

**THE EFFECTS OF PULVERIZED BURNT BRICK ON SELECTED CEMENT BRANDS
IN NIGERIA**

BY

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DECLARATION

I declare that the work in the project thesis entitled, the effects of pulverized burnt brick on selected cement brands in Nigeria, has been performed by me in the department of building under the supervision of Prof. M.M.Garba and Dr.D.D. Dauda. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this project thesis was previously presented for another degree or diploma at any university.

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Signature

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CERTIFICATION

This thesis entitled “The effects of pulverized burnt brick on selected cement brands in Nigeria” by Umar Mohammed, met the regulation governing the award of the degree of Master of Science (M.sc. Construction Technology) of Ahmadu Bello University Zaria, and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

This research is an investigation into the effects of pulverized burnt brick on selected cement brands used in Nigeria. Pulverized burnt brick obtained from grinding Adamawa burnt brick was used, the burnt brick was established to have the highest pozzalanic activity by Sa'ad(2006). The PBB was reactive at w/c = 0.65, 10% replacement of cement by PBB and 1:6 mortar mix ratio. Test such as specific gravity, setting times, soundness test, oxide composition and compressive strength were conducted. PBB gave the lowest specific gravity of 2.68 while for OPC, cement B gave the highest specific gravity of 3.35 and cement A gave the lowest specific gravity of 3.16. The highest and lowest initial setting times for the blended cement pastes were 206 and 118 minutes for cement E and D which was 98.8% and 78% of the control cement pastes respectively. The highest and lowest final setting times for the blended cement pastes were 257 and 162 minutes for cement C and D which was 107% and 66.94% of the control cement pastes respectively. Control cement pastes did not undergo expansion except for cement A and D. The former and latter underwent expansion of 1mm and 0.5mm respectively while for the blended cement pastes all cement brands underwent expansion of 1mm each except cement C which did not undergo expansion. The brands of cement satisfied the oxide composition for cement as stated in ASTM C150 – 07. The highest and lowest composition of SiO₂ (A) was 13.2% and 6.3% for cement A and E while for CaO (A) was 82.63% and 71.66% for cement D and A respectively. The highest and lowest composition of Al₂O₃ (6% max) was 2.6% and 1% for cement A and D while for Fe₂O₃ (6% max) was 5.79% and 4.52% for cement E and C respectively. At the end of 90 days of curing, blended mortar cubes made with cement C gave the highest compressive strength of 5.03N/mm² with the PBB followed by cement E with 3.54N/mm². The former and latter compressive strengths were 106% and 145% of their control mortar cubes. The experiments indicate cement C to be suitable with the PBB.

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LIST OF SYMBOLS AND ABBREVIATIONS

(A)	-	Not Applicable
A/F	-	Aluminium/Iron Ratio
ASTM	-	American Standard for Testing Material
BS	-	British Standard
C ₃ A	-	Tricalcium Aluminate
C ₄ AF	-	Tetracalcium Aluminoferrite
C ₂ S	-	Dicalcium Silicates
C ₃ S	-	Tricalcium Silicates
C-S-H	-	Calcium Silicate Hydrate
K	-	Potassium
KN	-	Kilo Newton
Max	-	Maximum
Min	-	Minimum
Na	-	Sodium
NF	-	Not Formed
OPC	-	Ordinary Portland Cement
PBB	-	Pulverized Burnt Brick
PVC	-	Polyvinyl Chloride
µm	-	Micron Meter
W _s	-	Wet Strength
w/c	-	Water/Cement Ratio
XRD	-	X-ray Diffraction

LIST OF CEMENT

Cement A	-	Ashaka cement
Cement B	-	BUA cement
Cement C	-	Dangote cement
Cement D	-	Elephant cement
Cement E	-	Sokoto cement

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND STUDY

Nigeria is a developing country with annual increasing stock of buildings and infrastructure. The main material used for these indices of development is cement. Ordinary Portland Cement (OPC) is the basic material used for the construction of buildings and infrastructure universally (Salau, 2008). In the National Housing Policy of 1980 in Nigeria, housing problem in Nigeria was described as a “huge shortfall” with concomitant increase in backlog of housing supplies and substandard housing, suffering from overcrowding, lack of utilities and poor environmental conditions. The policy therefore has, as its objective, the provision of housing for all by the year 2000. In the 1987 report of the Nigerian Building and Road Research Institute (NBRRI, 1987), it was estimated that Nigeria would require over twenty (20) million new housing units to achieve the objective of housing for all by the year 2000. Kolawole and Efeovobokan (1990) put the figure at about fifteen (15) million; now the needed housing units had increased tremendously based on the increase in the population within 10 years by about 30%. The increasing demand of housing required, coupled with informal settlements constantly expanding, is underlined by the crucial necessity to research new methods of design and material technologies (UN-Habitat, 2008). Pozzolanic materials as defined by the American Society of Testing Materials (ASTM) specification C618 – 01 are materials that have siliceous or siliceous-aluminous contents which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. The reaction is called pozzolanic reaction and its characteristic feature is that it is initially slow with the result that heat of hydration and

strength development will be accordingly slow. The reaction involves the consumption of Ca(OH)_2 and not production of Ca(OH)_2 thus improving the durability of the cement paste by making the paste dense and impervious (Shetty, 2004). Natural pozzolanas are usually substances of volcanic origin or sedimentary rocks with suitable chemical and mineralogical composition (Lea, 2004). The natural pozzolanas have lost their popularity in view of the availability of more active artificial pozzolanas (Shetty, 2004). Artificial pozzolanas are either calcined clays or byproducts of various industrial and agricultural processes whereby calcination has occurred (Carr, 1995). Others from steel and coal production are pulverized fly ash, electric arc furnace slag, blast furnace slag, silica fume, and others (Anwar *et al*, 2000). There are various types of pozzolanas depending on their composition. Portland pozzolana is a blend of Portland cement and pure pozzolana such as volcanic ashes or rice-husk ash. Lime pozzolana is a blend of natural pozzolana with lime. Clay pozzolana is a blend of shale or clay with pure pozzolana (Adepegba, 1990). The only difference between Portland and Pozzolana cement is that Pozzolana cement takes about 60 to 90 days depending on composition, to attain the 28 days strength of Ordinary Portland Cement (Salau, 2008). Pozzolanic activity of some selected Pulverized Burnt Brick (PBB) in Nigeria have been studied by Sa'ad (2006), the study established varied activities of the PBB. Investigation into the possible use of PBB and OPC admixture for sandcrete block production was carried out by Bungwon (1996), the study established low cost saving with numerous advantages will be achieved when blended cements (OPC + 20% optimum replacement by PBB) is used to produce sandcrete blocks.

1.2 STATEMENT OF THE PROBLEM

Ordinary Portland cement reacts with water to produce monosulphoaluminate (Ettringite). Ettringite is formed when C_3A reacts with gypsum and Ca(OH) . Ettringite are long needle-like compounds which are not cementitious, this develops micro cracks in

hardened cement paste. Through this micro cracks deleterious compounds can penetrate and cause deterioration.

1.3 JUSTIFICATION FOR THE STUDY

The fundamental property of a pozzolana is its ability to chemically combine with lime (Carr, 1995). Lime is the by-product of OPC when it undergoes hydration in the presence of water and it is also an agent of deterioration in concrete. The pozzolana chemically reacts with lime and forms a binding agent, thus utilizing the agent of deterioration to form a cementitious material. The cementitious material makes the concrete denser and thus improves its strength. The reaction between the pozzolana and lime is affected by the type of pozzolana, w/c ratio, the temperature and the cement type (Balkema, 1992). The pozzolana, w/c ratio and the temperature has been established by Sa'ad (2006). PBB from Adamawa, 0.65 w/c ratio and the experiment was carried out at room temperature. Due to the variation of mineral composition of raw materials used to produce OPC and the geographical location of these materials, there is need to investigate the effect of pozzolana on the brands of cement in Nigeria. Identifying the cement that gives the highest strength with the pozzolana will provide means to produce a more durable concrete that will resist deterioration in hostile and non hostile environment.

1.4 AIM AND OBJECTIVES

1.4.1 Aim

The aim of this research is to determine the effects of pulverized burnt brick on mortar cubes made from the brands of cement used in Nigeria with a view to establishing the cement that gives the highest compressive strength with the PBB.

1.4.2 Objectives

- I. To assess the effects of PBB on the properties of the cement such as setting time and soundness.
- II. To determine the oxide composition of the PBB and the brands of cement.
- III. To determine the property of mortars made with the PBB and the selected cement brands such properties as density and compressive strength.
- IV. To identify the cement brand that gives the highest compressive strength with the PBB compared with the control cubes.

1.5 METHODOLOGY

The method adopted for this research is summarized under the following headings

Literature Review

This research was carried out through the review of unpublished research by Sa'ad (2006) and relevant literature in publications, journals unpublished research and other related data.

Experiment

The experiment was carried out in three stages:

In the first stage all relevant materials such as burnt brick from Adamawa, five brands of cement, water and sharp sand were made available in the building department laboratory.

The burnt brick from Adamawa was manually grounded using pestle and mortar and sieved using 75 μ m sieve (No 200) to obtain pulverized burnt brick. The burnt brick was sourced from Adamawa burnt brick factory located at Mubi L.G; cement was purchased from cement dealers in Zaria, Kano and Kaduna. Water and sharp sand were obtained from the department of building laboratory.

In the second stage preliminary tests such as specific gravity of PBB and brands of cement were carried out. Water absorption test of the sharp sand was carried out. Bulk

densities of the individual constituents of mortar (brands of cement, sharp sand and PBB) were carried out. The mix for mortar was carried out using 1:6 ratio and 0.65 w/c ratio as established by the research carried out by Sa'ad (2006), absolute volume of the individual constituents for mortar were calculated (See appendix B).

In the third stage the individual materials for mortar were mixed and cast according to the mortar mix in the second stage. OPC replacement level of 0% and 10% was used for each cement brand, three(3) mortar cubes was cast into (70 × 70 × 70) mm mould for every OPC replacement level; a total number of 210 cubes were cast and cured in water in a curing tank.

The following tests were carried out

- i. Specific gravity test of PBB and brands of cement.
- ii. Setting time tests on the PBB and OPC mixtures. The vicat apparatus was used.
- iii. Soundness tests on the PBB and OPC mixtures. Le Chatelier's apparatus was used.
- iv. Particle size distribution of the sharp sand. BS test sieve was used.
- v. Compressive strength of mortar cubes (control and blended cubes). The manual compressive strength machine was used.
- vi. Oxide composition of the PBB and the brands of cement. The Mini Pal PW 4030 X-ray spectrometer was used.

1.6 SCOPE AND LIMITATION

1.6.1 Scope

The research was confined to the use of Pulverized burnt brick from Adamawa and five brands of cement consumed in Nigeria.

1.6.2 Limitation

Only five (5) brands of cement were used, four indigenous cement and one foreign cement was used. Pulverized burnt brick from Adamawa was used. The research will be carried out at room temperature with w/c of 0.65; OPC replacement level of 0% and 10% was used. Ratio of 1:6 was used for mortar mix. Compressive strength test was carried out on the 3rd, 7th, 14th, 21st, 28th, 56th and 90th day only.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Pozzolana

American Society of Testing Materials (ASTM) specification C618 – 01 are materials that have siliceous or siliceous-aluminous contents which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties.

2.2 Types of Pozzolana

Pozzolanic materials can be divided into two groups: natural pozzolana and artificial pozzolana.

2.2.1 Natural Pozzolana

Natural pozzolans such as diatomaceous earth, clay and shale, pumicites, opaline cherts etc. needs further grinding and sometimes needs calcining to activate them so show pozzolanic activities. The natural pozzolans have lost their popularity in view of the availability of more active artificial pozzolans (Shetty, 2004).

- i. Clay and shale
- ii. Opaline Cherts
- iii. Diatomaceous Earth
- iv. Volcanic Tuffs and Pumicites.

ENV 197-1' “states that 'natural pozzolanas are usually substances of volcanic origin or sedimentary rocks with suitable chemical and mineralogical composition.' Natural pozzolanas” of volcanic origin occur in the vicinity of Naples and of Rome and also as the Santorin Earth from the Grecian island of Santorin. There are also vitreous rhyolites

from the Rocky Mountains in the USA and from the Bombay area of India. Another source of these materials is the German trasses. The pozzolanic activity is dependent upon their physical form and the amounts of glass and zeolites present. If they contain significant amounts of relatively unreactive clay minerals, this can appreciably lower their activity. “Chemical analyses of these types of materials are given in Table 2.1. In addition to the above materials of volcanic origin, there are diatomaceous earths, which are derived from waterborne deposits. These materials have a high water demand which does not make them attractive for use with cements. It has been shown to be possible to lower this with the use of a super-plasticizer” (Lea, 2004).

Table 2.1 Typical chemical analyses of natural pozzolana (%)

	Range	Chilean Pudahuell
Silica	50 – 75	68.9
Alumina	10 – 20	13.4
Ferric Oxide	3 – 9	1.9
Lime	2 – 9	2.0
Magnesia	1 – 6	0.6
Sodium Oxide (Na ₂ O)	1 – 3	3.4
Potassium Oxide (K ₂ O)	2 – 7	3.7

(Source: Lea, 2004)

2.2.2 Artificial Pozzolanas (Industrial Pozzolanas)

ENV 197-1 states that: “Industrial pozzolanas are thermally treated and activated clays and shales, air cooled slags from lead, copper, zinc and other products from the ferroalloys industry. Industrial pozzolanas shall not increase the water demand of the

cement appreciably, impair the resistance of the concrete or mortar to deterioration in any way or reduce the corrosion protection of the reinforcement. These include a wide range of materials from heat-treated clays and shales to ashes derived from burning rice husks as well as slags from various non-ferrous metal-processing industries. In common with natural pozzolanas, it is desirable that they should contain reactive silica and some glass. Some such as rice husks significantly increase the water demand. The non-ferrous slags are derived from copper, nickel, lead and zinc processing and, unlike the slags from iron manufacture, have very much lower lime contents. Silica is normally present in the range (20 – 40) %. However, the significance of the residual metal contents (up to 1.3% CuO and 3.9% ZnO in copper slags, up to 1.2 % nickel in nickel slags and as high as 4.8 % lead with 10-18 % zinc in lead slags needs careful consideration, both from the possible effect on cement hydration and also in connection with possible leaching from any products made from the cement in question - particularly when it has carbonated and the PH is lowered (Lea, 2004).

2.3 Properties of Pozzolana

After the development of natural cement during the latter part of the 18th century, the Portland cement in the early 19th century, the practice of using pozzolanas declined, but in more recent times, Pozzolanas have been extensively used in Europe, USA and Japan, as an ingredient of Portland cement concrete particularly for marine and hydraulic structures. It has been amply demonstrated that the best pozzolanas in optimum proportions mixed with Portland cement improves many qualities of concrete such as:

- i. Lower the heat of hydration and thermal shrinkage;
- ii. Increase the water tightness;
- iii. Reduce the alkali-aggregate reaction;
- iv. Improve resistance to attack by sulphate soils and sea water;

- v. Improve extensibility;
- vi. Lower susceptibility to dissolution and leaching;
- vii. Improve workability;
- viii. Lower costs.

In addition to these advantages, contrary to the general opinion, good pozzolanas will not unduly increase water requirement or drying shrinkage (Shetty, 2004).

2.3.1 Pozzolanic Reaction

The term 'pozzolanic activity' covers all reactions occurring among the active constituents of pozzolanas, lime and water. The definition, although approximate, is however acceptable from a technical and practical viewpoint. Notwithstanding the difficulty in following the evolution of pozzolanas active phases throughout the hydration process, the progress of pozzolanic reaction is commonly evaluated in terms of diminution of the free lime in the system or increase in the silica + alumina soluble in acid (Lea, 2004).

Factors Influencing Pozzolanic Reaction

Factors influencing the pozzolanic reaction of PBB are cement type, the temperature, the water/cement ratio and the type of pozzolana. Cement such as rapid hardening Portland cements (RHPC), develop a higher alkalinity faster than ordinary Portland cements (OPC). Consequently the pozzolanic reaction starts earlier (Balkema, 1992).

2.4 Pozzolana and Pozzolanic Cement

Pozzolana has two distinct meanings. The first one indicates the pyroclastic rocks, essentially glassy and sometimes zeolitised, which occur either in the neighborhood of Pozzuoli (the ancient Puteoli of the Roman times) or around Rome. The second meaning includes all those inorganic materials, either natural or artificial, which harden in water when mixed with calcium hydroxide (lime) or with materials that can release calcium

hydroxide (Portland cement clinker). The term 'pozzolana' will be referring to the latter meaning, definitely wider than the former, and will therefore embrace a large number of very different materials in terms of origin, composition and structure. Pozzolanic cements are by definition mixes of Portland cement and pozzolana which, if dispersed in excess water and kept under certain conditions, eventually give rise to unsaturated calcium hydroxide solutions (Lea, 2004).

2.4.1 Properties of Pozzolana and Pozzolanic Cement

When mixed with Portland cement and water, pozzolana reacts with the calcium hydroxide formed during hydration of the calcium silicates in the clinker. As a result of this reaction, the final portlandite content in the hydration products is always lower than that found in the control Portland cement. This applies to all pozzolanas, both natural and artificial, as well as to suspensions, pastes, mortars and concretes. The simultaneous presence of Portland cement and pozzolana modifies the respective reactions of hydration. This mutual influence needs to be thoroughly investigated in order to determine the conditions which allow the best technical performance to be obtained. Pozzolanic cements are by definition mixes of Portland cement and pozzolana which, if dispersed in excess water and kept under certain conditions, eventually give rise to unsaturated calcium hydroxide solutions. Conversely, pozzolana cements do not comply with this requirement in as much as their pozzolana content is insufficient - in terms of both quality and quantity - to combine all the portlandite which forms during the hydration of the clinker calcium silicates and to give unsaturated lime solution. As a consequence, whilst hardened pozzolanic cements lack, at least theoretically, free lime, pozzolana cements do not. The residual portlandite content depends on the activity of pozzolana, the amount of lime released by the clinker, as well as the pozzolana/cement ratio. Pozzolana can be added to Portland cement either at the cement plant or at the

building site. In the first case, pozzolana undergoes either simultaneous grinding with clinker and gypsum or separate grinding followed by mixing and homogenization (Lea, 2004).

2.5 Ordinary Portland Cement

ENV 197-1 states that Cement is a hydraulic binder, i.e. a finely ground inorganic material which, when mixed with water, forms a paste which sets and hardens by means of hydration reactions and processes and which, after hardening, retains its strength and stability even under water. Normal Portland cement is a synthetic mixture of calcium silicates formed in a molten matrix from a suitably proportioned and homogeneously prepared mixture of calcareous and argillaceous components. The calcination period, the reaction temperature and the residence time in the burning zone of the rotary kiln should be such as to minimize the uncombined lime and maximize the calcium silicates in the product which, through its basic proportioning, will yield a suitable ratio of 3CaOSiO_2 to 2CaOSiO_2 . The product, when ground to an optimum particle size distribution can then hydrate under certain conditions to agree with commercial requirements within the relevant national standard specifications (e.g. BS 12: 1991). Normal Portland cement (unlike earlier proto- or meso-Portland cement) will contain controlled amount of interground calcium sulfate as a setting retarder. ASTM C 219 - 01 defines Portland cement as hydraulic cement produced by pulverizing portland-cement clinker, and usually containing calcium sulfate (Lea, 2004).

2.6 Properties of Ordinary Portland Cement

The properties of various types of Portland cement differ because of relative proportions of the four compounds and the fineness to which the cement clinker is ground. The ordinary Portland cement or the setting cement is the basic Portland cement and is

manufactured in larger quantities than all the others. It is admirably suited for use in general concrete construction where there is no exposure to sulphates in the soil or in ground water (Punmia, 1990).

2.6.1 Strength

The strength of a hardened cement paste is defined as the maximum on the stress-strain curve determined by exposing a test specimen to an external, gradually increasing strain. Depending on the direction of the applied stress, one has to distinguish between compressive, tensile, flexural or torsional strengths. Other parameters which may be determined from the strain-stress curve are the 'modulus of elasticity', defined as the ratio stress/strain, and 'work of fracture' given by the area under the stress-strain curve. The 'strength of cement' is defined as the strength of mortar test specimens prepared, cured and tested according to a national or international testing standard, to eliminate the effect of factors other than cement quality on the obtained value. It is obvious that particular cement may yield different 'strength' values if tested according to different testing standards. The strength of a hardened cement paste is due to the presence of a continuous three-dimensional network of hydrate phases which can resist external stresses without being broken down. Of the three components of the hardened paste, i.e. hydrated material, non-hydrated residual cement and pores, the first is the constituent which is mainly responsible for the attained strength. The non-hydrated material present acts as filler and also exhibits the capacity to resist external stresses. However, at a constant porosity of the paste the strength increases with an increasing amount of hydrates being formed and a declining amount of non-hydrated material. The pores of the paste have an adverse effect on strength and above certain porosity the strength drops to zero (Shetty, 2004).

Compressive Strength

The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concrete is employed primarily to resist compressive stresses. In those cases where strength in tension or in shear is of primary importance, the compressive strength is frequently used as a measure of these properties. Therefore the concrete making properties of various ingredients of mix are usually measured in terms of the compressive strength. Compressive strength is also used as a qualitative measure for other properties of hardened concrete. No exact quantitative relationship between compressive strength and flexural strength, tensile strength, modulus of elasticity, wear resistance, fire resistance, or permeability have been established nor are they likely to be. However, approximate or statistical relationships, in some cases, have been established and these give much useful information to engineers. It should be emphasized that compressive strength gives only an approximate value of these properties and that other tests specifically designed to determine these properties should be useful if more precise results are required. For instance, the indicated compressive strength increases as the specimen size decreases, whereas the modulus of elasticity decreases. The modulus of elasticity in this case does not follow the compressive strength. The other case where the compressive strength does not indicate the useful property of concrete is when the concrete is subjected to freezing and thawing. Concrete containing about 6 percent of entrained air which is relatively weaker in strength is found to be more durable than dense and strong concrete. The compressive strength of concrete is generally determined by testing cubes or cylinders made in laboratory or field or core drilled from hardened concrete at site or from the non-destructive testing of the specimen or actual structure (Shetty, 2004).

Tensile Strength

Tensile strength is the maximum load that a material can support without [fracture](#) when being stretched, divided by the original cross-sectional area of the material. Tensile strengths have dimensions of [force](#) per unit area and in the English system of measurement are commonly expressed in units of pounds per square inch, often abbreviated to psi (Encyclopedia Britannica).

2.6.2 Heat of Hydration

The reaction of cement with water is exothermic. The reaction liberates a considerable quantity of heat. This liberation of heat is called heat of hydration. This is clearly seen if freshly mixed cement is put in a vacuum flask and the temperature of the mass is read at intervals. The study and control of the heat of hydration becomes important in the construction of concrete dams and other mass concrete constructions. It has been observed that the temperature in the interior of large mass at the time of placing are found to persist for a prolonged period (Shetty, 2004).

2.6.3 Setting Time

An arbitrary division has been made for the setting time of cement as initial setting time and final setting time. It is difficult to draw a rigid line between these two arbitrary divisions. For convenience, initial setting time is regarded as the time elapsed between the moments that the water is added to the cement, to the time that the paste starts losing its plasticity. The final setting time is the time elapsed between the moment the water is added to the cement, and the time when the paste has completely lost its plasticity and has attained sufficient firmness to resist certain definite pressure (Shetty, 2004).

2.6.4 Soundness

It is very important that the cement after setting shall not undergo any appreciable change of volume. Certain cements have been found to undergo a large expansion after setting causing disruption of the set and hardened mass. This will cause serious difficulties for the durability of structures when such cement is used. The testing of soundness of cement, to ensure that the cement does not show any appreciable subsequent expansion is of prime importance. The unsoundness in cement is due to the presence of excess of lime than that could be combined with acidic oxide at the kiln. This is also due to inadequate burning or insufficiency in fineness of grinding or thorough mixing of raw materials. It is also likely that too high a proportion of magnesium content or calcium sulphate content may cause unsoundness in cement. For this reason the magnesia content allowed in cement is limited to 6 percent. It can be recalled that, to prevent flash set, calcium sulphate is added to the clinker while grinding. The quantity of gypsum added will vary from 3 to 5 percent depending upon C_3A content. If the addition of gypsum is more than that could be combined with C_3A , excess of gypsum will remain in the cement in free state. This excess of gypsum leads to an expansion and consequent disruption of the set cement paste (Shetty, 2004).

2.6.5 Chemical Composition

The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form more complex compounds. The relative proportions of these oxide compositions are responsible for influencing the various properties of cement; in addition into rate of cooling and fineness of grinding (Shetty, 2004).

Composition of Portland Cement

The principal raw materials used in the manufacture of cement are:

- (a) Argillaceous or silicates of alumina in the form of clays and shales.
- (b) Calcareous or calcium carbonate, in the form of limestone, chalk and marl which is a mixture of clay and calcium carbonate.

The ingredients are mixed in the proportion of about two parts of calcareous material to one part of argillaceous material and then crushed and ground in ball mills in a dry state or mixed in a wet state. The dry powder or the wet slurry is then burnt in a rotary kiln at a temperature between 1400° and 1500°C. The clinker obtained from the kiln is first cooled and then passed on to ball mills where gypsum is added and it is ground to the requisite fineness according to the class of product (Punmia, 1990).

Table 2.2 The Chemical Constituents of Portland Cement

Constituents of Cement	Percentage
Lime (CaO)	(60 - 67) %
Silica (SiO ₂)	(17 - 25) %
Alumina (Al ₂ O ₃)	(3 - 8) %
Iron Oxide (Fe ₂ O ₃)	(0.5 - 6) %
Magnesia (MgO)	(0.1 - 4) %
Sulphur Trioxide (SO ₃)	(1 - 3) %
Soda and/or Potash (Na ₂ O + K ₂ O)	(0.5 - 1.3) %

(Source: Punmia, 1990)

R.H. Bogue's Compounds

The oxides present in the raw materials when subjected to high clinkering temperature combine with each other to form complex compounds. The identification of the major compounds is largely based on R.H. Bogue's work and hence it is called Bogue's Compounds. The four compounds usually regarded as major compounds are listed in table 2.3 (Shetty, 2004). It is to be noted that for simplicity's sake abbreviated notations are used. C stands for CaO, S stands for SiO₂, Al for Al₂O₃, F stands for Fe₂O₃ and H for H₂O (Shetty, 2004). When the ratio of percentages of aluminum oxide to ferric oxide (A/F) is 0.64 or more, the percentages of tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite shall be calculated from the chemical analysis as follows:

$$\text{Tricalcium Silicate} = (4.071 \times \% \text{ CaO}) - (7.600 \times \% \text{ SiO}_2) - (6.718 \times \% \text{ Al}_2\text{O}_3) - (1.430 \times \% \text{ Fe}_2\text{O}_3) - (2.852 \times \% \text{ SO}_3)$$

$$\text{Dicalcium Silicate} = (2.867 \times \% \text{ SiO}_2) - (0.7544 \times \% \text{ C}_3\text{S})$$

$$\text{Tricalcium Aluminate} = (2.650 \times \% \text{ Al}_2\text{O}_3) - (1.692 \times \% \text{ Fe}_2\text{O}_3)$$

$$\text{Tetracalcium Aluminoferrite} = 3.043 \times \% \text{ Fe}_2\text{O}_3$$

When the alumina-ferric oxide ratio (A/F) is less than 0.64, a calcium aluminoferrite solid solution (expressed as (C₄AF + C₂F)) is formed. Contents of this solid solution and of tricalcium silicate shall be calculated by the following formulas:

$$(\text{C}_4\text{AF} + \text{C}_2\text{F}) = (2.100 \times \% \text{ Al}_2\text{O}_3) + (1.702 \times \% \text{ Fe}_2\text{O}_3)$$

$$\text{Tricalcium silicate} = (4.071 \times \% \text{ CaO}) - (7.600 \times \% \text{ SiO}_2) - (4.479 \times \% \text{ Al}_2\text{O}_3) - (2.859 \times \% \text{ Fe}_2\text{O}_3) - (2.852 \times \% \text{ SO}_3).$$

No tricalcium aluminate will be present in cements of this composition. Dicalcium silicate shall be calculated as previously shown (ASTM C 150).

Table 2.3 Bogue's Compounds

Name of compound	Formula	Abbreviated Formula
Tricalcium Silicate	$3\text{CaO} \cdot \text{SiO}_2$	C_3S
Dicalcium Silicate	$2\text{CaO} \cdot \text{SiO}_2$	C_2S
Tricalcium Aluminate	$3\text{CaO} \cdot \text{Al}_2\text{O}_3$	C_3A
Tetracalcium Aluminoferrite	$4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$	C_4AF

(Source: Shetty, 2004)

Modification of the Bogue's Compound

The Bogue equations are most often cited for their shortcomings rather than their usefulness, but their contribution to cement chemistry and especially raw mix design are invaluable. The Bogue equations provide a simple and convenient method to find out the final composition of a clinker, which tells us a lot about its likely behavior. Technically, they indicate the potential composition since not all of the reactions that occur in the kiln will go to completion and since the cement phases are not ideal compounds. Plant chemists have used these equations for years, sometimes adjusting them based on their own raw materials and their own experience. An oxide analysis of the raw materials is the first step, which provides input for a wide variety of ratios and moduli that relate oxide compositions to one another. These include lime saturation factor (LSF), silica modulus or ratio (SM), alumina-to-iron ratio (A/F) and other lesser-used formulas like the hydraulic modulus. The basic principle behind raw mix design is the calculation of raw mix proportions from an oxide analysis and one of the pioneers that put Bogue back in vogue was Clyde Moore. Moore selected what he considered were the three most critical control parameters:

- i. Silica ratio
- ii. Alumina-iron ratio
- iii. Lime factor

The silica ratio represents the burnability of a raw mix. The burnability impacts how much energy is put into the system. As the ratio of silica to alumina plus iron increases, it becomes harder to “burn” — harder to combine the raw materials into the phases. As the ratio decreases, the tendency for fluxing (the ability of the solid materials to become liquid) increases, and the combining reactions become easier. Another consideration is that silica present as quartz is generally more difficult to combine than silica present as silicates. The alumina-to-iron ratio is important because it controls the potential C_3A/C_4AF ratio in the finished cement, which is important because of sulfate resistance, heat generation, and admixture compatibility issues. The lime saturation factor controls the potential C_3S to C_2S ratio in the finished cement. C_3S governs the early age strength development while C_2S governs the later age strength.

Moore’s Method

Moore discovered that Kind’s formula (which defines a modulus based upon the lime, alumina, iron, and silica amounts) can be further refined into what he defined as the lime factor. The importance of the lime factor is that it includes all four of the ingredients necessary for clinker production. Moore went a step further. He used this new lime factor along with the silica ratio and alumina-iron ratio to come up with a simple resource for raw mix design. By substituting the three moduli (lime factor, silica ratio, and alumina-iron ratio) into the Bogue equations and performing some basic algebra, Moore was able to define the four clinker phases by specifying just three control parameters. Moore’s method lies in recognizing that most plants obtain their raw materials from just one

source. Even if there is some variation, any difference can be distributed proportionally among the four clinker phases. The advantages to Moore's method are impressive:

- i. The four clinker phases (C_3S , C_2S , C_3A and C_4AF) are defined by just three parameters.
- ii. Equations can be derived directly for each of the phase compositions in terms of the control parameters.
- iii. The ratios of oxides can be used either on a clinker basis or on a raw-feed basis since the ratios are independent of loss on ignition.
- iv. There's no need to think in terms of potential clinker phases in the kiln feed where the clinker phases do not yet even exist.
- v. The relative error in the lime factor is less than the relative error calculated in C_3S content from the oxide analysis.
- vi. There's an easy check on the "real" lime factor through the use of XRD.

Moore developed a variety of examples to illustrate his method, including the design of a raw mix when three materials are available by using two parameters, such as the lime factor and silica ratio. Today's manufacturing environment uses rapid, in-stream sampling and analysis coupled with computerized proportioning to make almost continuous process improvements. It is a far cry from the matrix methods that helped Moore develop his quantitative relations between chemical control parameters and clinker phases. Moore's method may indeed seem simplistic. But the real benefit is that Moore's method makes raw mix design intuitively obvious for the new process engineer or plant chemist. It's a great teaching tool because it incorporates the basics.

$$\text{Silica ratio (SR or SM)} = \text{SiO}_2 / (\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3)$$

$$\text{Alumina-iron ratio (AR)} = \text{Al}_2\text{O}_3 / \text{Fe}_2\text{O}_3$$

$$\text{Lime factor} = C - (1.65A + 0.315F)/S$$

$$\text{Lime saturation factor (LSF)} = 100(\text{CaO} + 0.75\text{Mg}) / (2.85\text{SiO}_2) + (1.18\text{Al}_2\text{O}_3) + (0.65\text{Fe}_2\text{O}_3)$$

For MgO below 2%

$$\text{Lime saturation factor (LSF)} = 100(\text{CaO} + 1.5\text{Mg}) / (2.85\text{SiO}_2) + (1.18\text{Al}_2\text{O}_3) + (0.65\text{Fe}_2\text{O}_3)$$

For MgO above 2%

Bogue Equations for Potential Composition

$$C_3S = 4.071C - 7.6S - 6.718a - 1.43F$$

$$C_2S = 3.071C + 8.6S + 5.068A + 1.079F$$

$$C_3A = 2.65A - 1.692F$$

$$C_4AF = 3.043F$$

(Moore, 1982)

Properties of Bogue's Compound

During the course of reaction of C_3S and C_2S with water, calcium silicate hydrate, abbreviated C-S-H and calcium hydroxide $\text{Ca}(\text{OH})_2$ are formed. Calcium silicate hydrates are the most important products. It is the essence that determines the good properties of concrete. It makes up 50 – 60 % of the volume of solids in completely hydrated cement paste. C_3S readily reacts with water and produces more heat of hydration. It is responsible for early strength of concrete. Cement with more C_3S content is better for cold weather concreting. The quality and density of calcium silicate hydrate formed out of C_3S is slightly inferior to that formed by C_2S . The early strength of concrete is due to C_3S . The hydration of aluminates has been the subject of numerous investigations. The reaction of

C_3A with water is very fast and this may lead to flash set. The hydrated aluminates do not contribute anything to the strength of concrete. On the other hand, their presence is harmful to the durability of concrete particularly where the concrete is likely to be attacked by sulphates. As it hydrates very fast it may contribute a little to the early strength. C_4AF is believed to form a system of the form $CaO - Fe_2O_3 - H_2O$. This hydrated product also does not contribute anything to the strength. The hydrates of C_4AF show a comparatively higher resistance to the attack of sulphates than the hydrates of calcium aluminate (Shetty, 2004).

2.7 Burnt Clay

Clay minerals gain a distinct pozzolanic activity when burned at temperatures between 600 and 900°C. The use of burned clays for the preparation of hydraulic mortars dates back to ancient times and is particularly widespread in India. Owing to the chemical composition of clay and related materials, these artificial pozzolanas are mostly composed of silica and alumina. The loss of combined water due to the thermal treatment causes the crystalline network of the clay minerals to be destroyed, while silica and alumina remain in a messy, unstable, amorphous state. Heating does not affect anhydrous minerals such as quartz or plagioclase, so that pozzolanic activity depends only on the clay mineral content as well as on the thermal treatment conditions (Lea, 2004).

CHAPTER THREE

3.0 MATERIALS AND METHODOLOGY

The experiments were carried out at Building laboratory, Civil Engineering concrete laboratory at Ahmadu Bello University, Zaria and Centre for energy research and training. Specimens used include PBB and 5 brands of cement. Specimens were tested and materials were prepared according to relevant standards and codes of practice.

3.1 MATERIALS

Materials used in this research included PBB, five (5) brands of cement (four indigenous and one foreign), sharp sand and water. Burnt brick was sourced from Adamawa burnt brick factory which is located at Mubi Local Government (PLATE I). The burnt brick was ground using pestle and mortar and sieved using 75 μ m sieve. The material passing 75 μ m standard BS sieve (No 200) was used to conduct the experiment. The brands of cement used for the experiment was purchased from cement dealers in Zaria, Kano and Kaduna. The sharp sand and water provided by the building laboratory was used for the experiment.

3.2 EXPERIMENTS CONDUCTED

3.2.1 Physical Properties

Physical properties of the PBB, sharp sand and brands of cements were determined such properties as specific gravity, particle size distribution, setting time and soundness were conducted.

Specific Gravity

Specific gravity of the brands of cement and sharp sand was determined according to the requirements of BS 1377: 1975. The weight of glass jar was weighed dry; sample of the

finer (i.e brands of cement, PBB and sharp sand) was poured into the dry glass jar and weighed. The glass jar was filled to half of the glass jar and stirred to avoid sticking to the bottom of the bottle and to remove all the air bubbles, the glass jar was filled to the brim and weighed. The experiment was carried out three times to reduce bias of the results.

Particle Size Distribution

Particle size distribution of sharp sand was determined according to the requirements of BS 1377: 1975. Two kilogram of the sample was weighed and poured over the series of test sieves fitted with the receiver at the bottom for the maximum size of material and agitated so that the sample rolls in irregular motion over the test sieve. Particles were hand placed to see if they will fall through but they were not pushed through. The material passing each test sieve was expressed in percentage and the result was plotted on a particle size distribution chart.

Setting Times

Setting times of cements were determined according to the requirements of BS EN 196: Part 3. The Vicat apparatus was used. Four hundred grams (400g) of the cement was weighed and water was added until the standard consistency test was determined using a type G Vicat plunger.

Initial setting time is determined when a type C Vicat plunger fails to penetrate the cement paste between (5-10) mm from the bottom of the mould. The final setting time was determined when a type F Vicat plunger fails to make a circular impression on the surface of the cement paste. The above test was carried out for cement paste having 100% OPC and (90% OPC + 10% PBB) for the various brands of cement. Three trials were carried out for each specimen to reduce bias of the results.

Soundness Test

Soundness test was determined according to the requirements of BS EN 196: Part 3 and BS 812-121: 1989. The cement pastes were prepared to their standard consistencies; the paste was cast into Le Chatelier's mould and immersed in water for 24 hours. The cement pastes were removed from water and the distance between the pointers was measured. The cement paste was boiled for an hour at 100°C; the distance between the pointers was measured to determine the unsoundness of the cement paste. This procedure was carried out for 100% OPC and (90% OPC + 10% PBB) for the various brands of cement.

3.2.2 CHEMICAL PROPERTIES

Experiments were carried out on the OPC and the PBB samples. One of the experiments conducted was the oxide composition of the various brands of the OPC and the PBB.

Oxide Composition

The oxide composition of the OPC and the PBB were determined using an energy dispersive x-ray spectrometer (Mini Pal 4, PW 4030). 0.5 grams of the sample was weighed and mixed with three drops of organic binder (combination of toluene compound + PVC), the mixture is pressed in a hydraulic press into a pellet. The pellet is loaded in the sample chamber of the spectrometer and excited by x-ray produced from the instrument for 10 minutes. The spectrum from the sample is now analyzed to determine the concentration of the elements in the sample. This was carried out for all the brands of OPC and PBB.

3.3 MIX FOR MORTAR

The physical properties of the materials used for the mix for mortar are shown in table 3.1

Table 3.1 Physical Properties of Materials used in the Experiment.

Material	Density (Kg/m ³)	Specific gravity	
Cement B	1324.44	3.35	
Cement C	1475.56	3.30	
OPC	Cement A	1401.48	3.16
	Cement D	1543.70	3.31
	Cement E	1404.44	3.32
PBB	1125.93	2.68	
Sand	1659.26	2.56	
Water	1000	1.00	

The proportioning of mortar was carried out by volume. A (70 x 70 x 70) mm mould, 1:6 (Cement: sand) ratio mortar and 0.65 w/c ratio were used. The OPC replacement by PBB was 10% by volume. Samples with 100% OPC were used as control mixes. All calculations of materials were based on the absolute volume as shown in table 3.2 Individual materials were brought together and mixed before introducing water. The materials were mixed thoroughly and placed into the moulds in three layers. Each layer was tamped 25 times with a standard iron rod tamper of diameter of 16 mm, after the tamping the top was leveled off using a hand trowel. Specimens were allowed to stay for 24 hours before demoulding. The date as noted and the specimen were brought out at the end of the 3rd, 7th, 14th, 21st, 28th, 56th and 90th day to dry for 2 hours before crushing to determine their compressive strength. A manual crushing machine was used for the compressive strength test.

Table 3.2 Mix Proportion for the Mortar Mix

Cement type	Materials (Kg)	Control cubes	Blended cubes
	Sand	15.488	15.352
Cement B	Water	1.205	1.308
	Cement	1.854	1.838
	PBB	0	0.174

3.4 MECHANICAL PROPERTIES

Mechanical properties of mortar cubes were determined. The compressive strength test was conducted on hardened mortar cubes at the end of the stipulated crushing days.

3.4.1 Compressive Strength Test

Specimens were crushed to failure to determine the compressive strength using a manual crushing machine of a capacity of 1100 KN. Cube samples were removed at the end of curing period from water and allowed to surface dry for about two (2) hours before crushing test is conducted. Specimens were crushed at the end of 3rd, 7th, 14th, 21st, 28th, 56th and 90th days to determine their compressive strengths. During crushing the mortar cubes were centrally place in the compressive strength machine. Compressive strength is defined as the load applied per unit area expressed as

$$J = \frac{P}{A}$$

Where $J =$ Compressive strength (N/mm^2)

$P =$ Load applied at failure (N or KN)

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

CHAPTER FOUR

4.0 RESULT AND ANALYSIS

The result presented in this chapter is based on the tests results conducted on the different mortar specimens of the various mixes and the PBB. The results obtained were compared with standard (control mixes) values for mortar as given by BS 12:1991 were used as basis of comparison. The values of specimens with 100% OPC were used as control mix for the comparison against the blended mortar which is made up of (90% OPC + 10% PBB).

4.1 Specific Gravity

The results obtained from the experiment were carried out according to the BS 1377: 1975. Three trials were carried out for each sample to reduce bias. It was observed that the PBB gave the least value 2.68. Among the cement samples cement II gave the highest value 3.35 while cement I gave the least value 3.16. The difference in the results could be due to variation in the mineralogical composition and geographical location of the raw materials used to produce them. The technology behind the production process for the brands of cement could be another reason for the difference in specific gravity.

Table 4.1 Average Specific Gravity of PBB and Brands of Cement.

Samples	Exp. 1	Exp. 2	Exp. 3	Mean value
PBB	2.56	2.73	2.74	2.68
Cement A	3.07	3.30	3.11	3.16
Cement B	3.44	3.30	3.30	3.35
Cement C	3.42	3.33	3.15	3.30
Cement D	3.61	3.09	3.23	3.31
Cement E	3.38	3.30	3.28	3.32

4.2 Setting Time

The result of this experiment is presented in table 4.2. It was observed that for the control specimens (100% OPC) Cement E gave the highest initial (206 minutes) and final (275 minutes) setting times while Cement D gave the lowest initial (118 minutes) setting time and Cement A gave the lowest final (231 minutes) setting times. For the blended specimens (10:90)% Cement B gave the highest initial (166 minutes) setting time and Cement C gave the highest final (257 minutes) setting time while Cement D gave the lowest initial (92 minutes) and final (162 minutes) setting times. All the results fell within the range as specified for OPC by BS 12: 1991, the minimum average initial setting time is 45 minutes and the maximum average final setting time of 600 minutes. The average setting times of the cement brands were taken to reduce bias. The initial and final setting times increases with decrease in the C_3A present in the cements brands, See table 4.3. The irregularities in the setting times may be due to the change in weather condition which could affect the rate of reaction of the cement, this could affect the setting time.

Table 4.2 Average Setting Times of Brands of Cement

Cement		Cement A	Cement B	Cement C	Cement D	Cement E
Control (0:100)	Initial setting time	131	168	146	118	206
	Final setting time	231	270	240	242	275
Blended (10:90)	Initial setting time	135	166	157	92	157
	Final setting time	218	240	257	162	249

Table 4.3 Relationship between C₃A content and initial and final setting times of cement

Cement	C ₃ A	Initial		Final	
		Control	Blended	Control	Blended
Cement A	-1.94	131	135	231	218
Cement C	-3.94	146	157	240	257
Cement B	-5.36	168	166	270	218
Cement D	-6.72	118	92	242	162
Cement E	-6.88	206	157	275	249

4.3 Particle Size Distribution

Particle size distribution of sharp sand is presented in table 4.4. The particle size distribution is determined to standardize the fine aggregate used for the experiment; the material satisfied the requirements of ASTM C778-00.

Table 4.4 Particle Size Distribution of Sharp Sand

Sieve size	Weight retained	Weight passing	Percentage passing
5mm	65	935	93.5
2.36mm	110	825	82.5
1.18mm	355	470	47
600µm	255	245	24.5
300 µm	157.5	87.5	8.75
150 µm	30	57.5	5.75
Pan	15	42.5	4.25

4.4 Soundness

Change in volume undergone by cement during setting is known as Soundness. Unsoundness in a material denotes the presence of impurities liable to react chemically with moisture with resulting expansion. Le Chatelier apparatus is used to carry out the experiment. The result is given in table 4.5. It was observed that for control cubes (100% OPC), Cement A gave the highest expansion (1 mm) while Cement B, C and E did not undergo expansion (0 mm). For blended cubes (10:90) cement A, B, D and E gave the highest expansion (1 mm) while C cement did not undergo expansion (0 mm). This could be due to impurities and other compounds present in the cement, water or PBB.

Table 4.5 Soundness Test

Samples	Size of cubes (mm)	Control (100% OPC)		Blended OPC (10:90)	
		After boiling	Expansion	After boiling	Expansion
Cement A	70	71	1	71	1
Cement B	70	70	0	71	1
Cement C	70	70	0	70	0
Cement D	70	70.5	0.5	71	1
Cement E	70	70	0	71	1

4.5 Oxide composition

The most important factors in the composition of OPC are the amounts of cement minerals, calcium sulfate and alkalis (Na and K). During chemical analysis of cement the relative concentrations of each of the elements were determined. These values were then converted to the weight fraction of each element in oxide form. The result obtained is given in table 4.6; all the brands of OPC conform to the required content of Al_2O_3 (6 %

max.) and Fe₂O₃ (6 % max.). The brands of OPC conformed to the maximum value (3%) for SO₃ with the exception of Cement B. The composition of CaO (A) and SiO₂ (A) is not applicable in the standard. The difference in oxide composition could be due to variation in proportioning raw materials used to produce OPC.

Table 4.6 Oxide Composition of Brands of OPC against ASTM C150-07

Oxides	Chemical composition of cement type (I - IV) as stated in ASTM C150-07 (%)	Cement A (%)	Cement B (%)	Cement C (%)	Cement D (%)	Cement E (%)
SiO ₂	A	13.2	8.87	9.70	7.86	6.30
Al ₂ O ₃	6 max	2.6	1.2	1.40	1	1.10
Fe ₂ O ₃	6 max	5.22	5.05	4.52	5.54	5.79
CaO	A	71.66	76.38	78.20	82.63	80.93
MgO	6 max	-	-	-	-	-
SO ₃	3 max	2.47	3.94	2.01	1	2.34
Loss in ignition	3 max	-	-	-	-	-
Na ₂ O	A	-	-	-	-	-
K ₂ O	A	0.70	0.78	0.05	-	-
Insoluble	0.75 max	-	-	-	-	-

4.6 Compressive Strength

The compressive strength of mortars made with various brands of OPC for control cubes and blended cubes are presented in the following figures. Compressive strength of mortar cubes for both control and blended cements increased with increasing age. Each cement brand showed different characteristics in comparison with the other brands.

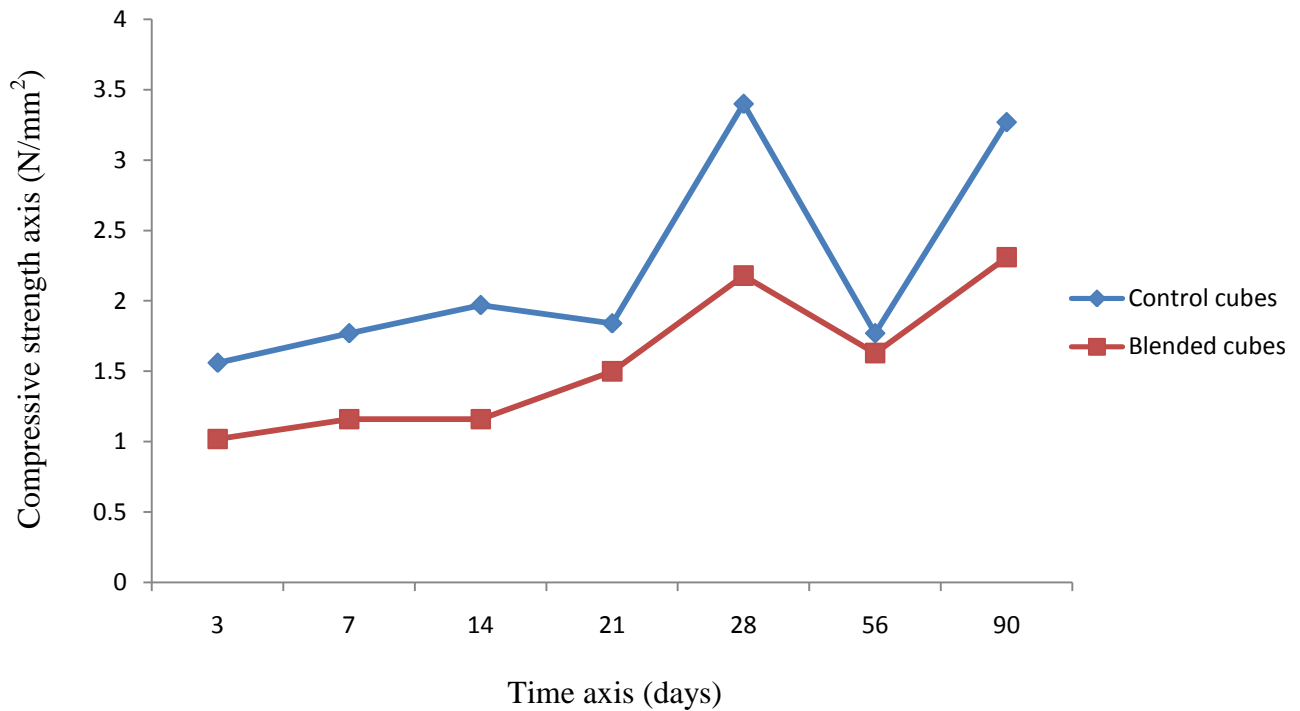


Figure 1: Compressive Strength of Mortar Cubes Cast with Cement A

Cement A: The compressive strength of the control cubes for the 3rd and 28th days was 1.56N/mm² and 3.40 N/mm² respectively while for blended cubes was 1.02N/mm² and 2.18N/mm². The compressive strength of blended cubes for the 3rd and the 28th day was 65% and 64% respectively of the control cubes. This could be as a result of the compatibility issues of the cement and the admixture as explained by Clyde Moore who opined that the A/F (alumina-to-iron) ratio is important because it controls the potential C₃A/C₄AF ratio in the finished cement, which is important because of sulfate resistance, heat generation, and admixture compatibility issues. The compressive strength for the blended mortar cubes was 92% and 71% of the control cubes for the 56th and 90th day respectively; the compressive strength was irregular, see figure 1. This could be due to excessive reaction caused by efflorescence and low temperature which resulted into wet strength.

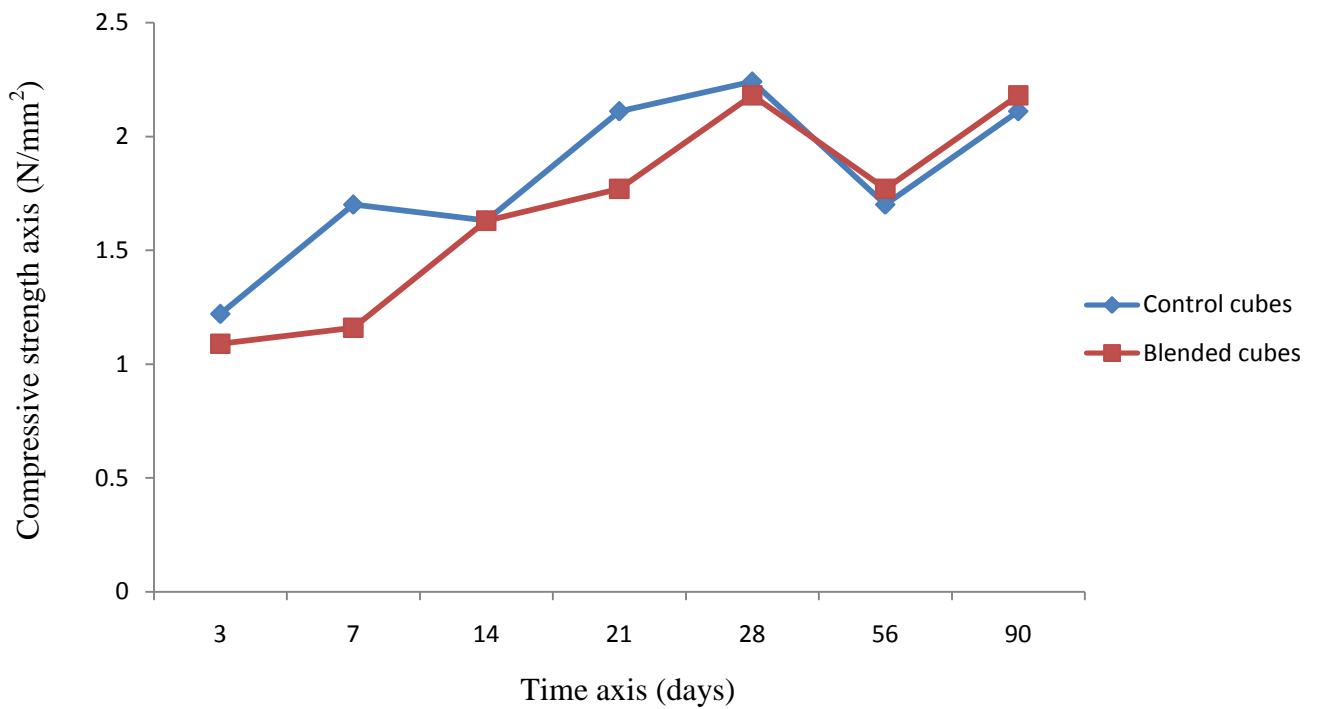


Figure 2: Compressive Strength of Mortar Cubes Cast with Cement B

Cement B: The compressive strength of the control cubes for the 3rd and 28th day was 1.22N/mm² and 2.24N/mm² while for blended cubes was 1.09N/mm² and 2.18 N/mm². The compressive strength of blended cubes for the 3rd and 28th day was 89% and 97% of the control cubes respectively. This indicates that the blended cubes rate of strength development improved indicating that hydration of PBB is taking place. The compressive strength for both control and blended mortar cubes for the 56th and 90th day was irregular; this could be due to excessive reaction due to efflorescence and lack of drying due to low temperature, see figure 2. The compressive strength of blended cubes after 28th day was greater than that of the control cubes; the compressive strength was 104% and 103% of the control cubes on the 56th and 90th day respectively.

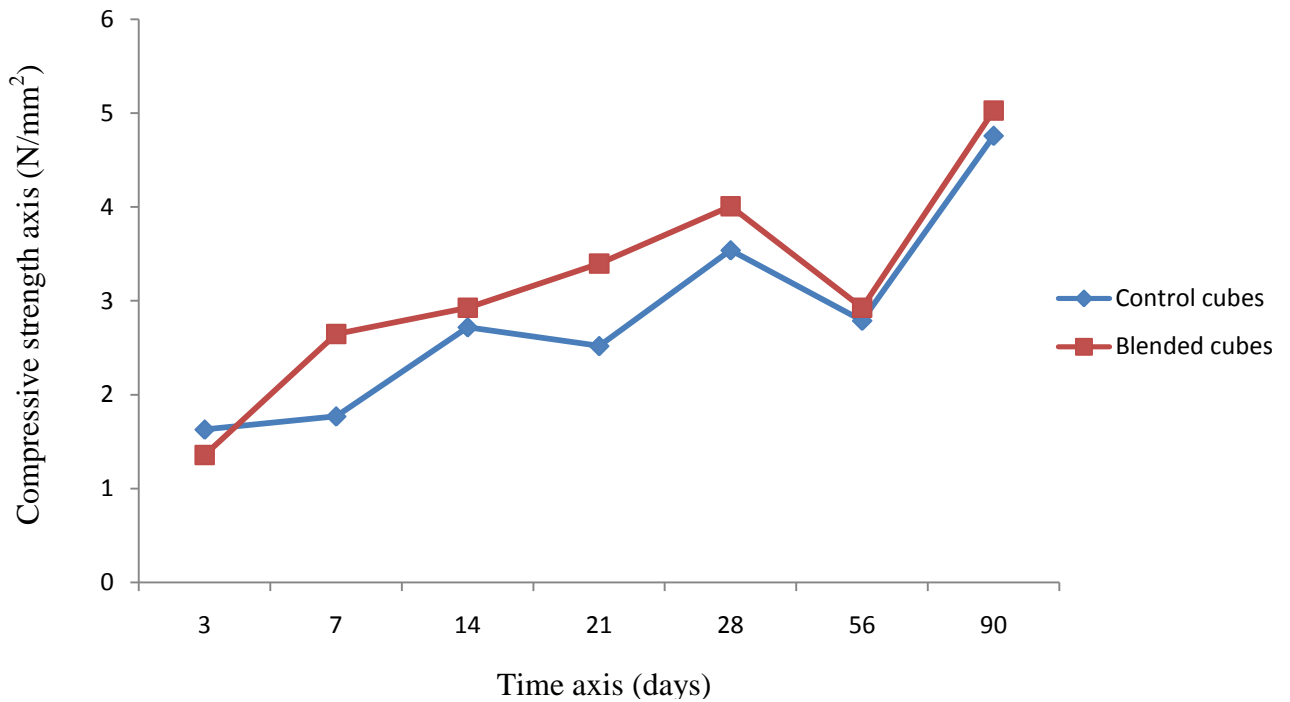


Figure 3: Compressive Strength of Mortar Cubes Cast with Cement C

Cement C: The compressive strength of the control cubes for the 3rd and 28th day was 1.63N/mm² and 3.54N/mm² while for blended cubes was 1.36N/mm² and 4.01 N/mm². The compressive strength of blended cubes for the 3rd and 28th day was 83% and 113% respectively of the control cubes. This indicates that the blended cubes rate of strength development improved indicating that hydration of PBB is taking place at a faster rate than both Cement B and A, see figure 7. The compressive strength for both control and blended mortar cubes for the 56th and 90th day was irregular due to excessive reaction due to efflorescence and lack of drying due to low temperature. The compressive strength of blended cubes after 28th day was greater than the control cubes; the compressive strength was 105% and 106% of the control cubes on the 56th and 90th day respectively, see Fig 3.

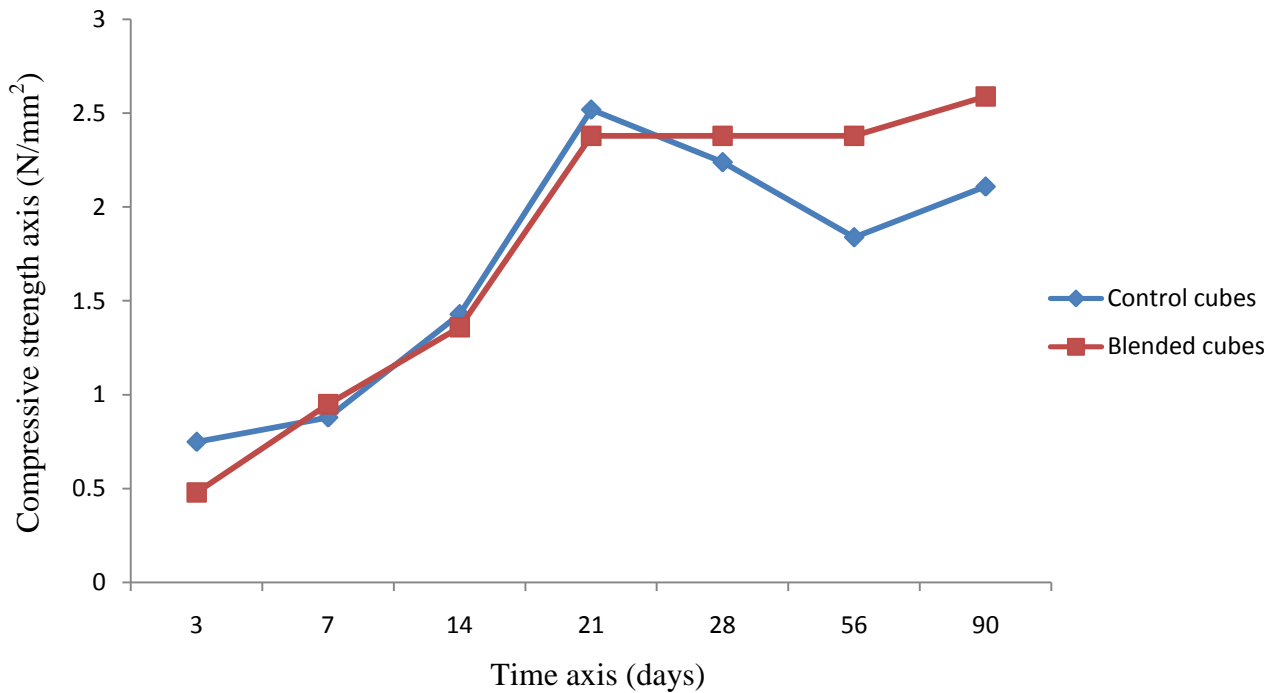


Figure 4: Compressive Strength of Mortar Cubes Cast with Cement D

Cement D: The compressive strength of the control cubes for the 3rd and 28th day was 0.75N/mm² and 2.24N/mm² while for blended cubes was 0.48N/mm² and 2.38 N/mm². The compressive strength of blended cubes for the 3rd and 28th day was 64% and 106% respectively of the control cubes, see figure 4. This indicates that the blended cubes rate of strength development improved indicating that hydration of PBB is taking place at a faster rate than in Cement A, see Figure 7. The compressive strength for both control and blended mortar cubes for the 56th and 90th day was irregular. The irregularity could be due to excessive reaction due to efflorescence and lack of drying due to low temperature. The compressive strength of blended cubes after 28th day was greater than the control cubes; the compressive strength was 105% and 106% of the control cubes on the 56th and 90th day respectively.

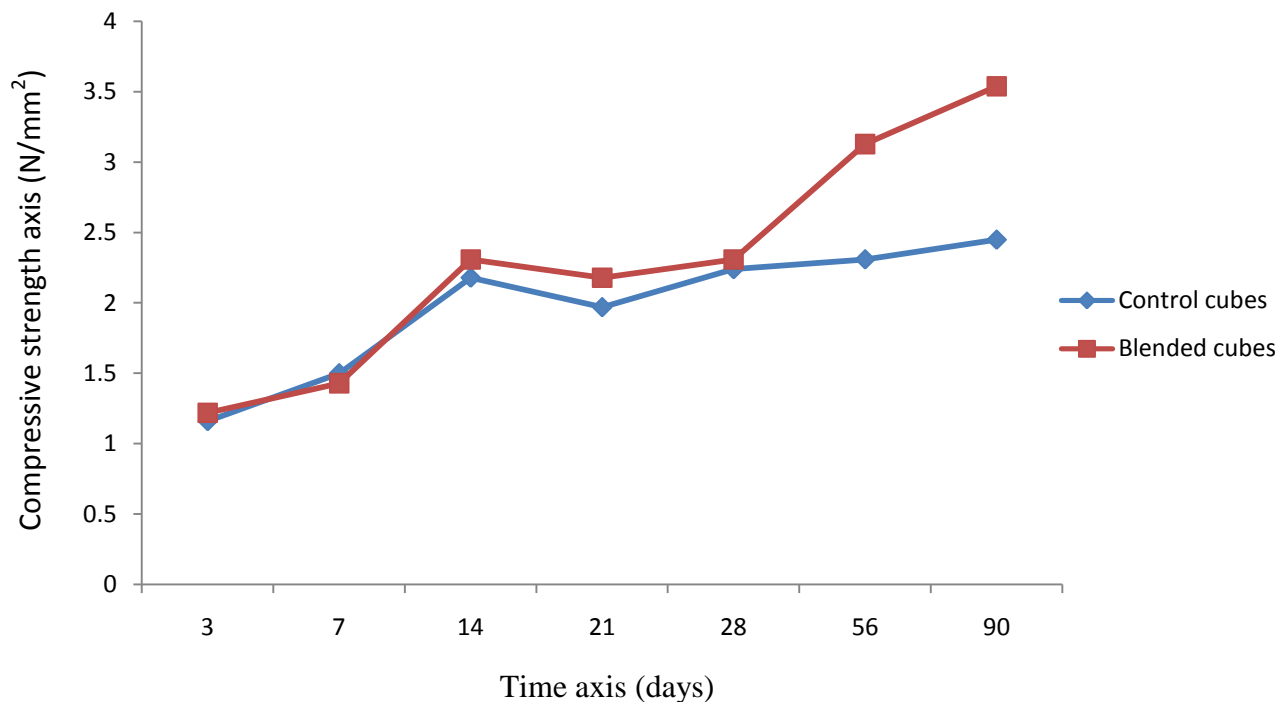


Figure 5: Compressive Strength of Cubes Mortar Cast with Cement E

Cement E: The compressive strength of the control cubes for the 3rd and 28th day was 1.16 N/mm² and 2.24N/mm² while for blended cubes was 1.22 N/mm² and 2.31 N/mm². The compressive strength of blended cubes for the 3rd and 28th day was 105% and 103% respectively of the control cubes. This indicates that the blended cubes rate of strength development improved indicating that hydration of PBB is taking place at a faster rate than the other brands of cement. The compressive strength for both control and blended mortar cubes for the 56th and 90th day was irregular due to excessive reaction due to efflorescence and lack of drying due to low temperature. The compressive strength of blended cubes after 28th day was greater than the control cubes; the compressive strength was 135 % and 145 % of the control cubes on the 56th and 90th day respectively, see figure 5.

PBB from Adamawa has been established as a pozzolana by Sa'ad (2006), from the oxide analysis it was seen to be very rich in SiO₂ (63.4%). The brands of cement have different

percentages of SiO_2 but the percentage of SiO_2 is not applicable as stated in ASTM C150 - 07. The PBB did not compliment the silica deficiency in the brands of cement rather it reacted with lime liberated when cement undergoes hydration in the presence of water to form a C-S hydrates which is cementitious and fills more pore spaces in the mortar. This makes the mortar more dense and impervious to deleterious materials. The compatibility of the brands of cement with PBB differs with the various brands of cement.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY OF RESEARCH FINDINGS

Through the various tests and experiments carried out in the previous sections the following findings were drawn

- i. PBB gave the lowest specific gravity of 2.68 while for OPC, cement B gave the highest specific gravity of 3.35 and cement A gave the lowest specific gravity of 3.16.
- ii. The highest and lowest initial setting times for the blended cement pastes were 206 and 118 minutes for cement E and D which is 98.8% and 78% of the control cement pastes respectively. The highest and lowest final setting times for the blended cement pastes were 257 and 162 minutes for cement C and D which is 107% and 66.94% of the control cement pastes respectively.
- iii. Control cement pastes did not undergo expansion except for cement A and D. The former and latter underwent expansion of 1mm and 0.5mm respectively while for the blended cement pastes all cement brands underwent expansion of 1mm each except cement C which did not undergo expansion.
- iv. The highest densities of the blended mortar cubes made with the brands of cement (A – E) were 2124.4 Kg/m³, 2042.8 Kg/m³, 2156.5Kg/m³, 2144.8 Kg/m³ and 2084.6 Kg/m³ which are 98.29%, 97.86%, 103.02%, 105.04% and 103.27% of the densities of the control mortar cubes respectively. See Appendix A, table 1 - 5.
- v. Cement C gave the highest compressive strength with the PBB at the end of 90 days of curing with an optimum compressive strength of 5.03 N/mm² which is 106% of the control mortar cubes.

- vi. The brands of cement satisfied the oxide composition for cement as stated in ASTM C150 – 07. The highest and lowest composition of SiO_2 (A) was 13.2% and 6.3% for cement A and E respectively. The highest and lowest composition of CaO (A) was 82.63% and 71.66% for cement D and A respectively. The brands of cement satisfied the oxide composition for Al_2O_3 (6% max) and Fe_2O_3 (6% max).
- vii. The compressive strength of blended mortar cubes made with the brands of cement surpasses that of the control mortar cubes except for cement A.

5.2 CONCLUSIONS

From the research findings, the cement brands reacted differently with the PBB. Blended mortar cubes made with Cement C gave the highest compressive strength of 5.03 N/mm^2 which was 106% of the compressive strength of the control mortar cubes.

5.3 RECOMMENDATION

Based upon the findings of this research, the following recommendations are made

- i. The PBB made from Adamawa burnt brick could be used with cement C to produce blended cement mortar.
- ii. Blended cement mortar could be used in production of sandcrete blocks, interlocking blocks and kerbs etc.
- iii. The PBB made from Adamawa burnt brick could be used to reduce the formation of calciumsulphoaluminate (Ettringite) when cement reacts with water. Since the pozzolanic reaction and formation of Ettringite both depend on reaction with lime.

5.3.1 RECOMMENDATION FOR FURTHER RESEARCH

- i. Research on the compatibility of PBB and OPC using oxide composition should be carried out. A/F (alumina-to-iron) ratio in OPC is important because it controls admixture compatibility. This may reduce time and cost.

5.4 CONTRIBUTION OF KNOWLEDGE

The following contribution to knowledge were made based on the research findings, it has been established that

- i. The brands of Ordinary Portland Cement (OPC) react differently with pulverized burnt brick (PBB) from Adamawa.
- ii. Cement C gave the best results with pulverized burnt brick from Adamawa.
- iii. The brands of Ordinary Portland Cement used for the research have different oxide compositions.

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APPENDIX A

Table 1 Average Density and Compressive Strength of Mortar Cubes for Cement A

Crushing day test	Control cubes		Blended cubes	
	Density (Kg/m ³)	Compressive Strength (N/mm ²)	Density (Kg/m ³)	Compressive Strength (N/mm ²)
3	2125.4	1.56	1956.3	1.09
7	2048.6	1.77	2043.7	1.16
14	2046.7	1.97	1957.2	1.63
21	2010.7	1.84	1902.8	1.77
28	2128.3	3.40	1959.2	2.18
56	2060.3	1.77(W _s)	1885.3	1.63(W _s)
90	2161.3	3.27(W _s)	2124.4	2.31(W _s)

Table 2 Average Density and Compressive Strength of Mortar Cubes for Cement B

Crushing day test	Control cubes		Blended cubes	
	Density (Kg/m ³)	Compressive Strength (N/mm ²)	Density (Kg/m ³)	Compressive Strength (N/mm ²)
3	2039.8	1.22	2017.5	1.09
7	2037.9	1.70	2019.4	1.16
14	1897	1.63	1879.5	1.63
21	2087.5	2.11	2042.8	1.77
28	1987.4	2.24(W _s)	1969.9	2.18(W _s)
56	1963	1.70(W _s)	1895	1.77(W _s)
90	2034.01	2.11	1970	2.18

Table 3 Average Density and Compressive Strength of Mortar Cubes for Cement C

Crushing day test	Control cubes		Blended cubes	
	Density (Kg/m ³)	Compressive Strength (N/mm ²)	Density (Kg/m ³)	Compressive Strength (N/mm ²)
3	2089.4	1.63	2089.4	1.36
7	2103	1.77	2136.1	2.65
14	2033	2.72	2016.5	2.93
21	1947.5	2.52	1962.1	3.40
28	2097.2	3.54	2042.8	4.01
56	1982.5	2.79(W _S)	2016.5	2.93(W _S)
90	2093.3	4.76	2156.5	5.03

Table 4 Average Density and Compressive Strength of Mortar Cubes for Cement D

Crushing day test	Control cubes		Blended cubes	
	Density (Kg/m ³)	Compressive Strength (N/mm ²)	Density (Kg/m ³)	Compressive Strength (N/mm ²)
3	1951.4	0.75	1953.4	0.48
7	2080.7	0.88	2062.2	0.95
14	1950.4	1.43	1968.9	1.36
21	1984.5	2.52	1917.4	2.38
28	2041.8	2.24(W _S)	2144.8	2.38(W _S)
56	1977.7	1.84(W _S)	2021.4	2.38(W _S)
90	1991.3	2.11 (W _S)	2016.5	2.59(W _S)

Table 5 Average density and compressive strength of mortar cubes for Cement E

Crushing day test	Control cubes		Blended cubes	
	Density (Kg/m ³)	Compressive Strength (N/mm ²)	Density (Kg/m ³)	Compressive Strength (N/mm ²)
3	2071.9	1.16	1966	1.22
7	2018.5	1.50	2084.6	1.43
14	1999	2.18	2028.2	2.31
21	1914.5	1.97	1940.7	2.18
28	1986.4	2.24	2070	2.31
56	1929.1	2.31(W _s)	1924.2	3.13(W _s)
90	1905.7	2.45(W _s)	1999	3.54(W _s)

APPENDIX B

Table 1 Setting Time Test Using Vicat Apparatus

CEMENT B	
Control cement	Blended cement
10:10	10:00
10:20	10:10
10:30	10:20
10:40	10:30
10:50	10:40
11:00	10:50
11:10	11:00
11:20	11:10
11:30	11:20
11:40	11:30
11:50	11:40
12:00	11:50
12:10	12:00
12:20	12:10
12:30	12:20
12:40	12:30
12:48 Initial setting time	12:36 Initial setting time
1:00	12:50
1:10	1:00
1:20	1:10
1:30	1:20
1:40	1:30
1:50	1:40
2:00	1:50
2:10	1:58 Final setting time
2:20	
2:30	
2:32 Final setting time	

Table 2 Bulk density test (fine aggregate)

Trial	1	2	3
Weight of container (W_1)	1.6 Kg	1.6 Kg	1.6 Kg
Weight of container + Fine aggregate (W_2)	7.3 Kg	7.2 Kg	7.2 Kg
$W_2 - W_1$	5.7 Kg	5.6 Kg	5.6 Kg

$$\begin{aligned} \text{Mean bulk density of sharp sand} &= \frac{(5.7\text{Kg} + 5.6\text{Kg} + 5.6\text{Kg})}{3} \\ &= 5.6\text{ Kg} \end{aligned}$$

$$\begin{aligned} \text{Density} &= \frac{\text{Mass}}{\text{Volume}} = \frac{5.6\text{ Kg}}{(0.15 \times 0.15 \times 0.15)\text{m}^3} \\ &= 1659.259\text{ Kg/m}^3 \\ &= 1659.26\text{ Kg/m}^3 \end{aligned}$$

Table 3 Water absorption test (Fine aggregate)

Weight of oven dried sharp sand (W_1)	500 grams
Weight of sharp sand after soaking in water for 2 hours and surface dried (W_2)	514 grams
Percentage of water absorbed ($(W_2 - W_1) / W_1$)	2.8 %

Table 4 Specific gravity of Fine aggregate

Weight of container (M ₁)	823 grams
Weight of container and fines (M ₂)	1328 grams
Weight of container, fines and water (M ₃)	2641 grams
Weight of container and water (M ₄)	2333 grams

$$\begin{aligned}
 G_s &= \frac{(M_2 - M_1)}{(M_4 - M_1) - (M_3 - M_2)} = \frac{1328 - 823}{(2333 - 823) - (2641 - 1328)} \\
 &= \frac{505}{1510 - 1313} \\
 &= 2.56
 \end{aligned}$$

Sample calculations for materials

$$\text{Absolute volume} = \frac{D \times R}{S.G}$$

Where $D = \text{Density}$

$R = \text{Ratio in mix proportion}$

$S.G = \text{Specific gravity}$

Absolute volume for the materials is as follows

$$PBB = \frac{(1125.93 \times 1)}{2.50} = 450.372 \text{ m}^3$$

$$OPC = \frac{(1324.44 \times 9)}{3.35} = 3558.20 \text{ m}^3$$

$$\text{Sand} = \frac{(1659.26 \times 60)}{2.56} = 38888.91 \text{ m}^3$$

$$\text{Water} = (1324.44 \times 9 + 1125.93 \times 1) \times 0.65 = 8479.83 \text{ m}^3$$

$$\text{Total absolute volume of material} = 51377.312 \text{ m}^3 = 51.38 \text{ m}^2$$

Quantity of materials in 1 m³ of mortar

$$PBB = \frac{(1125.93 \times 1)}{51.38} = 21.91 \frac{Kg}{m^3}$$

$$OPC = \frac{(1324.44 \times 9)}{51.38} = 232 \frac{Kg}{m^3}$$

$$Sand = \frac{(1659.26 \times 60)}{51.38} = 1937.63 \frac{Kg}{m^3}$$

$$Water = \frac{[(1324.44 \times 9 + 1125.93 \times 1) \times 0.65]}{51.38} = 165.04 \text{ Kg/m}^3$$

Volume of 21 moulds of 70mm x 70mm x 70mm

$$\begin{aligned} \text{Volume of materials + 10\% waste} &= 1.10 \times 21 \times 0.07^3 \text{ m}^3 \\ &= 0.0079233 \text{ m}^3 \end{aligned}$$

Materials for 21 cubes

$$PBB = 0.0079233 \times 21.91 = 0.174 \text{ Kg} = 174 \text{ grams}$$

$$OPC = 0.0079233 \times 232 = 1.838 \text{ Kg} = 1838 \text{ grams}$$

$$Sand = 0.0079233 \times 1937.63 = 15.352 \text{ Kg} = 15352 \text{ grams}$$

$$Water = 0.0079233 \times 165.04 = 1.308 \text{ Kg} = 1308 \text{ grams}$$

APPENDIX C



Plate I: Waste burnt brick at Mubi Burnt brick factory, Adamawa state.



Plate II: Collecting burnt brick at Mubi Burnt brick factory, Adamawa State.



Plate III: Five brands of cement and PBB.



Plate IV: Weighing materials for mortar before batching.



Plate V: Setting time test for control and blended cement paste.



Plate VI: Hardened cement paste specimens for setting time test.



Plate VII: Mortar cubes undergoing drying under the sun for 2 hours



Plate VIII: Mortar cubes suffered from efflorescence as at the 56th day of curing.



Plate IX: Mortar cubes suffered from efflorescence as at the 90th day of curing.



Plate X: Mini Pal 4, PW 4030



Plate XI: Toluene + PVC, grinding dish and pallet mould



Plate XII: Pallet of cement sample

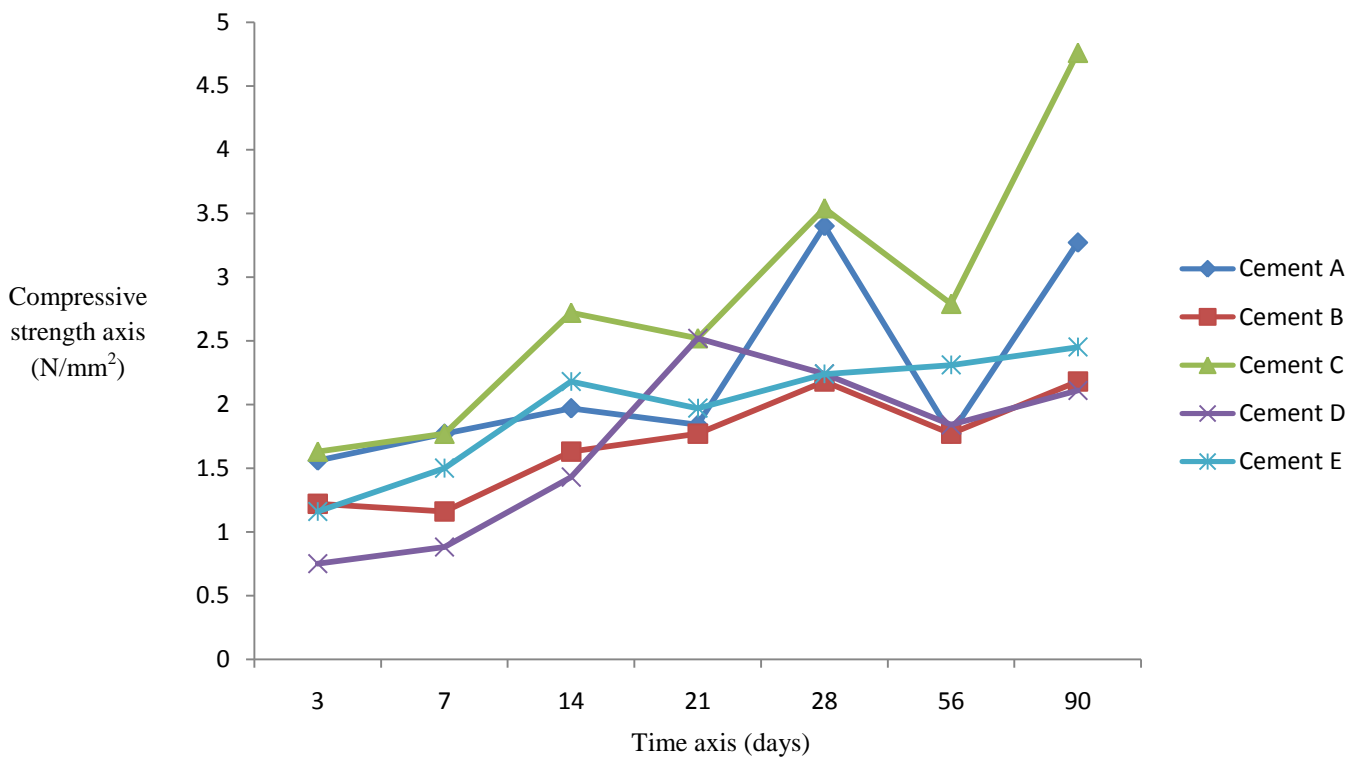


Figure 6 Average Compressive Strength For Brands of Cement (Control)

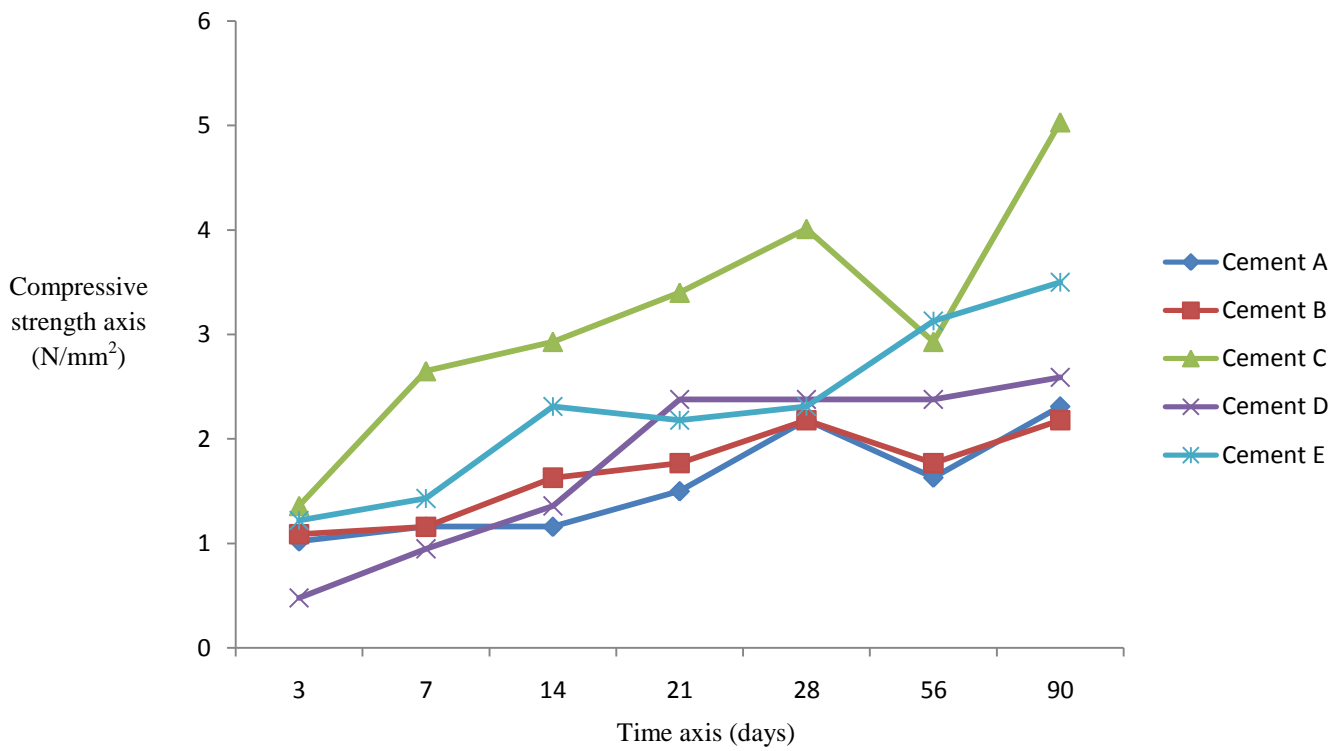


Figure 7 Average Compressive Strength For Brands of Cement (Blended Cement)

APPENDIX D

Table 1

Specific Gravity of PBB and Brands of Cement

	PBB			Cement C			Cement B			Cement A			Cement E			Cement D		
Trial	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
M ₁	823	823	823	823	823	823	823	823	823	823	823	823	823	823	823	823	823	823
M ₂	923	905	897	905	923	905	885	922	922	906	932	941	911	912	918	888	891	894
M ₃	2394	2385	2380	2391	2403	2389	2377	2402	2402	2389	2409	2413	2395	2395	2399	2380	2379	2382
M ₄	2333	2333	2333	2333	2333	2333	2333	2333	2333	2333	2333	2333	2333	2333	2333	2333	2333	2333
G _S	2.56	2.73	2.74	3.42	3.33	3.15	3.44	3.30	3.30	3.07	3.30	3.11	3.38	3.30	3.28	3.61	3.09	3.23
G _{S(av)}	2.68			3.30			3.35			3.16			3.32			3.31		

$$G_s = \frac{(M_2 - M_1)}{(M_4 - M_1) - (M_3 - M_2)}$$

Where

G_s = Specific gravity

M_1 = Weight of container

M_2 = Weight of container and fines

M_3 = Weight of container, fines and water

M_4 = Weight of container and water

Table 2

Sieve Analysis

Sieve size	Weight retained	Weight passing	Percentage passing
5mm	65	935	93.5
2.36mm	110	825	82.5
1.18mm	355	470	47
600 μm	255	245	24.5
300 μm	157.5	87.5	8.75
150 μm	30	57.5	5.75
Pan	15	42.5	4.25

Table 3

Setting Times of Brands of Cement

Cement		B			E			C			A			D		
Trial		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Control	Initial setting time	168	162	174	191	216	211	141	148	150	127	135	130	106	119	128
	Final setting time	262	266	283	253	291	280	245	239	235	225	233	235	253	233	240
Blended	Initial setting time	156	165	178	163	143	165	153	155	162	136	133	137	102	97	76
	Final setting time	238	238	243	248	242	257	250	255	267	216	219	220	179	167	140

Table 4

Water demand for consistency tests for brands of cement

Cement	A	B	C	D	E
Control (0:100)	155ml	140ml	126ml	125ml	152ml
Blended (10:90)	151ml	145ml	130ml	128ml	148ml

Table 5

Bulk density of PBB and brands of cement

Material	PBB			Cement A			Cement B			Cement C			Cement D			Cement E			
	Trial	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Weight of container (Kg)		1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Weight of container + material		5.4	5.4	5.4	6.4	6.2	6.4	6.1	6.0	6.1	6.75	6.5	6.5	6.8	6.8	6.82	6.42	6.3	6.3
Weight of material (Kg)		3.8	3.8	3.8	4.8	4.6	4.8	4.5	4.4	4.5	5.15	4.9	4.9	5.2	5.2	5.22	4.82	4.7	4.7
Average weight (Kg)		3.8			4.73			4.47			4.98			5.21			4.74		
Density (Kg/m ³)		1125.93			1401.48			1324.44			1475.56			1543.70			1404.44		

$$\begin{aligned}
 \text{Bulk density(Elephant)} &= \frac{\text{Mass}}{\text{Volume}} = \frac{5.21 \text{ Kg}}{(0.15 \times 0.15 \times 0.15)m^3} \\
 &= 1543.703 \text{ Kg/m}^3 \\
 &= 1543.70 \text{ Kg/m}^3
 \end{aligned}$$

Cement B

Crushing Day Test	Date	Control (0%)			Blended (10%)		
		Trial	Weight (grams)	Failure load (KN)	Trial	Weight (grams)	Failure load (KN)
3	9/9/11 (Friday)	1	734	7	1	702	7
		2	676	4	2	678	4
		3	689	7	3	696	5
7	13/9/11 (Tuesday)	1	702	6	1	719	6
		2	693	9	2	685	6
		3	702	10	3	674	5
14	20/9/11 (Tuesday)	1	635	8	1	684	11
		2	675	10	2	625	5
		3	642	6	3	625	8
21	27/9/11 (Tuesday)	1	714	9	1	676	9
		2	710	10	2	696	8
		3	724	12	3	730	9
28	4/10/11 (Tuesday)	1	670	10 (Ws)	1	670	11 (Ws)
		2	705	13 (Ws)	2	702	10 (Ws)
		3	670	10 (Ws)	3	655	11 (Ws)
56	1/11/11 (Tuesday)	1	645	8 (Ws)	1	635	9 (Ws)
		2	705	9 (Ws)	2	650	7 (Ws)
		3	670	8 (Ws)	3	665	10 (Ws)
90	5/12/11 (Monday)	1	719	10	1	667	10
		2	700	11	2	660	12
		3	674	10	3	700	10

Cement C

Crushing day test	Date	Control (0%)			Blended (10%)		
		Trial	Weight (grams)	Failure load (KN)	Trial	Weight (grams)	Failure load (KN)
3	10/9/11 (Saturday)	1	739	8	1	702	4
		2	710	7	2	747	10
		3	701	9	3	701	6
7	14/9/11 (Wednesday)	1	753	8	1	707	8
		2	710	10	2	753	18
		3	701	8	3	738	13
14	21/9/11 (Wednesday)	1	705	15	1	710	20
		2	702	15	2	670	15
		3	685	10	3	695	18
21	28/9/11 (Wednesday)	1	654	10	1	670	18
		2	684	13	2	675	12
		3	666	14	3	674	10
28	5/10/11 (Wednesday)	1	738	12	1	713	21
		2	708	20	2	677	20
		3	712	20	3	712	18
56	2/11/11 (Wednesday)	1	685	12 (Ws)	1	705	12 (Ws)
		2	680	14 (Ws)	2	680	16 (Ws)
		3	675	15 (Ws)	3	690	15 (Ws)
90	6/12/11 (Tuesday)	1	743	20	1	736	28
		2	703	28	2	740	20
		3	708	22	3	743	26

APPENDIX E

Cement A

Crushing day test	Date	Control (0%)			Blended (10%)		
		Trial	Weight (grams)	Failure load (KN)	Trial	Weight (grams)	Failure load (KN)
3	11/9/11 (Sunday)	1	733	7	1	683	4
		2	735	10	2	645	5
		3	719	6	3	685	6
7	15/9/11 (Thursday)	1	701	13	1	695	6
		2	715	7	2	704	5
		3	692	6	3	704	6
14	22/9/11 (Thursday)	1	715	10	1	680	8
		2	716	8	2	662	4
		3	675	11	3	672	5
21	29/9/11 (Thursday)	1	677	5	1	660	8
		2	652	10	2	638	8
		3	740	12	3	660	6
28	6/10/11 (Thursday)	1	720	16	1	685	11
		2	748	18	2	656	10
		3	722	16	3	675	11
56	3/11/11 (Thursday)	1	690	8 (Ws)	1	600	10 (Ws)
		2	700	10 (Ws)	2	650	6 (Ws)
		3	730	8 (Ws)	3	690	8 (Ws)
90	7/12/11 (Wednesday)	1	739	14 (Ws)	1	731	10 (Ws)
		2	735	18 (Ws)	2	741	14 (Ws)
		3	750	16 (Ws)	3	714	10 (Ws)

Cement E

Crushing day test	Date	Control (0%)			Blended (10%)		
		Trial	Weight (grams)	Failure load (KN)	Trial	Weight (grams)	Failure load (KN)
3	11/9/11 (Sunday)	1	731	7	1	679	8
		2	709	5	2	644	5
		3	692	5	3	700	5
7	15/9/11 (Thursday)	1	700	8	1	713	5
		2	683	7	2	712	8
		3	694	7	3	720	8
14	22/9/11 (Thursday)	1	685	10	1	700	11
		2	685	10	2	682	15
		3	687	12	3	705	8
21	29/9/11 (Thursday)	1	638	9	1	667	12
		2	655	10	2	668	10
		3	677	10	3	662	10
28	6/10/11 (Thursday)	1	680	15	1	670	9
		2	694	9	2	730	12
		3	670	9	3	730	13
56	3/11/11 (Thursday)	1	700	10 (Ws)	1	675	20 (Ws)
		2	635	16 (Ws)	2	655	16 (Ws)
		3	650	8 (Ws)	3	650	10 (Ws)
90	7/12/11 (Wednesday)	1	639	10 (Ws)	1	699	18 (Ws)
		2	667	12 (Ws)	2	689	16 (Ws)
		3	655	14 (Ws)	3	669	18 (Ws)

Cement D

Crushing day test	Date	Control (0%)			Blended (10%)		
		Trial	Weight (grams)	Failure load (KN)	Trial	Weight (grams)	Failure load (KN)
3	12/9/11 (Monday)	1	665	3	1	684	2
		2	684	4	2	664	2
		3	659	4	3	662	3
7	16/9/11 (Friday)	1	731	4	1	687	3
		2	723	5	2	748	5
		3	687	4	3	687	6
14	23/9/11 (Friday)	1	642	8	1	660	5
		2	680	5	2	660	5
		3	685	8	3	706	10
21	30/9/11 (Friday)	1	675	15	1	670	11
		2	692	12	2	665	12
		3	675	10	3	638	12
28	7/10/11 (Friday)	1	708	12 (Ws)	1	717	10 (Ws)
		2	675	10 (Ws)	2	740	10 (Ws)
		3	718	11 (Ws)	3	750	15 (Ws)
56	4/11/11 (Friday)	1	685	10 (Ws)	1	705	13 (Ws)
		2	695	9 (Ws)	2	695	10 (Ws)
		3	655	8 (Ws)	3	680	12 (Ws)
90	8/12/11 (Thursday)	1	665	10 (Ws)	1	690	14 (Ws)
		2	694	10 (Ws)	2	691	12 (Ws)
		3	690	11 (Ws)	3	694	12 (Ws)

RH BOUGUE COMPOUNDS AGAINST CLYDE MOORE

Cement	A/F	C ₂ S		C ₃ S		C ₃ A		C ₄ AF	
A	0.5	-81.2	-87.74	157.79	166.48	NF	-1.94	14.34	15.88
B	0.24	-134.87	-146.75	212.48	228.25	NF	-5.36	11.11	15.37
C	0.31	-137.94	-144.76	219.71	228.76	NF	-3.94	10.63	13.74
D	0.18	-168.69	-175.12	253.48	262.01	NF	-6.72	11.53	16.86
E	0.19	-173.13	-182.53	253.43	265.92	NF	-6.88	12.16	17.62