QUALITY OF PORTLAND CEMENT PR0DUCED IN NIGERIA

BY

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DATE: AUGUST 1991.

THESIS DECLARATION

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

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



SAMBO MOHAMMED AMINU

AUGUST, 1991.

DEDICATION

This work is dedicated to the following:

1. The Almighty Allah, for his wisdom, kindness and guidance, bestowed on me throughout the course of my study.

2. My parents for their unrelenting support and encouragement all through the period of my education up to this level.

CERTIFICATION

This thesis entitled "Quality of Portland Cement Produced in Nigeria" by Mallam Sambo, Mohammed Aminu meets the regulations governing the award of the degree of Master of Science (Structural Engineering) in Civil Engineering Department of Ahmadu Bello University, and is approved for its contribution to knowledge.

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ABSTRACT

The need to know the quality of construction material used in any country cannot be overemphasized if such country is to go by standard product. The quality of cement is of vital importance since it is the bindinq material in concrete which is widely used in construction industry.

This thesis is set out to investigate the quality or ordinary Portland Cement produced in Nigeria. Cement samples were obtained from six cement factories scattered all over Nigeria and both physical and chemical tests were carried out on them. Informations on each factory as well as current literature on cement are presented in the thesis.

Results show that while most factories obtained 95 percent of their raw materials locally Gypsum is imported. Secondly, all the cement samples pass both initial and final setting time tests, except sample E, which could not meet the specified minimum of greater than or equal to 45 minutes, in this case the initial set was recorded at exactly 20 minutes of mixing. All the samples passed the soundness test. The maximum expansion of 2.0mm was recorded in sample E while all the rest was below 2.0mm.

It has been observed that the rate of strength development after 7 days in all the samples are very low, because the values obtained are substandard. Samples A, B, C, D, E and F have 28 days

compressive strength of 25.74N/mm^2 , 26.42N/mm^2 , 25.08N/mm^2, 20.00N/mm^2 , 16.12N/mm^2 and 22.41N/mm^2 respectively, while an equivalent concrete cube strength are 26.G7N/mm^2 , p8.89N/mm^2 , 22.22N/mm^2, 23.1lN/mm^2 , 20.74N/mm^2 and 25.93N/mm^2 respectively for all the samples.

Finally results obtained from chemical analysis of the samples was characterised by low lime contents, high sulphur content, high loss on ignition and silicate contents. In all six (6) samples were tested.

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August, 1991.

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ABBREVIATION

B.S	-	British Standard
N.I.S	-	Nigerian Industrial Standard
A.S.T.M	-	American Society For Testing Materials
C_3S	-	Tricalcium Silicate
C_2S	-	Dicalcium Silicate
C_3A	-	Tricalcium Aluminate
C_4AF	-	Tetracalcium alumino ferrite
^oC	-	Degrees Centigrade
%	-	Percentage
r.h	-	Relative Humidity
L.S.F	-	Lime saturation factor
SO_3	-	Sulphur trioxide
CaO(C)	-	Calcium Oxide (Lime)
SiO_2(S)	-	Silicon Oxide
AL_2O_3(A)	-	Aluminium Oxide
Fe_2O_3(F)	-	Iron Oxide
H_2O(H)	-	Water in hydrated Cement
Mgo	-	Magnessium Oxide
Mn_2O_3	-	Manganese dioxide
K_2O	-	Potassium Oxide }
Na_2O	-	Sodium Oxide } - (Alkalis)
$Ca(OH)_2$	-	Calcium hydrates
$C_3S_2H_3$	-	Calcium Silicate hydrates
Cal/g	-	Calories per gramme
J/g	-	Joules per gramme
$CaCO_3$	-	Calcium carbonate

ABBREVIATION CONT'D

$MgCO_3$	-	Magnessium carbonate
$Mg(OH)_2$	-	Magnessium hydroxide
FeO	-	ferrous oxide
R.S.P	-	Reinforced Suspension Preheater
A.P.C.M	-	Associated Portland Cement Manufacturers
KVa	-	Kilovolts
N.S.P.A	-	National Electric Power Authority
U C C	-	Ukpilla Cement Company
L.O.I	-	Loss On Ignition
Km_nO_4	-	Potassium Permanganate
Hcl	-	Dilute Hydrochloric Acide
NH_4SCN	-	Ammonium thiocyanite
PPt	-	Precipitate
NH_4OH	-	Ammonium Hydroxide
$BaCl_2$	-	Barium Chloride.

CHAPTER ONE

1.0 INTRODUCTION

Cement is a vital commodity for the achievement of man's objectives. Right from the building of shelter needed by mankind for his protection down to the construction of roads, water works, factories, educational and health institutions without which life remains incomplete, cement is an essential constituent in terms of physical development process.

In the bid to provide enough food to feed the world's population, the part which cement plays especially in the building of irrigation dams and storage facilities, is very prominent. For military purposes, cement is no less important, since the construction of military installations, cannot be done without it.

The manufacture of portland cement requires stringent control, and a number of tests are performed in the cement works laboratory to ensure that the cement is of the desired quality and it conforms to the requirements of the relevant national standards.

Experts during the 7th Annual Conference in Sokoto State have identified that lack of quality control in the production of building materials is responsible for some of the building or structural failures in the country (Nigeria) /17/.

Therefore there is need to ensure quality of portland cement produced.

Ordinary portland cement is most widely and commonly used in Nigeria and it is manufactured to conform to the requirements of the following standards:

a) British Standards (B.S 12: 1958)

b) Nigerian Industrial Standard (N.I.S. 11: 1974)

c) American Standard (A.S.T.M: C150 - 56)

These specifications specify tests for fineness, soundness, setting time and compressive strength all classified as physical requirement of cement and chemical analysis for determination of chemical composition of the cement.

Samples of cement from various factories were obtained and most of the tests mentioned above were carried out on them. Results obtained are presented and figures illustrating the strength development for both mortar and concrete cubes are shown. The results are compared with the requirements of the Nigerian Industrial Standard. Compound composition like tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A) and tetracalcium alumino ferrite (C_4AF) are calculated using Bogue's equation. Results show that all the cement factories import Gypsum. Samples from various factories indicate that the rate of strength development and silicate contents are low. Finally conclusions and recommendations were made.

CHAPTER TWO

2.1.0 LITERATURE REVIEW

Cement, the greyish powder product from burned lime and clay can be described as a material with adhesive and cohesive properties which make it capable of bonding mineral fragment into compact whole. Cement has through the years been the source on which much development arises.

Used for building and civil engineering works as far back as the Roman and Egyptian civilizations, cement is so important that today, its consumption per head of population is an index for measuring the level of economic development of any country /1/. For constructional purposes the term cement is restricted to the bonding materials used with stones, sand, bricks, building blocks etc.

This principal constituents of this type of cement are compounds of lime, so that in building and civil engineering, we are concerened with calcareous cement. The cements of interest in the making of concrete have the property of setting and hardening under water by virtue of chemical reaction with it.

2.1.1 HISTORICAL DEVELOPMENT OF CEMENT

The ancient Egyptians used calcined impure gypsum and the Greeks and the Romans used calcined limestone and later learned to add to lime water, sand and crushed stone or brick and broken tiles /1/. This was the first concrete in history. For

construction under water the Romans ground together lime and a volcanic ash or finely ground burnt clay tiles since lime mortar does not harden under water. The active silica and alumina in the ash and the tiles combined with the lime to produce what became known as Pozzolanic Cement from the name of the village of Pozzuoli, near vesuvius, where the volcanic ash was first found. Some of the Roman structures in which masonry was bonded by mortar, such as the coliseum in Rome and the Pont du Gard near Nimes have survived to this day, with the cementitious material still hard and firm. In the ruin at Pom Peli, the mortar is often less weathered than the rather soft stone.

In the middle ages, there was a general decline in the quality and use of cement and it is only in the 18th century that an advance in the knowledge of cement can be reported.

In 1756, John Smeaton /5/ found that the best mortar was produced when Pozzolana was mixed with lime containing a high proportion of clayey matter. By recognising the role of the clay which was considered undesirable, Smeaton was the first to understand the chemical properties of hydraulic lime /5/.

There followed a development of other hydraulic cement obtained by Joseph Parlar by calcining nodules of argillaceous limestone, culminating (reaching the highest point) in the patent for "Portland Cement" taken out by Joseph Aspdin, a lead builder in 1824 /5/.

2.1.2 PORTLAND CEMENT

The basic material for the manufacture of Portland Cement are usually forms of limestone and clay. Chalk or marl commonly provides the calcareous material in the form of calcium carbonate, while clay or shale provide the argillaceous material, which is mainly alumina and silica.

2.1.3 MANUFACTURE OF PORTLAND CEMENT

Usually in the manufacture of Portland Cement, the sites of cement work's are normally chosen at places where both these types of material occur adjacent to one another.

Three processes of manufacture are employed:-

a) The Dry Process - no water is used at initial stage

b) The Wet Process - water is applied during the crushing and grading of the raw materials.

c) Semi-Dry Process - water is added after the grading of the materials.

The wet process is used, in general, for the softer materials such as chalk or clay, and the dry or semi-dry process is used for the harder rocks such as limestone and shale. It should be noted that the dry and semi-dry processes are more energy efficient than the wet-process.

Generally, the process of manufacture consists essentially of grinding the raw materials, mixing them intimately in certain proportion and burning in a large rotary kiln at a temperature

of approximately 1,400 to 1,500°C. The materials partially fuses into balls called clinkers. The clinker is cooled and ground to a fine powder, with some gypsum added and the resulting product (compound) is the Portland Cement.

2.1.4 PORTLAND CEMENT IN NIGERIA

Nigeria was said to have been importing its cement for consumption before 1954 when the first cement plant was established at Nkalagu.

Trade reports for the years 1925 to 1954 /11/ put Nigeria's cement imports as follows:

TABLE 1: CEMENT IMPORT IN NIGERIA - (1925 - 1954)

PERIOD	CEMENT IMPORTS	
	(IN TONS.)	(IN BAGS)
1925 - 45	40,000 - 80,000	800,000 - 1.6m
1946	95,988	1,919,760
1947	107,306	2,146,120
1948	131,655	2,633,100
1949	161,959	3,239,180
1950	153,861	3,077,220
1951	261,057	5,221,140
1952	205,169	4,103,380
1953	297,436	5,948,720
1954	368,108	7,362,160

With the rising level of importation of cement after the 2nd World War, a need arose for the erection of a cement plant in Nigeria.

Today, there are 8 cement plants in Nigeria. These include the Nkalagu Cement Company Limited (Nigercem brand) having been established near Enugu, the Enugu State capital, in the early sixties. The second to be established is the West African Portland Cement Company Limited (Elephant Brand) which has two plants or branches - one at Ewekoro and later at Shagamu, the Ewekoro plant was also established in the early sixties /15/. The third is the Cement Company of Northern Nigeria, (the Sokoto Cement). Others includes, the Benue Cement Company Limited (Lion Brand) in Benue State, the Ashaka Cement Company Limited (Ashaka Cem Brand) in Bauchi State, the Bendel Cement Company Limited (Rhino Brand) in Ukpilla Bendel State and the Calabar Cement Company Limited (Calcemco Brand) in Cross Rivers State. Plans are however underway to establish a new plant in Gongola State (now Adamawa State). Fig. 1(a) shows the factories and their locations.

There are many factors that contributed to the quality of Portland Cement produced, and these are enumerated below:

a) The amount of deposits of the raw materials.

b) The purity or richness of the raw materials.

c) The amount of raw materials available locally and the method of obtaining the raw materials.

d) Financial stand of the company.

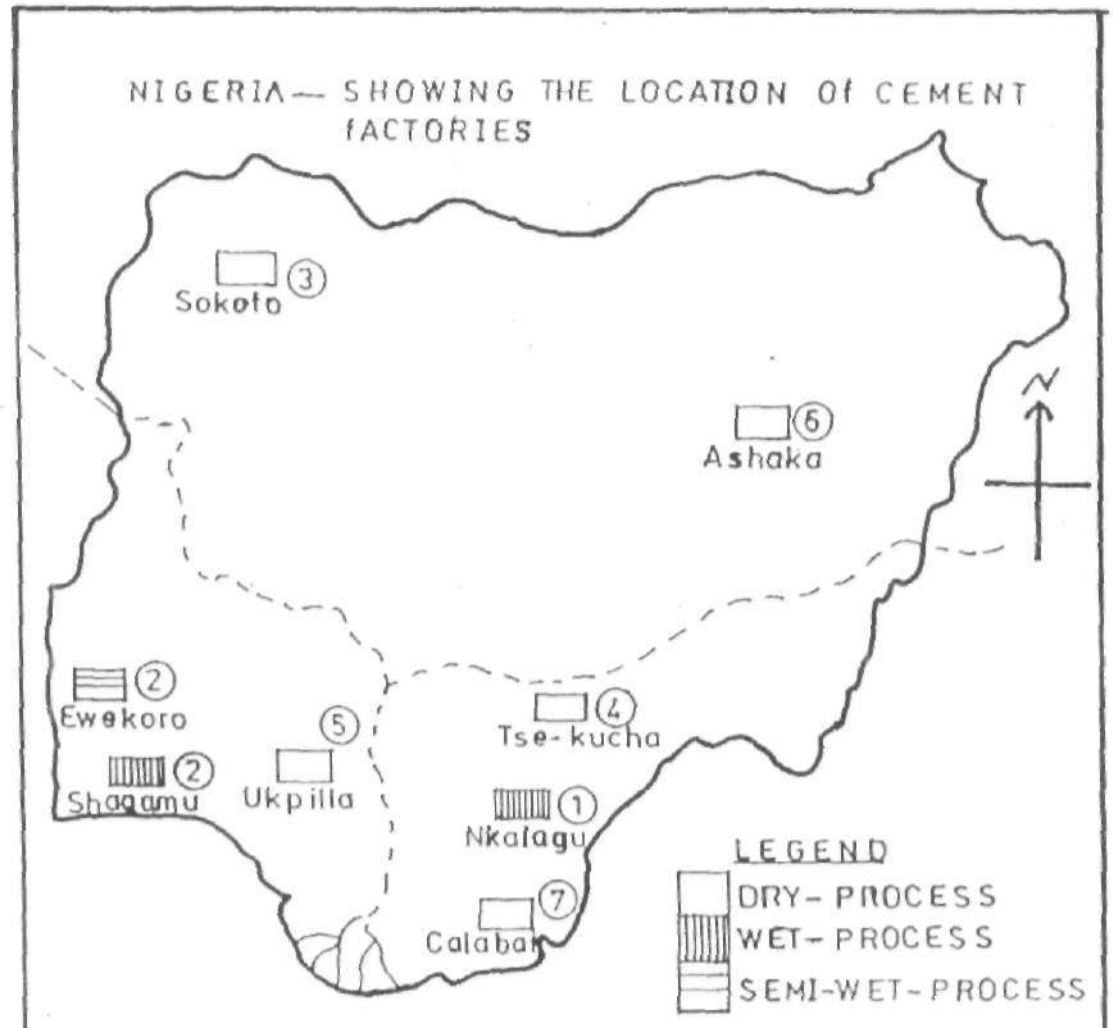


FIG. 1(a) LOCATION OF CEMENT COMPANIES IN NIGERIA.

e) Management.

f) Services available.

g) Type of plant in use and maintenance.

h) Production Process.

i) Technical know how of the workers, training and experiance.

j) Political aspect of the company.

k) Number of professionals available.

l) Physical and chemical tests at each manufacturing stage.

The above factors interwoven processes affecting every stage of production from the quarry to the finished product. For quality control purposes, samples are collected and tested physically and chemically according to standards. These standards include the Nigerian Industrial Standard Specification (NIS 11: 1974), and British Standard Specification (B.S 12: 1958). Others include: the ASTMC 114 - 61T (for chemical analysis), ASTMC 151 - 60 (for soundness), ASTMC 266 - 58T or C191 - 58 (for setting time) and ASTMC 109 - 58 (for compressive strength) of cement /9/. The specifications usually define the product by its constituent ingredients, give the important physical and chemical properties, and what method of sampling testing are appropriate and also sets the minimum standard requirements for control.

2.1.5 PHYSICAL REQUIREMENTS

The Nigerian industrial standard specifications for Ordinary Portland Cement gives the following physical requirements:-

a) FINENESS

This is a measure of the specific surface which is defined as the ratio between the total surface area of a sample and its total weight usually expressed in square centimeters per gramme. The test covers the determination of the fineness of Portland Cement, using blaine air permeability apparatus, in terms of the specific surface and it is covered in NIS 11: 1974 /13/ Appendix A.

When tested, the cement shall have average specific surface of not less than 2500cm^2/g.

In 1967, Malthotra, V.M (in England) /10/ came out with a new method for determining the fineness of cement using the Alpine air-jet sieve.

The machine makes use of an air current to disperse the material on the sieve and to carry the finer fractions through it. It works without any mechanical movement of the sieve or other part in contact with the material. Three series of test results are represented comparing the percentage retained on a No. 200 sieve using the standard hand sieving method and the new technique. Statistical analysis of the data indicate that the Alpine air-jet sieve gives more consistant results than the standard hand sieving method and that the new technique is ideally suited for in-plant quality control and inter laboratory studies.

b) SOUNDNESS

This is defined as the measure of freedom of the cement from expanision by a specific test. The test covers the procedure for determining the soundness of the cement by the 'le Chatelier methods and is covered in NIS 11: (1974) /13/ Appendix C.

When tested, ordinary Portland Cement shall not have an expansion of not more than 10mm.

In 1967, /10/ Van Rensburg, studies the expansion characteristics of an ordinary Portland Cement with a high Autoclave - Expansion. In the study, specimen of hardened pastes and mortar bars were examined for expansion during continuous:-

a) Moist curing at 22^{o}.

b) Immersion in Boiling water.

c) Autoclaving.

Comparative tests were also made on a Portland Cement with autoclave - expansion, results showed that the high autoclave expansion and the expansion during immersion in boiling water are influenced by the pre-curing (at 22^{o}C and 95% r.h) /10/. Expansion during immersion in boiling water increase with pre-curing time. This increase in expansion is maximum between 8 and 16 days, after which there was a gradual decrease in expansion. The autoclave expansion decreased with increased pre-curing time.

c) COMPRESSIVE STRENGTH

This is defined as the maximum load that a test piece can sustain. The test for compressive strength covers the procedure for determining the strength of cement as indicated by compressive strength tests on mortar cubes compacted by means of a standard vibration machine and also on concrete cubes, this test is covered in NIS 11: 1974 /13/ Appendix D for mortar cubes and Appendix E for concrete cubes.

d) SETTING TIME

This is defined as the time required by a freshly mixed paste of water and cement to acquire an arbitrary degree of stiffness as measured by a specific test. The setting time of cement when tested by the method described in NIS 11: (1974) /13/ Appendix B shall conform to the following requirements:

a) Initial setting time: Not less than 45 minutes.

b) Final setting time: Not more than 10 hours.

Zimonyi and Udomanyos /10/ described a method which depends on plotting the potential differences between electrodes embedded in the concrete specimen. Thus a function is obtained, the maxima of which correspond to the maxima Ca^{++} ion concentrations, and the first and second minima to the initial and final setting stages of the concrete.

2.1.6.0 CHEMICAL REQUIREMENTS

The Nigerian Industrial Standard specification also requires that the chemical composition of the cement shall comply with the following requirements:

a) The lime saturation factor (L.S.F) shall not be greater than 1.02 and not less than 0.66 when calculated by the formula:

$$0.66 \leq \frac{(CaO) - 0.7(SO_3)}{2.8(SiO_2) + 1.2(AL_2O_3) + 0.65(Fe_2O_3)} \leq 1.02$$

Where each symbol in brackets refers to the percentage (by weight of total cement) of the oxide, excluding any contained in the insoluble residue referred to in (b) below.

b) The weight of insoluble residue, as determined by the method described in Appendix F, shall not exceed 1.9%

c) The weight of magnesia contained in the cement shall not exceed 4.0%

d) The permitted content of total sulphur in the cement, expressed as sulphur trioxide (SO_3), shall not exceed the values in table: 2 below

TABLE 2: PERMITTED CONTENT OF TOTAL SULPHUR IN CEMENT EXPRESSED AS (SO_3)

Tricalcium aluminate (% by weight)	Maximum total sulphur expressed as SO3 (% by weight)
7 or less	2.50
Greater than 7	3.00

e) The total loss on ignition at a temperature of $950 \pm 50^{o}C$ shall not exceed 4.0%

f) Ratio of percentage of aluminium to that of iron oxide shall not be less than 0.66.

2.1.7 CHEMICAL COMPOSITION OF PORTLAND CEMENT

The main material in the manufacture of cement are lime, silica, alumina and iron oxide.

Cement can be considered as being in frozen equilibrium i.e. the cooled products are assumed to reproduce the equilibrium existing at the clinkering temperature. The above assumption is made in the calculation of the compound composition of commercial cements. The potential composition is calculated from the measured quantities of oxides present in the clinker as if full crystallization of equilibrium products had taken place.

Cement consists of four major constituents. The main compound with their abbreviation is shown in table 3 below

TABLE 3: MAIN COMPOUND OF PORTLAND CEMENT

Name of Compound	Oxide Composition	Abbreviation
Tricalcium silicate	$3CaO.SiO_2$	C_3S
Dicalcium Silicate	$2CaO.SiO_2$	C_2S
Tricalcium Aluminate	$3CaO.Al_2O_3$	C_3A
Tetracalcium Alumino ferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF.

The silicates in cement are not pure compounds but contains minor oxides in solid solution. These oxides have significant effects on the atomic arrangements, crystal form and hydraulic properties of the silicates.

The calculation of the potential oxide composition of Portland Cement is based on "Boque composition".

The Boque equation for the percentages of main compounds in cement is given below:-

1) $C_3S = 4.07\ (CaO) - 7.60(SiO_2) - 6.72(Al_2O_3) - 1.43\ (Fe_2O_3) - 2.85(SO_3)$.

2) $C_2S = 2.87(SiO_2) - 0.754(3CaO.SiO_2)$

3) $C_3A = 2.65(AL_2O_3) - 1.69(Fe_2O_3)$

4) $C_4AF = 3.04(Fe_2O_3)$.

Where the symbols in brackets represents the percentage of the given oxide in the total weight of cement.

In addition to the four main compounds, there exist minor compounds, and these are - Mgo, TiO_2, Mn_2O_3, K_2O and Na_2O. They are usually 1 - 2% /5/ of the weight of cement. Na_2O and K_2O are alkalis which have been found to react with aggregates to produce a compound/product causing disintegration of the concrete and was observed also to affect the rate of gain of strength of cement.

The term minor compound refers primarily to their quantity and not necessarily to their importance. The quantities of alkalis and Mn_2O_3 can be determined using spectrophotometer. Table 4 below shows the percentage oxide contents of portland cement according to N.I.S Standard Specification.

TABLE 4: OXIDE COMPOSITION OF PORTLAND CEMENT

Oxide	Content (%)
Lime (CaO)	60 - 67
Silica (SiO_2)	17 - 25
Alumina (Al_2O_3)	3 - 8
Iron (Fe_2O_3)	0.5 - 6.0
Minor-Compounds	
Mgo	0.1 - 4.0
Alkalis	0.2 - 1.3
SO_3	1 - 3

2.1.8 HYDRATION OF CEMENT

In the presence of water, the silicates and aluminates form the products of hydration, which in time produce a firm and hard mass - the hardened cement paste.

There are two ways in which compounds of the type present in cement may react with water. First a direct addition of some molecules of water takes place - this is being a true reaction of hydration. The second reaction with water is call hydrolysis (which is a chemical decomposition of a compound by water). It is convenient to apply the term hydration to all chemical reactions of cement with water.

The two calcium silicates (C_3S, S_2S) are the main cementatious compounds in the cement /12/, and the physical behaviour of cement during hydration is similar to that of these two compounds alone.

Microscopic examination of hydrated cement shows no evidence of channelling of water into the grains of cement to hydrate selectively the more reactive compound e.g. C_3S which may lie in the centre of the particles. It is also probable that small grains of C_2S hydrate before the hydration of large grains of C_3S would be completed /5/.

The main hydrates can be broadly classified as calcium silicate hydrates and Tricalcium Aluminate hydrates. C_4AF is believed to hydrate into tricalcium aluminate hydrate and an amorphous phase probably $CaO. - Fe_2O_3$. It is possible also that some Fe_2O_3 is present in solid solution in tricalcium aluminate hydrate /5/.

2.1.9 CALCIUM SILICATE HYDRATES

When hydration takes place in a limited amount of water, as is the case in cement paste in concrete, C_3S is believed to undergo hydrolysis producing a calcium silicate of lower basicity with the released lime separating out as $Ca(OH)_2$. There exists, however, a considerable uncertainty as to whether C_3S and C_2S result ultimately in the same hydrate. There is a strong evidence that the ultimate product of hydration of C_2S has a lime silica ratio of 1.65. This may be due to the fact that hydration of C_3S is controlled by the rate of diffusion of irons through the overlying hydrate films while the hydration of C_2S is controlled by its slow intrinsic rate of reaction.

Furthermore, temperature may affect the products of hydration of the two silicates as the permeability of the gel is affected by temperature. The rate of hydration of C_3S and C_2S in a pure state differ considerably /12/.

The overal composition of the silicate hydrates is approximately $C_3S_2\ H_3$ and they are sometimes referred to as Tobermorite because of structural similarity to a natural occurring mineral of this name.

Assuming that $C_3H_2\ H_3$ is the final product of hydration of both C_3S and C_2S, the reaction of hydration can be written as:-

$$2C_3S + 6H \longrightarrow C_3S_2H_3 + 3\,Ca(OH)_2$$

$$100 + 24 \longrightarrow 75 + 49$$

$$2C_2S + 4H \longrightarrow C_3S_2H_3 + Ca(OH)_2$$

$$100 + 21 \longrightarrow 99 + 22$$

Thus on weight basis both silicates require approximately the same amount of water for their hydration, but C_3S produces more than twice as much $Ca(OH)_2$ as is formed by hydration of C_2S.

It is **likely** that in commercial cements the calcium silicates in fact contain small impurities of some of the oxides present in the clinker. The "impure" C_3S is known as alite and the "impure" C_2S as belite. These impurities have a strong effect on the properties of the calcium silicate hydrates.

The use of calcium 45 tracer (A radioactive ion behaves chemically like its non-reactive isotope but its movement can be traced) /12/ has shown that the calcium silicates do not hydrate in the solid state but the anhydrous silicates probably first pass into solution and then react to form less soluble hydrated silicates which separate out of the supersaturated solution. This is the type of mechanism of hydration first envisaged by le Chatelier in 1881 /12/.

Bernal studies shows that calcium silicate hydrates are in the form of very thin fibrous crystals with a short repeat unit of $3.65A^{\circ}$. This is interpreted to mean that there exist

silicate tetrahedral joined by hydrogen bonds.

Other studies have indicated the existence of fibrous particles with sheaf-like ends, similar to the swelling clay mineral called halloysite.

2.1.10 TRICALCIUM ALUMINATE HYDRATE AND THE ACTION OF GYPSUM

The amount of C_3A present in most cements is small but its behaviour and structural relationship with the other phases in cement make it of interest. The C_3A hydrate forms a prismatic dark interstitial material, possibly with other substances in solid solution, and is often in the form of flat plates.

The reaction of pure C_3A with water is violent and leads to immediate stiffening of the paste, known as flash set. To prevent this happening, gypsum ($CaSO_4.2H_2O$) is added to cement clinker. Gypsum and C_3A react to form insoluble calcium sulpho-aluminate ($3CaO.Al_2O_3.3CaSO4.31H_2O$) /5/. But eventually a tricalcium aluminate hydrate is formed. Although it is proceeded by a metastable $3CaO.Al_2O_3.CaSO4.12H_2O$ produced at the expense of the original high-sulphate calciumsulpho aluminate.

The peak in the rate of heat development normally observed within five minutes of adding water to cement means that some calcium aluminate hydrate is formed directly during that period, the conditions for the retardation by gysum not yet having been established.

The amount of gypsum added to the cement clinker has to be very carefully watched; in particular, an excess of gypsum leads to an expansion and consequent distruption of the set cement paste. The optimum gypsum content is determined by observation of the generation of heat of hydration. The amount of gypsum required increases with the C_3S content and also with the alkali content of the cement. The amount of gypsum added to cement clinker is usually expressed as the weight of SO_3 present; this is limited by B.S 12 1958 to a maximum of 2.5% /5/ when the C_3A content is not more than 7%, and to 3% when the amount of C_3A exceeds 7%.

Ershon /10/ conducted experiments which showed that a small addition (0.1 to 3.0%) of TiO_2, BaO, B_2O_3, P_2O5 considerably intensifies hydration of Portland Cement, which in effect causes increase in strength of concrete by 16 - 20% /10/.

Perhaps the least controversial issue with regard to the effects of C_3A on cement performance is the effect on the heat of hydration.

Woods et al /10/ attempted to correlate composition with the heat of hydration, but their data are absolete.

Later, Verbeck et al /10/ used the multiple linear regression approach. Their results indicated that the cement richest in C_3A evolves the highest heat of hydration, whereas the cement highest in silica has the lowest.

In accordance with other findings Verbeck and Foster /10/ in one of their attempts took the SO_3 content of the cement also into their consideration. The results show that this makes a substantial difference, particularly at early ages.

Verbeck and Foster /10/ attempted to establish a correlation also on the basis of a microscopic determination of the cement constituents. Later on, Gourdin /10/ did the same thing based on X-ray diffraction analysis. Their calculations indicate an increases of the heat of hydration of 3 cal/g (12.6 J/g) and 1.6 cal/g (6.7 J/g) respectively for each percent increase of the C_3A content.

As a tentative conclusion it seems reasonable to admit that the increase in the heat of hydration due to an increase of the C_3A content by 1% ranges somewhere between 1 and 3 cal/g, (4 and 13 J/g), depending on how the C_3A content is increased.

2.1.11 TYPES OF OXIDES IN CEMENT

a) CALCIUM OXIDE

Calcium Oxide (CaO) or lime is an essential component of all the cements, and is mostly derived from the decomposition of calcium carbonate ($CaCO_3$) it is a white, amorphous and friable material with a specific gravity varying from 3.08 to 3.03 /12/ units, the value being greater the higher the temperature at which the lime is burnt. The chemical reactivity of lime, like its specific gravity depends on the temperature at which it is prepared. Lime which has not been heated above 1,000°C "slakes" instantly on the addition of water, while a more strongly

ignited product requires a considerable time of hydration. Similar reaction is observed when steam is used.

A lump of crystalling lime, placed in water is dissolved very slowly at the surface, the hydration being so gradual that no apparent rise of temperature is observed. The finely powdered crystals of lime on the other hand appear explosive when mixed with water, after a few minutes.

b) CALCIUM HYDROXIDE

One of the product of hydration of line by water is calcium hydroxide. $Ca(OH)_2$ decomposes into lime in presence of water vapour at about 400°C in a free atmosphere the vapour reaches 1 atmosphere at 547°C as given by equation:-

$$Ca(OH)_2 \longrightarrow CaO + H_2O$$

It is therefore not found in cement clinker immediately after burning. It is usually produced to a small extent during the grinding of cement by action of water released from the added gypsum. It is also obtained when lime "slakes" as a white amorphours powder. It crystallizes slowly as the hydration of Portland Cement proceeds, forming well developed crystals.

Calcium hydroxide reacts with carbondioxide to form calcium carbonate as shown in equation $Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$ /5/. This is referred to as carbonation in existing structures.

C) MAGNESIUM OXIDE

Magnesium oxide or magnesia, (MgO) is only present in small quantities in Portland Cement, being derived from magnesium

carbonate present in the original limestone in the form of dolomite $CaCO_3 \cdot MgCO_3$ or to a small extent from the clay or shale.

Pure magnesium oxide, if not heated to high a temperature possesses distinct hydraulic properties. Porous magnesia combines with water to form the hydroxide $Mg(OH)_2$ but without setting whilst dense magnesia prepared at full red heat sets, yielding a coherent mass, although of $1500^{o}C$ yields a product which reacts only very slowly with water; it is used as a refractory.

Magnesia is only very slightly soluble in lime at high temperatures and for all practical purposes it may be assumed that the compounds crystallizes independently from their fused mixtures. If the double carbonate, dolomite, is ignited at $650 - 750^{o}C$ /5/ mixture of magnesium oxide and calcium carbonate is obtained.

d) SILICON DIOXIDE

Silicon dioxide or silica is the most abundant of all minerals on earth surface and in a compound components of the vast group of silicates among which are the clays. It is present in cements in a state of combinations and is derived from the clay or shale used as raw material. It is the main component of pozzolanas and is used in the form of sand as a constituent of mortar.

e) ALUMINIUM OXIDE

Aluminium oxide or alumina, Al_2O_3 occurs in nature as corrundom (Al_2O_3). Its melting point has usually been reported to be about 2000°C but there is some doubt as to the accuracy of this value. It occurs freely in a hydrate form, mixed with a proportion of ferric oxide and smaller amounts of titania and silica in bauxite. This is used in the manufacture of high alumina cement.

f) FERRIC OXIDE

The oxide of iron only occur to a relatively small extent in Portland Cements, being derived from the clay or shale, but are an important constituent of high alumina cements where they are derived from the bauxite, ferrous oxide (FeO) dues not usually occur in more than small amounts ranging from a trace to about 0.4%.

It resembles alumina in character and acts as an acid radical in cements, being combined with bases (mainly CaO) present. The melting point of pure Fe_2O_3 is unknown as it dissociates under atmospheric pressure before reaching its melting point.

CLASSIFICATION OF CEMENT ACCORDING TO A.S.T.M

The A.S.T.M. specification of C150 - 63 has classified Portland Cement into 4 types:

Type I: Used in general concrete construction when no special properties are specified.

Type II: Used in general concrete construction exposed to moderate sulphate action, or where moderate heat of hydration is required.

Type III: Used when high early strength is required.

Type IV: Used when low heat of hydration is required.

The chemical composition of these types of cement are given in Appendix A1 while physical composition is given in Appendix A-2.

THE REINFORCED SUSPENSION PREHEATER (RSP) PROCESS IN JAPAN

In most cement factory, wet, dry or semi-wet processes are used. However in Japan, a process known as R S P process is used and it is described below.

Instead of coal, oil is used for firing clinker. Japan depends on imports for most of its heavy oil for use, in its cement industry before the last global oil crisis in 1974. This is because of economical reasons. Since the emergence of the crisis, the oil price remarkably increased and become so scarce by 1985. The Japanese Cement industries therefore decided to reconsider its energy resources to be used in the future. The use of coal as a substitute for oil, was therefore investigated in Japan and it was proved viable. Some plants which have coal storage and grinding facilities therefore switched to coal in place of imported fuels.

In 1978, the annual cement production in Japan was 89 million tons /17/ and it is expected to increase to 120 million tons by 1985 /17/. This will cause a responding increase in energy requirements especially in fuel for burning the raw meal in a kiln.

The R S P is a new kind of suspension which has the second firing in the pre-heater structure. The pre-heater structure consists of a four-stage cyclone pre-heater with a swirl furnace and a mixing chamber with an adjustable orifice underneath. The basic pre-heater mechanical arrangement of the R S P is illustrated in Figure 1 on page 29.

As shown, the raw meal enters the pre-heater in advance of C_1, after which it moves' counter-current to the gas flow to C_2 and then enters C_3 from which it is fed into the swirl calciner at two points.

Following the swirling, intimate mixing and endothermic reaction in the swirl calciner, the combustion gas and material exit from the bottom of the swirl furnace and flow through an interconnecting duct to the mixing chamber, where the kiln exit gases are introduced. After further intimate interchange between materials and gases during movement from the mixing chamber to C_4 decarbonated raw meal enters the kiln and is processed through the kiln and clinker cooler.

The operation of all R S P processes in Japan and elsewhere have shown satisfactory results as reported in various technical publications /17/. The R. S. P. process is an energy saving process, especially from the view point of total energy saving, with less heat and refractory brick consumption and less investment and labour cost.

To confirm that coal can be used as an efficient fuel in the R S P process, as earlier stated, Onado Cement /17/ therefore conducted a detailed technical study to clarify the contribution of swirl furnace design, number and position of coal burners, characteristics of coal, etc., by using the Tahara R S P test plant. Since the company already possessed sufficient experience for the coal firing of rotary kilns, coal was used only in the swirl furnace during the tests, while heavy oil was used for firing the rotary kiln /17/. From the results of tests on coal firing, the production rate of clinker and heat consumption was almost similar when compared with that of oil firing. The fuel distribution ratios between the R S P and the kiln are 57.43 and 55.45 respectively for coal and oil firing /17/.

2.2.0 CEMENT FACTORIES IN NIGERIA

In this study, informations about the various cement factories were obtained by personal visit to the factories, visit to their representative at the last Kaduna International Trade Fair and letters written to the factory's managements requesting for their manuals. Other informations were simply obtained from literature.

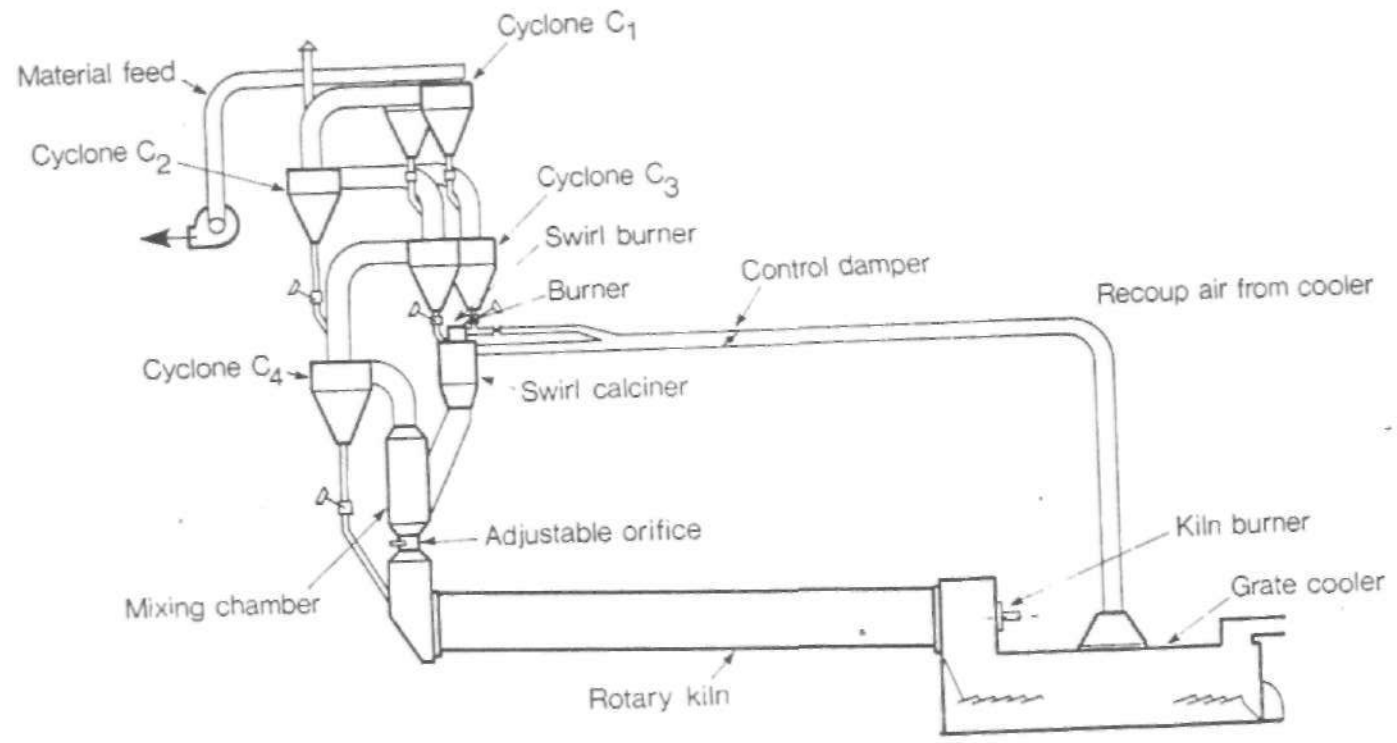


Figure 1: Schematic diagram of the RSP process.

On the basis of the above informations, each cement factory is discussed under the following sub-headings.

a) Genesis

b) Raw materials

c) Type and cement production

d) Problems

e) Growth and development.

2.2.1 THE NIGERIAN CEMENT COMPANY LIMITED NKALAGU (NIGERCEM BRAND)

a) Genesis

The Nigerian cement company limited was established in 1950 /11/, by a British company named the Associated Portland Cement Manufacturers Limited (APCM). APCM, supplied over fifty percent of Nigeria's cement imports /11/.

The actual work on the Nigerian cement commenced in November 1954 /11/ at Nkalagu, fifty-one kilometers east of Enugu /11/.

The site was first connected with a railway and a major road. By an arrangement with the Nigerian Railway Corporation, a rail line of about 13 kilometers was laid from Ogbaho (a town between Enugu and Eha-Amufu) to the factory site at Nkalagu.

b) Raw Materials

The raw materials used in the production of Nigercem cement are basically limestone and gypsum, in the proportion 96% limestone and 4% gypsum.

The limestone deposits from which good quality portland cement could be produced was discovered at Nkalagu. A detailed analysis of samples from the deposits firmly established that the deposits were of a very high quality. The deposits are of three grades of varying carbonate contents ranging between 74 and 88 percent /11/.

Results of total carbonate content of Nkalagu limestone analysis shows that the carbonate values through stratigraphic section varies within a broad range of between 94.7% /11/ in the basal limestone beds to less than 1% in the black shale units. Carbonate content distribution patterns show that the basal limestones are by far the "purest" limestones with values fluctuating between 94.7% to 84.0% in the beds. The interbedded marls have somewhat lower total carbonate content values of between 78.7 and 61.3% /11/.

The upper limestone beds generally show lower carbonate content values (57.5 to 44.0%) but may reach as high as 93.8% as in the upper most unit /11/.

Type and Cement Production

The brand of portland cement being produced by the Nkalagu Cement Company Limited is the NIGERCEM cement. The method used in the manufacture of NIGERCEM cement at Nkalagu is the "wet process" /11/.

Three grades of limestones of varying carbonate contents ranging between 74 and 88 percent are quarried by blasting. The limestone is crushed and conveyed to separate storage bunkers, blended in correct proportions and then ground finely in the 'raw' mill with water to

produce slurry, which is then pumped into storage silos, where it is kept continuously agitated. From the silo it is pumped to kiln burned to form clinker.

Problems

As a result of the Nigerian civil war, which began in 1967, the factory was closed down on 20th August, 1967. At the end of the war in 1970, sight at the Nigerian Cement Company, Nkalagu, was gloomy and disheartening. The destruction suffered by the factory, partly from legitimate tear and wear of the plant over the years and partly as a result of the 30 - months civil war in the country was more than enough to daunt even the most courageous and most resourceful.

All the four kilns, the key-points in cement production were out of service. Some electric mortors and gear boxes from the plant were removed, the sack factory was destroyed by fire, while several sensitive quarry equipment were submerged in water and consequently out of order.

Also the years of 1978 to 1982 was a very critical period in the history of the Nigerian Cement Company. From 1978, the company suffered reverse both in production and profit. This is shown in table 5 below.

TABLE 5: COMPANY'S CEMENT PRODUCTION BETWEEN 1977 to 1980

YEAR	1977	1978	1979	1980
Cement (tons)	397,784	320,103	351,726	398,694
Paper sacks (Nos)	8,055,550	6,793,320	6,362,709	7,964,679
Sales (tons)	399,071	322,375	344,276	397,520
Profit before tax (₦)	7,237,665	2,655,236	2,324,736	1,671,808

Several factors accounted for the declining fortunes of the company and these include:

1. The uncompleted expansion scheme, which began in 1974, was prematurely cut up by the loan repayment schedule. The loans which, instead of being on long term basis, were on short term thus bringing undue pressure and drain on the reserves of the company.
2. Age of plant and machinery and the resultant breakdowns.
3. Shortage of coal (which is being used by the factory).
4. Frequent power failure from NEPA.
5. High maintenance and replacement costs.
6. Political interference.

The frequent dissolution of Boards and summary dismissal of management contributed largely to blur the public image and rating of the company. As a result of this, Nigerian Cement Company Limited was running out of a precious asset-confidence. Most damaging were the series of complicated industrial unrests and breakdown of law and

order in the factory which led to the closure of the company without notice on 31st October, 1981.

During the period of the closure, the debt owed by the company to the banks accumulated at compound interest, while the plant, machinery and the whole estate deteriorated.

Growth and Development

In 1958, its first year of commercial production of the Nigercem cement, the company put 120,000 tonnes of cement into Nigerian market. The company progressively increased its production capacity to 240,000 tonnes in 1961, 360,000 tonnes in 1962, 480,000 tonnes in 1964. In 1966, about 1.1 million tonnes of cement were used in the country; the company accounted for 465,000 tonnes. The fact that the Nigerian Cement Company was able to capture a large parts of the market was largely due to high quality NIGERCEM product /11/, this is certified by well known independent exports as well as by its users /11/.

TABLE 6: EXPANSION PROGRAMME OF THE NIGERIAN CEMENT COMPANY LIMITED, DURING ITS FIRST EIGHT YEARS OF OPERATION

Year ended 31st March	Net profit (x 1000)	Issued capital (x1000)	Capital and reserves (x 1000)	Capital Issued (%)	Rate of return on capital and Reserves (%)
1959	424	1,750	2,027	24.2	20.9
1960	450	1,750	2,302	25.7	19.5
1961	696	2,100	2,789	33.1	25.0
1962	1,021	2,100	3,600	48.6	20.4
1963	826	1,200	5,034	10.7	16.4
1964	916	4,200	5,426	21.0	17.0
1965	874	4,200	5.604	20.8	15.3
1966	1,212	4,200	6,345	28.9	10.0

The above shows the company's reports.

Aba depot was constructed in 1964, and on 23rd March, 1965 a technical school - the Nigercem Trade Training School - was opened to provide training facilities for workers. The school was necessary in order to ensure that there were enough skilled men available for the maintenance and operation of the cement factory at Nkalagu.

TABLE 7: COMPARATIVE PRODUCTION FIGURES FOR 1966, 1967 AND 1973

YEAR	1966	1967	1973
Cement (tons)	509,684	491,717	491,619
Paper sack (Nos)	10.2 million	9.9 million	9.1 million

The sales for the year 1973 compare very favourably with the figures for 1966 and 1967, it shows that in 1966, 508,784 tonnes, 494,619 tonnes in 1967 and 492,268 tonnes in 1973, was sold.

TABLE 8: PROFIT BEFORE TAXATION (1966 - 1967)

YEAR	1966	1967	1973
Profit before taxation	N2.4 million	N2.5 million	N3.6 million

Since 1984, the company enjoys industrial peace. There has been an injection of new blood into the management cadre. Other successes of the company within this period include:- substantial reactivation of the plant resulting in the increase of the daily production figure of 300 tonnes (6,000 bags) in 1984, to present daily average of 1,200 tonnes (24,000 bags) and successful management of loans and payment of current interest on the company's outstanding debts to commercial banks. There has been a success in fabrication of spare parts locally and a research into the production of very high heat resistant bricks and more effective way of burning coal have been commissioned.

For the future expansion, the company hope to go into full modernisation of cement production (wet, dry or semi-wet process). The trend is a shift from the wet to the dry process because of the enormous savings in cost /11/.

Nigercem is using coal for firing the 6 kilns. Double firing system is employed to accomodate usage of either coal or oil or both.

The company's water works will also be rehabilitated and partially modernised. At the end of the programme, the water works will be producing 1.5 million gallons per day (raw water) plus recycled cooling water amounting to 201,000 gallons per day. The water production will therefore make available for use (industrial and potable) 1.7 million gallons per day. The company's direct requirement (industrial and potable) will be 1.5 million gallons per day.

With the Nigercem's new 33/3.3KW electric power sub-station recently completed at Nkalagu, Nigercem is in a position to take from NEPA the 12.5M.W of power it needs to operate the factory when fully rehabilitated.

There are also the two electric generators, each with a capacity to produce 3.4 M.W. and when run together in series, they will give a combined output of 6.8 M.W. which is about 50 percent of Nigercem's requirement. They are stand-by set installed to operate only when NEPA supply is inadequate or fails completely.

In addition to the periodic on-the-job training programmes, the training of Nigerians was recognised as a matter of utmost importance. Artisans, skilled and semi-skilled tradesmen, and more importantly, Nigerians were recruited as trainees and placed under the supervision of the staff of the consulting engineers and managing agents.
Table 9 below shows the current equity holding position of the company.

TABLE 9: CURRENT EQUITY HOLDING POSITION

	(₦1000)	%
Anambra and Imo States Govts. (now Anambra, Imo, Abia & Enugu)	6,475.2	51.39
Federal Govt. of Nigeria	1,350.7	10.72
Insurance companies and other industrial investors and Banks	1,424.6	11.35
Other Nigerian public	3,344.0	26.54
Total	12,600.0	100.00

2.3.0 THE WEST AFRICAN PORTLAND CEMENT COMPANY LIMITED (ELEPHANT CEMENT)

Genesis

The West African Portland Cement was established about 1959 /15/. The first factory of the company at Ewekoro in Ogun State was commissioned in 1960 with an initial production capacity of 200,000 tonnes (about 4.0 million bags) per annum. The capacity grew with demand and a second factory, at Shagamu also in Ogun State, was commissioned in 1978 /15/.

Raw Materials

The raw materials used in producing Elephant cement are;- limestone, shale, alluvium and gypsum. Of the total raw materials, only gypsum is imported, however efforts are being initiated by the

cement manufacturers association of Nigeria (CMAN) to determine the possibility for local sourcing of gypsum in commercial quantities. The success in this direction will lead to 100% local raw materials sourcing for cement. As of now limestone, shale and red-alluvium are found readily in Nigeria. In fact, 96% of the raw materials needs of the cement industry are available locally /15/.

TYPE AND CEMENT PRODUCTION

The brand of Portland Cement being produced by the West African Portland Cement Company Limited is the Elephant Cement /15/. The first step in Elephant Cement production is obtaining and proportioning the raw materials - limestone, shale and alluvium. Limestone, being a hard chalk is obtained by blasting from the quarry which requires further breakage before it is reduced to a size that is convenient to handle.

Both in Ewekoro and Shagamu works fresh pure limestone from the quarry go through a preliminary crushing stage before being transported to the works. The primary crushers(mobile crushers) are located not too far from the quarry where they are supplied with limestone by dumpers (large tippers). After crushing, the limestone is then transported to the works through convey or belt for further processing. The details of the cement making process vary widely. No two works are the same and there may well be differences within a single works as new kilns and their associated equipment are added to those already existing. For instance in Shagamu works, a wet-process is employed while in Ewekoro, a semi-wet process is in operation /15/.

The finished cement is stored in silos for a relatively short time before being dispatched to the customers in bags or in bulk.

PROBLEMS

The West African Portland Cement Company uses approximately 1% of the Nations electricity supply /15/ enough to light 400,000 sixty watts bulbs or a town of 100,000 people. A substantial percentage of the electricity used is generated by National Electric Power Authority /15/.

Regular power failures in the works, have affected both factories in terms of meeting set production targets and satisfying consumers demands.

To minimise or control the serious effect of power failure on production, the company acquired two new generators, one for each factory, at the cost of ₦4.0 million.

Although the power situation has improved considerably since these generators came on stream, NEPA power failures still continue to wreck some havoc on the works operations.

One major problem which had affected the company's performance in the past five years was the inadequacy of spare parts supply. This problem had affected the company's capability at meeting the demand trend of its product.

This problem was caused by the small quota of import license allocated to the company in relation to its actual needs during the particularly harrowing import license severely affected the maintenance of the company's heavy machinery with the resultant fall in output in 1986 /15/.

GROWTH AND DEVELOPMENT

The West African Portland Cement Company Limited, which started with an initial production capacity of 200,000 tonnes per annum at Ewekoro works, has now grew to capacity of about 1.5 million tonnes (30 million bags) per annum /15/. Between the two works (Ewekoro and Shagamu), which is about 50% of the total cement currently being produced in Nigeria /15/, the maximum installed capacity is 1.65 million tonnes (36 million bags) per annum /15/.

The company, with a total workforce of about 2,500 /15/ workers, believes that its members of staff should be well trained and developed in order to maintain the standard expected of the company's overall performance, quality of its products, and service to its customers. A training school was established at Ewekoro site which runs courses in cement production and in-service training as well as courses for management staff, in collaboration with reputable management consultants. Also there is an apprentices training centre where young men are being trained as craftsmen and technicians under four year programme. The centre started with 15 students and by 1987 a total of about 200 students had successfully passed out of the centre /15/. It conducts a retraining programmes for staff as well.

As a result of the present difficulty in meeting the demand of Elephant cement, the company is planning to embark on an expansion programme which will greatly enhance the output from Shagamu and Ewekoro factories. Planning is now well advanced to install a third kiln and anciallory machinery at Shagamu works and the refurbishment of Ewekoro works has already begun. The Shagamu expansion programme will add half a million tonnes per annum to the company's production capacity. The company is convinced that the demand for cement in Nigeria will continue to increase and that the future prosperity of the company lies in its ability to play its part in fulfilling this demand for a strategic basic commodity essential to the development of the Nation.

2.4.0 THE BENUE CEMENT COMPANY LIMITED (LION BRAND)

GENESIS

In the early sixties, traces of limestone deposit were discovered at Mbayion in Gboko Local Government Area of Benue State, by the geological survey department of the Federal Ministry of Mines and power /2/. Following the feasibility study, by 1972 the company was established /2/. This give rise to an upward review of the confirmative study reports of cementia holding AG of Zurich, Switzerland, and also led to a modification of the projected 600,000 tonnes cement plant to 900,000 tonnes per annum /2/. This study was completed in 1975.

The limestone deposit at Mbayion coupled with the high demand for cement throughout the country therefore made the setting-up of Benue Cement Company Limited at Tse-Kucha, a distance of 72km along Makurdi - Gboko road, a viable venture. The plant gets its water supply from a nearby dam for its operations.

RAW MATERIALS

The Lion Brand Portland Cement has about 97% of its contents obtained locally /2/. The main raw materials used for the production of Lion brand Portland Cement are: limestone, clay, sand additive and gypsum - which is the only material that is imported as of now.

However, the same efforts are being intensified by the Cement Manufacturers Association of Nigeria (CMAN) and the exploration division of the Federal Ministry of Mines and Power to look into alternative raw material to replace gypsum /2/.

TYPE AND CEMENT PRODUCTION

The brand of Portland Cement being produced by the Benue Cement Company, is the Lion Cement. The production process starts with the mining of the limestone and clay from the quarry behind the factory. A proportion of limestone to clay is tipped using dumpers into impact crushers situated at the quarry location. The crushed limestone and clay are then transported by belt conveyors to circular, dome-shaped stockpile. The type of production process employed by the company, is the Dry-process. High (pure) limestone /2/ is also crushed and conveyed separately to the crane hall to be used as additive. Then other processes continue - in the usual way.

Benue Cement Company is reknowned for producing the finest Ordinary Portland Cement conforming to the Nigerian industrial standard NIS 11: /13/ and the British Standard B S 12 (1959) /2/.

Lion brand Portland Cement is superior from the high quality limestone which is unsurpassed by any in the country. Tests have been carried out in Switzerland and Germany by several construction companies which show that, lion brand Portland Cement meets their requirements as special cement of high strength and durability for construction of bridges, flyovers, skyscrapers etc.

PROBLEMS

The main problem affecting the Benue Cement Company, is the inadequacy of spare parts, for the maintenance and refurbishment of plants.

GROWTH AND DEVELOPMENT

Since the first bag of lion brand portland cement was placed in the Nigerian market in August 1980 the production plant with a capacity of 600,000 tonnes (1.2 million bags) has been changed to a capacity of 900,000 tonnes (1.8 million bags) in 1981 /2/, the following year. It is also capable of being expanded to 1.2 million tonnes per annum. In 1985, the highest production of 810,538 tonnes (1.6 million bags) was recorded /2/.

The Benue Cement Company has established its Area/Sales/Liaison offices at Gboko, Makurdi, Jos, Enugu, Kaduna, Lagos, Abuja and Otukpo.

Share holding within the company is shown in table 10 below:

TABLE 10: SHARE HOLDING AS AT 1975

	Share Capital (%)
Federal Government	39
Benue State Government	21
Plateau State Government	14
Cementia holding A.G. of Zurich	11
Nigeria Bank of Commerce and Industry (NBCI)	7
Nigerian Industrial Development Bank (NIDB)	3
New Nigerian Development Company (NNDC)	5

In 1990, the Federal Government privatised part of its shareholding.

2.5.0 THE ASHAKA PORTLAND CEMENT COMPANY LIMITED (ASHAKACEM)

GENESIS

As far back as 1960, geological survey carried out by the Blue Circle Industries of the United Kingdom has discovered a large limestone deposit at Ashaka on the Gongola river, some 160 kilometers South West of the then North-Eastern State capital Maiduguri. However, the deposits became economically viable and put into use in the early seventies. Due to the increased demand of cement at that time; particularly in the Northern part of the country, it was clear that a cement works is needed.

Results of surveys confirmed the potential viability of cement works in the North-East part of Nigeria. The Ashaka cement company was therefore established in 1974 /1/, at the initiative of the Nigerian Industrial Development Bank (NIDB).

Blue Circle was given the responsibility for designing and building the new works and also participating as management partners, and the factory was completed in 1979 at a cost of N146 million and has since then been in continuous production.

RAW MATERIALS

Like other cement industries, the raw materials used in producing Ashakacem are limestone, sand additive, alluvium and gypsum /1/.

The two kiln works has been built over Bima sandstone on a sloping site 7 kilometers from the village of Ashaka close to a limestone deposit estimated to contain more than 35 million tonnes /1/.

The nearby river Gongola provides water supply for the works operation as well as domestic use.

TYPE AND CEMENT PRODUCTION

The brand of Portland Cement being produced by the Ashaka Cement Company Limited, is the Ashaka Cem. Ashaka Cem works is essentially a twin stream plant on the major production units with a total planned output of 700,000 to 800,000 tonnes per annum, and employing "Dry Process" of manufacture /1/. The raw materials are obtained and proportioned and limestone being a hard chalk is obtained by blasting from the quarry.

PROBLEMS

In 1985, the company suffered a general down turn in business caused by the country's economic difficulties /1/. Other problems associated with the company includes import license, spare parts for maintenance or refurbishment of plants, inadequate finance to install more new plants. Although about 96% of the company's raw materials are obtained locally, the company still have to import its gypsum elsewhere. This is another problem in which the company is looking into alternative raw material. This alternative raw materials to replace gypsum will make its local sourcing of raw

materials 100%. This is being done through the joint efforts with the Cement Manufacturers Association of Nigeria (CMAN) and the exploration division of the Federal Ministry of Science and Technology.

GROWTH AND DEVELOPMENT

Ashaka Cement Company Limited won general acceptability right from the start, because of the high quality of its products. It has started with an initial capacity of 600,000 tonnes (1.2 million bags) per annum. Ashaka Cem is presently capable of producing more than 800,000 tonnes (1.6 million bags) of cement per annum /1/.

To confirm its viability, Ashaka works has been making steady profit since 1981 and such profit is shown in the table 11 below /1/.

TABLE 11: ASHAKA CEM COMPANY PROFIT WITHIN 1981 TO 1989

Year	Profits (₦)	Year	Profits (₦)
1981	8.1 Million	1986	18.4 Million
1982	14.0 Million	1987	28.0 Million
1983	13.5 Million	1988	35.2 Million
1985	13.4 Million	1989	59.9 Million

All the technical and administrative posts are now completely undertaken by Nigerian /1/. The share holding of the Company is shown in table 12 below:

TABLE 12: ASHAKA CEM SHARE HOLDINGS

Share holders	%	Equity (N)
Federal Government of Nigeria (F.G.N.)	25.0	39,000,000
Blue Circle Industries PLC	25.0	39,000,000
Bauchi State Government	5.4	8,424,000
Borno State Government	5.95	9,282,000
Gongola State Government	5.31	8,294,000
Nigerian Industrial Development Bank (NIDB)	4.17	6,000,000
Nigerian Bank for Commerce and Industry	4.17	6,000,000
Public	20.83	32,800,00
Total Equity		156,000,000

Recruitment and training of the initial work force of 800 needed, by the company dates back to 1976 when the physical shape of the factory started to sprout from the ground.

Management personnel recruited in the United Kingdom and Nigeria attended technology and management courses at Blue Circle's training School, Dunbar and Hope works in the United Kingdom before returning to Ashaka. More than 100 skilled artisans - mechanical and electrical fitters were recruited from Northern Nigeria and trained at Ashaka new works training centre. However, training of staff at home and

overseas to improve their knowledge and technical know-how is a continuing exercise.

2.6.0 THE BENDEL CEMENT COMPANY LIMITED (THE RHINO CEMENT)

GENESIS

The Bendel Cement Company Limited formerly known as the Ukpilla Cement Company Limited was incorporated in 1964 with a share capital of ₦2.2 million (BDSG 90% and UCC 10%) to produce 150,000 tonnes (3.0 million bags) of cement per annum.

The company was commissioned in 1972 because of the Civil War and lack of power supply. This was after 3 No. 1600 Kva generating sets had been installed by a firm of Indian management agents by name Jaipur Udgog. The limestone deposits known as the Ubo limestone deposit was acquired from Ado Ibrahim and Company AICO at ₦1.75 million. From the above amount, ₦440,000 was used by AICO to acquire 20% of the equity in Ukpilla Cement Company Limited.

RAW MATERIALS

The raw materials used in producing Bendel cement are:- limestone, clay and gypsum. The limestone deposits was estimated at about 21 million tonnes, and 95% pure. Of the total raw materials, gypsum is the only imported materials. The traditional suppliers of gypsum to the company are Anglo Norman Shipping Company Limited (ANSIL) of Paris. However, it is on record that traces of gypsum were found at Aviele near Auchi. But no organised arrangement has been done with regards to its drilling for usage. The company is currently having

a dialogue with University of Ife which has core-drilling factories to collaborate with a unit of the company to drill the gypsum.

TYPE AND CEMENT PRODUCTION

The brand of Portland Cement being produced by the Bendel Cement Company Limited is the Rhino Cement, employing the "Dry Process" of manufacture.

The limestone which is about 1.5 miles away from the factory is quarried by open cast method. It is then tipped using dumpers into impact crushers to the various manufacturing stages which is normal in cement manufacturing.

PROBLEMS

The main problems confronting the company as of now are due to the old age of the two Kilns (Kilns No. 1 and No. 2). At present Kiln No. 1 which is the largest is not working. Only Kiln No. 2 is working and this hinders effective production. Other problems include that of exchange rates, importation of spare parts and insufficient fund for refurbishment of Kiln No. 1.

GROWTH AND DEVELOPMENT

The Bendel Cement Company Limited has grown from an initial production capacity of 150,000 tonnes (3.0 million bags) of cement per annum in 1972, to 450,000 tonnes (9.0 million bags) per annum in 1975 as expansion programme. The new production line was commissioned in 1978.

NEPA transmission line was run through Ukpilla supplying power to Ukpilla Cement Company (UCC).

In addition to the above the company now have two power houses with two sets of generating plant. The first is a 3 No. 1600Kva Ruston/AEI generating sets and the second 3 No. 4900Kva Man/Siemens generating sets. This was installed in 1976 at a total cost of about ₦6 million. So with regards to power the company has no problem, it operates fully 24 hours service.

Initially, Ojirami Dam (Igarra) has been connected up to UCC water reservoir in the factory as standby. It has rarely ever been necessary to use it as UCC gets enough water all - the - year - round from both across river Usha and the huge reserve of water that has covered up to the old deep quarry. The supply from Ojirami is metered by the water board and UCC will have to pay according to the quantity consumed if any. In fact, the test carried out showed that it would be unwise to rely on water from Ojirami Dam as there is no adequate storage to serve UCC continuously for any length of time. UCC now has its own water supply system instead of Ojirami Dam.

The Bendel Cement Company Limited with a total staff strength of about 750, out of which 86 are senior staff, have continued to place high premium on training. The company has no training centre, but ensures consistent training of its members of staff. This cost the company about ₦0.5 million annually. Apart from the 9 months in-plant training, the company have sent a number of staff overseas for training and exposure.

The shareholdings are shown in table 13 below:

TABLE 13: EQUITY STRUCTURE AS AT NOW

Bendel State Government	78.9%	Fully paid
Ado Ibrahim & Co. Ltd.	20.0%	Only 2.2% paid
Coutinho, Caro & Co. Ltd.	1.1%	Fully paid

CHAPTER THREE

3.1.0 EXPERIMENTATION

3.1.1 PHYSICAL AND CHEMICAL TESTS

This chapter contains tests carried out on cement produced by the various cement manufacturing factories of Nigeria. Most of the cement samples were collected from acredited dealers in the markets and a few others at the last Kaduna Internation Trade Fair held in February, 1991.

The various samples obtained from the various factories are labelled A, B, C, D, E and F. The labelling of the samples has no relation with factory concerned nor has it anything to do with the quality of the product. It is just simply to identify each sample.

Cement sample from the Nigerian cement factory Nkalagu was not obtained. All efforts to obtain the sample within the time stipulated proved abortive. However, samples were obtained from the rest of the factories in Nigeria. Statistically therefore, six samples out of seven is representative enough.

For each sample both physical and chemical tests were performed. All physical tests presented in this chapter were performed in accordance to NIS 11: (1974) and B.S 12: (1958) / 13/. Chemical tests to determine composition of oxide were also performed in accordance with NIS 11: /13/.

The results obtained from the tests are presented below while the raw data during the tests are presented in the appendix.

3.1.2 INITIAL AND FINAL SETTING TIME TEST

The test was conducted as described in Appendix B of the Nigerian Industrial Standard NIS 11: (1974). The results obtained are shown in table 14 below:

TABLE 14: INITIAL AND FINAL SETTING TIME

Sample	Initial Setting Time	Final Setting Time	Specified Initial Setting (Time)	Specified Final Setting time
A	3hrs. 03mins	4hrs. 48mins		
B	3hrs. 02mins	4hrs. 52mins		
C	2hrs. 30mins	3hrs. 37mins	≥ 45mins	≤10hrs.
D	2hrs. 44mins	3hrs. 56mins		
E	20mins	2hrs. 58mins		
F	1hr. 26mins	2hrs. 17mins		

The raw data measured is shown in Appendix A7

3.1.3 SOUNDNESS

The procedure for determining the soundness of the cement is covered by the Le chatelier method, and it was conducted as described by Nigerian Industrial Standard NIS 11: (1974) Appendix C. The results are shown in table 15 below: while the raw data is shown in Appendix A-8.

TABLE 15: SOUNDNESS OF CEMENT

Sample	Expansion (mm)	Specification (mm)
A	0.00	
B	0.75	
C	0.00	≤10
D	0.93	
E	2.00	
F	0.50	

3.1.4 COMPRESSIVE STRENGTH TEST

This test is carried out in accordance with Appendix D and E of NIS 11: (1974). Appendix D is the procedure for mortar cubes while E is for concrete Cubes. The results are presented in tables 16 and 17 below. The cement - sand mortar cubes were prepared at a ratio of 1:3 and water/cement ratio of 0.40 for each sample, and 3 cubes were tested for each curing age. The raw data for the test results for samples A - F are shown in Appendix A9.

The average compressive strength for 3 mortar cubes at each particular curing age were obtained and the results are shown as stated below in table 16.

TABLE 16: MORTAR CUBE COMPRESSIVE STRENGTH

Age (in days)	COMPRESSIVE STRENGTH (N/mm^2) Samples Designation					
	A	B	C	D	E	F
3	17.82	18.13	16.15	13.07	11.70	16.45
7	19.86	23.21	20.26	19.19	12.11	18.79
14	21.00	23.31	21.40	19.59	13.19	20.46
21	23.87	25.22	24.41	19.79	15.51	21.94
28	25.74	26.42	25.08	20.00	16.12	22.41

The code specifies that the average compressive strength of three mortar cubes, for 3 days (72 $\pm$ 1h): shall not be less than 15MN/m^2 (15N/mm^2), and for 7 days (168 $\pm$ 2 h): shall not be less than 24 MN/m^2 (24 N/mm^2), and for 28 days, it should not be less than 41N/mm^2.

3.1.5 CONCRETE CUBES

Concrete Cubes were prepared using a mix ratio of 1: 2:4 and water/cement of 0.60. Three concrete cubes for each sample were tested at 7, 14, 21, and 28 days strength, and the average compressive strength for 3 cubes at each particular curing age were obtained and results are shown in table 17 below.

TABLE 17 : CONCRETE CUBE COMPRESSIVE STRENGTH

Age (days)	Compressive Strengths (N/mm^2)					
	Sample Designation					
	A	B	C	D	E	F
7	17.48	21.04	16.26	14.52	14.37	19.85
14	20.15	25.48	18.22	18.37	15.11	22.07
21	22.67	28.59	20.30	20.40	20.29	24.89
28	22.67	28.89	22.22	23.11	20.74	25.93

The code specifies that the average compressive strength of the concrete cubes, for 3 days (72 $\pm$ 1h), shall not be less than 8 MN/m^2 and for 7 days shall not be less than 14 MN/m^2 (14 N/mm^2), and for 28 days it should not be less than 29 N/mm^2. The mix design and the calculations are shown in appendix A-5, while the raw data for the test results for samples A-F are shown in appendix A10.

However, before casting the concrete cubes, tests were performed on the coarse aggregate as well as fine aggregates.

Such tests are impact value as well as crushing test of the coarse aggregates, sieve analysis of both coarse and fine aggregate, mix design, slump test and compacting factor test.

The impact value and crushing tests of the coarse aggregate are found to be 26 percent. The sieve analysis are shown in figure 2 and 3 for fine and coarse aggregates while the slump test and compacting factor tests are shown in tables 18 and 19 respectively. The raw data for test results are shown in the appendix A-3, A-4, A-5, A-6, and A-7.

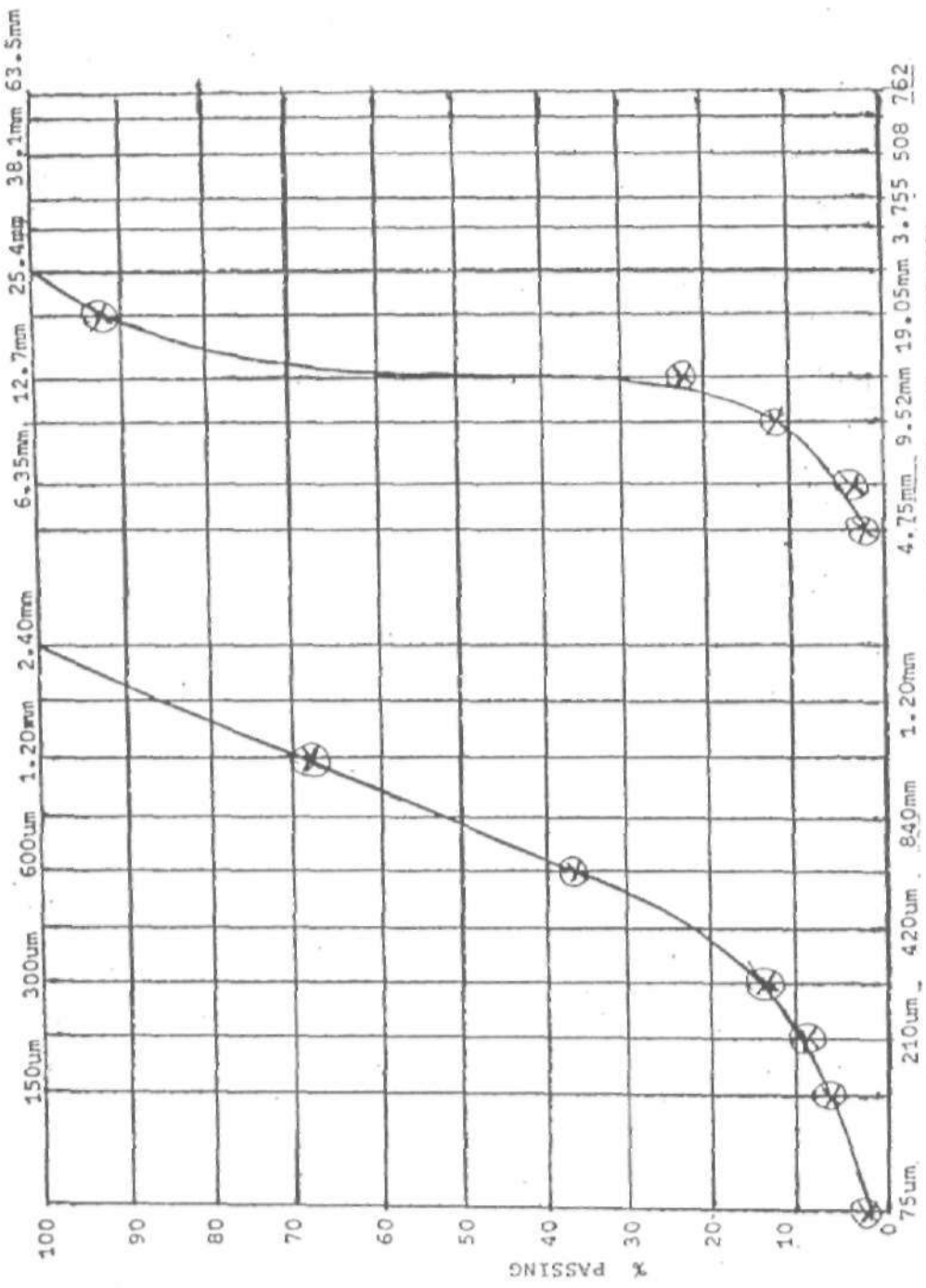


FIG.3 PARTICLE SIZE DISTRIBUTION
- COARSE AGGREGATES.

FIG.2 PARTICLE SIZE DISTRIBUTION
- FINE AGGREGATES

TABLE 18: SLUMP TEST RESULTS

Sample	Slump Measured (mm)
A	30
B	23
C	23
D	16
E	16
F	16

Also table 18 below gives the results of the compacting factor test.

TABLE 19: COMPACTING FACTOR TEST RESULTS

Sample	Compacting Factor
A	0.941
B	0.840
C	0.920
D	0.864
E	0.902
F	0.895

The results of the compressive strength obtained are shown in tbtable 19 for all the samples tested.

Tests were carried out on the Cube Specimens of sizes 150 x 150 x 150mm. The cubes were tested immediately on removal from the curing water as specified. Care was taken that no packing was used between the faces of the test cubes and the steel platens of the machine. The axis of each cube was carefully aligned with the centre ofthe thrust of the spherically seated platen. The load was applied without shock and increased continuously at a rate of approximately 14 MN/m^2 per minute untill no greater load can be sustained.

That of 3 days age was not tested as a result of insufficient cube moulds in the laboratory where the test was conducted.

3.2.0 CHEMICAL TESTS

The chemical tests for the samples were performed in the National Research Institute for Chemical Technology. It was carried out at the department of industrial chemistry laboratory in accordance to NIS 11: (1974) /13/ standard. The percentage values of the following oxide composition were determined CaO, SiO_2, Al_2O_3, Fe_2O_3, MgO, SO_3, Ma_2O, K_2O and Loss on ignition (LOI).

Before performing the tests, the samples were grounded to much finer powdered particles and sieved using 850 mm sieve and pan. The ones retained in the pan were used. The samples were later transfered to

porcelain crucibles and dried in an oven at 110°C to expel all the free air. They were later transfered to closed plastic containers to the weighing room where 1gm of each sample was taken for each test.

3.2.1 DETERMINATION OF LOSS ON IGNITION (LOI)

For the determination of LOI, platinum crucible is used, which can withstand higher temperatures. The weight of the crucible and sample is taken before heating using weighing balance and later transferred to the muffle furnace, and heated to a temperature of 900°C for 1 hour. Loss in weight on ignition of cement at higher temperature is primarily due to the loss of water and carbondioxide. Thus the difference in weight divide by the weight of the container multiplied by hundred gives the percentage loss on ignition.

The samples are later brought into solution by diluting with concentrated hydrochloric acid and heated to dryness. Hot distilled water is added and filtered using whatman 40 filter paper in conical flask. The filtrate is known as stock solution from which all other determinations were made.

3.2.2 DETERMINATION OF IRON OXIDE (Fe_2O_3)

For the determination of Iron Oxide (Fe_2O_3), 5ml of the stock solution is taken and oxidised with potassium permanganate (Km_nO_4) and 2ml. dulute hydrochloric acide (HCL), finally 2ml. of Ammonium thiocyanite (NH_4SCN) is added and rate of absorbence is measured from the solutions.

3.2.3 DETERMINATION OF ALKALIS (Na_2O and K_2O)

The percentage of Alkalis were determined by taking about 25ml. of the stock solution plus drops of bromine water. This solution is brought to boil and approximately 2gm. of Ammonium chloride (NH_4CL) added. Few drops of Ammonium hydroxide are added, (dropwise). The precipitate (PPt.) is filtered on whatman 40 (WH0) paper and washed with 1 percent hot Ammonium chloride solution. Emmissions were measured on a flame photometer, and the percentage of Alkalis calculated.

3.2.4 DETERMINATION OF CALCIUM OXIDE (CaO)

Radium Oxide (R_2O_3) is filtered and the filterate is acidified with diluted hydrochloric acid (HCl). 10ml. of 5 percent Ammonium Oxalate is added to the acidified filterate. The 5 percent Ammonium Oxalate is neutralized by diluted Ammonium hydroxide (NH_4OH) for 30 minutes, on a hot plate. The precipitate (PPt.) is filtered on whatman 40 (WH0) paper and washed with warm water. This is then dissolved in 5ml. 1:1 sulphuric acid (H_2SO_4) and titrated with 0.1N pottassium permanganate ($KMnO_4$) to a parmanent pink colour. The level at which the colour was attained is then taken and the percentage of lime (CaO) determined.

3.2.5 DETERMINATION OF MAGNESSIUM OXIDE (MgO)

10ml. of 5 percent eight-hydroxyquinoline is added to a lime (CaO) filterate. Fifteen (Ml.) of Ammonium Hydroxide (NH_4OH) is added to filterate colution, stirred for 5 minutes

and left overnight. The precipitate is then filtered on whatman 40 (WH0) paper and ashed at 900°C for 1 hour in muffle furnace. After removal from turnace and allowed to cool, the crucible plus the ashed PPt. is measured and the percentage weight determined.

3.2.6 DETERMINATION OF SULPHUR TRIOXIDE (SO_3)

For the determination of SO_3, 25ml. of the stock solution is taken into a clean beaker about 2mls of 1 percent barium chloride ($Bacl_2$) solution is added to the beaker and boiled for 30 minutes. The boiled solution is transferred onto a water bath for an hour. This is removed and filtered through whatman 40 paper and washed with hot water and ashed for 1 hour at 900°C in a furnace. The percentage of SO_3 is equal to $BaSO_4$ multiply by 0.3430 (factor from table).

The results obtained for oxide composition of the cement samples are shown in table 20 below. While the raw data for the determination of the oxider compositions are shown in Appendix A_{11} - A_{18}.

TABLE 20: OXIDE COMPOSITION OF CEMENT SAMPLES

S/NO	PERCENTAGES						
	OXIDE	A	B	C	D	E	F
1.	CaO	60.29	55.24	60.01	62.11	60.57	60.29
2.	SiO_2	19.17	17.72	20.60	20.65	17.10	20.31
3.	Al_2O_3	10.72	12.61	9.26	11.00	11.35	11.81
4.	Fe_2O_3	0.68	0.59	0.44	0.81	0.65	0.49
5.	MgO	0.24	0.71	0.28	0.77	0.35	0.15
6.	SO_3	3.84	3.40	3.46	1.72	5.04	3.95
7.	Na_2O	0.018	0.076	0.008	0.008	0.040	0.042
8.	K_2O	0.064	0.090	0.124	0.030	0.080	0.135
9.	Loss on Ignition	4.55	5.50	4.66	1.60	4.40	2.79
10.	Others (MMO_2, TiO_2 etc.)	0.42	4.06	1.16	1.30	0.42	0.10
	TOTAL	100.00	100.00	100.00	100.00	100.00	100.00

3.2.7 CALCULATION OF C_3S, C_2S, C_3A, C_4AF AND LIME SATURATION FACTOR (L.S.F.)

The percentages of the above compounds are calculated using the Boque equations.

The calculation is shown below:

SAMPLE A

From Table 21:

CaO	=	C	=	60.29
SiO_2	=	S	=	19.17
Al_2O_3	=	A	=	10.72
Fe_2O_3	=	F	=	0.68
SO_3			=	3.84

$\therefore$ % $C_3S = 4.07\ (CaO) - 7.60\ (SiO_2) - 6.72\ (Al_2O_3) - 1.43(Fe_2O_3) - 20.35\ (SO_3)$.

$= 4.07 \times 60.29 - 7.60 \times 19.17 - 6.72 \times 10.72 - 1.43 \times 0.68 - 2.85 \times 3.84$

$= 245.38 - 145.692 - 72.038 - 0.972 - 10.94$

$= \underline{\underline{15.71\%}}$

% $C_2S = 2.87\ (SiO_2) - 0.754\ C_3S$

$= 2.87 \times 19.17 - 0.75 \times 15.74$

$= 55.018 - 11.868$

$= \underline{\underline{43.15\%}}$

% $C_3A = 2.65 \times 10.72 - 1.69 \times 0.68$

$= 28.408 - 1.149$

$= \underline{\underline{27.259\%}}$

% $C_4AF = 3.04(0.68)$

$= \underline{\underline{2.067\%}}$

$$\therefore \quad L.S.F = \frac{(CaO) - 0.7\,(SO_3)}{2.8(SiO_2) + 1.2\,(Al_2O_3) + 0.65\,(Fe2O_3)}$$

$$= \frac{60.29 - 0.7\,(3.84)}{2.8(19.17) + 1.2\,(10.72) + 0.65\,(0.68)}$$

$$= \frac{60.29 - 2.688}{53.676 + 12.864 + 0.442} = \frac{57.602}{66.982}$$

$$= \underline{\underline{0.86}}$$

This implies that the lime saturation Factor of SAMPLE A is within the range of $0.66 \leqslant L.S.F \leqslant 1.02$ according to NIS 11: (1974).

The silicate compounds and L.S.F of the other samples are calculated in similar way and the values are shown in table 21 below:

TABLE 21: COMPOSITION OF MAIN COMPOUNDS OF TESTED CEMENTS

Compound	A	B	C	D	E	F
C_3S	15.74	-5.12	14.96	15.87	24.99	-0.30
C_2S	43.15	54.72	47.84	47.30	30.23	58.52
C_3A	27.26	32.42	23.79	27.78	28.98	30.47
C_4AF	2.07	1.79	1.34	2.46	1.98	1.49
L.S.F	0.86	0.81	0.83	0.85	0.92	0.81

CHAPTER FOUR

4.1.0 DISCUSSION OF RESULTS

4.1.1 SETTING TIME

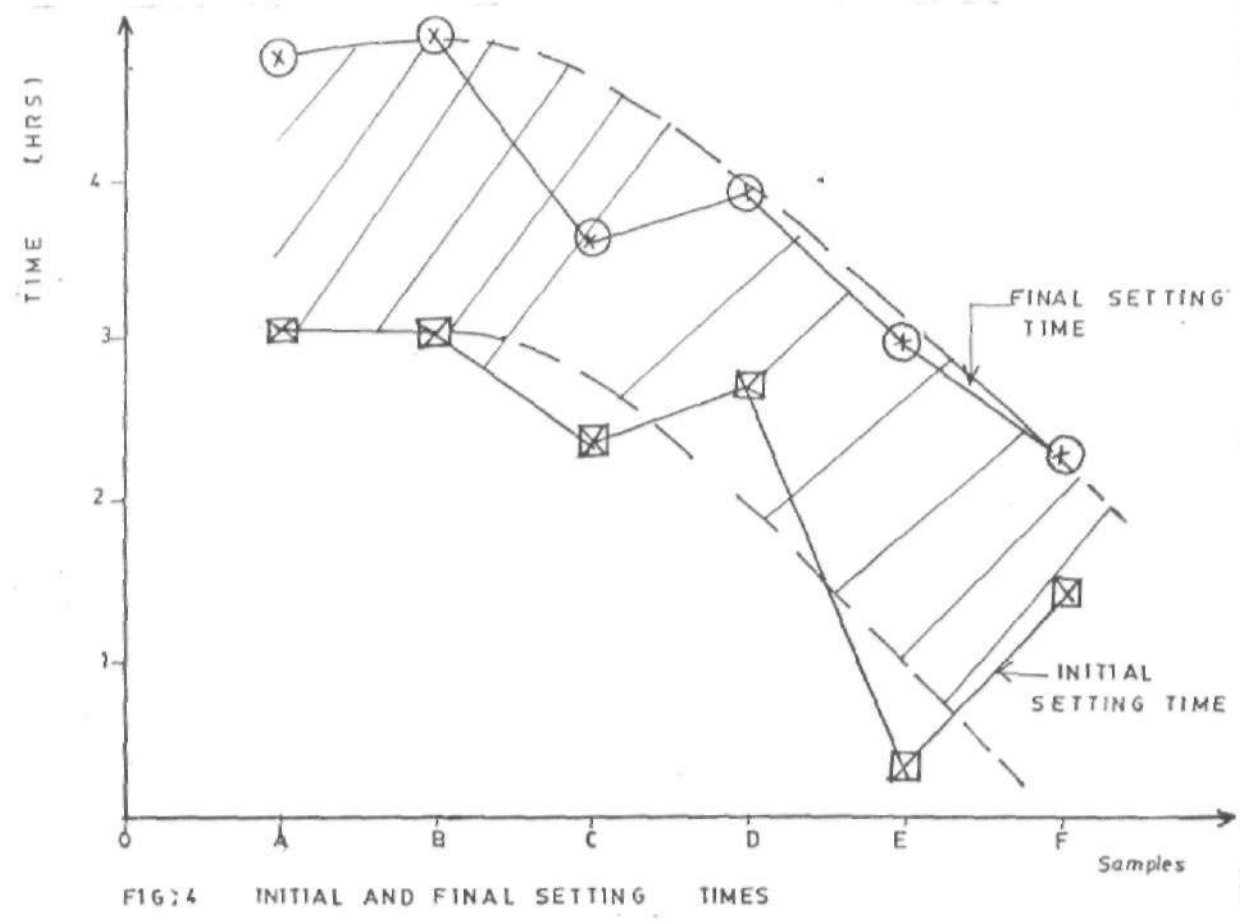
The results presented in table 14 of chapter three for the initial and final setting time of all the samples show that apart from sample E, all others satisfy the minimum requirements for the initial setting time of 45 minutes. For the sample E, the initial setting time was found to be 20 minutes. All the samples satisfy the requirement of not more than 10 hours for the final setting time as specified by the Nigerian Industrial Standard NIS 11: (1974)/13/. However, the action of sample E can be said to be false set. This false set can be attributed to the following.

a) Dehydration of gypsum when interground with too hot a clinker resulting into hemihydrate ($CaS_{O4} \cdot \frac{1}{2}H_2O$) or anhydrite ($CaS_{O4}$). When the cement containing these hemihydrate is mixed with water, it hydrate to form gypsum rather than stopping the false set. Thus false set takes place with a resulting stiffening of the paste. Sample E has the highest oxide of 5.04 percent of sulphur (Table 20 Chapter three).

b) Another cause of false set may be associated with the alkalis in the cement. During storage they may carbonate, and alkali can also react with calcium hydroxide ($Ca(OH)_2$) liberated by hydrolysis of tricalcium silicate (C_3S) to form alkali carbonate. This precipitates and induces a rigidity of the paste. Sample E has second highest amount of potassium oxide of 0.08 percent and sodium oxide of 0.040 percent. However, the percentage alkalis in the samples tested are below the standard recommended range of 0.2 to 1.3 percent. This false set in sample E might not be due to the low alkalis contents in the cement.

c) It can also be observed that in table 21 (Chapter three) sample E gives the highest value of tricalcium silicate (C_3S), this therefore support strongly the argument in (b) above.

It can be observed from the graph (figure 4) that a mean line (dotted) drawn between initial and final setting times has a time of roughly two hours. Thus it can be said that the Nigerian Cement after initial set, takes about 2 hours to set fully. Assuming a initial setting time of three hours for Nigerian Cement, it can be said that Nigerian Cement can fully set after five hours of mixing. Therefore the mixed cement cannot be longer than five hours on transit.



FIG; 4 INITIAL AND FINAL SETTING TIMES

4.1.2 SOUNDNESS

It is essential that a cement paste, once it has set, does not undergo a large change in volume. In particular, there must be no appreciable expansion, which under conditions of restraint could result in a disruption of the hardened cement paste. Such expansion may take place due to the delayed or slow hydration or other reaction of some compounds present in the hardened cement, namely freelime, magnesia, and calcium sulphate.

If the raw materials fed into the kiln contain more lime that can combine with the acidic oxides, the excess will remain in a free condition. This hard burnt free lime hydrates only very slowly but slaked occupies a larger volume than the original free lime, giving rise to expansion. Cements which exhibit this expansion are known as unsound, usually have expansion of more than 10mm.

A cement can also be unsound due to the presence of magnessium oxide (MgO), which reacts with water in a manner similar to lime. However, only crystalline magnessium oxide is deteriously reactive and MgO present in glass is harmless.

Calcium sulphate is the third compound liable to cause expansion. In this case, calcium sulpho aluminate is formed. It may be recalled that a hydrate of calcium sulphate (gypsum) is added to cement clinker in order to prevent flash set, but if gypsum is present in excess of

the amount that can react with C_3A during setting, unsoundness in the form of a slow expansion will result. In table 15 (chapter 3) however, it can be observed that samples A and C show zero expansion, while the others show little expansion with sample E giving the highest expansion of 2.0mm. Generally all the samples satisfy the NIS 11: (1974) standard in which all the values are far less than 10mm, the samples are therefore said to be sound.

4.1.3 COMPRESSIVE STRENGTH

The crushing or compression test gives a better indication of the quality of cement. The strength of mortar or concrete depends on the cohession of the cement paste, its adhesion to the aggregate particles, and to a certain extent on the strength of the aggregate itself.

Strength tests are not made on a neat cement paste because of difficulties of moulding and testing with a consequent large variability of test results. Cement-sand mortar and, also concrete of prescribed proportions are made with specified materials under strictly controlled conditions. These are used for the purpose of determining the strength qualities of cement.

The results of strength development of mortar cubes for all the samples tested are given in table 16, and based on the values, curves were plotted for each sample illustrating the strength development of the cements.

.The figures for samples A, B, C, D, E and F are shown in figures 5, 6, 7, 8, 9, and 10 respectively.

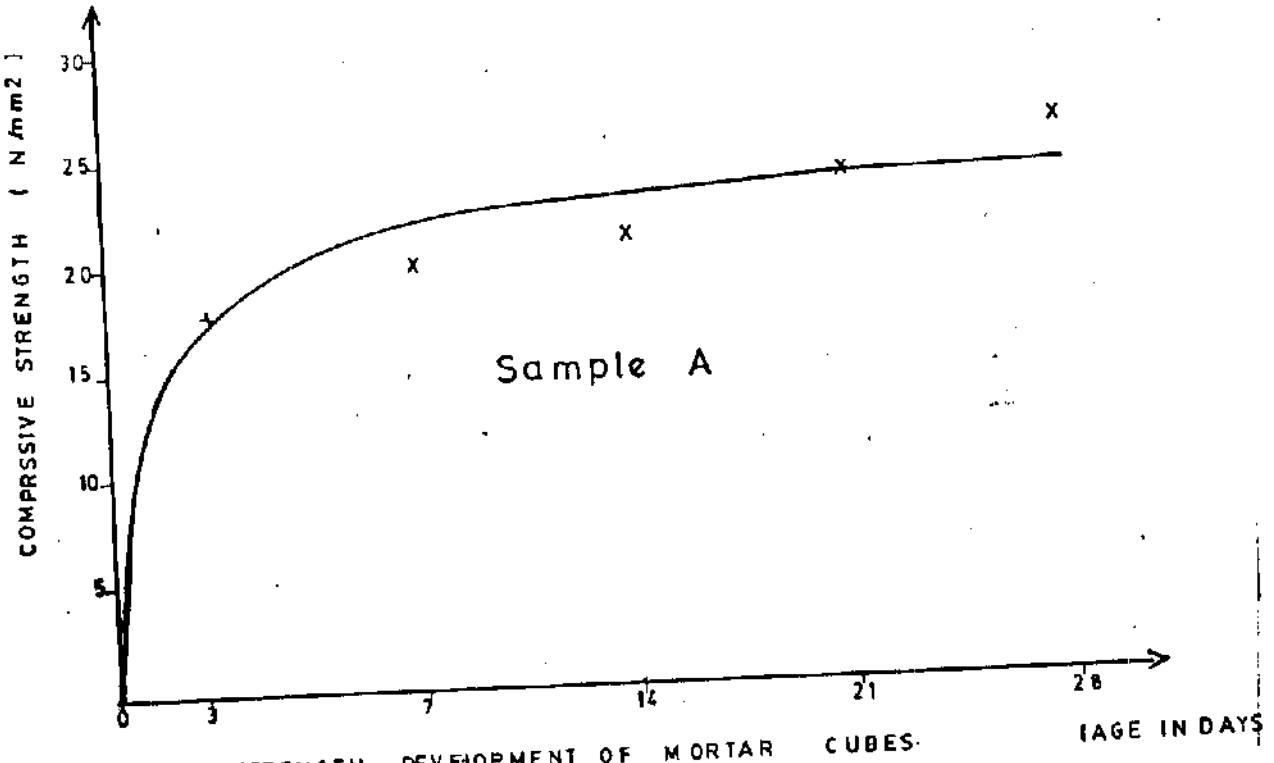


FIG:5 STRENGTH DEVELOPMENT OF MORTAR CUBES

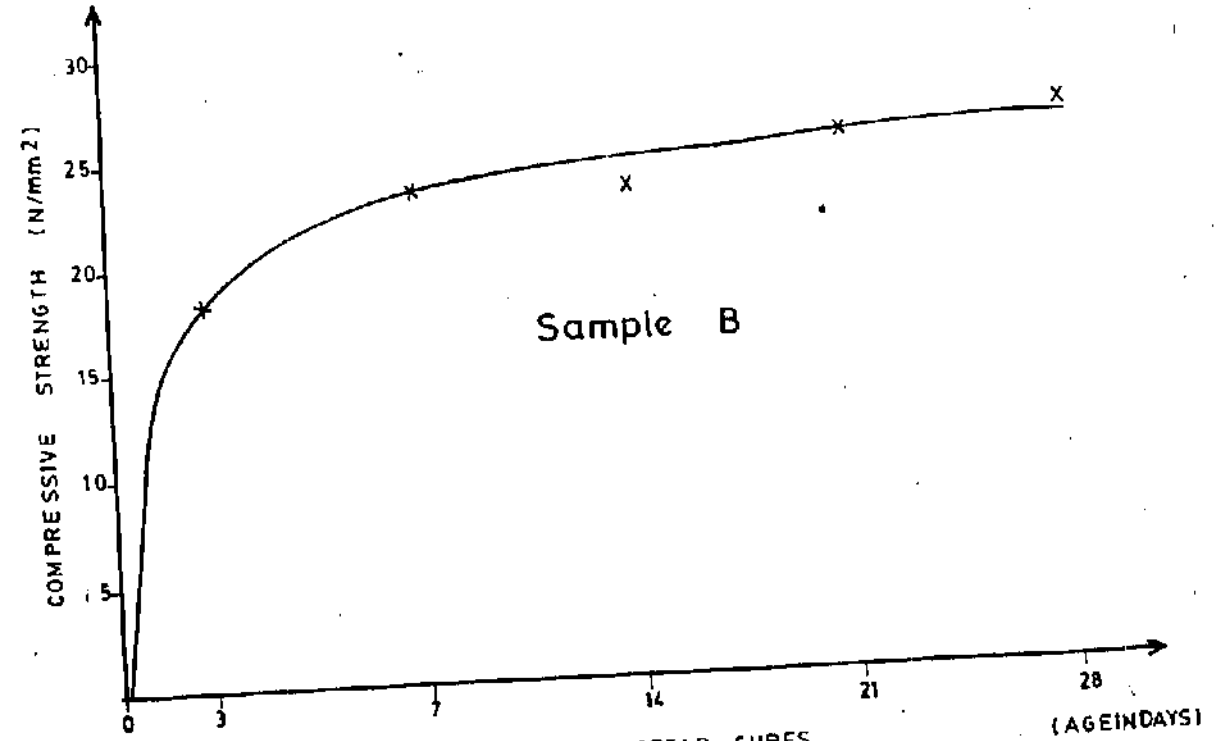


FIG:6 STRENGTH DEVELOPMENT OF MORTAR CUBES

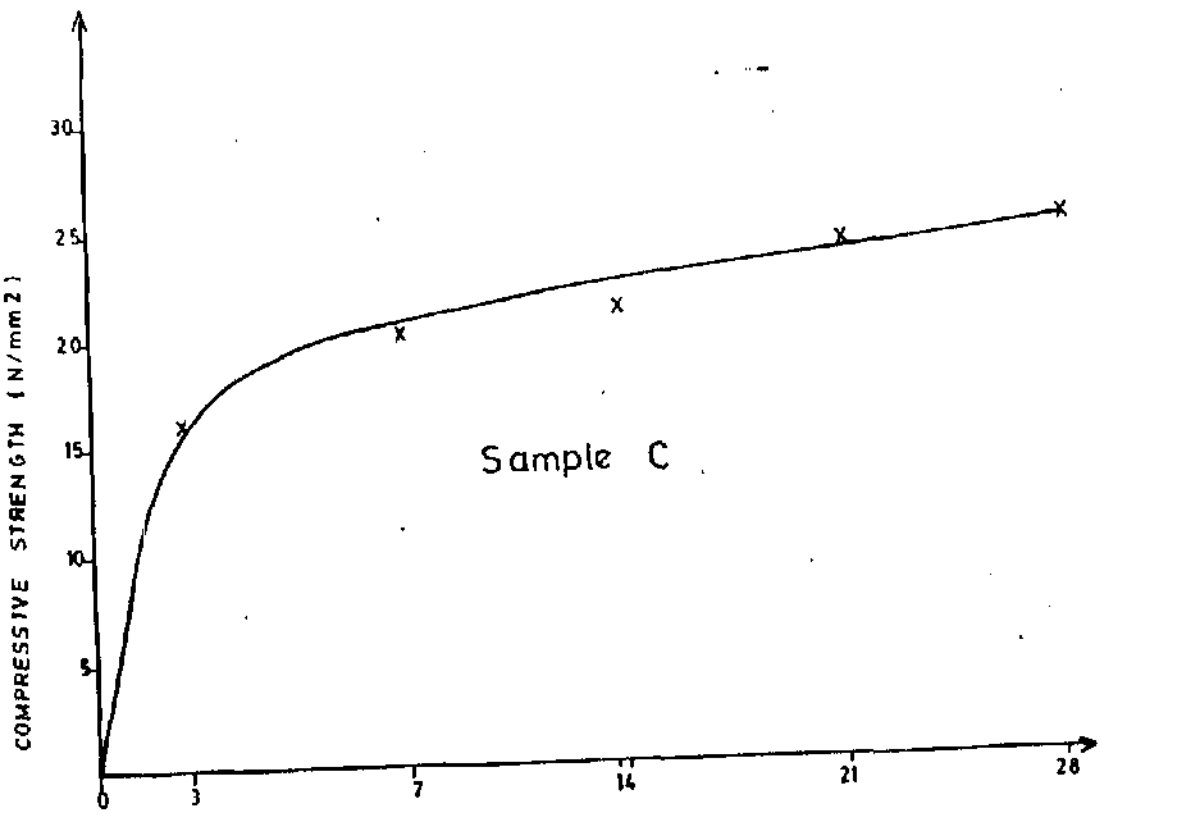


FIG : 7. STRENGTH DEVELOPMENT OF MORTAR CUBES

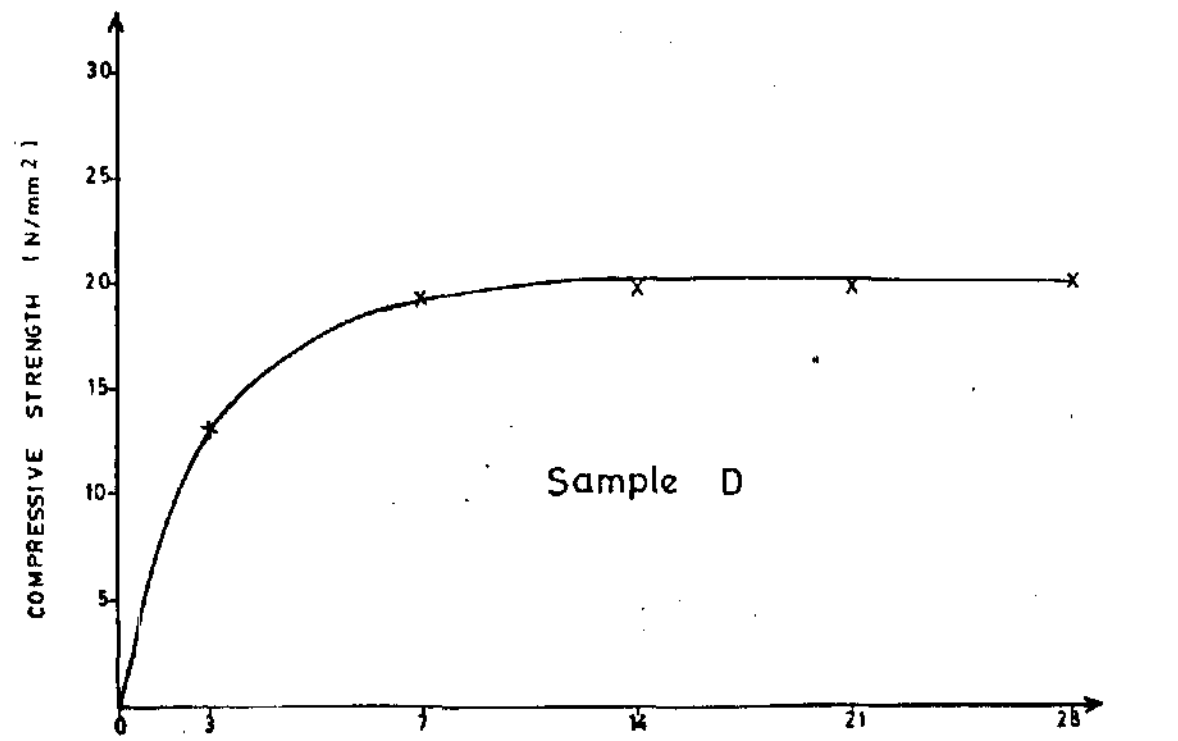


FIG:8 STRENGTH DEVELOPMENT OF MORTAR CUBES

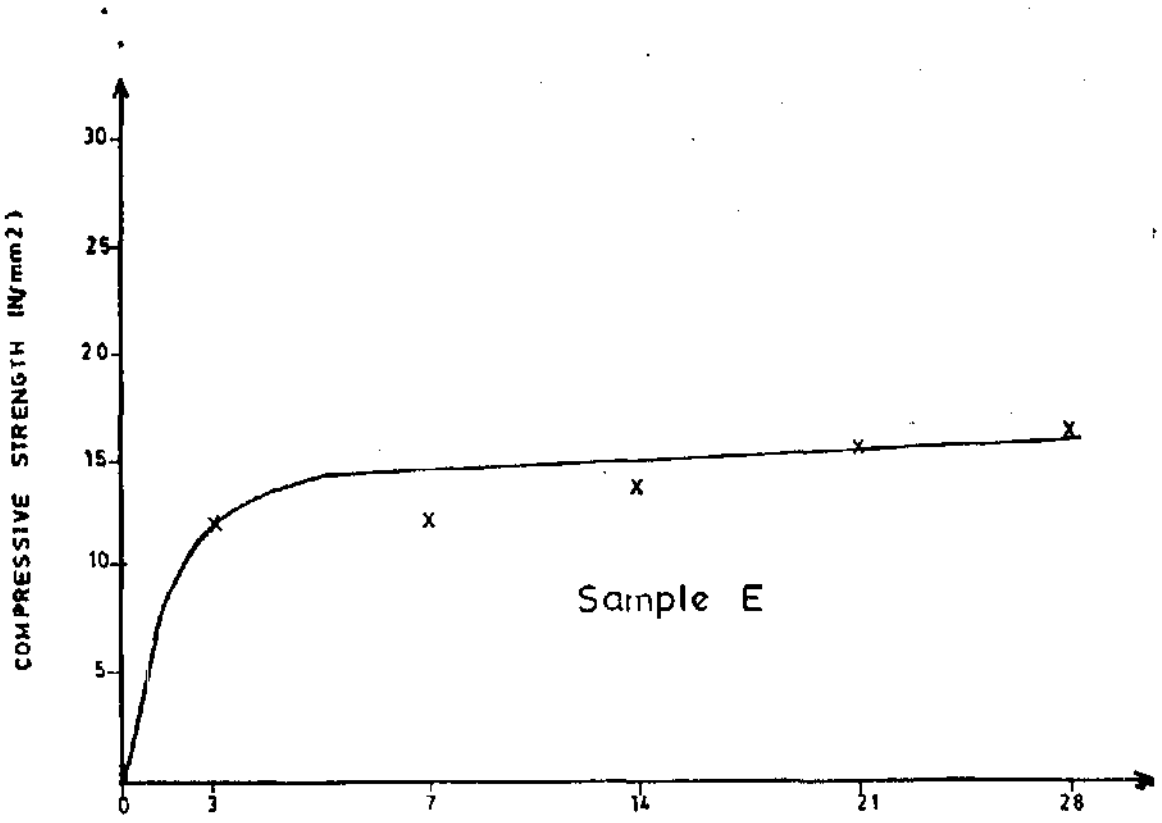


FIG :9 STRENGTH DEVELOPMENT OF MORTAR CUBES (AGE IN DAYS)

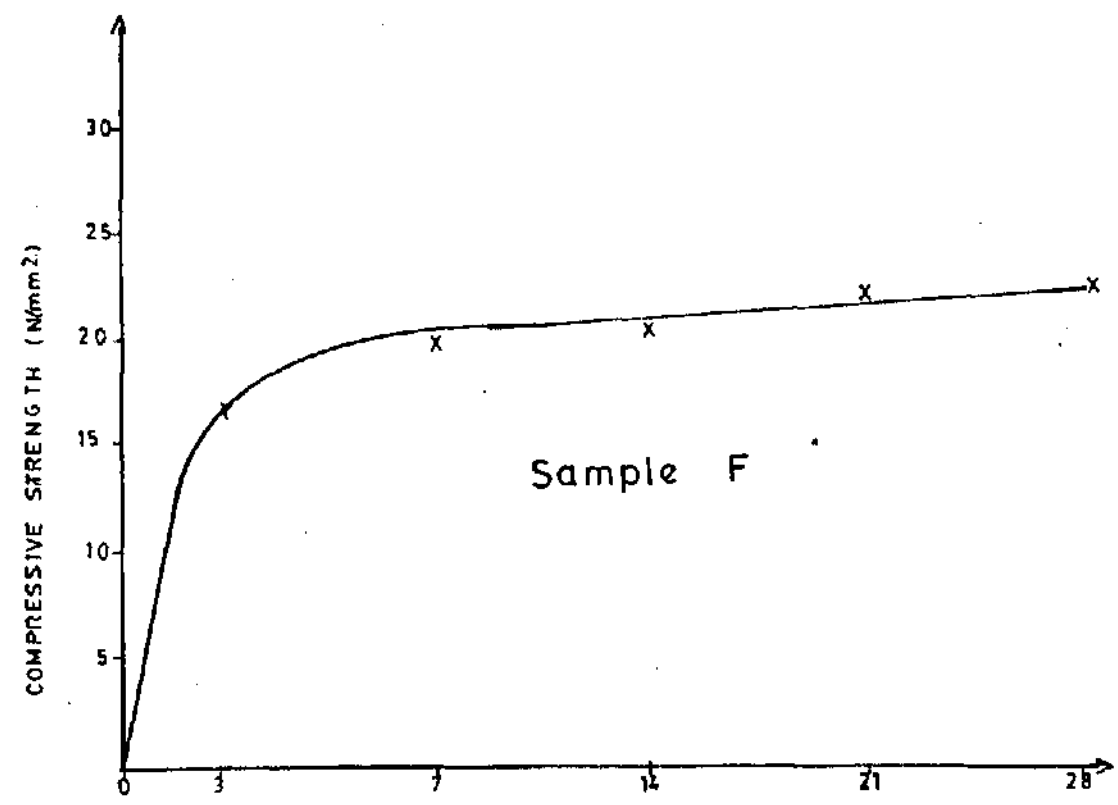


FIG: 10 STRENGTH DEVELOPMENT OF MORTAR CUBES (AGE IN DAYS)

The results of strength development of concrete cubes for all the samples tested are also given in table 19. The curves plotted for samples A, B, C, D, E, and F are shown in figures 11, 12, 13, 14, 15 and 16 respectively.

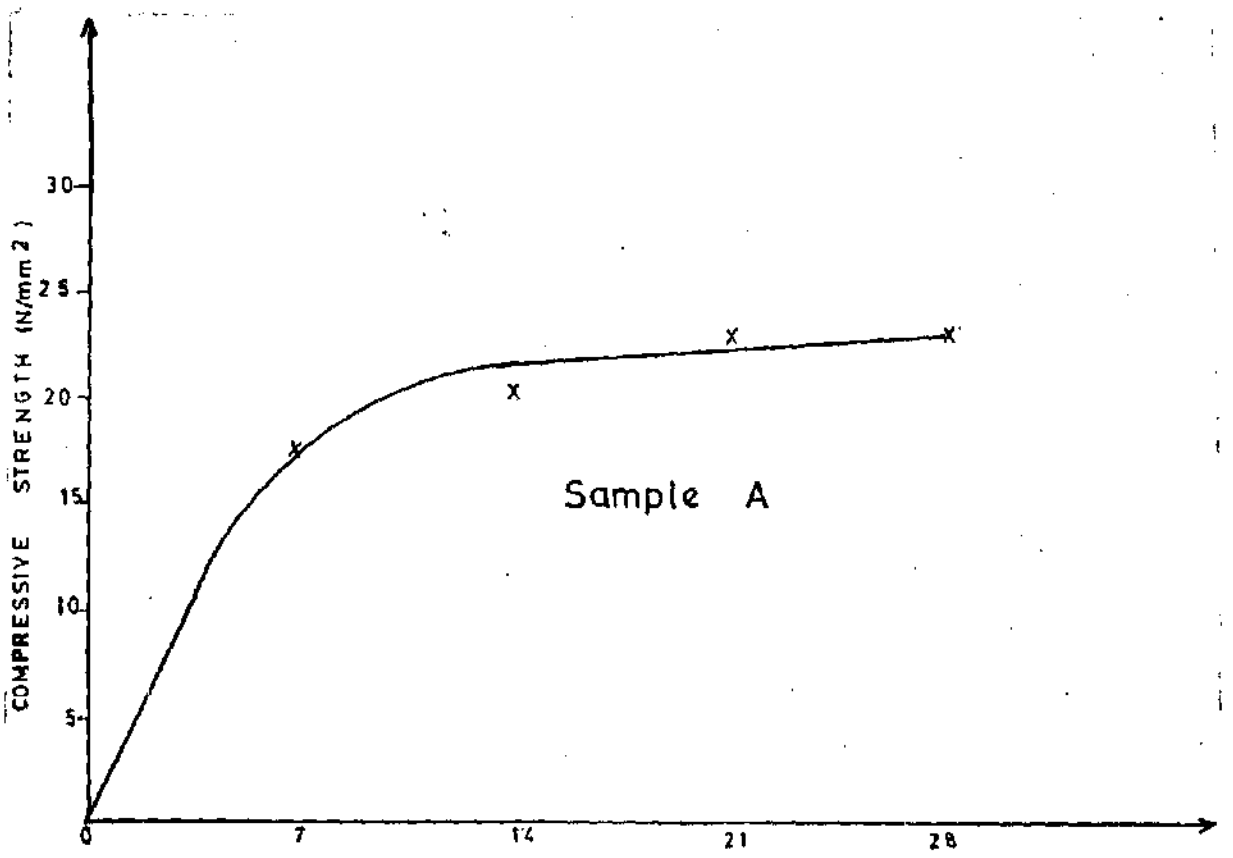
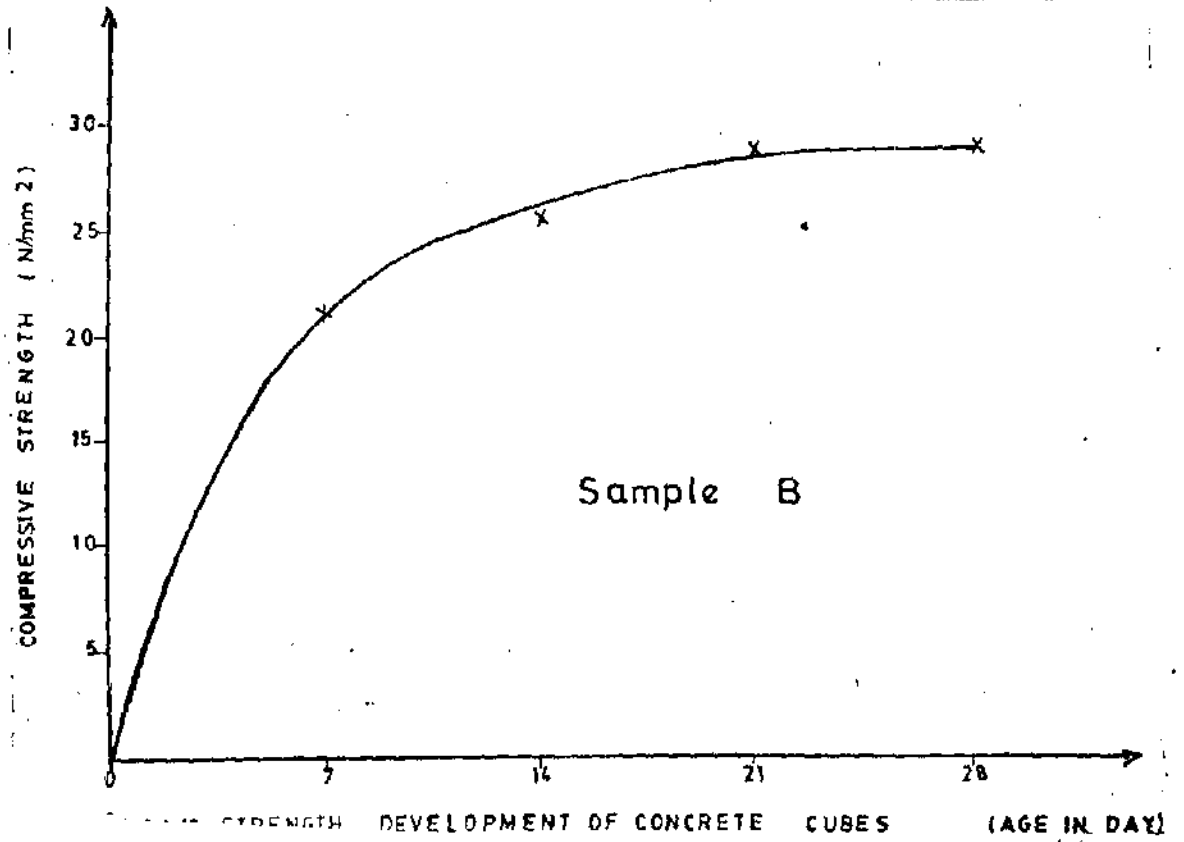


FIG: 11 STRENGTH DEVELOPMENT OF CONCRETE CUBES



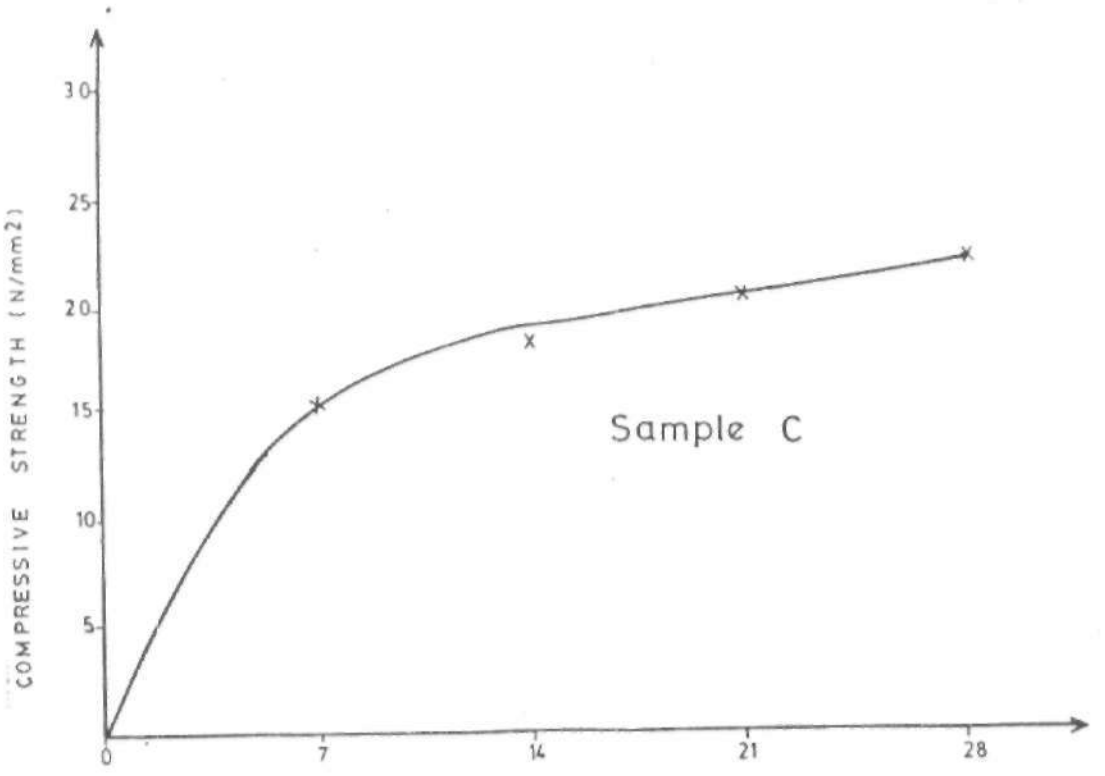


FIG:13 STRENGTH DEVELOPMENT OF CONCRETE CUBES

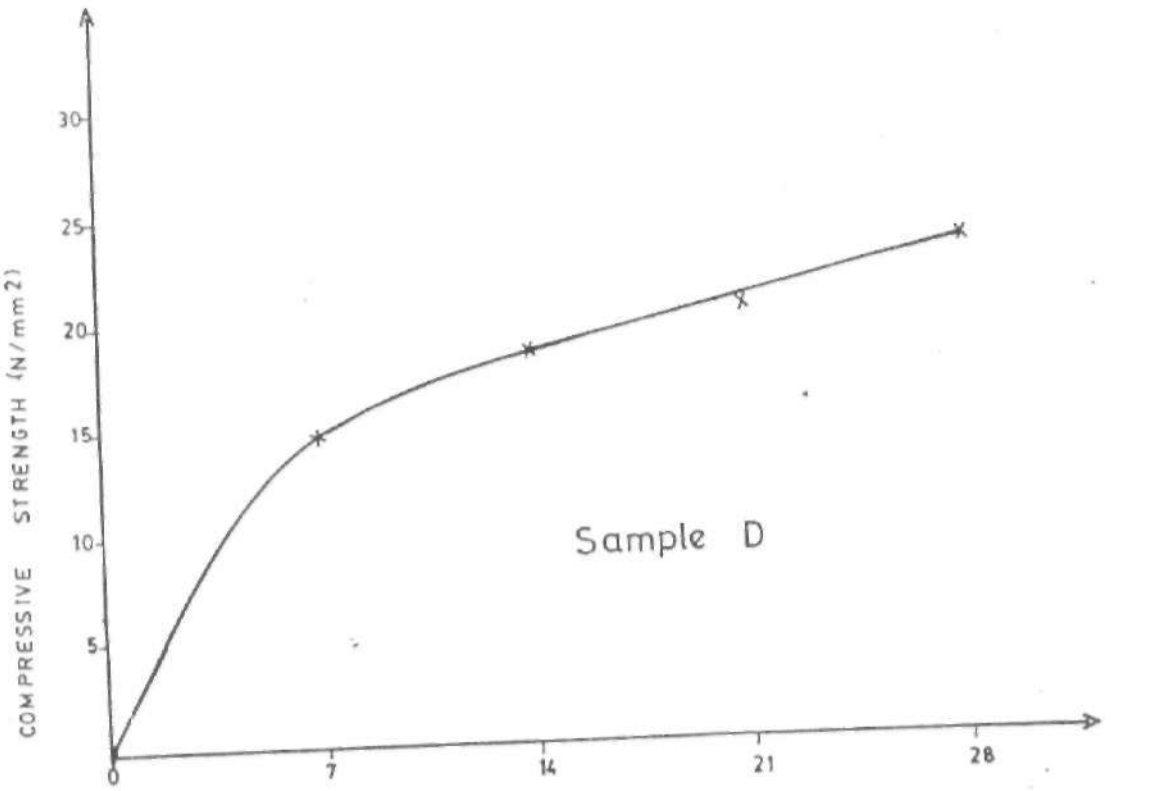


FIG:14 STRENGTH DEVELOPMENT OF CONCRETE CUBES

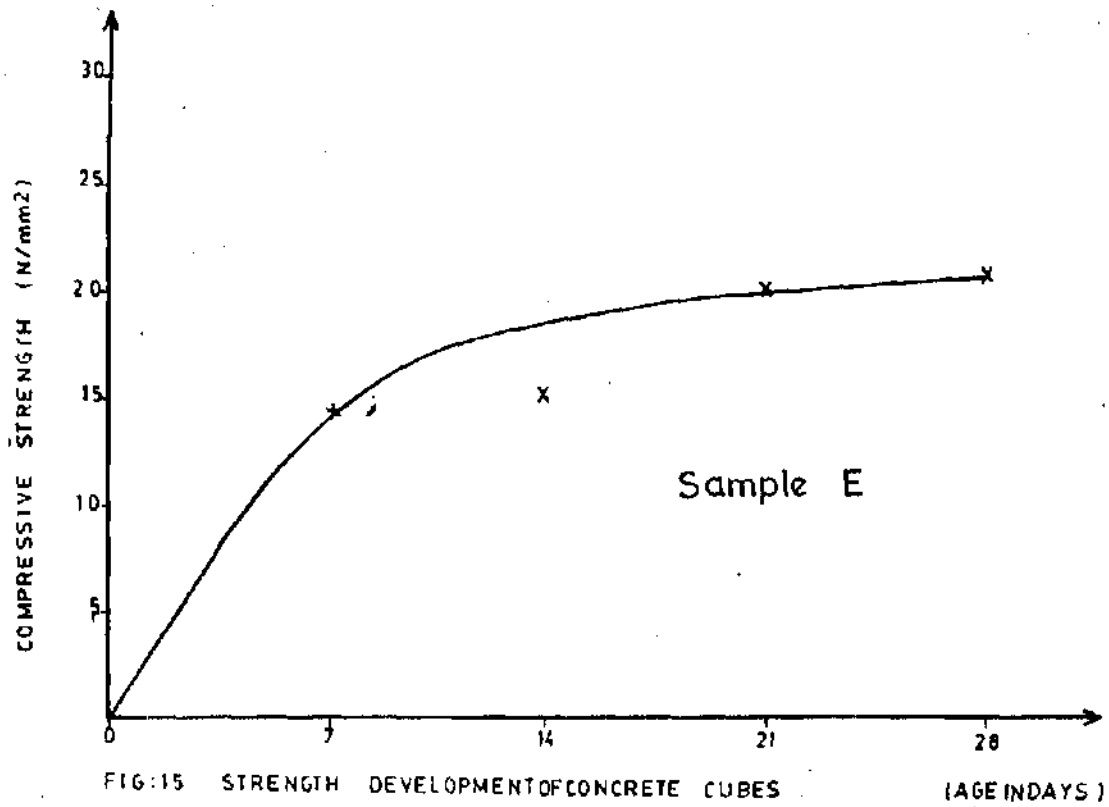


FIG:15 STRENGTH DEVELOPMENT OF CONCRETE CUBES

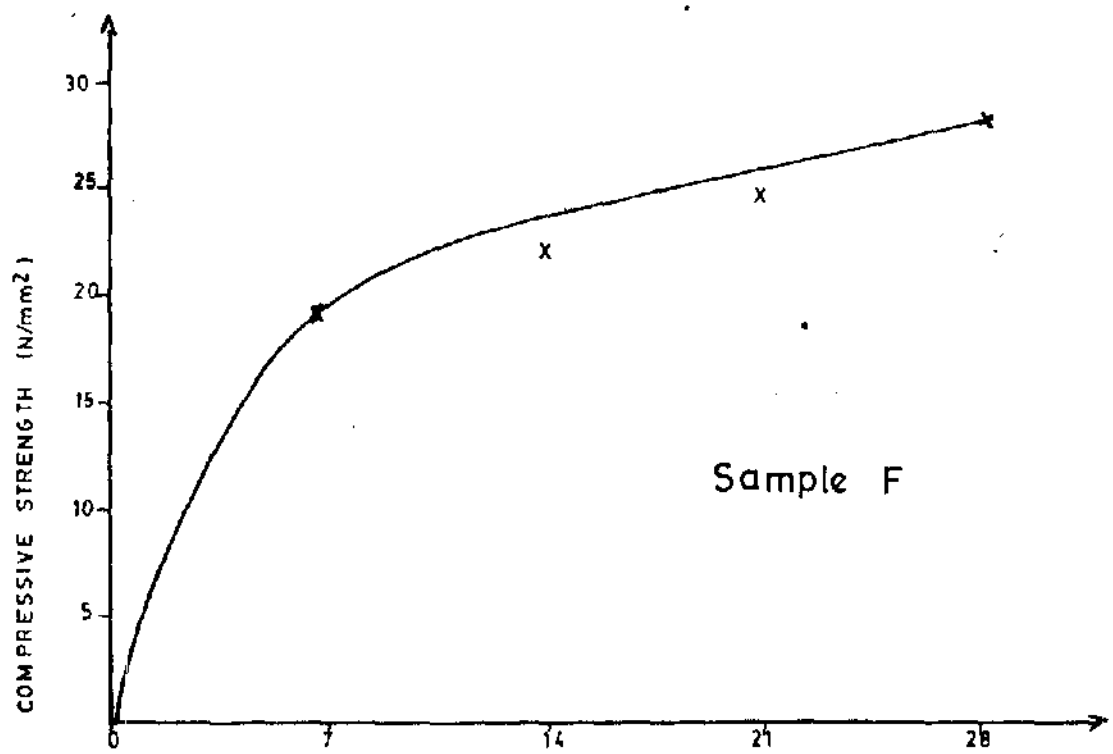


FIG :16 STRENGTH DEVELOPMENT OF CONCRETE CUBES

Figure 17 however shows the strength development of mortar cubes for all the samples plotted.

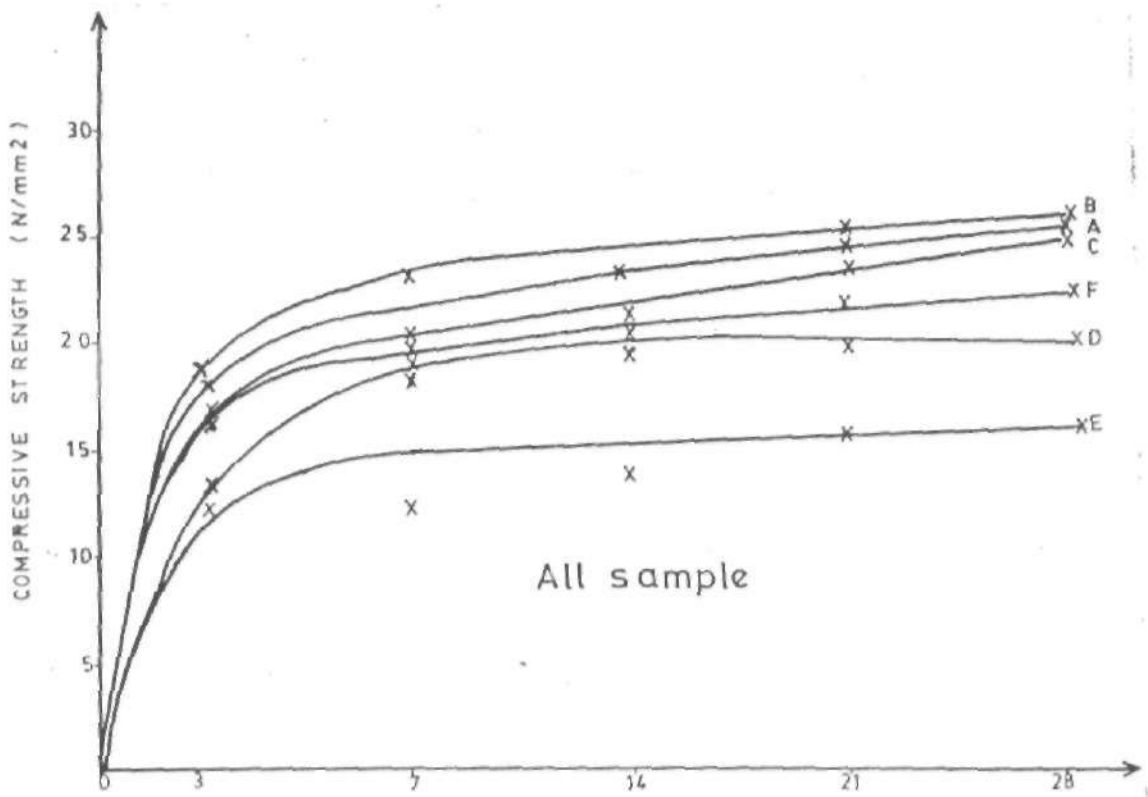


FIG: 17 STRENGTH DEVELOPMENT OF MORTAR CUBES

It can be observed that sample B gives the highest value of strength for all the curing ages. This is followed by A C F D respectively with E showing the least. The Nigerian Industrial Standard NIS 11: (1974) specified that the average compressive strength of three mortars cubes, for 3 days (72 ± 1hr.) shall not be less than $15MN/m^2$ ($15N/mm^2$), and for 7 days (168 ± 2hr). Shall not be less than $24MN/m^2$ ($24N/mm^2$). As can be seen from table 16 figure 17 samples A, B, C, D, E and F have compressive strength of mortar at 3 days of 17.85, 18.13, 16.15, 13.07, 11.70 and $16.45N/mm^2$ respectively. However, even though most of sample satisfy the 3 days, they could not satisfy the 7 days requirement of $24MN/m^2$ ($24N/mm^2$) as specified above. There is low rate of strength development for all the samples tested. The standard specification of mortar cubes for 28 days strength is $41N/mm^2$.

Similarly, figure 18: shows the strength development of concrete cubes for all the samples tested.

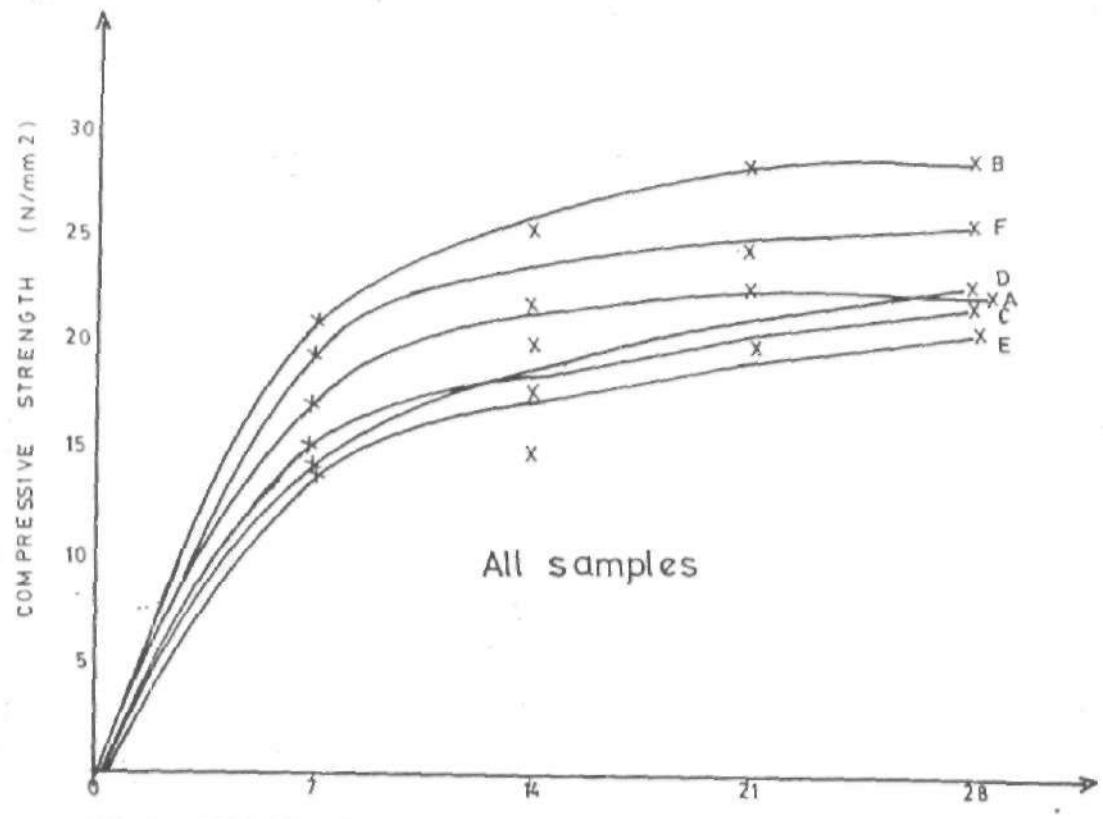


FIG : 18 STRENGTH DEVELOPMENT OF CONCRETE CUBES (AGE IN DAYS)

Again sample B yielded the highest value of strength for 7, 14, 21 and 28 days curing ages. This is followed by samples F, D, A, C and E respectively. Sample E again gives the lowest value of strength for concrete cubes. But all the samples satisfy the 7 days requirement of $14MN/m^2$ ($14\ N/mm^2$) according to NIS 11: (1974) specification for ordinary Portland Cement.

However, it is observed again that all the samples failed to meet the strength requirement at age of 28 days. Sample B however passed the strength requirement as it has an average strength of $28.9\ N/mm^2$ when compared to the standard strength requirement of $29\ N/mm^2$.

The nature of strength of concrete is complex and not yet fully understood. However, it can be said that strength is primarily depended on water/cement ratio, i.e. the ratio of the weight of the mixing water to that of the cement in the mixture. Also the lower the water/cement ratio the higher is the strength. To hydrate completely cement needs to combine with about 38% by weight of water but in practice complete - hydration of the cement does not take place and is not aimed at. Under practical conditions, irrespective of water/cement ratio used, the cement combines with only about 23% water by weight. However, with a water/cement ratio as low as 23%, the concrete is very dry and difficult to place and compact; additional water is therefore required to lubricate the mix i.e to provide the necessary workability.

The strength of concrete improves with proper curing after it is cast. By curing, it is meant the provision of moisture and a favourable temperature for the cement to continue to hydrate, thereby increasing the strength of the concrete. It is difficult to be precise about the effect of temperature on concrete but generally speaking it is good practice to maintain a temperature between about $5^{\circ}C$ and $20^{\circ}C$ during the first half day or so after placing the concrete. During this initial period, a much higher temperature might retard the later development in strength, while a much lower temperature

such as would cause the fresh concrete to freeze might permanently impair the strength.

After this initial period, the strength development increases with the maturity, which is the product of age and temperature. This age is measured from the time of mixing and the temperature from a datum, which is taken as 11.7°C. This assumes the presence of moisture for the cement to continue to hydrate. It should be noted that even when the concrete is not specially protected against drying, the evaporable water is not immediately lost under ordinary climatic conditions, and hence the strength will continue to increase for some time. However, it can be observed that the rate of strength increase is low in all the samples tested.

4.2.0 CHEMICAL COMPOSITION

The chemical tests conducted is to determine the oxide composition of the samples of the cement. These oxide compositions are: Lime (CaO), Silicon (SiO_2), Aluminium (Al_2O_3), Iron (Fe_2O_3), Magnesium (MgO), Sulphur (SO_3), Alkalis sodium and Potassium (Na_2O and K_2O) respectively and loss on ignition (LOI). The percentage of each in the samples are presented in the tables below and compared with the standard specification.

TABLE 22: PERCENTAGE OF LIME (CaO)

SAMPLE	% CaO	Specification %
A	60.29	
B	55.24*	
C	60.01	60 - 67
D	62.11	
E	60.57	
F	60.29	

From the above table 22, it can be seen that only sample B fall short of the specified minimum lime content, with 55.24 percent. Sample D gives greater percentage of 62.11. However, even though the rest of the samples pass the minimium specification, the percentage is generally low.

TABLE 23: PERCENTAGE OF SILICON OXIDE (SiO_2)

Sample	% SiO_2	Specification %
A	19.17	
B	17.72	
C	20.60	17 - 25
D	20.65	
E	17.10	
F	20.31	

All the samples satisfy the requirement of 17 to 25 percent of silicon oxide. This is shown in table 23 above.

TABLE 24: ALUMINIUM OXIDE PERCENTAGE (AL_2O_3)

Sample	% AL_2O_3	Specification %
A	10.72	
B	12.61	
C	9.26	3 - 8
D	11.00	
E	11.35	
F	11.81	

All the samples have aluminium oxide percentage greater than the specified range of 3 to 8 percent. This is shown in table 24 above.

TABLE 25: IRON OXIDE PERCENTAGE (Fe_2O_3)

Sample	% Fe_2O_3	Specification %
A	0.68	
B	0.59	
C	0.44	0.5 - 6.0
D	0.81	
E	0.65	
F	0.49	

Table 25 shows the Iron oxide percentage of each sample.

From the above table (Table 25), samples C and F shows low values of iron oxide. While the rest satisfy the requirement of 0.5 to 6.0 percent.

TABLE 26: MAGNESSIUM OXIDE (Mgo) CONTENT

Table 26 below shows the magnessium oxide percentage content in the samples tested.

Sample	% Mgo	Specification %
A	0.24	
B	0.71	
C	0.28	0.1 - 4.0
D	0.77	
E	0.35	
F	0.15	

All the samples in the above table (table 26) satisfy the requirement with samples D and B giving the highest values of MgO.

TABLE 27: PERCENTAGE ALKALIS (Na_2O and K_2O)

Table 27 below shows the percentage of alkalis of the samples

Sample	ALKALIS		Specification %
	% Na_2	% K_2O	
A	0.018	0.064	
B	0.076	0.090	
C	0.008	0.124	0.2 - 1.3
D	0.008	0.030	
E	0.040	0.080	
F	0.042	0.135	

The percentage values for all the samples does not meet the required percentage. They are all low.

TABLE 28: SULPHUR OXIDE (SO_3) PERCENTAGE

Sample	% SO_3	Specification %
A	3.84	
B	3.40	
C	3.46	1 - 3
D	1.72	
E	5.04	
F	3.95	

From the above table (table 28) it can be seen that only sample D is within the specified limit, with 1.72 percent. All the rest are above the specified limit. Which is 1 to 3 percent.

TABLE 29: LOSS ON IGNITION (LOI) PERCENTAGE

The table below (table 29) shows the percentages of the loss on ignition of the samples

Sample	% L O I	Specification %
A	4.55	
B	5.50	
C	4.66	$\leq$ 4.0
D	1.60	
E	4.40	
F	2.79	

Samples D and E satisfy the requirement according to NIS 11: (1974), while the rest are above 4.0 percent.

TABLE 21 (reproduced), PERCENTAGE COMPOSITION OF CEMENTS

COMPOUND	A	B	C	D	E	F
C_3S	15.74	-5.12	14.96	15.87	24.99	-0.30
C_2S	43.15	54.72	47.84	47.30	30.23	58.52
C_3A	27.26	32.42	23.79	27.78	28.98	30.47
C_4AF	2.07	1.79	1.34	2.46	1.98	1.49
L.S.F	0.86	0.81	0.83	0.85	0.92	0.81

From table 21 reproduced above, tricalcium silicate (C_3S) content in samples B and F gives negative values, and generally is very low with the rest of the samples. The negative values in B and F may imply that the C_3S content is very negligible or non-existence, it should be noted that in sample B, the value of lime (CaO) is 55.24 percent which is below the specified minimum of 60 percent and this contributed much to the negative value of tricalcium silicate content, and the value for the loss on ignition is far above the specified value of less than or equal to 4 percent according to NIS, standard. The loss on ignition shows the extent of carbonation and hydration of free lime and free magnesia due to the exposure of cement to atmosphere. Although sample B gives the highest compressive strength for both mortar and concrete cubes, the low values of tricalcium silicate content and lime (CaO) indicate that it cannot endure exposure to

atmosphere for short time. The same thing applies to sample F. The samples for chemical test were kept for about 5 to 7 days under air-tight containers. This is because the test were carried out in the Nation Research Institute for Chemical Technology (NARICT) Zaria and one has to buy one or two chemicals from Kaduna as NARICT ran out of them. However, one feel that this does not affect the result as all the samples are under air-tight condition. It is important to note that the samples generally have low strength development as shown in the graph and could not meet the 28 day strength.

The two silicates - tri and di - calcium silicates which are the most hydration compounds, together form 70 to 80 percent of the constituents in the cement and contribute most to the physical strength development of concrete. Table 30 below show the values of combined percentage of tricalcium and dicalcium silicates for the various samples tested.

TABLE 30 COMBINED PERCENTAGE OF TRICALCIUM AND DICALCIUM SILICATES

Sample	$C_3S + C_2S$	Specification (%)
A	58.89	
B	49.60	
C	62.80	70 - 80
D	63.17	
E	55.22	
F	58.22	

The above table (table 30) show the values of C_3S and C_2S for the various sample tested. This show that non of the samples satisfy the minimum percentage of the constituents (70 percent), with sample B showing the least value.

When cement comes into contact with water, tricalcium silicate (C_3S) begins to hydrate rapidly, generating a considerable amount of heat and making a significant contribution to the development of the early strength, particularly during the first 14 days. In contrast dicalcium silicate (C_2S) contents, which hydrates slowly and is mainly responsible for the development in strength after about 7 days, may be active for a considerable period of time. It is generally believed that the cement rich in C_2S result in a greater resistance to chemical attack and a smaller drying shrinkage than do other Portland Cements. It can also be observed from table 21, that C_3S is lower than C_2S which should not be the case. Normally C_3S is greater than C_2S in cement. Thus C_3S hydrate early and the remaining C_3S and C_2S contents hydrate at later age resulting to low strength.

The hydration of tricalcium aluminate (C_3A) is extremely exothermic and takes place very quickly, producing little increase in strength after about 24 hours. Of the other four principal compounds tricalcium aluminate, (C_3A) is the least stable and cements containing more than 10 percent of this

compound produce concretes which are particularly susceptible to sulphate attack.

Tetracalcium aluminoferrite (C_4AF), is of less important than the other three compounds when considering the strength ofthe cement paste at one to three days, and possibly longer, but decreases with time at an advanced age.

The effects of the minor compounds on the strength of the cement paste have not been thoroughly investigated as these compounds were not thought to be of importance as far as strength is concerned. Potassium oxide (K_2O) is believed to replace one molecule of lime (CaO) in C_2S with a consequent rise in the C_3S content above that calculated. Tests on the influence of alkalis have shown that the increase in strength beyond the age of 28 days is strongly affected by the alkali content. The greater the amount of alkali present the lower the gain in strength. This has been confirmed by two statistical evaluations of strength of several hundred commercial cements. However, test of age beyond 28 days is not carried out in this thesis. As such one cannot conclude from this observation.

With reference to cements made by the dry process, which sometimes contain relatively large amounts of alkalis.

It may be noted that the use of pre-heaters in cement plants has led to an increase in the alkali content of

cement made from given raw materials. Limiting the alkali content too severely results in an increased energy consumption. A more efficient dust collection also increases the alkali content of the cement because the dust contains a large amount of alkalis; this may be as high as 15 percent, in which case the dust has to be removed. In this however, the alkali contents are very low and the above reason may not apply.

4.3.0 STRUCTURAL FAILURE AS A RESULT OF BAD CEMENT

The Nigerian cements, mostly ordinary portland cement, are use in everyday constructional purposes, to load bearing structures as beams, slabs, columns, shear walls and foundation footings. Today, there is every need to mandate the cement manufacturers to adhere strictly to specification as stated by the Nigerian industrial standard (NIS 11: 1974). This will help a lot in alleviating the occurence of unfortunate structural failures in the country. To mention but few examples: In Kebbi State, part of the House of Assembly structure collapse and investigation shows that the use of bad cement contributed a lot to the structural failure. The cement used was sample D according to this test.

Also in Jigawa State, the state judiciary building collapse as a result of the use of bad cement in which sample C was used.

Furthermore, the state's secretariat at Lokoja in Kogi State and Jalingo in Taraba State had some section of the reinforcement exposed as a result of the use of bad cement for concrete biscuits,

it crushed when mass concrete was casted, thus exposing the reinforcement to atmosphere. The reinforcements are liable to corrosion which is a very serious structural defect.

Structural failure is a contribution of many factors, one major factor is the use of bad cement, since cement is the major component in concrete production. Cement, binds the material together when mixed with water into compact whole on setting, it makes concrete hard and stone like. Samples A, B, and C with higher strengths at 28 days for mortar cubes test, can be use in such structures as beams, slabs, columns and foundation structures, while others (samples D, E and F), can best be use for plastering and other finishes where strength are not all that important.

CHAPTER FIVE

5.1.0 CONCLUSION AND RECOMMENDATION

5.1.1 CONCLUSIONS

Based on the experiment and the results obtained, the following conclusions are made;

1. The cement factories in Nigeria, uses about 95 percent of locally obtainable raw materials in cement production. Gypsum is the only imported raw material for cement production in most of the factories.

2. According to the infromations obtained from the cement factories, all the factories in Nigeria apparently have large deposits of pure limestone in their quarries. However, these pure lime differ in percentage purity.

3. Tests conducted on the cement samples collected from the various factories have shown that all the samples satisfy the setting time requirement for both initial and final setting time except sample E which could not meet the initial setting requirement.

4. All the cement samples from various factories tested for expansion are found to be sound.

All the samples are tested for compressive strength requirements using mortar cubes and concrete cubes. It was observed that:

5. All the samples for mortar cubes passed 3 and 7 days strength requirement except samples D and E.

6 All the samples tested for concrete cubes passed the 3 and 7 days strength.

7. All samples failed the 28 days strength for mortar cubes.

8. All the samples except sample B failed the 28 days strength requirement for concrete cubes.

9. The samples tested generally have low lime (CaO) contents.

10. They have high sulphur content (SO_3) which means more gypsum might have been added to the cement. There may be a danger of sulphur reacting with the basic medium to form sulphate.

11. The samples generally have low strength development as from 7 days.

12. Sample B has more minor compound contents, followed by samples D and C.

13. There are higher values of loss on ignition especially in samples A, B, C and E. This implies that the samples cannot endure exposure to atmosphere in a short time. Thus when a bag is more than one year on storage it may not meet the requirement for the strength.

14. The samples generally have low values of tricalcium silicates (C_3S) compared to dicalcium silicates (C_2S).

15. The sum of silicate content for all the samples are low (less than 70 percent).

5.1.2 RECOMMENDATIONS

From the work done, the following are recommended for further work.

1. There is a need for the Nigerian Industrial Organisation Standards (NIS) to constitute a committee that will be in charge of testing the quality of cement produce in the country periodically.

2. It is also desirable for the purchasers to have certificate of tests from the producers signed by Nigerian Industrial Standard Organisation. This is to guide against cement failure on site.

3. There is a need for the research institutes, Universities, Polytechnics to join hand with the Cement Manufacturers Association of Nigeria (CMAN) and the exploration division of the Federal Ministry of Science and Technology, to

search for ways of producing gypsum, or look for an alternative raw material to replace gypsum. This will make the local sourcing of raw materials for cement production 100 percent.

4. The Federal Government should ease the importation of spare parts or research into producing such locally.

5. The Federal Government should also establish more railway lines to connect the cement factories. So that all the cement factories will be linked by the network of rails and roads for easy transportation to all parts of the country.

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APPENDIX A1

TABLE 5: CHEMICAL REQUIREMENTS FOR PORTLAND CEMENT ACCORDING TO A.S.T.M. SPECIFICATION (150-63)

	TYPE I	TYPE II	TYPE III	TYPE IV	TYPE V
Silicon dioxide (SiO_2) Min, %	-	21.0	-	-	-
Aluminium Oxide (Al_2O_3), Max. %	-	6.0	-	-	a
Ferric Oxide (Fe_2O_3), Max.%	-	6.0	-	6.5	a
Magnesium Oxide (MgO) Max.%	5.0	5.0	5.0	0.50	4.0
Potassium Oxide ($CaSO_4$) in hydrate Portland Cement mortar at 24 $\pm$ $\frac{1}{4}$hr. espressed as SO_3, Max.g/lt.%	0.5	0.5	0.5	0.5	0.5
Loss on ignition, Max. %	3.0	3.0	3.0	2.3	3.0
In soluble residue, Max. %	0.75	0.75	0.75	0.75	0.75
Tricalcium Silicate ($3CaO, SiO_2$) Min. %	-	50.0	-	33.00	5.00
Dicalcium Silicate ($2CaO, SiO_2$) Min. %	-	-	-	40.00	-
Tricalcium Aluminate ($3CaO, Al_2O_3$), Max. %	-	8.0	15.0	7.0	5.0

Where:

a = The tricalcium aluminate shall not exceed 5%, and the tetracalcium Aluminoferrite ($4CaO.Al_2O_3$) plus twice the amount of tricalcium aluminate shall not exceed 20%.

APPENDIX A2

PHYSICAL REQUIREMENTS OF A.S.T.M SPECIFICATION FOR CEMENTS

	TYPE I	TYPE III	TYPE III	TYPE IV	TYPE V	TYPE IA	TYPE IIA	TYPE IIIA
Fineness, specific surface, Sq CM/gm (alternate methods) Turbidimeter test average value min.	1600	1600	-	1600	1600	1600	1600	-
Minimum value any sample	1500	1500	-	1500	1500	1500	1500	-
Air permeability test Average value, Min.	2800	2800	-	2800	2800	2800	2800	-
Min. value any sample	2600	2600	-	2600	2600	2600	2600	-
Soundness Autoclave expansion, max. percent	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Time of setting (alternate methods) Gillmore test initial set, minute not less than	60	60	60	60	60	60	60	60
Final set, hrs. not more than	10	10	10	10	10	10	10	10
Vicat test (method C191) set, minutes not less than	45	45	45	45	45	45	45	45
Air content of mortar, prepared and tested in accordance with method C185, max, percent by Vol.	12.0	12.0	12.0	12.0	12.0	19±3	19±3	19±3

Compressive Strength, Psi. The Compr
The compressive strength of mortar cubes, composed of 1 part cement and 2.75 parts graded standard sand, by weight, prepared and tested in accordance with method C 109, shall be equal to or higher than the values specified for the ages indicated below

A2 - Continues

	TYPE I	TYPE II	TYPE III	TYPE IV	TYPE V	TYPE IA	TYPE IIA	TYPE IIA
1 day in moist air	-	-	1700	-	-	-	-	1300
1 day in moist air, 2 days in water	1200	1000	3000	-	-	900	750	2500
1 day in moist air, 6 days in water	2100	1800	-	800	1500	1500	1400	-
1 day in moist air, 27 days in water	3500	3500	-	2000	3000	2800	2800	-
Tensile strength, Psi. The tensile strength of mortar briquets composed of 1 part cement and 3 parts standard sand, by weight, prepared and tested in accordance with method C190, shall be equal to or higher than the values specified for the ages indicated below								
1 day in moist air	-	-	275	-	-			
1 day in moist air, 2 days in water	150	125	375	-	-			
1 day in moist air, 6 days in water	275	250	-	175	250			
1 day in moist air, 27 days in water	350	325	-	300	325			
Heat of hydration, cal/gr. The heat of hydration of cement when tested according to C186 shall be not greater than indicated below. These requirements apply only when specifically requested in which case the strength requirements shall be 80 percent of the vvalues listed 7 days	7	70					70	
28 days		80					80	

APPENDIX A_3

IMPACT VALUE TEST OF COARSE AGGREGATES

Test for the impact value of the aggregates used was conducted and the following results obtained:-

Weight of Cylinder = 830g

Weight of Cylinder + Aggregate =

1st test = 1,200g, weight passing 2.40mm sieve = 96g

2nd test = 1,190g, weight passing 2.40mm sieve = 92g

3rd test = 1,200g, weight passing 2.40mm sieve = 96g

$\therefore$ Total weight of sample

1,200 - 830 = 370g

1,190 - 830 = 360g

$\therefore$ % Passing the 2.40mm sieve = $\frac{96}{370} \times 100$

= 25.9 = 26%

and 92/360 x 100 = 25.6 = 26%

The impact value of the coarse aggregate

= 26%

CRUSHING TEST OF COARSE AGGREGATES

Weight of Cylinder = 12560g

Weight of Cylinder + Aggregate = 16410g

Weight of fines passing 2.40mm sieve = 980g

$\therefore$ % = $\frac{980}{16410-12560} \times 100$ = 25.5

= 26%

APPENDIX A4

SIEVE ANALYSIS OF COARSE AND FINE AGGREGATES

The results of sieve analysis conducted on the coarse and fine aggregates are given in the appendix below.

(a) SIEVE ANALYSIS FOR COARSE AGGREGATES, TOTAL WEIGHT SIEVED =10,000g

B.S Sieve (MM)	Weight retained (g)	Percentage Retained (%)	Cummulative Percentage Passing (%)	Cummulative Percentage Retained (%)
19.05	800	8.00	92.00	8.00
12.70	7000	70.00	22.00	78.00
9.51	1,100	11.00	11.00	89.00
6.35	700	7.00	4.00	96.00
4.76	200	2.00	2.00	98.00
Passing 4.76	200	2.00	0.00	100.00
Total	10,000			

(b) SIEVE ANALYSIS FOR FINE AGGREGATES, TOTAL WEIGHT SIEVED = 3,000g.

B.S Sieve (MM)	Weight Retained	Percentage Retained (%)	Cummulative Percentage Passing (%)	Cummulative Percentage Retained (%)
1.20	956.00	31.87	68.13	31.87
600mm	934.00	31.13	37.00	63.00
300mm	700.00	23.33	13.67	86.33
212mm	130.00	4.33	9.34	90.66
150mm	90.00	3.33	6.34	93.66
75mm	58.00	1.93	4.41	95.59
Passing 75	60.00	2.00	2.41	97.59
Total	2,928.00			

APPENDIX A5

DESIGN CALCULATION

To determine the total quantity of materials of concrete, the specific gravity method of batching is employed, as follows:

$$\text{Absolute Volume} = \frac{\text{Unit Weight of Material}}{\text{Specific gravity of material}}$$

∴ Unit Weight of Materials

Cement = 1440 kg/m^3

Sand = 1600 kg/m^3

Gravel = 1500 kg/m^3

Water = 1000 kg/m^3

Specific Gravities

Cement = 3.15

Sand = 2.65

Gravel = 2.65

Water = 1.00

Mix Proportion = 1:2:4

Water/Cement ratio = 0.60

∴ $\text{Absolute Volume} = \frac{\text{Unit Weight}}{\text{Specific gravity}}$

Cement = $\frac{1440 \times 1}{3.15}$ = 457.14 lt.

Sand = $\frac{1600 \times 2}{2.65}$ = 1207.551t.

Gravel = $\frac{1500 \times 4}{2.65}$ = 2264.151t.

Water = $\frac{1440 \times 0.6}{1}$ = 864.001t.

Total = 4792.841t.

Convert to metres.

$$4792.84\text{lt} = \frac{4792.84}{1000} = 4.7928\text{4m}^3$$

$$\text{Amount of Material} = \frac{\text{Unit Weight}}{\text{Total absolute volume}}$$

$\therefore$

$$\text{Cement} = \frac{1440 \times 1}{4.79284} = 300.45\text{kg/m}^3$$

$$\text{Sand} = \frac{1600\text{xx } 2}{4.79284} = 667.67\text{kg/m}^3$$

$$\text{Gravel} = \frac{1500 \times 4}{4.79284} = 1251.88\text{kg/m}^3$$

$$\text{Water} = \frac{1440 \times 0.6}{4.79284} = 180.27\text{kg/m}^3$$

$$\text{Total} = 2400.27\text{kg/m}^3$$

Material Cement ratio

$$\text{Cement} = \frac{300.45}{300.45} = 1.00$$

$$\text{Sand} = \frac{667.67}{300.45} = 2.22$$

$$\text{Gravel} = \frac{1251.88}{300.45} = 4.17$$

$$\text{Water} = \frac{180.27}{300.45} = 0.60$$

$$\text{Total} = 7.99$$

$$\text{Volume of each cube} = (0.15\text{x}0.15\text{x}0.15)\text{m}^3$$

$$= \underline{\underline{0.003375\text{m}^3}}$$

Weight of 1 Cube = (0.003375 x 2400.27) Kg

= 8.1kg

Add 10% waste = $8.\frac{1}{1}$ x $\frac{110}{100}$ = 8.91kg

Quantity of Materials/Cube

Cement = $\frac{1}{7.99}$ x 8.91 = 1.12kg

Sand = $\frac{2.22}{7.99}$ x 8.91 = 2.48kg

Gravel = $\frac{4.17}{7.99}$ x 8.91 = 4.65kg

Water = $\frac{0.60}{7.99}$ x 8.91 = 0.67kg

Quantity of Materials for 12 Cubes

Cement = 1.12 x 12 = 13.44kg

Sand = 2.48 x 12 = 29.76kg

Gravel = 4.65 x 12 = 55.80kg

Water = 0.67 x 12 = 8.04kg

APPENDIX A6

(a) COMPACTING FACTOR TEST

The compacting factor test gives the nearest indecation of the degree of workability of a concrete mix. The degree of compaction, that is comfacting factor, is the ratio of the density of the same concrete when fully compacted.

The results obtained for each sample is calculated below:-

$$\text{Compacting factor} = \frac{\text{Weight of partially compacted concrete}}{\text{Weight of concrete to fill cylinder without voids.}}$$

(b) QUANTITY OF MATERIALS OF CONCRETE FOR CALCULATING THE COMPACTING FACTOR

COMPACTING FACTOR TEST RESULTS

Materials	Weight (kg)	Proportion by weight	Specific gravity	Proportion by weight specific gravity
Cement	13.44	1.00	3.15	0.32
Sand	29.76	2.22	2.65	0.84
Gravel	55.80	4.17	2.65	1.57
Water	8.04	0.60	1.00	0.60
Total		7.99		3.33

c) SAMPLE A

Water/Cement = 0.60

Volume of Cylinder = $5450cm^3$

Wt. of empty cylinder = 7.80kg

Wt. of partially compacted = 20.1kg - 7.80kg = 12.3kg

Wt. of fully compacted = 20.8kg - 7.80kg = 13.0kg

∴ Weight of concrete to fill cylinder without voids.

$$= \frac{7.99 \times 5450}{3.33} = 13076.73g$$

13.077kg

$$\text{Compacting factor} = \frac{12.3}{13.077} = \underline{0.941}$$

(d) SAMPLE B

Water/Cement = 0.60

Volume of Cylinder = $5450.00cm^3$

Wt. of Empty Cylinder = 7.80kg

Wt. of partially compacted = 18.77kg - 7.80kg

= 10.97kg

Wt. of fully compacted = 20.90 - 7.80 = 13.1kg

∴ Weight of concrete to fill cylinder without voids.

$$= \frac{7.99 \times 5450}{3.33} = 13076.73g \text{ or } \underline{13.077kg}$$

$$\text{Compacting factor} = \frac{10.97}{13.077} = \underline{0.840}$$

(e) SAMPLE C

Water/Cement = 0.60

Volume of Cylinder = $5450.00cm^3$

Wt. of Empty Cylinder = 7.80kg

Wt. of partially compacted = 19.78kg - 7.80kg

= 11.98kg.

Wt. of fully compacted = 20.90kg - 7.80kg

= 13.10kg

∴ Weight of concrete to fill cylinder without voids:

$$= \frac{7.99 \times 5450}{3.33} = 13076.73 = 13.077\text{kg}$$

$$\text{Compacting factor} = \frac{11.98}{13.077} = \underline{\underline{0.920}}$$

(f) SAMPLE D

Water/Cement = 0.60

Volume of Cylinder = 5450.00cm^3

Wt. of Empty Cylinder = 7.80kg

Wt. of partially compacted = 19.10kg - 7.80kg

= 11.30kg

Weight of fully compacted = 20.99kg - 7.80kg

= 13.19kg.

∴ Weight of concrete to fill cylinder without voids:

$$= \frac{7.99 \times 5450}{3.33} = 13076.73\text{kg or } 13.077\text{kg}$$

$$\text{Compacting factor} = \frac{11.30}{13.077} = 0.864$$

(g) SAMPLE E

Water/Cement = 0.60

Volume of Cylinder = 5450.00cm^3

Wt. of Empty Cylinder = 7.80kg

Wt. of partially compacted = 19.60kg - 7.80kg

= 11.80kg

Wt. of fully compacted = 21.15kg - 7.80kg

= 13.35kg.

∴ Weight of concrete to fill cylinder without voids:

$$= \frac{7.99 \times 5450}{3.33} = 13076.73g \text{ or } \underline{\underline{13.077kg}}$$

$$\text{Compacting factor} = \frac{11.80}{13.077} = \underline{\underline{0.902}}$$

(h) SAMPLE F

Water/Cement = 0.60

Volume of Cylinder = $5450.00cm^3$

Wt. of Empty Cylinder = 7.80kg

Wt. of partially compacted = 19.50kg - 7.80kg

= 11.70kg

Wt. of fully compacted = 21.00kg - 7.80kg

= 13.20kg

∴ Weight of concrete to fill cylinder without voids:

$$= \frac{7.99 \times 5450}{3.33} = 13076.73kg \text{ or } 13.077kg$$

= 13.077kg

$$\text{Compacting factor} = \frac{11.70}{13.077} = 0.895$$

APPENDIX A7

TABLE FOR NORMAL CONSISTENCY, INITTIAL AND FINAL SETTING TIMES

(a) SAMPLE A

Paste	1	2
Room Temperature, °C	25	25
Weight of Cement, g	500	500
Time, Start of Operation	10:08am	10:28am
Water - Cement ratio %	30	30
Penetration (mm)	6.0	6.5
Starting time (t_0)	10:08am	10:28am
Initial setting (t_1)	1:10pM	1:32PM
Initial setting time (t_1-t_0)	3hrs:02mins.	3hrs:04mins.
Mean time (t_m)	3hrs:03mins.	
Final Setting (t_2)	2:50PM	3:16PM
Final Setting time (t_2-t_0)	4hrs.47mins.	4hrs.48mins
Mean time (tm)	4hrs.48mins	
Initial Setting time for A	3hrs.03mins	
Final setting time for A	4hrs.48mins.	

(b) SAMPLE B

Paste	1	2
Room Temperature ^{o}C	25	25
Weight of Cement, g	500	500
Time, Start of Operation (t_0)	10:50am	11:17am
Water - Cement ratio %	30	30
Penetration (mm)	6.0	6.5
Initial Setting (t_1)	1:50PM	2:20PM
Initial Setting time (t_1-t_0)	3hrs.00mins	3hrs.03mins
Mean time (t_m)	3hrs.02mins.	
Final Setting (t_2)	3:40PM	4:10PM
Final Setting time (t_2-t_0)	4hrs.50mins	4hrs.53mins.
Mean time (t_m)	4hrs.52mins	
Initial Setting time for B	3hrs.02mins.	
Final setting time for B	4hrs.52mins.	

(c) SAMPLE C

Paste	1	2
Room Temperature, ^{o}C	26	26
Weight of Cement, g	500	500
Time, Start of Operation (t_0)	10:30am	10:50am
Water-Cement ratio (%)	30	30
Penetration (mm)	5.0	5.5
Initial Setting (t_1)	1:04PM	2:16PM
Initial Setting (t_1-t_0)	2hrs.34mins	2hrs.26mins.
Mean time (t_m)	2hrs.30mins.	
Final Setting (t_2)	2:08PM	2:26PM
Final Setting time (t_2-t_0)	3hrs.38mins.	3hrs.36mins.
Mean time (t_m)	3hrs.37mins.	
Initial Setting time	2hrs.30mins.	
Final Setting time	3hrs.37mins.	

(d) SAMPLE D

Paste	1	2
Room Temperature ^{o}C	30	30
Weight of Cement, g	500	500
Time, Start of Operation (t_0)	10:47am	11:06am
Water - Cement ratio (%)	30	30
Penetration (mm)	6.5	5.7
Initial Setting (t_1)	1:35PM	1:46PM
Initial Setting time (t_1-t_0)	2hrs.48mins	2hrs.40mins
Mean time (t_m)	2hrs.44mins.	
Final Setting (t_2)	2:37P.M.	3:08P.M.
Final Setting time (t_2-t_0)	3hrs.50mins	4hrs.02mins.
Mean time (t_m)	3hrs.56mins.	
Initial Setting time	2hrs.44mins.	
Final Setting time	3hrs.56mins.	

(e) SAMPLE E

Paste	1	2
Room Temperature ^{o}C	32	32
Weight of Cement, g	500	500
Time, Start of Operation (t_0)	11:51am	12:07P.M
Water - Cementratio (%)	38	38
Penetration (mm)	5.5	5.0
Initial Setting (t_1)	12:14P.M.	12:24P.M.
Initial Setting time (t_1-t_0)	23Mins.	17Mins.
Mean time (t_m)	20Mins.	
Final Setting (t_2)	2:42P.M.	3:12P.M.
Final Setting time (t_2-t_0)	2hrs.51mins.	3hrs.05mins.
Mean time (tm)	2hrs.58mins.	
Initial Setting time	20mins.	
Final Setting time	2hrs.58mins.	

(f) SAMPLE F

Paste	1	2
Room Temperature ^{o}C	29	29
Weight of Cement, g	500	500
Time, Start of Operation (t_0)	11:38am	12:01P.M.
Water - Cement ratio (%)	28	28
Penetration (mm)	5.0	5.0
Initial Setting (t_1)	1:08P.M	1:22P.M.
Initial Setting time (t_1-t_0)	1hr.30mins.	1hr.21mins.
Mean time (tm)	1hr.26mins.	
Final Setting (t_2)	2:02P.M.	2:10P.M.
Final Setting time (t_2-t_0)	2hrs.24mins.	2hrs.09mins.
Mean time (tm)	2hrs.17mins.	
Initial Setting time	1hr.26mins.	
Final Setting time	2hrs.17mins.	

APPENDIX A8

SOUNDNESS OF SAMPLES OF CEMENT

(a) SAMPLE A

Paste	1	2	3	4
Initial Measurement (mm)	18.50	22.00	17.50	24.00
Final Measurement (mm)	18.50	22.00	17.50	24.00
Expansion (mm)	00.00	00.00	00.00	00.00
Specification	≯ 10mm			

(b) SAMPLE B

Paste	1	2	3	4
Initial Measurement (mm)	21.00	23.50	26.00	21.00
Final Measurement (mm)	22.00	24.00	26.50	22.00
Expansion (mm)	00.10	0.50	0.50	1.00
Specification (mm)	≯ 10			

(c) SAMPLE C

Paste	1	2	3	4
Initial Measurement (mm)	33.00	13.00	21.50	24.00
Final Measurement (mm)	33.00	13.00	21.50	24.00
Expansion (mm)	00.00	00.00	00.00	00.00
Specification (mm)	≯ 10			

(d) SAMPLE D

Paste	1	2	3	4
Initial Measurement (mm)	17.00	21.00	19.00	17.00
Final Measurement (mm)	18.00	22.00	20.00	18.50
Expansion (mm)	1.00	1.00	1.00	0.70
Specification (mm)	≤ 10			

(e) SAMPLE E

Paste	1	2	3	4
Initial Measurement (mm)	20.00	21.00	17.00	18.00
Final Measurement (mm)	21.00	23.00	20.00	20.00
Expansion (mm)	1.00	2.00	3.00	2.00
Specification (mm)	≤ 10			

(f) SAMPLE F

Paste	1	2	3	4
Initial Measurement (mm)	22.50	21.50	20.50	18.50
Final Measurement (mm)	23.00	22.00	21.00	19.00
Expansion (mm)	0.50	0.50	0.50	0.50
Specification (mm)	≤ 10			

APPENDIX A9

(a) SAMPLE A

Compressive Strength Table for Mortar Cubes Room Temperature = 26°C

Ident n. Mark	Date of Cast	Size (mm)	Weight (g)	Date of test	Age (days)	Failure load (KN)	Strength (N/mm^2)	Mean Strength (N/mm^2)
A1	22/1/1991	70.6x70.6x70.6	681	25/1/1991	3	87.00	17.45	17.82
A2			678			87.00	17.45	
A3			715			91.00	18.56	
A4	"	"	670	29/1/1991	7	99.00	19.86	19.86
A5			682			95.00	18.66	
A6			708			105.00	21.07	
A7	"	"	714	5/2/1991	14	100.00	20.06	21.00
A8			710			104.00	20.87	
A9			705			110.00	22.07	
A10	"	"	689	12/2/1991	21	110.50	22.17	23.87
A11			690			126.50	25.38	
A12			706			120.00	24.07	
A13	"	"	706	21/2/1991	28	120.00	24.07	25.74
A14			713			130.00	26.08	
A15			714			135.00	27.08	

(b) SAMPLE B

Compressive Strength Table for Mortar Cubes (Room Temperature = $26^{o}C$)

Ident^{n}	Date of	Size (mm)	Weight (g)	Date of test	Age (days)	Failure load (KN)	Strength (N/mm^2)	Mean Strength (N/mm^2)
B1	23/1/1991	70.6x70.6x70.6	700	26/1/1991	3	88.00	17.66	18.13
B2			690			91.00	18.26	
B3			715			92.00	18.46	
B4	"	"	706	30/1/1991	7	120.00	24.08	23.21
B5			713			112.50	22.57	
B6			706			114.50	22.97	
B7	"	"	714	6/2/1991	14	118.50	23.77	23.31
B8			725			120.00	24.08	
B9			693			110.00	22.07	
B10	"	"	722	13/2/1991	21	120.00	24.08	25.22
B11			733			120.00	24.08	
B12			715			137.00	27.49	
B13	24/1/1991	"	692	21/2/1991	28	140.00	28.09	26.42
B14			699			130.00	26.08	
B15			711			125.00	25.08	

(c) SAMPLE C

Compressive Strength for Mortar Cubes (Room Temperature = 27°c

Ident^n. Mark	Date of test	Specimen Size (mm)	Weight (g)	Date of test	Age (days)	Failure load (KN)	Strength (N/mm^2)	Mean Strength (N/mm^2)
C1			687			75.50	15.15	
C2	29/1/1991	70.6x70.6x70.6	698	1/2/1991	3	80.50	16.15	16.15
C3			677			85.50	17.15	
C4			676			95.00	19.06	
C5	"	"	703	5/2/1991	7	110.00	22.07	20.26
C6			660			98.00	19.66	
C7			672			100.00	20.06	
C8	"	"	670	12/2/1991	14	110.00	22.07	21.40
C9			684			110.00	22.07	
C10			675			120.00	24.08	
C11	"	"	675	19/2/1991	21	120.00	24.08	24.41
C12			661			125.00	25.08	
C13			680			120.00	24.08	
C14	"	"	690	26/2/1991	28	125.00	25.08	25.08
C15			670			130.00	26.08	

(d) SAMPLE D

Compressive Strength Table for Mortar Cubes (Room Temperature = 28°C)

Ident^n. Mark	Date of Cast	Specimen size (mm)	Weight (g)	Date of test	Age (days)	Failure load (KN)	Strength (N/mm^2)	Mean Strength (N/mm^2)
D1			687			70.50	14.14	
D2	5/2/1991	70.6x70.6x70.6	680	8/2/1991	3	63.50	12.74	13.07
D3			697			61.50	12.34	
D4			708			96.00	19.26	
D5	"	"	718	12/2/1991	7	100.00	20.06	19.19
D6			695			91.00	18.26	
D7			680			97.00	19.46	
D8	"	"	687	19/2/1991	14	97.00	19.46	19.59
D9			678			99.00	19.86	
D10			706			98.00	19.66	
D11	"	"	710	26/2/1991	21	98.00	19.66	19.79
D12			698			100.00	20.06	
D13			700			113.00	22.67	
D14	"	"	695	5/3/1991	28	91.00	18.26	20.00
D15			706			95.00	19.06	

(e) SAMPLE E

Compressive Strength Table for Mortar Cubes (Room Temperature = 32°C)

Identⁿ. Mark	Date of Cast	Specimen Size (mm)	Weight (g)	Date of test	Age (days)	Failure load (KN)	Strength N/mm^2	Mean Strength (N/mm^2)
E1			714			63.00	12.64	
E2	5/3/1991	70.6x70.6x70.6	675	8/3/1991	3	55.00	11.03	11.70
E3			666			57.00	11.44	
E4			710			59.00	11.84	
E5	"	"	708	12/3/1991	7	68.00	11.64	12.11
E6			705			64.00	12.84	
E7			700			69.00	13.84	
E8	"	"	690	19/3/1991	14	70.50	15.14	13.91
E9			685			68.50	13.74	
E10			710			70.00	14.04	
E11	"	"	680	26/3/1991	21	71.00	14.24	15.51
E12			680			91.00	18.26	
E13			714			94.00	18.86	
E14	"	"	720	2/4/1991	28	72.00	14.45	16.12
E15			704			75.00	15.05	

(f) SAMPLE F

Compressive Strength Table for Mortar Cubes (Room Temperature = 32°C)

Ident^n. Mark	Date of Cast	Specimen Size (mm)	Weight (g)	Date of test	Age (days)	Failure load (KN)	Strength (N/mm^2)	Mean Strength (N/mm^2)
F1			730			82.00	16.45	
F2	6/3/1991	70.6x70.6x70.6	710	9/3/1991	3	84.00	16.85	16.45
F3			710			80.00	16.05	
F4			720			92.00	18.46	
F5	"	"	730	13/3/1991	7	93.00	18.66	18.79
F6			740			96.00	19.26	
F7			700			96.00	19.26	
F8	"	"	698	20/3/1991	14	108.00	21.67	20.46
F9			710			102.00	20.46	
F10			710			108.00	21.67	
F11	"	"	695	27/3/1991	21	100.00	20.06	21.94
F12			680			120.00	24.08	
F13			670			120.00	24.08	
F14	"	"	700	3/4/1991	28	105.00	21.07	22.41
F15			700			110.00	22.07	

APPENDIX A-10

(a) SAMPLE A

Compressive Strength Table for Concrete Cubes (Room Temperature = 32°C)

Ident. Mark	Date of test	Specimen Size (mm)	Weight (Kg)	Date of test	Age (days)	Failure load (KN)	Strength (N/mm^2)	Mean Strength (N/mm^2)
A1			7.60			380	16.89	
A2	15/2/1991	150x150x150	7.60	22/2/1991	7	420	18.67	17.48
A3			7.65			380	16.89	
A4			8.00			460	20.44	
A5	"	"	7.60	1/3/1991	14	420	18.67	20.15
A6			7.90			480	21.33	
A7			8.04			520	23.11	
A8	"	"	8.15	8/3/1991	21	490	21.78	22.70
A9			8.32			520	23.11	
A10			7.80			490	21.78	
A11	"	"	8.05	15/3/1991	28	520	23.11	22.70
A12			8.15			520	23.11	

(b) SAMPLE B

Compressive Strength Table for Concrete Cubes (Room Temperature = $32^{o}C$)

Ident. Mark	Date of test	Specimen Size (mm)	Weight (Kg)	Date of test	Age (days)	Failure (KN)	Strength ($N/_{mm}^2$)	Mean Strength ($N/_{mm}^2$)
B1			8.20			480	21.33	
B2	26/2/1991	150x150x150	8.10	5/3/1991	7	500	22.22	21.04
B3			8.05			440	19.56	
B4			8.60			540	24.00	
B5	"	"	8.05	12/3/1991	14	600	26.67	25.48
B6			8.04			580	25.78	
B7			8.00			680	30.22	
B8	"	"	8.03	19/3/1991	21	650	28.89	28.59
B9			8.10			600	26.67	
B10			7.84			660	29.33	
B11	"	"	8.05	26/3/1991	28	650	28.89	28.89
B12			8.40			640	28.44	

(c) SAMPLE C

Compressive Strength Table for Concrete Cubes (Room Temperature = 30°C)

Ident. Mark	Date of cast	Specimen Size (mm)	Weight (Kg)	Date of test	Age (days)	Failure load (KN)	Strength (N/mm^2)	Mean Strength (N/mm^2)
C1	26/2/1991	150x150x150	8.10	5/3/1991	7	340	15.11	15.26
C2			8.10			340	15.11	
C3			8.10			350	15.56	
C4	"	"	8.00	12/3/1991	14	400	17.78	18.22
C5			8.15			430	19.11	
C6			8.14			400	17.78	
C7	"	"	8.10	19/3/1991	21	480	21.33	20.30
C8			8.14			440	19.56	
C9			8.14			450	20.00	
C10	"	"	7.95	26/3/1991	28	500	22.22	22.22
C11			8.10			480	21.33	
C12			8.10			520	23.11	

(d) SAMPLE D

Compressive Strength Table for Concrete Cubes (Room Temperature = 30°C)

Ident. Mark	Date of cast	Specimen Size (mm)	Weight (Kg)	Date of test	Age (days)	Failure load (KN)	Strength (N/mm^2)	Mean Strength (N/mm^2)
D1	27/2/1991	150x150x150	8.10	6/3/1991	7	330	14.67	14.52
D2			8.00			330	14.67	
D3			8.00			320	14.22	
D4	"	"	8.10	13/3/1991	14	420	18.67	18.37
D5			8.15			390	17.33	
D6			8.06			430	19.11	
D7	"	"	8.20	20/3/1991	21	460	20.44	20.44
D8			8.20			460	20.44	
D9			8.10			460	20.44	
D10	"	"	8.14	27/3/1991	28	540	24.00	23.11
D11			8.18			540	24.00	
D12			8.32			480	21.33	

(e) SAMPLE E

Compressive Strength Table for Concrete Cubes (Room Temperature = 29°C)

Ident. Mark	Date of Cast	Specimen Size (mm)	Weight (Kg)	Date of test	Age (days)	Failure load (KN)	Strength (N/mm^2)	Mean Strength (N/mm^2)
E1	19/3/1991	150x150x150	8.05	26/3/1991	7	320	14.22	14.37
E2			7.98			320	14.22	
E3			7.80			330	14.67	
E4	"	"	8.05	2/4/1991	14	350	15.56	15.11
E5			7.90			350	15.56	
E6			8.00			320	14.22	
E7	"	"	8.40	9/4/1991	21	460	20.44	20.29
E8			8.05			460	20.44	
E9			8.20			450	20.00	
E10	"	"	8.04	16/4/1991	28	440	19.56	20.74
E11			8.00			490	21.78	
E12			8.05			470	20.89	

(f) SAMPLE F

Compressive Strength Table for Concrete Cubes (Room Temperature = 31°C

Ident. Mark	Date of Cast	Specimen Size (mm)	Weight (Kg)	Date of test	Age (days)	Failure load (KN)	Strength (N/mm^2)	Mean Strength (N/mm^2)
F1	3/4/1991	150x150x150	7.92	10/4/1991	7	420	18.67	19.85
F2			7.85			470	20.89	
F3			8.15			450	20.00	
F4	"	"	8.30	17/4/1991	14	460	20.44	22.07
F5			7.80			530	23.56	
F6			8.10			500	22.22	
F7	"	"	8.35	24/4/1991	21	560	24.89	24.89
F8			7.90			560	24.89	
F9			7.90			560	24.89	
F10	"	"	7.80	1/5/1991	28	560	24.89	25.93
F11			8.10			600	26.67	
F12			8.05			590	26.22	

APPENDIX A 11

Loss On Ignition at 900°C for 1 hour

	A	B	C	D	E	F
Weight of crucible + sample B.H (i)	20.6329	20.6304	20.6306	20.6318	20.6300	20.6300
Weight of crucible + sample A.H (ii)	20.5874	20.5754	20.5840	20.6159	20.5860	20.6021
Weight of crucible only (iii)	19.6329	19.6304	19.6306	19.6310	19.6300	19.6300
Wt. of crucible (iv) = (i) - (iii)	1.0000	1.0000	1.0000	1.0008	1.0000	1.0000
Loss on Ignition (v) = (i) - (ii)	0.0455	0.0550	0.0466	0.0159	0.0440	0.0279
% Loss on Ignition = $\frac{(v)}{(iv)}$ x 100	4.550%	5.500%	4.660%	1.590%	4.400%	2.7900%

Where:

B.H - Means Before Heating

A.H - Means After Heating.

SiO_2:

1gm sample less LOI, treated with 10ml HCL evaporated to dryness; dissolved with dil. HCl and filtered on W40 paper. Residue washed thoroughly with hot water, while filtrate was recieved in 250 ml. Flask paper and residue taken in a weighed pt. crucible and ashed at 900°C, for 1 hour.

	A	B	C	D	E	F
Weight of Crucible + Ash.	19.8214	19.8062	19.8353	19.8361	19.8004	19.8369
Weight of Crucible only	19.6297	19.6290	19.6293	19.6294	19.6294	19.6298
Weight of SiO_2 only	0.1917	0.1772	0.2060	0.2067	0.1710	0.2071
% SiO_2	19.17	17.72	20.60	20.65	17.10	20.71

Fe: in Cement Samples.

5ml. Stock solution oxidised with $KMnO_4$ + 2 ml. dil HCl + 2 ml. NH_4SCN and 100ml. absorbance taken at 480 nm.

	A	B	C	D	E	F
Absorbance	0.532	0.458	0.347	0.633	0.508	0.380
PPM	4.767	4.100	3.099	5.678	4.551	3.397
% Fe $\frac{PPM}{10^6} \times \frac{250}{5} \times \frac{100}{5} \times \frac{100}{1}$	0.4767	0.4100	0.3099	0.5678	0.4551	0.3397
$\therefore$ % Fe_2O_3 $= \frac{Fe_2O_3}{2Fe} \times$ % Fe $=$ % Fe x 1.43	0.68	0.59	0.44	0.81	0.65	0.49

Where PPM - means parts per million.

APPENDIX A_{14}

Alkalis:

2ml. Stock solution transfered into 50ml. volume flask and diluted to Mark.

Emmissions were measured on a flame photometer.

	A		B		C		D		E		F	
	Na	K	Na	K K	Na	K	Na	K	Na	K	Na	K
Emmission	2.0	8.5	9.0	12.0	1.0	16.5	1.0	4.0	0.5	10.5	5.0	17.5
PPM (BO	0.2	0.85	0.9	1.2	0.1	1.65	0.1	0.4	0.05	1.05	0.5	1.75
% $\frac{B}{10^6} \times \frac{250}{2} \times \frac{50}{2} \times \frac{100}{1}$ $= B \times \frac{0.25}{4}$	0.013	0.053	0.056	0.075	0.006	0.103	0.006	0.025	0.03	0.066	0.031	0.11
% as oxide: For Na, x 1.3479 $\frac{(Na_2O)}{2Na}$	0.018	0.064	0.076	0.090	0.008	0.124	0.008	0.030	0.040	0.080	0.042	0.135
For K, X												

APPENDIX: A_{15}

R_2O_3:

25ml. Stock solution + drops of bromine water, boiled + ≈ 2g NH_4CL + NH_4OH dropwise. PPt. filtered on W40 paper and washed with hot 1% NH_4CL solution.

	A	B	C	D	E	F
Weight of Crucible + ash	19.6402	16.7180	29.4554	30.4264	30.4259	16.7156
Weight of empty crucible	19.6293	16.7048	29.4457	30.4146	30.4139	16.7032
Weight of ash only	0.0114	0.0132	0.0097	0.0118	0.0120	0.0124
% R_2O_3 = ash x $\frac{250}{25}$ x $\frac{100}{1}$	11.40	13.20	9.70	11.80	12.00	12.40
% Fe_2O_3	0.68	0.59	0.44	0.81	0.65	0.49
% Al_2O_3 = R_2O_3 - Fe_2O_3	10.72	12.61	9.26	11.0	11.35	11.91

APPENDIX: A_{16}

CaO:

Filtrate from R_2O_3 determination acidified with dil. HCl + 10 ml. of 5 percent Amonium Oxalate, neutralized with dil. NH_4OH and digested for 30 minutes on hot plate. PPt filtered on whatman No 40 paper washed with warm water dissolved in 5ml. 1:1 H_2SO_4 and titrated with 0.1N $KMnO_4$ to a parmanent pink colour.

	A	B	C	D	E	F
Final burette reading	21.50	19.70	21.40	22.15	21.60	21.50
Initial burette reading	0.00	0.00	0.00	00.00	0.00	0.00
Volume of 0.1N $KMnO_4$ Consumed, (α)	21.50	19.70	21.40	22.15	21.60	21.50
Titrate: 1ml 0.1N $KMnO_4$ = 0.00280g CaO. % CaO = x $\frac{250}{25}$ x $\frac{100}{1}$ x titrate = x 2.804	60.29	55.24	60.01	62.11	60.57	60.29

APPENDIX: A_{17}

MgO:

Filtrate from Lime (CaO) determination + 10ml. of 5 percent 8 - hydroxyquinoline + 15ml. Ammonium hydroxide (NH_4OH stirred for 5 minutes and stood overnight. The PPt. was filtered on Whatman No. 40 paper and ashed at 900°C for 1 hour.

	A	B	C	D	E	F
Weight of Crucible + ash	16.7594	17.5149	16.7044	17.0507	17.7385	19.6315
Weight of Crucible only	16.7570	17.5078	16.7016	17.0430	17.7350	19.6302
Weight of ash only	0.0024	0.0071	0.0028	0.0077	0.0035	0.0015
% MgO = ash x $\frac{250}{25}$ x $\frac{100}{1}$	0.24	0.71	0.28	0.77	0.35	0.15

SO_3:

25ml. of the stock solution taken into a clean beaker, followed by the addition of 2ml. of 10 percent $BaCl_2$ solution and boiled on short plate for 3 - minutes which was later transferred to a water bath for an 1 hour. This was removed and filtered through whatman 40 and washed with hot H_{20} and ashed for an hour at 900°C.

	A	B	C	D	E	F
Weight of Crucible + ash	17.0552	16.7682	17.5187	16.7071	17.7500	19.6416
Weight of empty Crucible only	17.0440	16.7583	17.5086	16.7021	17.7353	19.6301
Weight of ash only	0.0112	0.0099	0.0101	0.0050	0.0147	0.0115
% SO_3 as BaSO4 = ash x 1000	11.20	9.9	10.1	5.0	14.7	11.5
$\%SO_3$ = BaSO4 x 0.3430	3.84	3.40	3.46	1.72	5.04	3.95