partial replacement for lime in concrete and mortar mixes.

Though Vicat mentioned burnt clay pozzolan in papers published in 1843 and 1859, the first scientist to link the pozzolanic activity of clays on burning with temperature at which loss of water of hydration occurs was **Fremy (1968)**. Lea (1970) stated that the first commercially produced burnt clay as a pozzolan was by Leafarge company in France which it did up to 1915.

Powdered burnt clays as pozzolans have been for a partial replacement of or added to ordinary portland cement to produce concrete and mortars. Some notable and still standing construction made by partial replacement of cement or lime with burnt clays include Bridges of Fabrics, Elius and arches of Nero, Trogan all in the former Roman Empire. Others include Benneville dam in U.S.A. Aswan and Sennar dams in Egypt. In the construction of the Sennar dam, 30% powdered burnt clay and 70% Portland cement were used to produce the concrete used for its construction **(Mather, 1956)**.

The discovery of portland cement reduced the usage of powdered burnt clay because of its high strength advantage. But the use of the former may resurface much due to the increasing high cost of the latter. Also, improved technology available to enable the production of better quality clay pozzolan, easy grinding machines and burning facilities will go a long way to encourage its use. With the rising cost, clay product manufacturers will want to minimize wastage by grinding broken pieces which are usually much for sale.

2.6 Sandcrete Blocks

A block is defined as a walling unit exceeding in length, width, or height the dimension specified for a brick in BS 2028, 1364: 1968. The height of a block shall not exceed its length or six times its thickness to avoid confusion with slabs or panels.

Though there are many types of blocks, this research is focussed only on sandcrete blocks. Sandcrete blocks sometimes called stabilised sand are prismatic precast units made from lean (sand-cement) mortar mixes. Coarse or sharp or crushed rock dust mixed with cement and water is pressed into shape to produce sandcrete blocks. they are of rough porous surface and of cement grey colour. Sandcrete blocks are used widely in Nigeria but are being gradually replaced by the use of traditional lateritic blocks, probably due to the present economic hardships.

2.6.1 Classification of Sandcrete Blocks

There are different basis of classifying sandcrete blocks. In BS 2028, 1968, they are classified on the basis of density as follows:

1. Type A. These are dense aggregate concrete blocks. Their density is not less than 1500kg/cu.m. They are used in all locations below ground level.
2. Type B. These are lightweight aggregate concrete blocks for load bearing walls.
3. Type C. These are lightweight aggregate concrete blocks for non-load bearing partitions.

Sandcrete blocks are also classified into hollow and solid blocks. A block shall be deemed to be solid if the solid material is not less than 75% of the total volume of the block calculated from the overall dimensions. On the other hand, a block shall be deemed hollow if it has one or more large holes or cavities which pass through the block and the solid material is between 50% and 75% of the total volume of the block calculated from the overall dimensions. (BS 2028, 1364:1968). Also, hollow blocks for load bearing walls should have webs of less than 12.6mm thickness, **(Obande, 1981)**.

2.6.2 **Materials**

Sandcrete blocks are essentially a mixture of a cementitious material, fine aggregate and water in a definite proportion. Each of these components has its characteristic function and should be of best quality and within the prescribed cost limits of the job at hand.

The cementitious material is used to bind together the particles of the aggregate into a solid mass. Materials used for this purpose include lime, ordinary portland cement, portland-pozzolan cement (Rice Husk Ash).

Where only the cementitious material is used, the final product often shrinks during the process of hydration. This causes a lot of cracks. To reduce this aggregate, usually sharp sand, or crushed rock dust is used in conjunction with the cementitious material. The sand is also used for economic reasons since it is much cheaper than the cementing material. For this reason, it is usually higher in proportion to the cementing material. The sand which is an inert material should be clean and well graded, though on the coarse side. The grading should conform to BS 882:1973, preferably to its grading zone 1 or 2 as grading zone 3 & 4 are more fine. Sand used should not contain more than 10% silt.

The quality of water should be very high, say to a drinkable standard. It should be free from acids, alkalis, salts and organic substances. A high concentration of any of these will affect the time and rate of setting and eventual strength, **(Sidney, 1977)**. Also, they could cause efflorescence and scum especially when the environment is damp. The water provides a medium and causes the irreversible hydration of the cementing material.

A mixture of these material-cementitious material, sand and water is referred to as mortar. Though the term mortar is more often used for such mixture used as a bedding material for bricks, blocks and mansory especially where joints have significant thickness **(Adams, 1974)**.

2.6.3 Manufacture

Sandcrete blocks are made from numerous mortar mixes. the mix used at any point in time depends on properties required especially strength and economy. The specified nominal mixes for sandcrete blocks are 1:6 to 1:8 (cement:sand) with water/cement ratio lying between 0.6 to 0.9. Rich proportion usually on request is 1:4.5 with a water/cement ratio of 0.8. This mix is usually used when the thickness of the web of hollow blocks is 25mm or less. **(Obande, 1981)**. In general, mix proportions should be determined carefully in order that the resultant blocks meet specified standard. Stages in manufacture include the following:-

a) Batching

Batching of materials is done by volume or weight using gauge box whose capacities have been determined in advance or weighing machine respectively. This helps to ensure uniformity of batches in order to obtain blocks of averagely same properties of any particular mix used.

b) Mixing

Materials are to be mixed until a uniform and consistent mix is achieved. Better mortars are gotten by longer mixing, therefore, machine mixing is often preferred against the manual . Uniform mixes ensures uniform strength across the blocks section to be made. This is also true for other properties. In mixing, better results are obtained when the materials are first mixed dry before the addition of the required water. Excessive water causes shrinkage and so distortion of the blocks on drying **(Obande, 1981)**.

c) Molding

Molding, as mixing, can either be done manually or mechanically using appropriate tools or machines. The latter often gives better results as the combined effect of vibration and compression gives good compaction which is one major factor that determines block properties. De-moulding of fresh blocks should be carefully done to avoid vibrating, collapsing and distorting the fresh (green) block.

d) Curing

Demoulded blocks should be placed in a way to allow easy curing. Curing is essential to ensure sufficient hydration of the cement giving rise to expected strength and meeting other properties. To ensure adequate curing, blocks should not be left to the mercy of nature but placed under a shed and then ensure controlled curing. It should be started after initial setting and should be done for at least 7 days before usage especially where they are to be used for load bearing. Longer time is required for curing in the dry seasons except if walls made from the blocks will continue to be wetted.

In Nigeria, sandcrete blocks are moulded into various sizes. The common hollow blocks sizes include 450 x 230mm, 450 x 230 x 150mm, 450 x 150 x 330mm, 450 x 230mm and a solid size of 450 x 100 x 230mm(Obande, 1981).

e) Storage

Storage of blocks should be done carefully to avoid damage. For this reason, blocks are usually stacked away from major activity centres to avoid accidental breakages. Blocks are stacked on raised ground to avoid the soiling of bottom layers and being buried by mud. Stacked piles should not be too high as this could destroy the bottom layers due to the excessive weight they are made to carry from upper layers. Sandcrete blocks should be handled in such a way to prevent chipping of edges and corners. This is particularly important if the wall to be made is to be left un-rendered as aesthetic will be affected.

2.6.4 Properties of Sandcrete Blocks

Sandcrete blocks often acquire the colour of the cementing material. Where ordinary portland cement is used the blocks are grey in colour. A number of properties are associated with sandcrete blocks but the most important is strength especially of compression. This is because mortars from which sandcrete blocks are made have low tensile strength of just about 10% of its compressive strength **(Taylor, 1973)**. This is one of the reasons why sandcrete blocks are usually used for elements subjected to only compressive stresses.

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In order to maintain uniformity, high quality and meet other peculiar conditions, a draft code for Nigerian Industrial Standard (1975) specified that the average compressive strengths of blocks shall not be less than the appropriate values given in table 2.6 below. The author is however not aware of the adoption of this draft code.

Table 2.6: Compressive Strength for Sandcrete Block According to the Nigerian Industrial Standard (1975) (NIS)

BLOCK CLASSIFICATION	COMPRESSIVE STRENGTH N/sq.mm	
	INDIVIDUAL UNITS	AVERAGE OF 8 BLOCKS
TYPE A	7.5	5.5
TYPE B	5.0	4.0
TYPE C	2.5	3.5

Source: NIS Draft Code (1975).

The BS 6078:1981 on the other hand specifies that for sandcrete blocks of thickness of 75mm or more, the average crushing strength for 10 blocks be not less than 2.8N/mm^2 while for the individual block at least 80% of this value, implying not less than 2.24N/mm^2

Investigations, however, have shown that these standards are really difficult to meet and may need modification. From findings on four mixes of 1:12, 1:10, 1:8 and 1:6 (cement:sand) ratio, it was found that only the ratio cured either under wet sacks for 24 hours and in air at 94% Relative Humidity and 28°c or under wet sacks for 7 days and in air at 67% RH and 21°c meets the strength requirement of BS 2028: 1968. Also after investigating the quality of sandcrete blocks produced in Anambra and Imo states of Nigeria, it was concluded that most block factories lacked trained and skilled technicians to handle the production activities, hence the poor quality of block **(Uzomaka, 1975).**

Recently however, based on research findings and our local conditions, the Federal Ministry of Works in 1979 Annual Conference in Kano, recommended that the average 28 days compressive strength of three blocks should not be less than 2.1N/mm^2 and the lowest for individual blocks should be 1.7N/mm^2 **(Committee on Review of Decisions, 1985)**.

The quality of sandcrete blocks produced manually under laboratory condition and cured for 28 days in Benin City was discovered to give average compressive strengths of 2.74N/mm^2 and 1.78N/mm^2 for 1:6 and 1:8 (cement:sand) ratios respectively when river bed sand was used. With sand from borrow pits results were 2.25N/m^{2}m and 1.74N/mm^2. The water/ cement ratio used for all was 0.6 **(Okpala and Ihaza, 1987)**. However, from statistical analysis result on 90 blocks obtained from 30 moulding companies in Benin City, it was discovered that they gave a mean strength of 0.79N/mm^2 and 1.71N/mm^2 after partially cured for 7 days and 28 days respectively. Only 52% of blocks tested had up to a 28 day strength of 1.75N/mm^2 which is the minimum recommended for individual blocks by the Federal Ministry of Works and Housing committee 1985 **(Okpala and Ihaza, 1987).**

Sandcrete blocks undergo dimensional changes due to changes in temperature accompanied by drying and wetting. Though the changes might be small, the additional non-reversible shrinkage caused by chemical changes associated mainly with the precesses of carbonation, hydration and curing aggravate the problem **(Obande, 1981).** They have a relatively higher water permeability due to the high number of pores that it has. But lower permeability will be achieved by using pozzolanic cement. Once made to meet requirements and used appropriately, sandcrete blocks are very durable. Moreover, it is usually covered with rendering and painting, tyrolean, tilting etc, so that it is covered from the direct contact of adverse weather conditions.

Also, sandcrete blocks have adequate fire resistance of about 2 hours as given by CP111:1953 and Building Regulation 1976. They are also said to be of poor thermal insulating property except for lightweight blocks. Generally, the lighter the block, the higher the insulating property. For this reason, it is advisable not to fill holes of hollow blocks during building operation. But the sound transmission and absorption property of blocks reduces with increased lightness of the blocks.

CHAPTER THREE

SPECIMENS AND TESTS

All laboratory works were carried out at the laboratory of Department of Building, Ahmadu Bello University, Zaria. Specimens were produced and tested in accordance with the relevant codes of practice as stated and described in relevant sections below.

3.1 Materials used for this study

A number of materials were put into use in the course of this research work. Materials were chosen based on need and in accordance with the standard requirements of the relevant codes of practice. This was done in order to ensure that results obtained meet the scientific research work requirements in the present age. The powdered burnt brick and sand were preliminarily tested to ensure that they conformed to standard specifications.

3.1.1. Cement

Cement used in this study was Ordinary Portland Cement (OPC) from Ashaka Cement Company in Bauchi State. It was bought from a local supplier in Samaru, Zaria. Storage looked good and cement was free from lumps which are usually an indication of partial hardening. The OPC from the Ashaka Cement Company was produced to meet the requirements of BS 12:1958.

3.1.2. Powdered Burnt Brick (PBB)

This powder was gotten from broken burnt bricks obtained from the Nigerian Brick and clay products Ltd.,Kaduna. As one approaches the company along Kaduna Road, after NNPC Kaduna, large heaps of these broken bricks could be seen (plates 1A and 1B). They are not used for anything other than filling potholes along un-tarred roads. Only clay is used for the production of the bricks which is acquired locally from clay pits near the company. Clay used is of two types : - the lateritic and red clays mixed in the ratio 1:2





Plate 1A, 1B
Heaps of Burnt Bricks Waste at the Kaduna
Clay Product Factory

respectively. The whole production was in accordance to British standard No. BS 3921: 1965, 1969. The Kaduna factory is the only one out of the six in various states of the country that is presently in operation. The Nigerian Mining Corporation is planning to have at least one brick factory in no distant future in all states of the Federation. With this, since waste is inevitable, broken bricks will be in abundance with very little transportation cost.

The powder was made by first breaking the broken burnt bricks into smaller pieces. These were then ground in a mechanically operated crusher in the Workshop of Building Department, Kaduna Polytechnic, Kaduna. The resultant powder was sieved using a concrete vibrating table as the shaker. Only powder passing through the 75-um standard BS sieve was collected for use in order to fall within the acceptable limits for pozzolans. Powder was collected into bags and kept dry throughout usage.

The ordinary Portland cement (OPC) and the powdered burnt brick (PBB) formed the cementitious material to be used together or severally. The PBB was the pozzolanic material investigated.

3.1.3 Sand

River bed (dredged) sand as supplied to the Department of Building, Ahmadu Bello University, Zaria was used. It was sieved to remove silt and other impurities it had acquired over the long storage time. Standard BS Sieves were used and the particle size distribution showed that the fine aggregate conformed to grading zone 3 of BS 882, part 2: 1973.

In order to determine the effect of grading on the properties of mortar particularly strength the first grading was slightly altered and compressive test also conducted using it. The first was called grading A, while the second grading B. (figures 3.1). The two gradings of sand all fell within the grading zone 3 of BS 882, part 2, 1973. While grading A was more to the upper limit the grading B was more to the lower limit. This implies that grading A is less coarse to grading B. In general, sand that falls within this zone are used for the production of blocks and mortars.

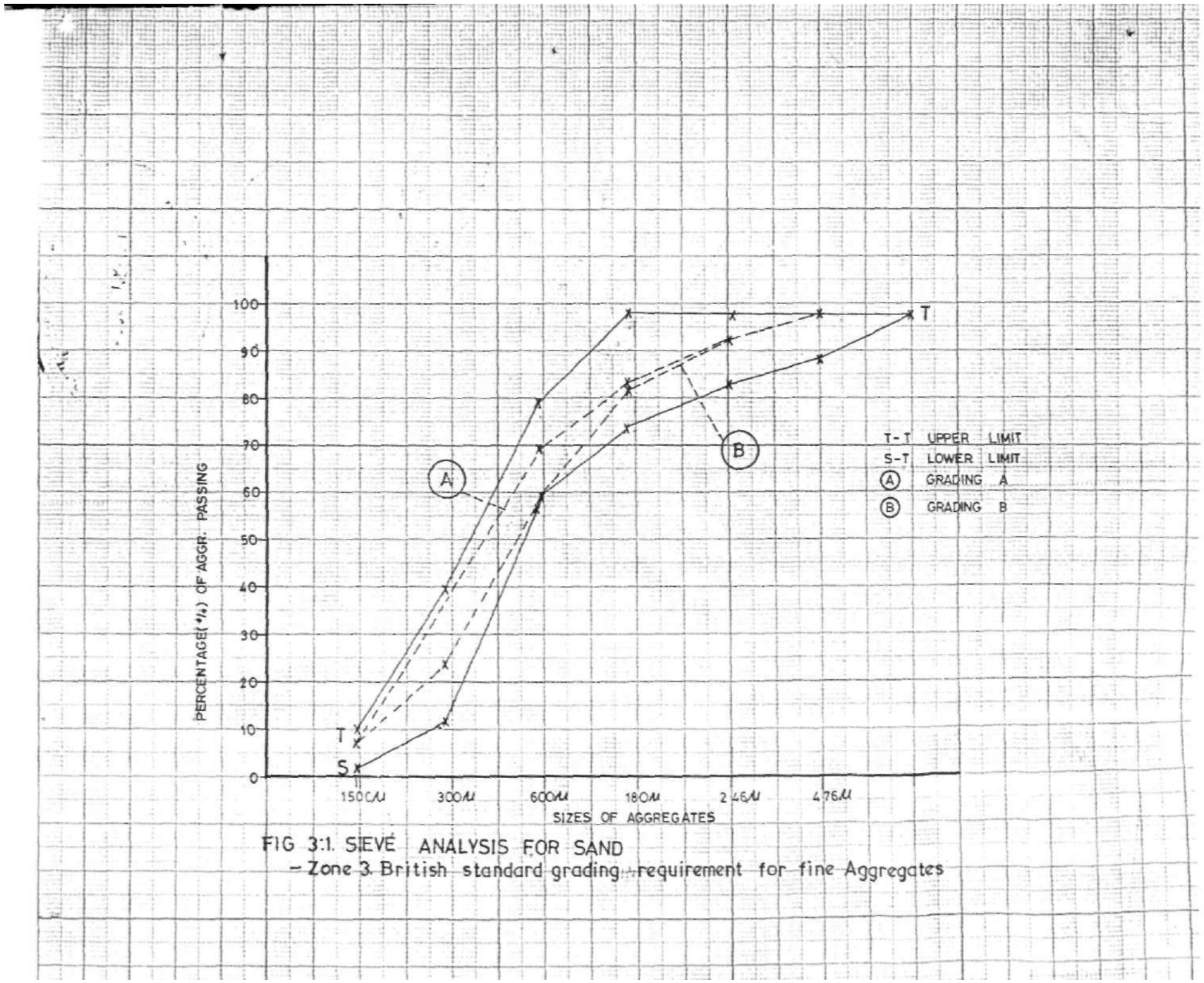


FIG 3:1 SIEVE ANALYSIS FOR SAND
– Zone 3 British standard grading requirement for fine Aggregates

3.1.4 Water

Tap water as supplied by the ABU, Zaria water works was used for this research. It was of drinkable standard and free from harmful matter as required by BS 3148: 1980.

3.2 Tests on the Powdered Burnt Bricks (PBB)

A number of tests were carried on the burnt brick powder (pozzolan) to determine some of its properties. The results were used in mix design calculations.

3.2.1 Bulk Density of Powdered Burnt Bricks

Bulk density sometimes called weight per unit volume is the weight of a material held by a container of unit volume when loosely filled or compacted under defined conditions as specified by BS 12: 1958. It is affected by moisture content, grading of aggregates and the compactive effort used in filling the container if applicable. The bulk density of fine aggregates is usually about 10% greater than that of coarse aggregates of similar composition, **(Orchard, 1962)**. Bulk density is used in void content determination and mix design calculations. The compacted value is always used, as specified by BS 12:1958.

A metal mould weighing 2.75kg of dimensions 70mm x 70mm x 70mm was used as the container, (see plate **IIA**. It is strong and so does not change its shape in use. For the compacted bulk density, the mould was filled in three layers with each layer tamped 25 times with a 20mm diameter rod. The last layer was allowed to overflow with the surplus struck off carefully with a straight edge.

Bulk density was determined using the formula below:-

$$B = W/V kg/m^3 \quad \text{.....3.1}$$

where B = Bulk Density (Kg/m^3)

W = Weight of powder (Kg)

V = Volume of powder (mould) (m^3)

Table 3.1: Bulk densities for powdered burnt brick (PBB).

	Weight of Mould kg	Weight of Mound & Powder kg	Weight of Powder kg	Bulk Density kg/m^3	Average Bulk Density kg/m^3
Uncompacted	2.75	3.06	0.31	904	904
		3.05	0.30	875	
		3.07	0.32	933	
		3.06	0.31	904	
Compacted	2.75	3.14	0.39	1137	1115
		3.13	0.38	1108	
		3.13	0.38	1108	
		3.13	0.38	1108	

From the table above, the compacted bulk density of 1115 kg/m^3 was used for calculations.

3.2.2 Specific Gravity

The density of materials which is mass/unit volume is usually expressed relative to the density of water. It is therefore called relative density or specific gravity. It is a ratio of the weight of the material being considered to that of an equal volume of water, **(Orchard, 1962)**. Specific gravity values are used in mix design calculations.

The specific gravity for the PBB was determined on the air-dry basis because of the powdery nature of the material. In doing this the following were used: paraffin oil, water, density bottles, oven, weighing machine and PBB.

The density bottle was weighed dry, then filled to about one third with the PBB and re-weighed. The bottle having the powder was then filled with the oil and weighed after all air bubbles must have escaped. The bottle was emptied, washed, dried and filled with the oil and water differently and the respective weights noted. The specifications of BS 12:1958 were followed in conducting the test.

Results obtained from this test were presented in table 3.2.

A mean value of 2.53 was used for all calculations. In a mix where both the PBB and the OPC were used, their respective specific gravities were used to obtain a combine value.

Table 3.2: SPECIFIC GRAVITY OF POWDERED BURNT BRICK

Sample	1	2	3
Specific gravity (SG)	2.46	2.55	2.59

Mean Value 2.53.

3.2.3 Setting Time Test

Setting time is usually divided into initial and final setting times. BS 12:1958 gives the procedure for determining setting time for cementitious materials.

In accordance to the BS 12:1958 the paste of standard consistency was determined for each mix ratio using 300g of the cementitious materials. Three mix ratios were used as follows - 100% OPC, 90% OPC + 10% PBB, and 80% OPC + 20% PBB.

Mixing time was four minutes. Readings for the initial setting were taken at 20 minutes intervals while those for the final setting were at one hour interval.

Using the vicat apparatus, the initial set occurs when the needle fails to pierce the sample and reaches about 5mm from the bottom of the mould. On the other hand, the final set occurs when the extra needle being applied gently to the surface of the cementitious material makes an impression but the attachment to the needle fails to do so. The result obtained from the test is presented in chapter four.

3.3 Mix Design

In mix proportioning process there is always the problem of being exact in selecting appropriate aggr/cement and water/cement ratios to bring about optimum properties in the products to be made. To obtain exact proportions of each material, trial mixes were made and tested.

The result of these tests were used to determine the optimum water/cement ratio which was used for the production of the exact mixes. The trial mixes were also used to show the effect of different gradings of fine aggregate on strength of specimens made. A nominal mortar mix of **10:30** (cementitious : sand) often used for mortar test was used for tests.

Various water/cement ratios were used ranging between 0.4 to 0.8. The OPC replacement by the PBB was by weight and ranged from 10% to 50% at intervals of 10% with the 100% OPC used as a basis for comparison

Calculations of quantities of materials were based on absolute volumes and a typical example is shown below for a mix of (2:8):30(PBB:OPC):sand and a water/cement ratio of 0.50.

Table 3.4: **Physical Properties of Materials used in the study**

MATERIAL	DENSITY (Kg/m^3)	SPECIFIC GRAVITY
Cement (OPC)	1440	3.15
Powdered Burnt Brick (PBB)	1115	2.50
Sand	1600	2.65
Water	1000	1.00

Source: Properties of Materials (**Orchard, 1962**)

Sample calculation for materials:

$$\text{Absolute Volume} = \frac{D \times R}{S.G.} \quad \text{---------- 3.2}$$

Where:

D = Density;

R = Ratio in mix proportion;

S.G. = Specific gravity.

Absolute Volume for Sand = 1600 x 30/2.65 = 18113 Litres

Absolute Volume for PBB = (1115 x 2)/2.53 = 892.00 Litres

Absolute Volume for OPC = (1440 x 8)/3.15 = 3657.14 Litres

Absolute for water = (1440 x 8 + 1115 x 2)x.5(w/c) = 6875 litres

Total = 29537.35 litres = 29.54m^2

Quantity of materials in 1m^3 of mortar

PBB	=	(1115 x 2)/29.54	=	75.49 kg/m^3
OPC	=	(1440 x 8)/29.54	=	389.98 kg/m^3
Sand	=	(1600 x 30)/29.54	=	1685.85 kg/m^3
Water	=	(1115 x 2 + 1440 x 8)x .5	=	232.74 kg/m^3

4 moulds were used of 70mm x 70mm x 70mm

Therefore, volume = 0.07 x 0.07 x 0.07 x 4 = 1.372 x 0.001m^3

Add 10% for waste = 1.372 x 0.001 + 1.372 x 0.0001 = 1.51 x 0.001m^3

Materials for four cubes.

PBB = 1.51 x 0.001 x 75.49 = 0.114 kg = 114 g

OPC = 1.51 x 0.001 x 389.98 = 0.58 kg = 589 g

Sand = 1.51 x 0.001 x 1685.85 = 2.546 kg = 2546 g

Water = 1.51 x 0.001 x 232.74 = 0.35 kg = 350 g

Samples were made in accordance with BS 12:1958 as described below:

Mixing was done within 10 - 15 minutes and resultant mortar placed in mould in three layers. Each layer was tamped for 25 times, with a standard tamper of diameter 16mm rod. The last layer was truck off and levelled with a trowel. Specimens were allowed to stay for about 2 hours to attain initial setting before they were covered with wet sacks for 24 hours before de-moulding. These were then cured in clean water in a tank for 28 days before they were brought out and dried in open air for about 2 hours before they were crushed to determine their compressive strength. A manual crushing machine was used for the strength determination in the Department of Building, Ahmadu Bello University, Zaria's laboratory.

Two sand gradings were used in the tests - gradings A and B - as earlier stated in Section 3.1.3. For each mix a total of four cubes were made for the three sets of trial mixes. This was used to determine such parameters as optimum water/cement ratio, percentage of replacement of OPC by the PBB and the grading of sand used. For the first and second trial tests mixes, sand grading A was used while grading B was used for the third trial test mixes. Variation of water/cement ratio and strengths of specimens made from the various mixes are presented in figure 3.2, figure 3.3 and figure 3.4.

First Trial Test

The result of this test is presented in table 3.5 (appendix B). It was observed that for any particular mix, as the water/cement ratio increases from 0.4, the strength of specimens increased to a maximum when the water/cement ratio was 0.65. Thereafter, the strength decreased with increase in water/cement ratio. This relation is shown in figure 3.2.

The mix with 0% replacement developed a maximum strength of 11.2 N/mm^2 while the 20% replacement developed a maximum of 10.6N/mm^2 which was the highest strength of mixes

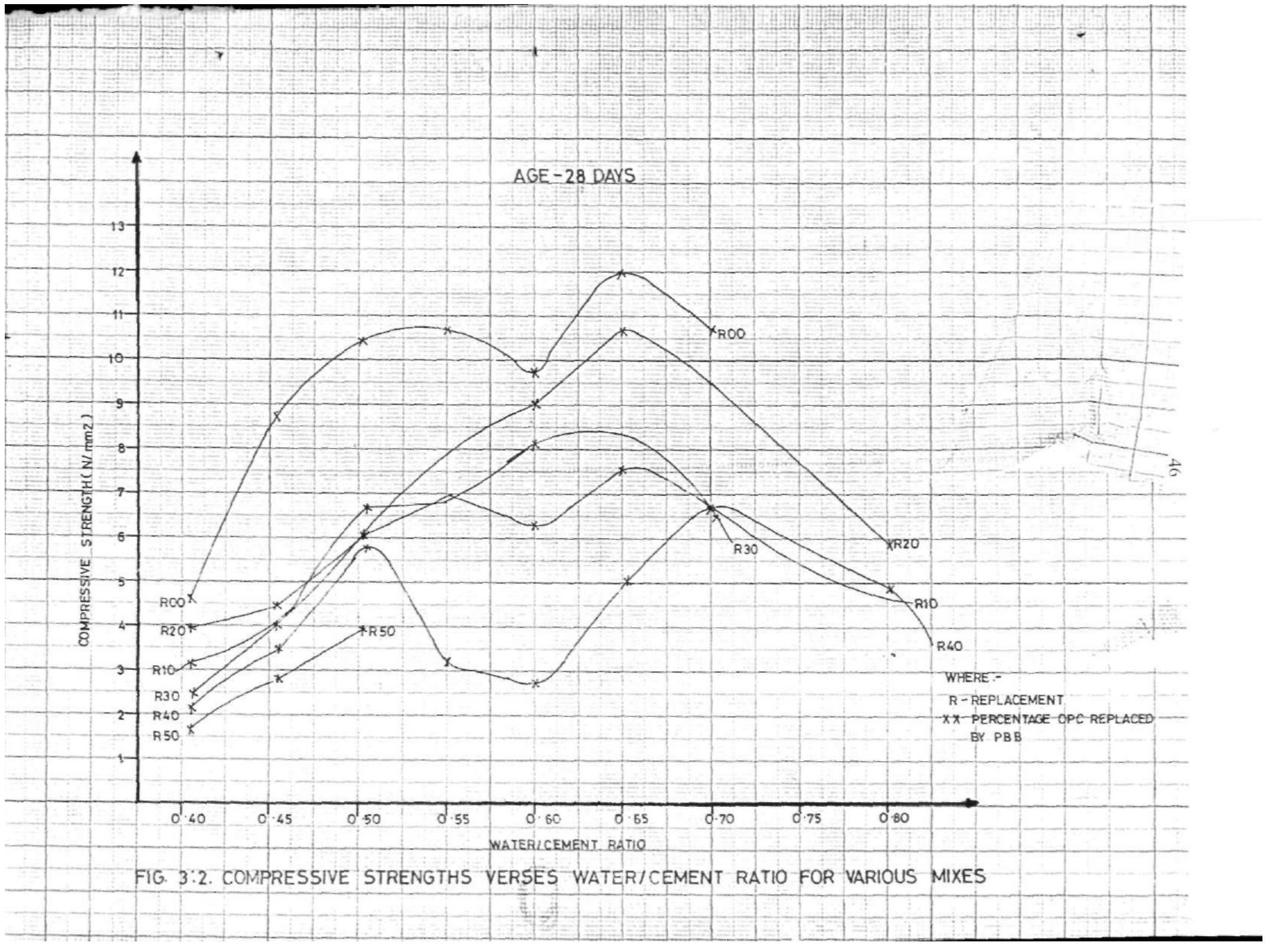


FIG. 3:2. COMPRESSIVE STRENGTHS VERSES WATER/CEMENT RATIO FOR VARIOUS MIXES

with certain percentages of PBB. This showed that for all points before the peak, there was no complete hydration due to inadequate water. The farther away the point, the more acute the deficiency. For points beyond the peak, the water was more than that required for hydration, therefore, excess water evaporated leaving pores which weakened the mortar.

It was also observed that mixes with 0%, 30% and 40% replacement had multiple peaks. This could have been due to errors in compacting and mix proportioning.

Strengths of all mixes were generally low when compared to the standard strength requirement of 15.8 N/mm^2 on the third day as stated by BS 12:1958 for mortars. This was probably due to the high presence of finer sand particles in the mix as shown figure 3.1 for grading A. This also implied that the mix needed higher quantity of cement due to the high total surface area of the sand to have developed the required strength.

Second Trial Test

The test was carried out with sand grading A with water/cement ratio ranging between 0.55 and 0.70 covering the range where multiple peaks occurred and where strengths were highest in the first trial test. Mixes with 40% and 50% replacements were left out because of the very low strengths in previous test. A single hand was used for compaction and mixing done thoroughly to ensure more accurate results.

The result of this test is presented in Table 3.6 (Appendix B). It was observed that the relation between strength and water/cement ratio was more linear when compared to the first trial test result, with other observations remaining basically the same. This relation is shown in figure 3.3.

Third Trial Test

The test was carried out using sand grading B and water/cement ratios ranging between 0.55 and 0.7. The result of this test is presented in Table 3.7 (Appendix B). The same pattern for strength growth as in the other two previous tests was observed. The relation is shown in figure 3.4.

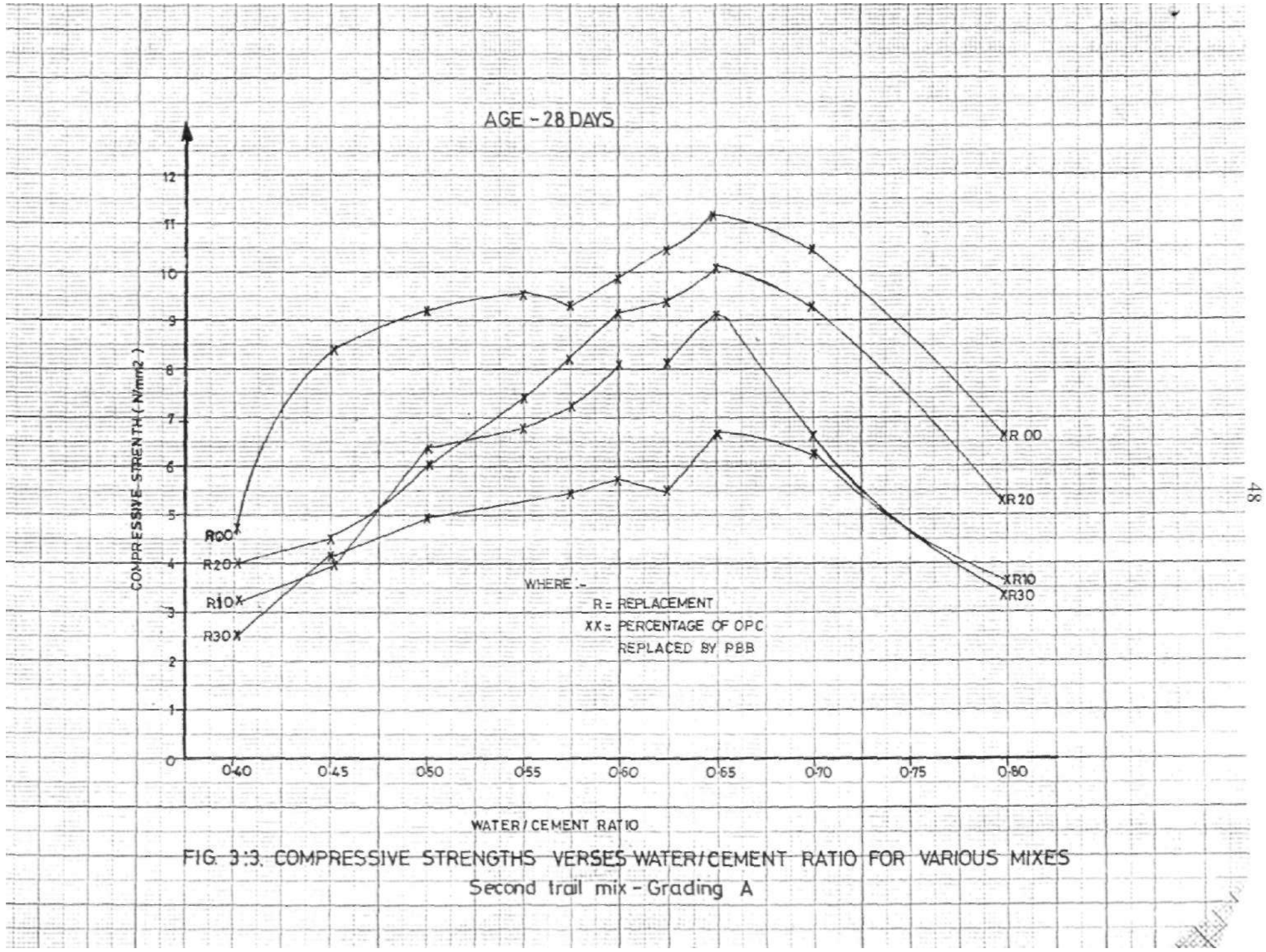


FIG. 3:3. COMPRESSIVE STRENGTHS VERSES WATER/CEMENT RATIO FOR VARIOUS MIXES
Second trail mix - Grading A

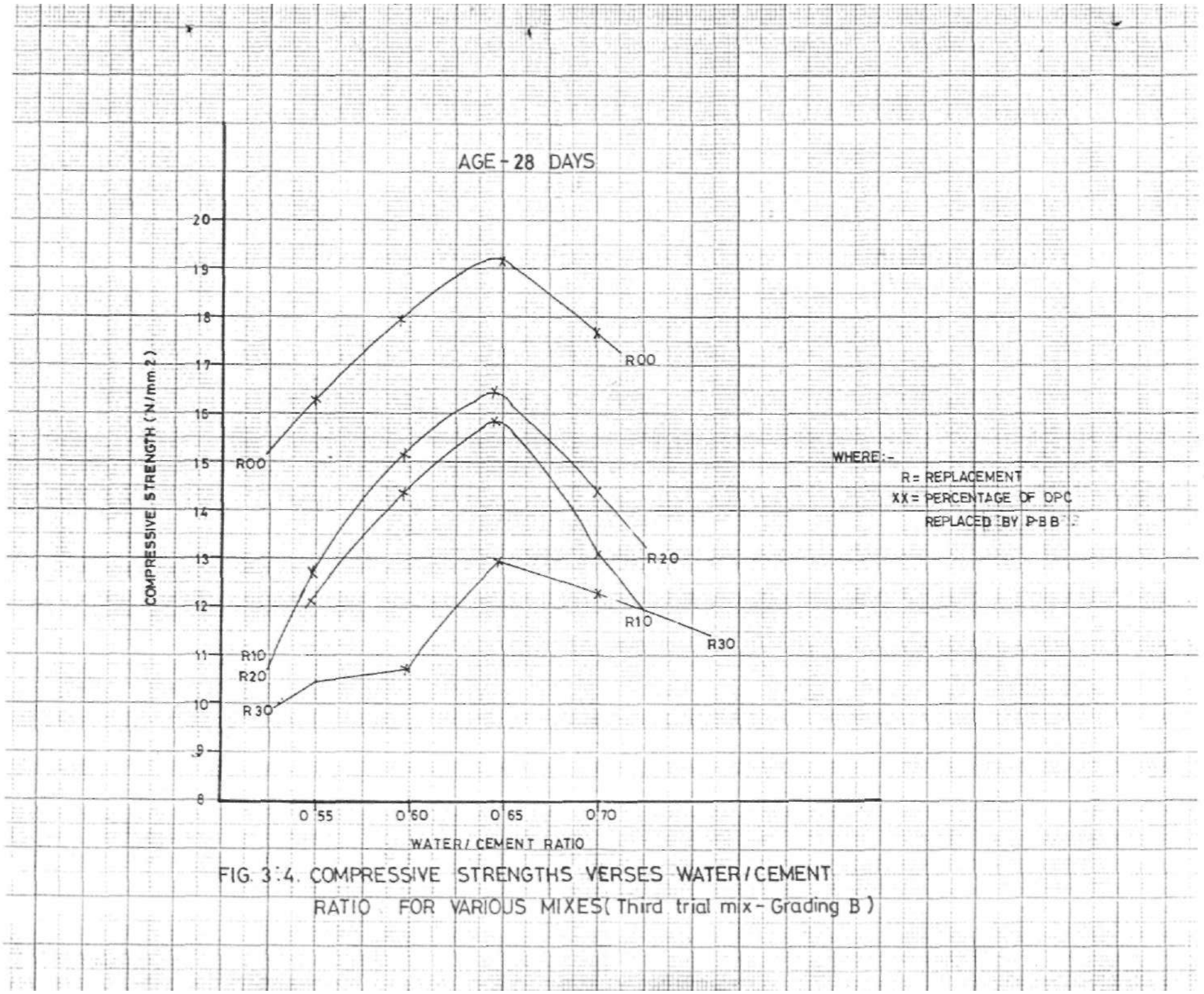


FIG. 3.4. COMPRESSIVE STRENGTHS VERSES WATER/CEMENT RATIO FOR VARIOUS MIXES(Third trial mix - Grading B)

However, the strengths were much higher than in previous tests with an average increase of 73%. This was an appreciable increase. Values of strength for mixes with 0%, 10% and 20% replacement though did not meet the BS 12:1958 requirement are generally high. The low strength, when compared to that of the code of practice was attributed to the quality of the cement used as period of storage was uncertain. The comparison of the result in this study therefore shall be with reference to 0% replacement mix results in order to have a good basis.

The reason for increase in strength of this test when compared to previous tests was attributed to the change in sand grading. Grading B being more coarse, had smaller total surface area implying less cement requirement.

Summary

i. The optimum water/cement ratio was observed to be 0.65.

ii. The specimens from 0% replacement mixes gave the highest strength values followed by 20%, 10% and 30% in this order.

iii. The optimum percentage replacement of the OPC with PBB was observed to be 20%.

For further and detailed investigations, mixes of 0%, 10% and 20% replacements were used. The water/cement ratio of only 0.65 was afterwards used.

3.4 Properties of Mortar

Since this research work is comparative in nature, properties of mortar made with 100% OPC and those from pozzolanic cement of varied proportions of OPC and PBB as cementitious materials were investigated.

The production of mortar for all tests was as in trial mixes in section 3.3 with the same precautions observed. A number of tests were carried out in laboratory on both the fresh and the hardened mortar made from these sets of mortar mixes. Tests were carried out in accordance with British standards and specification No **BS4551: Part 1: 1970** and BS 1881:1970

3.4.1 Observations on Mortar Mixes

Observations made from the various mixes of their fresh mortar include among others the following:-

- Mixes with 100% OPC as cementitious material were more plastic during preparation of the fresh mortar compared to those containing amounts of PBB with the same water/cement ratio. Also, the more the amount of PBB the more harsh or stiff the mix.

This was so because the admixture (pozzolanic cement) bulked on addition of water absorbing water, moreso that PBB is soft and porous. With the eye, one could see that mixes with 100% OPC contain more water than those with percentages of PBB prepared with the same water/cement ratio.

- Mixes with percentages of PBB were observed to be reddish in colour with the intensity increasing with an increase in the percentage of the PBB. Mixes with 100% OPC on the other hand, were brownish in colour.
- A slump test conducted using standard apparatus and taking appropriate precautions showed true slump for all the mixes at a w/c ratio of 0.65. This is expected for any mortar mix.

3.4.2 Tests On Hardened Mortar Specimens

Tests were conducted on various specimens to investigate certain properties of hardened mortar. For this research work only the most important mortar tests were carried out namely the compressive and tensile strength tests and also the setting time test. All the tests were conducted in the laboratory of Department of Building, Ahmadu Bello University, Zaria.

Compressive Strength Test

This is important for sandcrete blocks because of the function it performs as a compressive members. The was carried out according to the requirements of BS 12:1958. The size of specimens used was 70mm x 70mm x 70mm cubes (Plate IIB). A metal mould was used for the specimen production (Plate IIA). For each mix, a total of six samples were made.

Secimens were tested to failure to determine the compressive strength using a manual crushing machine of a capacity of 500 KN (Plate IIC&D)Samples were removed at the appropriate ages from the water in which curing was carried out and allowed to dry for about an hour before crushing. Specimens were crushed on the 3rd, 7th, 14th, 28th and 90th day to determine their strength. Care was taken to ensure that each specimen was placed centrally between the metal platens of the machine and load applied gradually at the constant rate of 14N/mm2/min until specimens crushes. The weight of each specimens was taken using a weighing balance. It was observed that cubes made from 0% replacement mixes weighed more with the gap increasing with increase of the PBB.

Compressive strength is defined as the load per unit area, expressed as:

$$f = P/A \quad - - - - \quad 3.3$$

where f = compressive strength (N/mm^2)

P = Load at failure (N)

A = Cross-sectional area of specimen (mm^2)

The results of this test at various ages were presented and analysed in Chapter Four.

Tensile Test:

The cylindrical split tensile test method was used to detmine the tensile strength of mortar of the various mixes. This method was chosen because it is said that strength obtained is independent of size of specimen (Sabapathi et al, 1967). Though tensile strength plays very little role in compressive members, test results will either arouse interest or otherwise

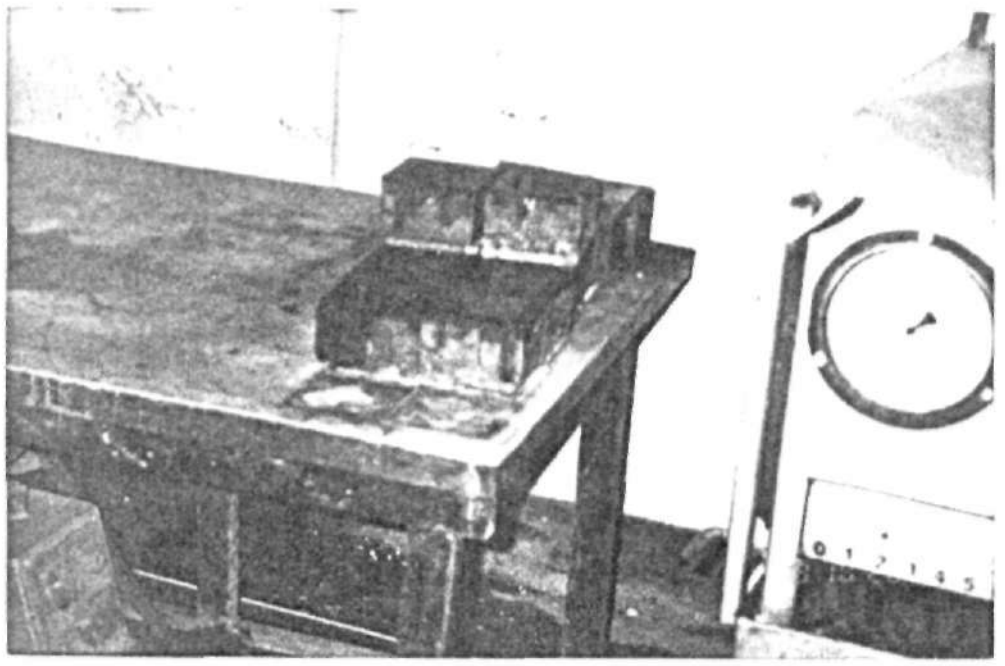


Plate IIA
Samples of mould used for making cubes specimens

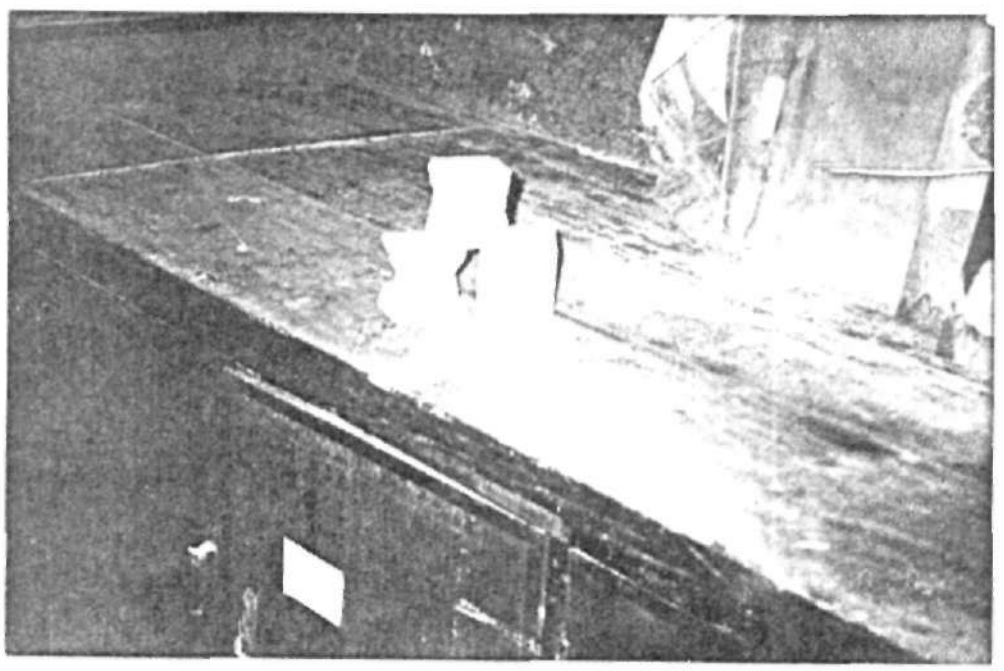


Plate IIB
Samples of Cubes

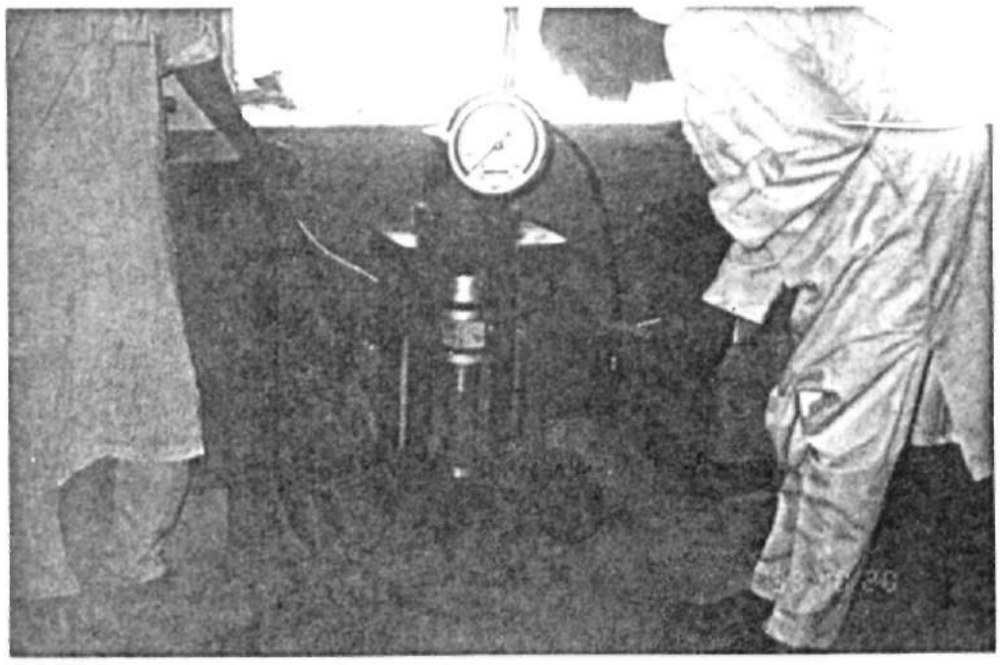


Plate II C
Samples of cube Specimens in position for the
Compressive test

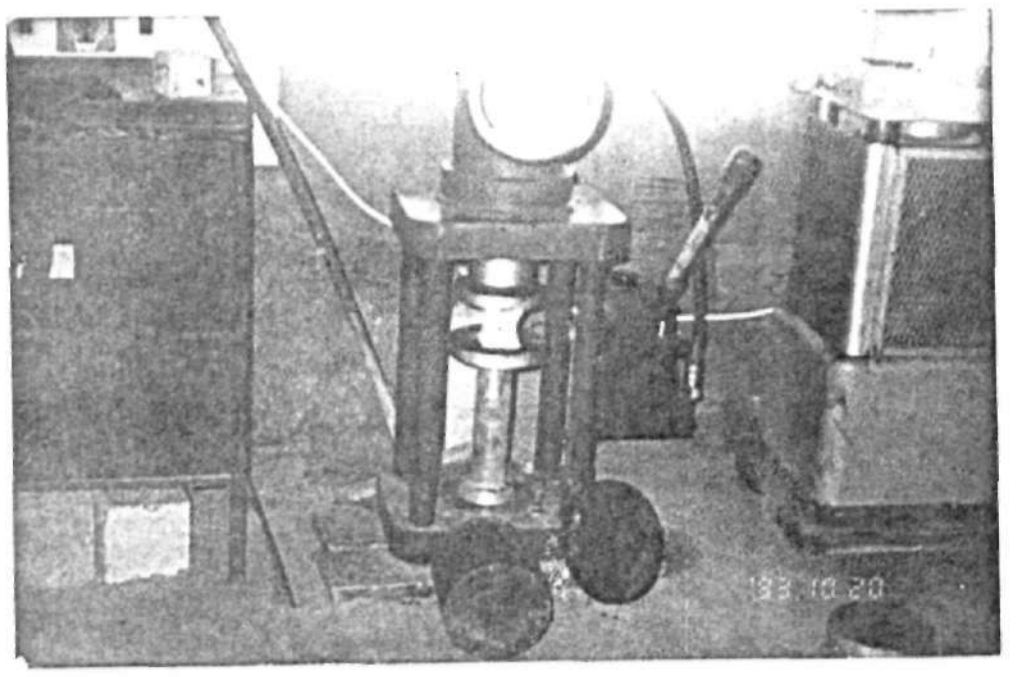


Plate II D

Cube sample after failure

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for further study of the material for tensile members. Test was carried in line with the requirements of BS 1881:Part 4:1970. Specimens were cylindrical having a size of 150mm as diameter and 300mm as length (Plate **III**B). Metal cylinders were used (Plate **III** A). Production of mortar was done as in compressive strength test. Only the 28th day tensile strength was determined

The manual crushing machine used for the compressive strength test was also used. The cylindrical specimens were each placed in between two wooden packing strips made of plywood of size 12mm wide x 3mm thick x 300mm long. This helps to reduce the effect of small surface irregularities and effectively distribute the load on the cylinder. This in turn was placed in between the platens of the machine along the length of the cylindrical specimen centrally. Load was applied gradually to failure at the rate of 14 N/mm^2/min. (Sabapathi et a l. 1967). Six samples were made from each mix. (see plate **IV ; V**)

The tensile strength was calculated using the formula:

$$ft = 2P/_{\pi}DL \quad - \quad - \quad - \quad 3.4$$

Where ft = tensile strength (N/mm^2).

P = Load at point of failure (N)

D = Diameter of cylinder (mm).

L = Length of cylinder (mm).

$_{\pi}$ = 22/7.

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Tensile strength of any mix is said to range between 1/8 to 1/20 of the mix's compressive strength (Elvery, 1963) or about 10% as opined by Taylor (1973).

Results of this test were presented and analysed in Chapter 4.

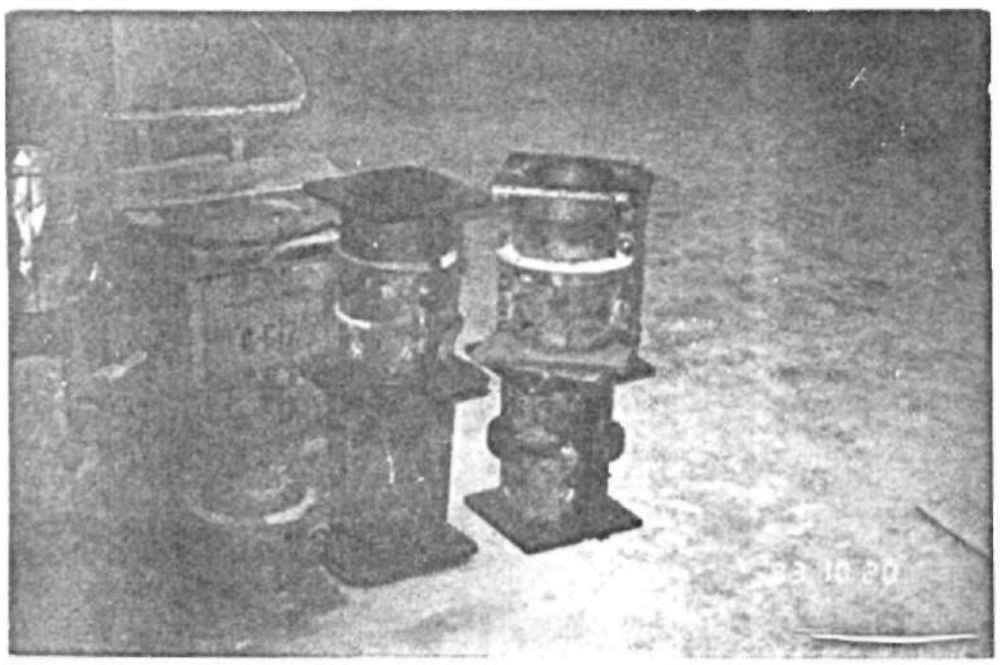


Plate IIIA

Cylindrical metal moulds used in moulding cylindrical specimens

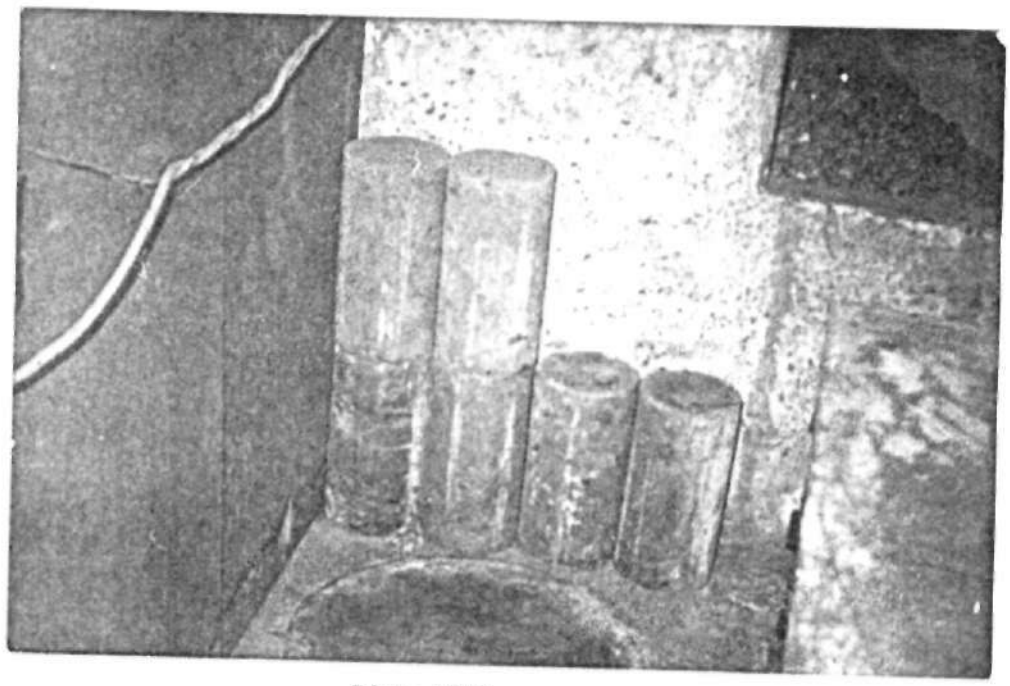


Plate III B
Sample of cylindrical specimens

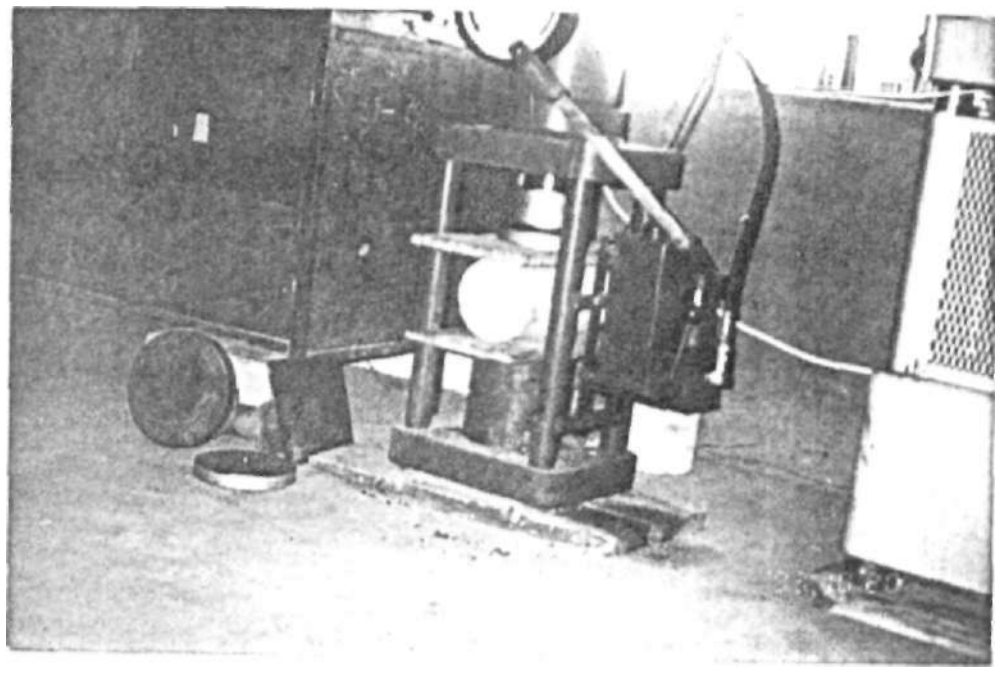


Plate IV
Samples of cylindrical specimens in position for the cylindrical split tensile test

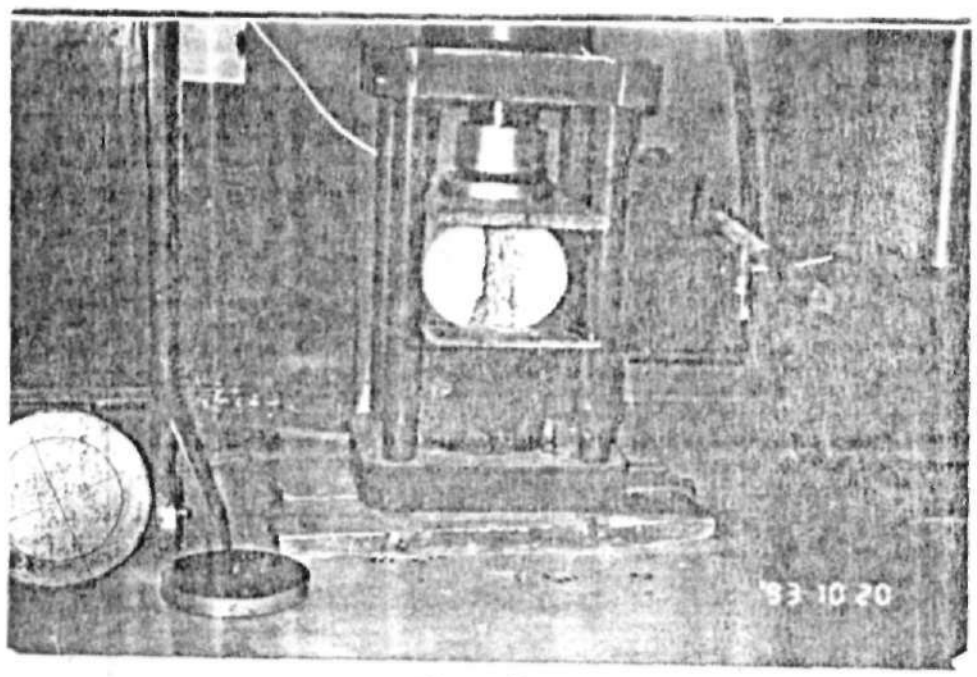


Plate V

Failure of cylindrical samples during the tensite test.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

The discussions presented in this chapter are based on the tests results carried out on the different mortar specimens of the various mixes and the burnt brick powder.

The results obtained were compared with standard values for mortars as given by BS12:1958. Also, the provisions of BS6078:1981 and NIS:1975 (for blocks) were used as basis of comparison since the material being investigated is intended to be used for the production of sandcrete blocks.

These provisions notwithstanding the test values of specimens with 0% replacement were used as a major basis of comparison because of the peculiar nature of the material - powdered burnt brick - being investigated as a pozzolan and the uncertainty of the period of storage and its variability with respect to its essential ingredients affecting strength development.

To ease the discussion and also provide a vivid picture of results, a summary of the tests results were presented in tables and illustrated in figures.

4.1 Method of Analysis

The properties of various mortar mixes cannot be the same even when produced under same experimental conditions. This is because of factors like varying water contents in aggregates, temperature changes in the mix, relative humidity among others. The data obtained in this study was analysed using a computer programme based on Novgorosky's(1973) method. The method was basically statistically in nature. Below are the basic formulae involved in the method.

i. Arithmetic mean,

$$X = \sum_{1}^{n} (X)/n \quad \text{---------- 4.1}$$

Where: $\hat{x}$ = Arithmetic mean.

$\bar{x}$ = Individual strength values of each sample.

n = number of samples.

This gives the average of result obtained for any particular mix.

ii. Standard Deviation,

$$SD = \pm \sqrt{\sum_{1}^{n} [E(x - x)^2/(n - 1)]} \quad - - \text{--------} \quad 4.2$$

Where SD = standard deviation, other symbols are as described above.

This is used to establish the value of the control warning limits where tolerance for the quality of the products are not specified.

iii. Accuracy of Measurement,

$$E = + t.\hat{Sx} \quad - \quad - \quad - \quad 4.3$$

where E = Accuracy of Measurement (N/mm^2)

t = reliability contant determined from table(Novgorosky) (Appendix E).

Sx = Mean square error.

$$\hat{Sx} = \pm \sqrt{E (\hat{x} - \bar{x})^2/n(n - 1)} \quad - - - \quad 4.4$$

Accuracy of measurement defines a range within which if test result falls in, then the result becomes acceptable. This is sometimes expressed as a percentage of the arithmetic mean.

It shows the error of measurement with respect to the mean value.

$$\text{Percentage error} = \left(E/\hat{x}\right) . 100 \quad \text{- - - } 4.5$$

iv. Lower & Upper Limits.

$$LL = x - E \quad \text{--------} \quad 4.6$$

$$UL = x - E \quad \text{--------} \quad 4.7$$

These limits define the range within which every individual sampe for each mix should fall. Any value outside this range is often considered unreliable. This procedure was developed into a computer programme to carry out the computations. The source programme is presented in appendix F.

4.2 **Compressive Strength**

Two sets of results with respect to mix proportion were considered and analysed. The mixes are:-

a) Mix 10:30 cubes only - 70mm x 70mm

b) Mix 10:60 - (i) cubes - 70mm x 70mm x 70mm.

(ii) full blocks - 230mmx230mmx230mm.

4.2.1 Analysis of Result of Mix 10:30

Three different mixes were made of (PBB:OPC): sand as follows:-

i. (0:10):30 [(PBB/OPC)] : Sand

ii. (1:9):30 " "

iii. (2:8):30 " "

Table 4.1: Compressive Strengths at Various ages for 10:30 (OPC:SAND) mix

Ages of Cubes (Days)	Mean Value (N/mm^2)	Standard Deviation (N/mm^2)	Accuracy of Measurements (N/mm^2)	%	Ranges Lower Upper (N/mm^2)
3	12.28	0.57	0.93	7.6	11.35 - 13.21
7	15.27	1.11	1.86	12.1	13.11 - 17.13
14	17.72	0.83	1.37	7.1	16.35 - 19.09
28	19.39	0.68	1.13	5.8	18.26 - 20.52
90	22.61	0.47	0.97	4.3	21.64 - 23.58

Table 4.2: Compressive Strengths at Various Ages for (1:9):30 (PBB:OPC):SAND mix

Ages of Cubes (Days)	Means Value (N/mm^2)	Standard Deviation (N/mm^2)	Accuracy of Measurements (N/mm^2)	%	Ranges Lower Upper (N/mm^2)
3	10.95	0.56	0.93	8.5	10.02 - 11.88
7	12.43	0.70	1.17	9.4	11.25 - 13.59
14	15.07	0.83	1.28	8.3	13.83 - 16.32
28	15.99	0.63	1.01	6.3	14.98 - 17.00
90	19.25	0.87	1.45	7.5	17.80 - 20.70

Table 4.3 Compressive Strengths at Various Ages for (2:8):30 (PBB:OPC):SAND mix

Ages of Cubes (Days)	Mean Value (N/mm^2)	Standard Deviation N/mm^2)	Accuracy of Measurements (N/mm^2)	%	Ranges Lower-Upper
3	8.4	0.51	0.85	10.1	7.55 - 9.25
7	11.57	0.76	1.25	10.8	10.32 - 12.82
14	14.46	0.43	1.09	7.5	13.37 - 15.55
28	16.60	0.68	1.13	6.8	15.47 - 17.73
90	21.29	0.95	1.57	7.4	19.72 - 22.86

The results of this test are presented in table 4.1, table 4.2 and table 4.3 above. It was observed that the strength for all mixes increases gradually with age. This relation is shown in figure 4.1. The shape of curves in the figure agrees with standard curves for the strength of cement- BS12:1958.

The strength for all mixes falls below the BS12:1958 standard requirement of a min. of 23.9 N/mm^2 on the 7th day. The much differences observed in this work might be due to variation in cement as compared to its fresh form. Other factors that might have affected the result of this work are as earlier outlined in section 4.1 of this study.

Comparing the results of the various mixes- It was observed from figure 4.1 that:-

i Mix with 0% replacement gave highest strength for all ages but gap reduces with age especially with the 20% replacement. For example, while the 3rd day strength of the 20% replacement was 68% of that of 0% replacement, the 90th day strength of the former is 94% of the later. This closure in gap is quite considerable. This happened as a result of the hydration of the PBB which often happens at a later age utilising a by-product of OPC's hydration. Details are presented in table 4.4 (appendix C).

ii for all mixes, the growth rate is higher at early ages but reduces with age. This is normal for cementitious material.

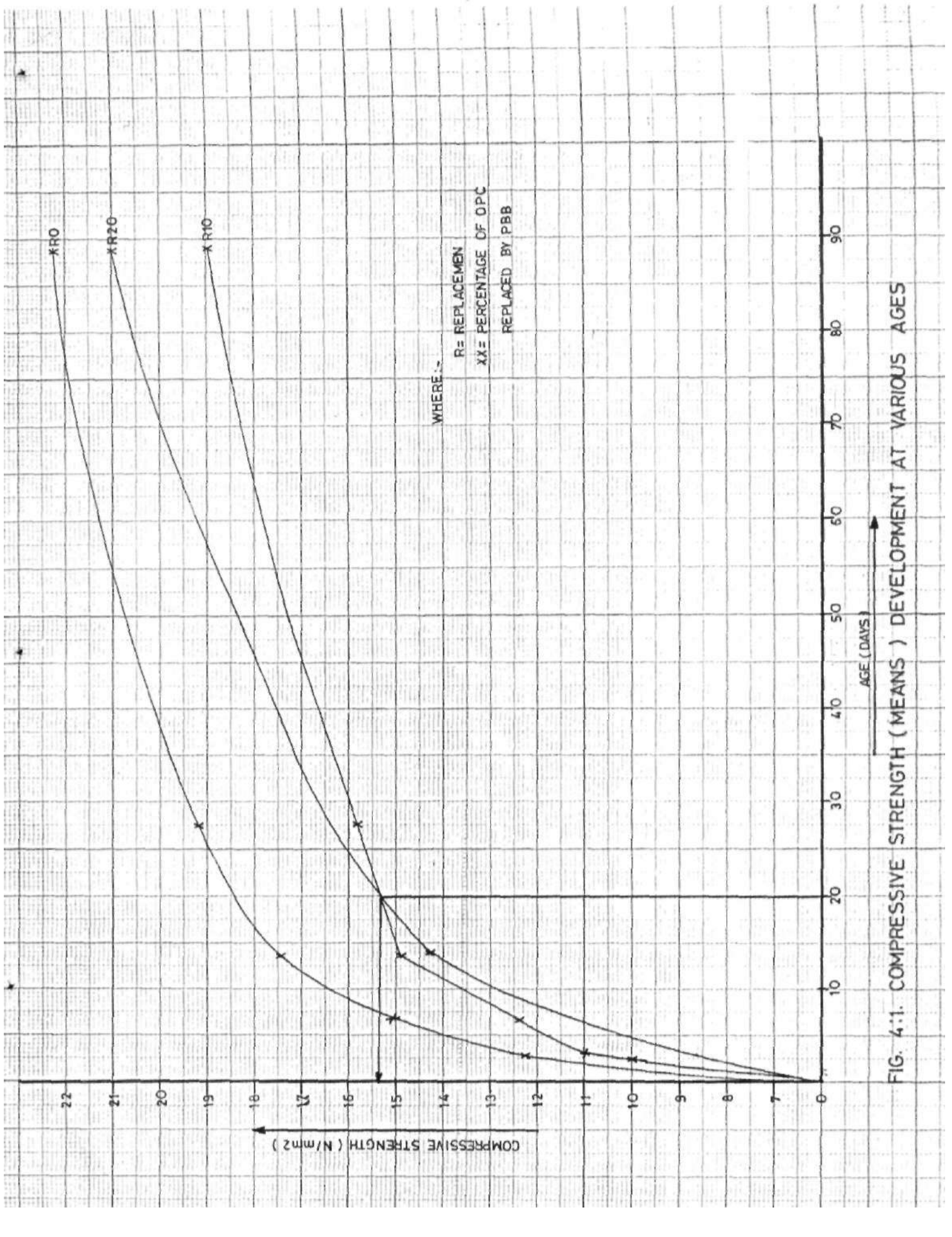


FIG. 4:1. COMPRESSIVE STRENGTH (MEANS) DEVELOPMENT AT VARIOUS AGES

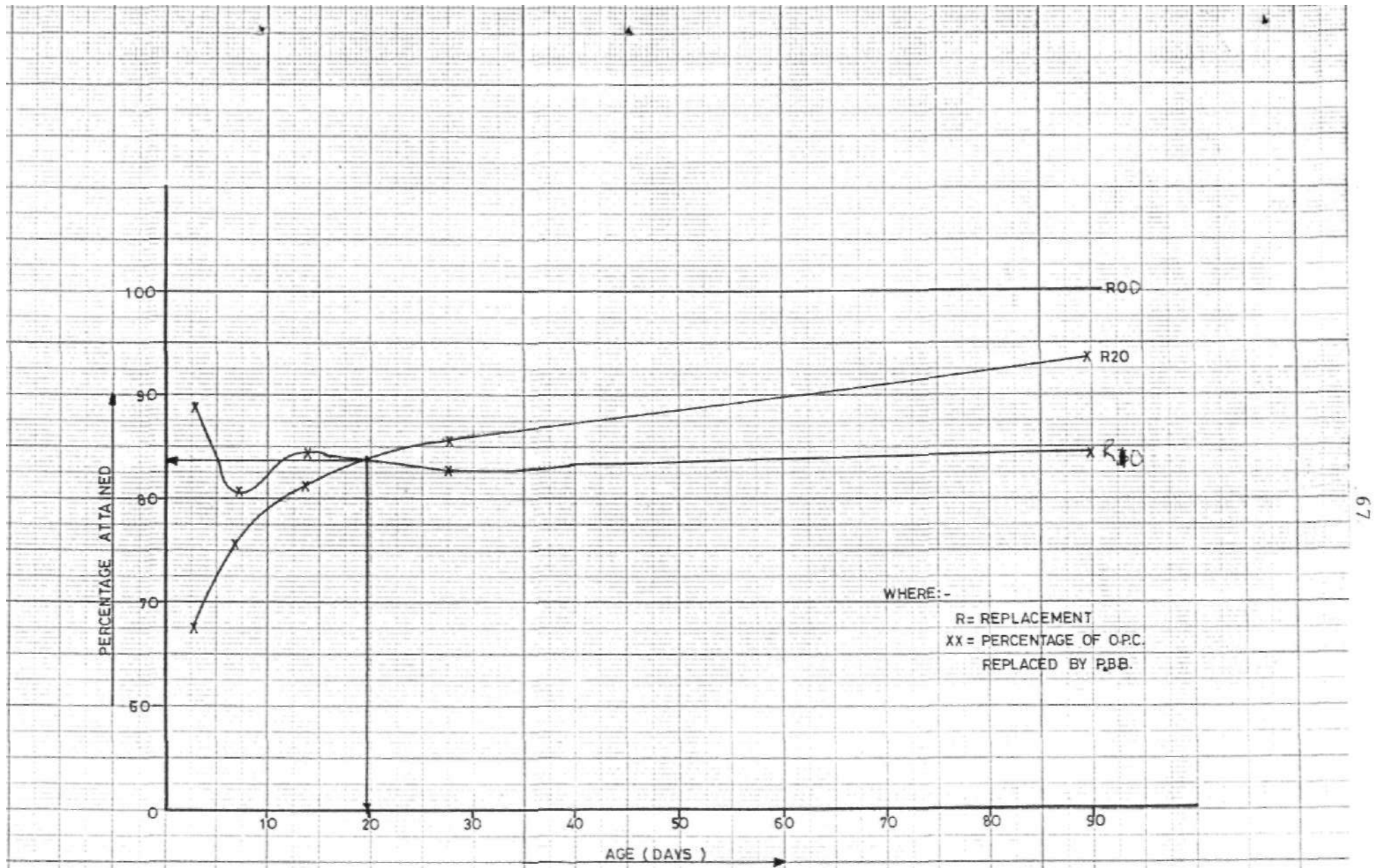


FIG. 4:2. VARIATION OF STRENGTH GROWTH WITH 0% REPLACEMENT AS BASE

iii the 20% replacement has lowest strengths at early ages. This was so because the 20% replacement of the OPC by the PBB affected the initial strength growth with the PBB initially being inactive and only becomes active after the release of the by-product of OPC hydration which it uses for its hydration. This action is explained using equations 2.1 and 2.2.

iv analysing the results further it was observed as presented in figure 4.3 that while 0% replacement developed 63% of its 28th day strength on the 3rd day, the 20% replacement developed only 57%. On the otherhand, the 0% replacement developed only17% increase in strength beyond its 28th day strength while the 20% replacement attained up to 28% strength increase as tested on the 90th day. Details are presented in table 4.5 (appendix C) This is expected of pozzolans as the use by-product of OPC hydration. The rate of hydration os pozzolanic cements is generally lower than that of OPC with the hydration of the former containing over a longer period (see Section 2.2.2).

v for all the mix results, the accuracy of measurement which is the same as the percentage error with respect to mean value ranged between 4.3% - 12.1%.

vi all the individual strength values, fell in between the lower and upper limits for any particular mix indicating that all individual test results with reference to the mean values are reliable.

4.2.2 **Analysis of Mix 10:60**

Since the mortar made from these mixes is ultimately intended to be used for the production o sancrete blocks, a typical sandcrete block mix of 10:60 (PBB/OPC): sand was produced and tested for its strength.

The mix ratio of 10:60 was used to make two sets of specimens for investigation as presented and analyised below. Specimens were tested for only the 28th day strength. Six specimens were made from any particular mix.

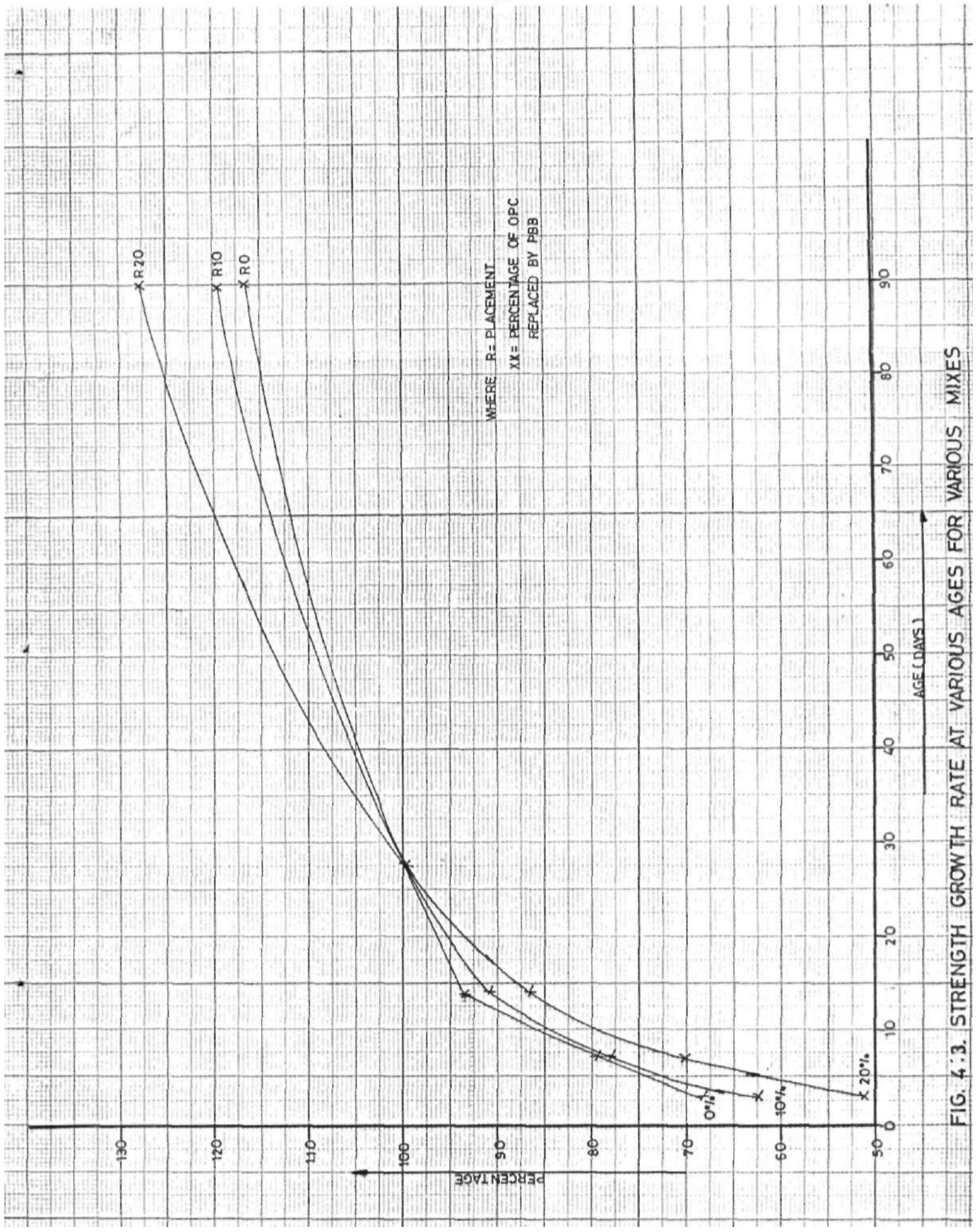


FIG. 4.3. STRENGTH GROWTH RATE AT VARIOUS AGES FOR VARIOUS

a) The first set of specimens made were 70mm x 70mm x 70mm cubes of two mix ratios. The first mix ratio had 0% replacement while the second 20% replacement of OPC by the PBB - (0/10):60 and (2/8):60 respectively.

Result of this test is presented in table 4.6 below. It was observed that with the change in the mix proportioning, the mix containing 0% replacement of the OPC developed only 17% of the strength of the 0% replacement of mix 1:3. The mix containing 20% replacement developed 16% of its corresponding 20% replacement of the 1.3 mix ratio. This is a drastic change in strength. It follows therefore, that a change in cementitios material/aggregate ratio causes much changes in strength. A change of cementitious material/aggregate ratio from 0.33 to 0.17 caused as much as 83% decrease in strength. The percentage error is as high as 21% for the mix with 20th replacement.

The higher percentage error may be due to the low cement/aggr. ratio making causes of deviations more prominent.

Table 4.6: Comprressive Strength for 1:6 Mix Ratio

Mix Proportion	Mean Value N/mm^2	Standard Deviation (SD)	Accuracy of Measurement		Limits Lower-Upper N/mm^2
			N/mm^2	%	
(0:10):60	3.30	0.35	0.58	17.45	2.27 - 3.87
(2:8):60	2.66	0.34	0.56	21.01	2.10 - 3.21

b) The second set of specimens made were full blocks of 450mm x 230mm x 230mm produced manually and crushed in the Civil Engineering Laboratory of Ahmadu Bello Univerisyt, Zaria. Specimens were of three mixes:-

i. (0:10):60 (PBB:OPC):sand
ii. (1:9):60 " " "
iii. (2:8):60 " " "

Only 3 samples were made from each mix. (Plate VI)

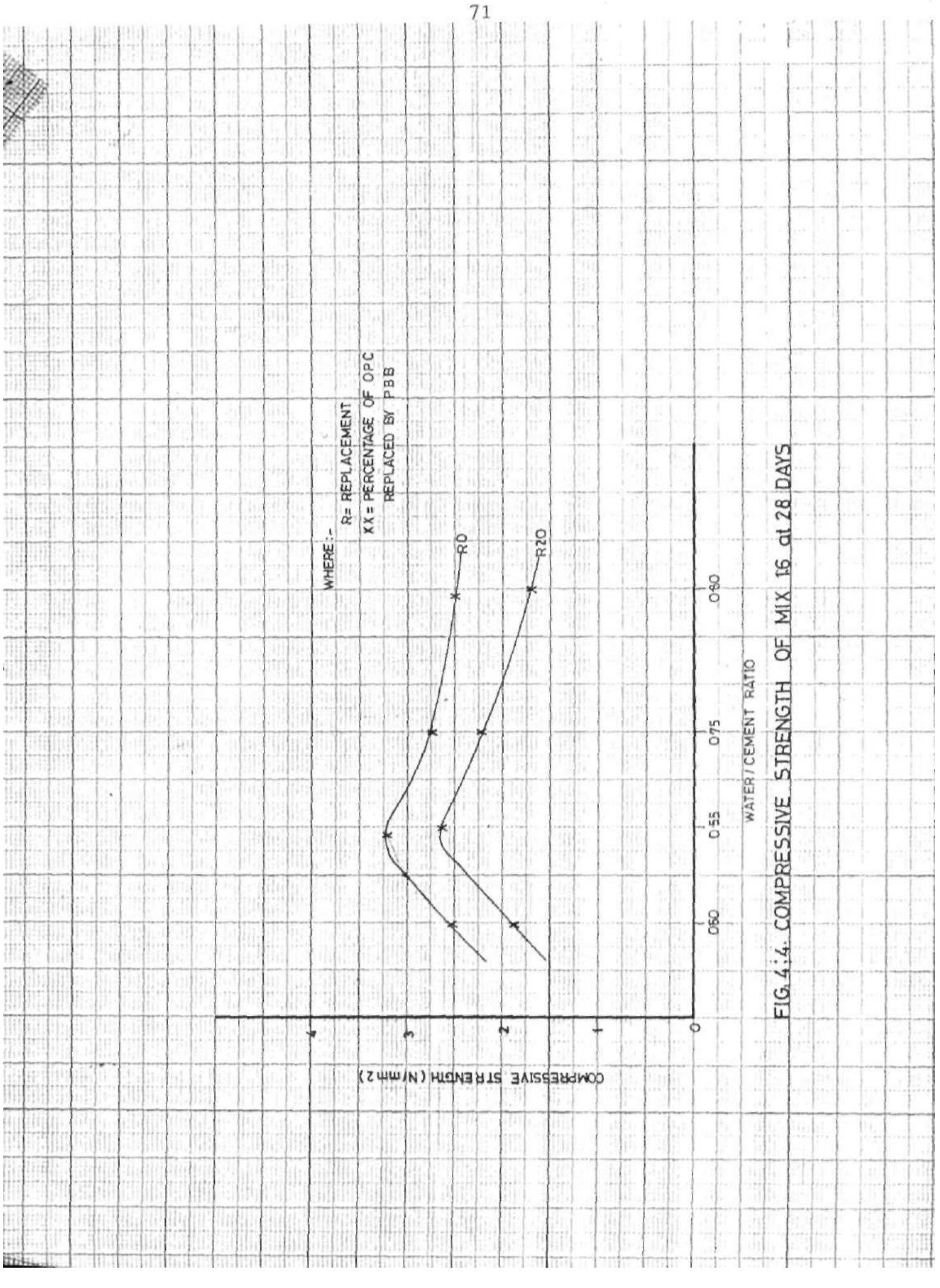


FIG.4:4. COMPRESSIVE STRENGTH OF MIX 16 at 28 DAYS

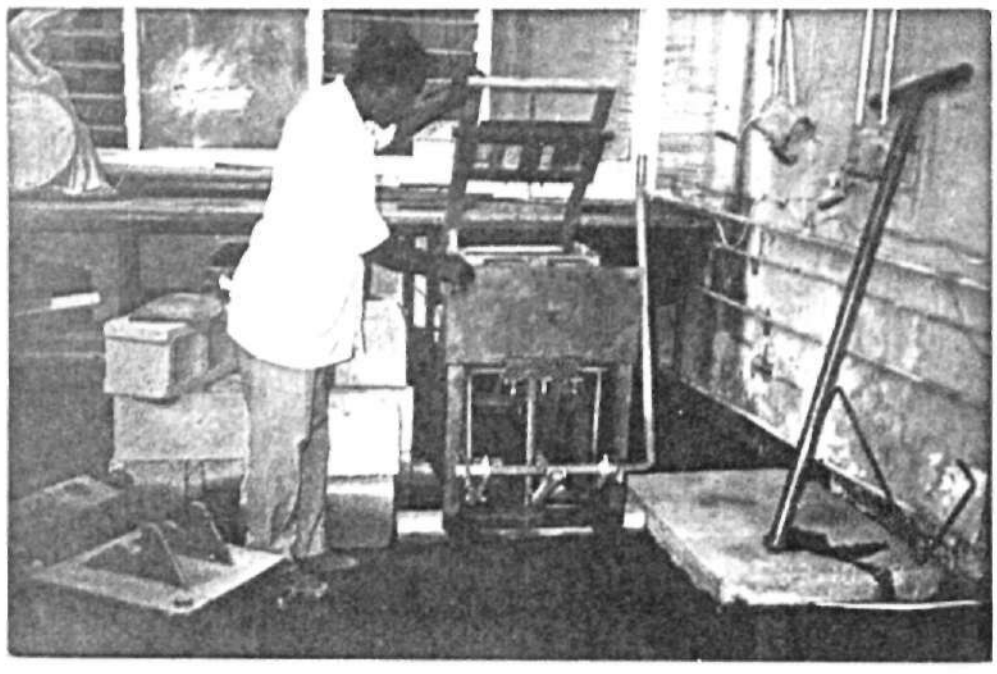


Plate VI
Mould used in moulding full size blocks.

The result of this test is presented in table 4.7. It was observed that the strength of full blocks was 18% for the 0% replacement and 19% of the mixes of their corresponding 10:30 mix ratios, which is very similar to that of the cubes in (a) above. But the percentage error is lower than that observed for the cubes with the highest being 12%. The reduction is due to the size effect being that the bigger the size the smaller the effect (Sabapathi:1967). Also, the compaction might have been better than with the cubes.

It was also observed that the mean strength of specimens meets the requirements of BS6078:1981 (for blocks) which require that the mean strength of blocks should not be less than 2.8N/mm^2 on their 28th day of age. On the other hand, the requirements of the Nigerian Industrial Standard - N.I.S. 1975 (for blocks) which specify a minimum average of 3.5N/mm^2 for 8 blocks was not met by specimens. As mentioned earlier, the latter does not seem realistic.

The compressive strength for other days could be gotten by interpolation using table 4.1, table 4.2 and table 4.3 alongside table 4.7.

Example:- The third day strength for the 20% replacement mix by interpolation is:-

- ratio of third day strength/28th day strength, for mix 10:30

  = 8.4/16.6 = 0.506.

- Using mix 10.60, the ratio of the two corresponding strength are also

  = 0.506.

- therefore,3rd day strength for 20%replacement is

  = 0.506 x 3.14 = 1.59N/mm^2.

Table 4.7: Compressive Strength of Full Blocks on 28th Day of Production.

Mix Proportion	Mean Value N/mm^2	Standard Deviation (SD)	Accuracy of Measurement		Limits Lower Uper N/mm^2
			N/mm^2	%	
(0:10):60	3.39	0.07	0.38	11.24	3.01 - 3.78
(1:9):60	3.02	0.07	0.37	12.36	2.64 - 3.39
(2:8):60	3.14	0.05	0.29	9.20	2.85 - 3.43

4.3 Tensile Strength

As with other tests, three mixes were investigated of the (0:10):30 mix ratio. Differences are in the cementitious materials as usual. The first contains 100% OPC, the second 90% OPC and 10% PBB and the third contains 80% OPC and 20% PBB. Number o samples for each mix was six and were crushed after being cured for a period of 28 days. Results of this test are presented in table 4.8.

Table 4.8: Tensile Strength at 28th day for various mix ratios

Mix Proportion	Mean Value,x N/mm²	Standard Deviation (SD)	Accuracy of Measurement N/mm²	Accuracy of Measurement %	Limits Lower Upper N/mm²
(0:10):30	1.60	0.07	0.12	7.5	1.48 - 1.72
(1:9):30	1.64	0.08	0.14	8.4	1.50 - 1.78
(2:8):30	1.77	0.05	0.08	4.7	1.69 - 1.85

It was observed from the table above, that tensile strengths are quite small compared to compressive strength of the same mix. They lie between 8 - 11% of the latter which agrees with the established facts that tensile strength of concrete/mortar elements are about 10% of the compressive strength of elements of the same mix as stated earlier in Section 3.4.2.

Also, it was observed that mixes with PBB had higher tensile strength values e.g. the mix with 20% replacement has a tensile strength of about 110% that of 0% replacement. The 10% of the latter. This conforms with established performance of pozzolans as earlier stated in section 2.4.5. The percentage error is quite low falling below 10% for all samples and non of the individual values fell outside the range as specified by the upper and lower limits.

4.4 Setting Time

Results of this test are presented in table 4.9. From the table, it was observed that the 0% replacement mix had the highest average initial setting time of 2.04 hrs but the lowest average final setting time of 8.29hrs. The 20% replacement mix had the least average initial setting time of 1.5hrs but the highest average final setting time of 9.12hrs.

All results fell within the range as specified for OPC by BS12:1958 in which the minimum average initial setting time of 45mm and a max average final setting time of 10hrs.

Table 4.9 Results of Setting Time Test.

PBB/OPC Combination in %	Average Initial Setting Time (HRS)	Average Final Setting Time (HRS)
0/100	2.04	8.29
10/90	1.75	8.75
20/80	1.5	9.125
0/100 Standard for BS12:1958	Min. 0.75	Max 10.0

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The reseach was aimed at establishing the suitability or otherwise of using an admixture of powdered burnt brick (PBB) and ordinary portland cement (OPC) for sandcrete block production. In doing this, a series of tests were carried out in the laboratory at the Building Department of Ahmadu Bello University, Zaria. Tests conducted include specific gravity, setting, time, split tensile and compressive tests.

Care was taken at all stages of the various tests to ensure that only appropriate scientific methods and procedures were used implying that reliable results were obtained. Data stated below were either used or obtained during the course of the research work.

(i) Only powdered burnt brick of a fineness of 70-um was used for all tests. Its specific gravity lies between 2.45 and 2.59

(ii) Three sets of trial mixes were carried out at the preliminary stages to establish such parameters as optimum water/cement ratio, optimum percentage replacement of OPC by the PBB, and the grading of fine aggregate to use.

(iii) Using three mixes of (0:10):30, (1:9):30, (2:8):30, a total of 111 specimens were used for the compressive strength test while 18 specimens for the split tensile test.

(iv) For the compressive strength, specimens were crushed on 3rd, 7th, 14th, 28th and as long as 90th day to enable a good comparative analysis. But for the tensile strength, specimens were tested for 28th day only. Elaborate test was not done for the latter because sandcrete blocks are mainly subjected to compression.

(v) A total of 9 full sized sandcrete blocks of 225mm x 225mm x 450mm, 3 blocks for each mix used, were made and crushed on the 28th day to correlate results with those of the much smaller specimens used as stated earlier.

(vi) It was observed that for all mixes containing PBB, the rate of hydration (strength growth) was slower at the early ages but later increased to be higher than those mixes without PBB. Also, a more appreciable increase in strength occurred for the tests beyond the conventional 28th day strength used for elements made with the latter, e.g. while the 3rd day strength for specimens containing 20% replacement was 51% of its 28th day strength, the 0% replacement specimens had 63%. Again, the former developed a 28% increase in strength over its 28th day strength but the latter developed only 17% on the 90th day.

On the other hand, the tensile strength of specimens made using blended cement was higher than with those made using OPC as the only binding agent.

(vii) It was observed that mixes with the admixture have smaller initial setting times but longer final setting times compared with mixes without PBB.

(viii) The 90th day compressive strength (being age at which the design strength for pozzolanic cement is measured) for specimens of 20% replacement is 10% above that of the 28th day strength (being age at which strength of elements made from OPC measured), for specimens of 0% replacement (Mather, 1956).

5.2 Conclusions

The following conclusions were drawn from the research:

(i) Powdered Burnt Brick (PBB) meets the requirements of being a pozzolan because it does not have a cementitious property on its own but when combined in the mix, it affected the strength growth rate and eventual final strength developed.

(ii) Values of the compressive strength obtained from mixes with 20% replacement and 0% replacement for the specimens and the full sized blocks compare favourably. Therefore, the admixture can be effectively used for the production of sandcrete blocks.

(iii) The admixture improves the tensional strength of elements.

(iv) The mortar produced using the admixture can be used in tropical climates where temperatures are high because of its low hydration.

5.3 Recommendations for further works

The following recommendations are based on the results of the study:-

(i) With reference to 5.1 (viii) above, similar research be conducted for concrete using the material.

(ii) Stone crushing machines should be used for crushing the burnt bricks to powder since manual grinding could be very tedious, expensive and time consuming.

(iii) Government to encourage brick companies to grind their waste burnt clay products for sale as a pozzolan.

(iv) The construction of proto-type buildings using the material should commence.

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3. BS 882: Part 2 1973 - "Aggregates from natural sources for concrete including granolithic"
6. CP111:1953 "Structural Recommendations for load bearing walls"
7. BS 3921:1965/69 "Specifications for Bricks and Blocks of fired brick as clay and shale."
8. BS 3148:1980 "Tests for water for making Concrete (including notes on the suitability of the water)"
9. BS 4551: Part 1:1970 "Methods of testing mortars and specification for mortar testing sand.
10. BS 1881: Part 2:1970 "Methods of testing fresh concrete"

BS 1881: Part 3: 1970 "Methods of making and curing test specimens"

BS 1881: Part 3: 1970 "Methods of testing concrete for strength"

AMERICAN SOCIETY FOR TESTING MATERIALS

1. ASTM 618-79 "Specification for fly ash and raw or calcined Natural Pozzolun for use as a mineral admixture in Portland Cement Concrete"

2. ASTM 595-79 "Specification for blended hydraulic cements"

NIGERIAN INDUSTRIAL STANDARDS

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2. N.I.S. 1975 "Sandcrete blocks (draft code)" Nigerian standard organization, Federal Ministry of Industries, Lagos

APPENDIX A

Table 3.2: **Determination of the Specific Gravity of Powdered Brick**

	EXPERIMENTS		
	1	2	3
	14.00	13.75	14.00
Mass of bottle	19.76	16.90	20.12
Mass of bottle + powder	5.76	3.15	6.12
Mass of powder used (E)	37.45	34.40	36.66
Mass of bottle + powder + oil to fill	16.54	17.50	16.54
Mass of oil used (A)	32.60	22.30	32.55
Mass of bottle + oil + oil to fill	18.60	18.55	18.55
Mass of oil only to fill (B)	35.10	35.50	35.75
Mass of bottle + water to fill	21.10	21.75	21.75
Mass of water only to fill (C)	0.88	0.85	0.85
Specific gravity of oil B/C = D	2.06	1.05	2.01
Mass of oil of same volume as PBB = (B-A)/D	2.35	1.24	2.36
Specific gravity of PBB ED/B-A	2.46	2.55	2.59
		2.59	
Average			

APPENDIX B

Table 3.5: Average Compressive Strengths for Specimens of first trial mixes (N/mm^2)

Mix (Pozz:Cem):Sand	Water : Cement Ratios (w/c)							
	.40	.45	.50	.55	.60	.65	.70	.80
(0:10):30	4.7	8.9	9.3	10.9	9.8	11.2	10.9	6.6
(1:9):30	3.2	4.0	6.7	6.9	8.3	9.1	6.7	3.8
(2:8):30	4.0	4.5	6.2	8.1	9.1	10.6	5.3	-
(3:7):30	2.5	4.1	6.1	7.0	6.3	7.7	6.6	3.6
(4:6):30	2.2	3.5	5.9	3.1	2.7	4.1	6.8	2.8
(5:5):30	1.8	2.8	4.0	-	-	-	-	-

Table 3.6: Average Compressive strengths of Specimens for second set of trial mixes(N/mm^2)

M I x (Pozz:Cem):Sand	Water : Cement Ratios (w/c)					
	0.55	0.575	0.600	0.625	0.650	0.700
(0:10):30	10.3	10.6	10.9	10.4	11.3	10.5
(1:9):30	6.9	7.2	8.3	8.6	9.3	6.0
(2:8):30	7.8	8.9	9.3	9.6	10.3	9.9
--- (3:7):30	6.4	6.5	5.8	6.0	7.0	6.1

Table 3.7: Average Compressive Strengths of Specimens for third set of trial mixes(Nmm^2)

M I x (Pozz:Cem):Sand	w/c* = 0.55	0.6	0.65	0.70
(0:10):30	16.4	18.1	19.4	17.8
(1:9):30	12.2	14.5	16.0	13.2
(2:8):30	12.8	15.3	16.6	14.5
(3:7):30	10.5	11.7	12.8	11.4

APPENDIX C

Table 4.4: Variation of Strengths of Various mixes with the base Mix

Age of Sample (Days)	Strength as a percentage of strengths of mix (0:10):30		
	Mix (0:10):30 Strength	Mix (1:9):30 Strength	Mix (2.8):30 Strength
3	100	89	68
7	100	81	76
14	100	85	82
28	100	83	86
90	100	85	94

Table 4.5 Percentage growth rate of strengths for various mixes-using each mix 28th day strength as base

Age of Sample (Days)	Strength as a percentage of strengths of mix (0:10):30		
	Mix (0:10):30 Strength	Mix (1:9):30 Strength	Mix (2.8):30 Strength
3	63	68	51
7	79	78	70
14	91	94	87
28	100	100	100
90	117	120	128

APPENDIX D

COMPRESSIVE STRENGTHS (N/MM^2) OF SAMPLES

NUMBER OF SAMPLES = 6

AGE - 3 DAYS, L-ALPHA = 0.99

Mix 10:30 Sample value	Mix (1:9):30 Sample value	Mix (2:8):30 Sample value
11.43	10.82	7.76
12.86	11.84	8.78
11.84	11.02	8.16
12.86	11.23	8.18
12.25	10.61	8.37
12.45	10.20	8.16

73.690

MEAN	=	12.282
STANDARD DEVIATION	=	0.569
MEAN SQUARE ERROR	=	0.232
ACCURACY	=	0.937
LOWER LIMIT	=	11.345
UPPER LIMIT	=	13.218
PERCENTAGE ERROR	=	7.626

APPENDIX D

AGE - 7 DAYS

Mix 10:30 Sample value	Mix (1:9):30 Sample value	Mix (2:8):30 Sample value
14.29	12.25	10.41
14.69	12.86	11.43
13.88	11.43	12.65
16.33	12.45	11.63
16.12	13.47	12.04
16.33	12.04	11.23

AGE - 14 DAYS

Mix 10:30 Sample value	Mix (1:9):30 Sample value	Mix (2:8):30 Sample value
18.98	15.92	14.49
17.14	14.29	15.10
16.71	15.92	14.29
17.35	15.31	13.88
17.76	14.69	15.31
18.37	14.29	13.67

APPENDIX D

AGE - 28 DAYS

Mix 10:30 Sample value	Mix (1:9):30 Sample value	Mix (2:8):30 Sample value
20.41	16.74	16.12
19.39	16.33	16.74
19.18	15.92	17.14
18.37	14.90	15.71
19.80	16.12	17.55
19.18	15.92	16.33

AGE - 90 DAYS

Mix 10:30 Sample value	Mix (1:9):30 Sample value	Mix (2:8):30 Sample value
22.04	19.59	21.63
22.86	18.37	21.23
22.45	20.41	22.45
23.27	18.78	20.41
24.49	20.00	20.00
22.45	18.37	22.04

APPENDIX D

AGE - 28 DAYS

Mix 10:60 Sample value	Mix (2:8):60 Sample value
3.47	2.25
3.06	2.65
3.67	2.25
2.86	2.86
3.06	2.86
3.67	3.06

AGE - 28 DAYS --BLOCKS SAMPLE NUMBER = 3

Mix 10:60 Sample value	Mix (1.0):60 Sample value	Mix (2.8):60 Sample value
3.41	3.08	3.19
3.45	3.02	3.09
3.32	2.95	3.13

AGE - 28 DAYS - CYLINDER

Mix 10:30 Sample value	Mix (2:8):30 Sample value	Mix (1:9):30 Sample value
1.53	1.84	1.75
1.67	1.81	1.56
1.56	1.70	1.53
1.58	1.77	1.70
1.53	1.73	1.63
1.70	1.77	1.67

APPENDIX E

TABLE FOR RELIABILITY VALUES

N-1	Value t with Probability o			
	0.95	0.98	0.99	0.999
1	12.706	31.821	63.657	636.619
2	4.303	6.965	9.925	31.589
3	3.182	4.541	5.841	12.941
4	2.776	3.747	4.604	8.610
5	2.571	3.365	4.032	6.859
6	2.447	3.143	3.707	5.959
7	2.365	2.998	3.499	5.405
8	2.306	2.896	3.355	5.041
9	2.262	2.821	3.250	4.781
10	2.228	2.764	3.169	4.587
11	2.201	2.718	2.106	4.487
12	2.179	2.681	2.055	4.318
13	2.160	2.650	3.012	4.221
14	2.145	2.624	2.977	4.140
15	2.131	2.602	2.947	4.073

SOURCE: Novgorodsky (1973).

SOURCE PROGRAMME - APPENDIX F.

```
c               STATISTICAL DETERMINATION OF THE PROPERTIES
c               OF MORTAR SPECIMENS FOR SAMPLES LESS THAN
c                           TWENTY-FIVE.
c               Age at crushing:-
c               Mix:-
c               Input data:
c                        i,number of samples
c                       ii,values of samples
c                      iii,reliability
c
                program probdet
                dimension x(25),sqev(25)
                character*20 fnout
                write(*,1)
              1 format(2x,'INPUT NUMBER OF SAMPLES')
                read(*,*)n
                write(*,2)
              2 format(2x,'INPUT EACH SAMPLES VALUE')
                read(*,*)(x(i),i=1,n)
                write(*,3)
              3 format(2x,'INPUT L-ALPHA')
                read(*,*)alpha
                k=2
                sum=x(1)+x(k)
             10 k=k+1
                sum=sum+x(k)
                if(k.gt.n)go to 20
                go to 10
                open(6,file=fnout,status='new')
             20 write(*,30)sum
             30 format(2x,f12.3)
c             ************************************
c             *      COMPUTE  THE  MEAN          *
c             ************************************
                xdash=sum/n
c             ************************************
c             *    FIND  STANDARD  DEVIATION     *
c             ************************************
                do  40 i=1,n
                dev=x(i)-xdash
                sqev(i)=dev**2
             40 continue
                k=2
                totsdv=sqev(1)+sqev(k)
             50 k=k+1
                totsdv=totsdv+sqev(k)
                if(k.gt.n)go to 60
                go to 50
             60 t=totsdv/(n-1)
                sd=sqrt(t)
c             ************************************
c             *      FIND   MEAN    SQUARE      *
c             ************************************
```

```
                w=totsdv/(n*(n-1))
                ems=sqrt(w)
                j=n-1
c           ************************************
c           *  START  TO CALCULATE  ACCURACY   *
c           ************************************
                if(j.eq.1)go to 61
                if(j.eq.2)go to 62
                if(j.eq.3)go to 63
                if(j.eq.4)go to 64
                if(j.eq.5)go to 65
                if(j.eq.6)go to 66
                if(j.eq.7)go to 67
                if(j.eq.8)go to 68
                if(j.eq.9)go to 69
                if(j.eq.10)go to 70
                if(j.eq.11)go to 71
                if(j.eq.12)go to 72
                if(j.eq.13)go to 73
                if(j.eq.14)go to 74
                if(j.eq.15)go to 75
   61           talf=63.657
                go to 76
   62           talf=9.925
                go to 76
   63           talf=5.841
                go to 76
   64           talf=4.604
                go to 76
   65           talf=4.032
                go to 76
   66           talf=3.707
                go to 76
   67           talf=3.499
                go to 76
   68           talf=3.355
                go to 76
   69           talf=3.250
                go to 76
   70           talf=3.169
                go to 76
   71           talf=3.106
                go to 76
   72           talf=3.055
                go to 76
   73           talf=3.012
                go to 76
   74           talf=2.977
                go to 76
   75           talf=2.947
                go to 76
```

SOURCE PROGRAMME - APPENDIX F. (Continued)

```
      acrcy=talf*ems
c     ***********************************
c     *      FIND      RANGE            *
c     ***********************************
            rl=xdash-acrcy
            ru=xdash+acrcy
c     ***********************************
c     *    PERCENTAGE    ERROR          *
c     ***********************************
            perr=(acrcy/xdash)*100
c     ***********************************
c     *   CHARACTERISTIC  STRENGTH      *
c     ***********************************
            cst=xdash-1.64*sd
            write(*,80)xdash,sd,ems,acrcy,rl,ru,perr,cst
80          format(/,2x,'MEAN=',F8.3/,2x,'STANDARD DEVIATION=',F8./3,2x,
     1      'MEAN SQUARE ERROR=',F8.3/,2x,'ACCURACY =',F8.3/,2x,
     2      'LOWER LIMIT=',F8.3/,2x,'UPPER LIMIT =',F8.3/,2x,/,2x,
     3      'PERCENTAGE ERROR =',F8.3/,2x,'CHARACTERISTIC STRENGTH=',F8.3
            STOP
            END
```