USE OF COCONUT SHELL AS COARSE AGGREGATE IN LIGHTWEIGHT CONCRETE

BY

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DECLARATION

I declare that the work in this dissertation entitled "**Use of coconut shell as coarse aggregate in lightweight concrete"** has been carried out by me in the Department of Civil engineering. The information derived from the literature has been duly acknowledged in the text and list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other Institution.

AFOLAYAN Jacob Oyeniyi _____ _____

Signature Date

CERTIFICATION

This dissertation entitled **"USE OF COCONUT SHELL AS COARSE AGGREGATE IN LIGHT WEIGHT CONCRETE"** by Jacob Oyeniyi AFOLAYAN meets the regulations governing the award of the degree of Ph.D degree in Civil Engineering, of Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation

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DEDICATION

This Dissertation is dedicated to the blessed memory of my mother MRS COMFORT AJONI APE AFOLAYAN and my eldest sister MRS OLUFUNMILAYO ADUKE NINIOLA SUBERU.

ABSTRACTS

This research work reports the investigation carried out to determine the use of coconut shell as an aggregate in light weight concrete. Concrete samples were produced with different mix ratios, to determine the best and economic proportions that will give acceptable compressive strengths. Coconut shell aggregate exhibits low impact, crushing, and abrasion values of 1.3%, 1.16% and 2.23% respectively compared with normal aggregate with 19.23%, 25.60% and 27.67% respectively. Coconut shell, however, has high percentage of water absorption capacity, *elongation* index and flakiness index of 23.72%, 26.69% and 86.12% respectively compared with that of normal aggregate of 1.80%, 8.78% and 36.89% respectively. Concrete specimen were produced with coconut shell as coarse aggregate, ordinary river sand as fine aggregate and ordinary Portland cement as binders. Trial mixes which include (1:1:1, 1:1½:2, 1:2:2, 1:2½:3, 1:1½:3, 1:2:4, 1:2:3, 1:3:3, 1:3:4, 1:4:4) were done and it was observed that mix ratio 1:1:1 and 1:2:2 gave good consistency and workability with water cement ratio 0.5. The mix ratio 1:1:1; 1:2:2 gave compressive strength of 16N/mm^2 and 7.71N/mm^2 at 28day strength test respectively. In addition Partial replacement of normal coarse aggregate with coconut shell was also carried out using the following percentages of 0%, 25%, 50%, 75% and 100% for a mix ratio1:2:4 .The results shows that 25% to 50% normal coarse aggregate replacement with coconut shell results gave 28N/mm^2 and 22.5N/mm^2 at 28day with water cement ratio 0.5.

TABLE OF CONTENTS

CONTENT		PAGES
Title page		i
Declaration		ii
Certification		iii
Acknowledgment		iv
Dedication		v
Abstract		vi
Table of contents		viii
List of Appendices		xii
List of tables		xiii
List of Figures		xv
List of Plates		xvi
CHAPTER ONE: INTRODUCTION		
1.0	Preamble	1
1.1	Statement of Research Problem	2
1.2	Scope of Work	3
1.3	Aims and Objective of the Study	4
1.4	Justification of the study	4

CHAPTER TWO: LITERATURE REVIEW **5**

2.1 Introduction 5

2.1 Coconut Shell 23

2.1.1 Anatomy of Coconut Fruits 27

2.2 Aggregates 39

2.3.1 Classification of Aggregates 40

2.3.1.1 Classification According to Geological Origin 40

2.3.1.2 Classification According to Size 40

2.3.1.3 Classification According to Shape 41

2.3.1.4 Flaky and Elongated Aggregates 41

2.3.1.5 Classification Based on Unit Weight 41

2.3.2 Light Weight Aggregate 41

2.3.3 Aggregates manufactured from natural raw material 42

2.3.3.1 Industrial by product lightweight aggregate 43

2.3.3.2 Naturally occurring lightweight aggregate 44

CHAPTER THREE: MATERIAL AND METHODS **46**

3.1 Material tests 46

3.2 Ordinary Portland Cement test 46

3.2.1 Experiments 46

3.2.2 Soundness of cement paste 47

3.2.3 Setting time of cement paste 48

3.2.4 Fineness test 48

3.2.4 Chemical composition test of the OPC used 49

3.3 Aggregates 51

3.3.1 Fine Aggregate 51

3.3.2 Coarse Aggregate 53

3.3.3 Coconut Shell Aggregate 61

3.4 Water 71

3.5 Trial mixes 71

3.6 Mix design 75

3.7 Partial replacement of normal aggregate with coconut shell 78

CHAPTER FOUR: RESULTS AND DISCUSSION 79

4.1 Ordinary Portland cement (OPC) test 79

4.1.1 Cement Soundness 79

4.1.2 Setting time of cement paste 79

4.1.3 Cement fineness 80

4.1.4 Chemical composition of OPC used 81

4.2 Mechanical properties of the aggregates 83

4.2.1 Specific gravity of aggregates 83

4.2.1.1 Specific gravity of fine aggregates 83

4.2.1.2 Specific gravity of Coconut shell aggregates 84

4.2.1.3 Specific gravity of Crushed stone aggregates 84

4.2.2 Aggregate bulk density 84

4.2.2.1 Fine aggregate bulk density 84

4.2.2.2 Crushed stone aggregate bulk density 84

4.2.2.3 Coconut shell aggregate bulk density 84

4.2.3 Aggregate particle size distribution analysis 85

4.2.3.1 Fine aggregate particle size distribution 85

4.2.3.1 Coarse aggregate particle size distribution 87

4.2.3.1 Coco nut shell particle size distribution 88

4.2.4 Aggregate impact Value 89

4.2.4.1 Coco nut shell aggregate Impact Value 89

4.2.4.2 Crushed stone aggregate Impact Value 90

4.2.5 Aggregate Crushing Value 90

4.2.5.1 Coconut Shell Aggregate Crushing Value 90

4.2.5.2 Crushed stone Aggregate Crushing Value 90

4.2.6 Aggregate Abrasion Value 91

4.2.6.1 Coconut Shell Abrasion Value 91

4.2.6.2 Crushed stone Abrasion Value 92

4.2.7 Aggregate Porosity/Water absorption capacity 92

4.2.7.1 Coconut Shell aggregate Porosity/Water absorption capacity 92

4.2.7.2 Crushed stone aggregate Porosity/Water absorption capacity 93

4.2.8 Aggregate elongation Index 93

4.2.8.1 Coconut shell aggregate elongation Index 93

4.2.8.2 Crushed stone aggregate elongation Index 93

4.2.9 Aggregate flakiness index 94

4.2.9.1 Coconut Shell aggregate flakiness index 94

4.2.9.2 Crushed stone aggregate flakiness index 94

4.3 Compressive Strength test Results 121

4.3.1 Compressive strength test results of coconut shell concrete (agg size 10mm) 95

4.3.2 Compressive strength test results of coconut shell concrete (agg size 12mm) 95

4.3.3 Compressive strength test results of coconut shell concrete (agg size 16mm) 95

4.3.4 Compressive strength test results of coconut shell concrete (agg size 16mm) with mix ratio 1:2:2 95

4.4 Partial replacement of normal aggregate with coconut shell aggregate 96

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION 100

5.1 Conclusion 100

5.2 Recommendation 101

REFERENCES 102

LIST OF APPENDICE

APPENDIX I: Value of length and diameter of sample of fibre 116

APPENDIX II: Aggregate Specific gravity 134

APPENDIX III: Bulk density 140

APPENDIX IV: Particle size distribution Analysis 143

APPENDIX V: Aggregate impact value 146

APPENDIX VI: Aggregate Crushing Value 149

APPENDIX VII: Aggregate Abrasion Value 152

APPENDIX VIII: Aggregate Absorption Capacity 155

APPENDIX IX: Aggregate elongation Index 157

APPENDIX X: Aggregate Flakiness Index 160

APPENDIX XI: Compressive strength results 163

LIST OF TABLES

Table 2.1	Chemical Composition of Coconut shell	23
Table 2.2	Coefficient of thermal expansion of lightweight aggregate Concrete	31
Table 2.3	Variation of cement content aggregate cement ratio	39
Table 3.1	Soundness test results of ordinary Portland cement used	47
Table 3.2	Initial and final setting time for the OPC used	47
Table 3.3	Fineness test results of OPC used	48
Table 3.4	Fineness test results of cement according to NIS 11 (1974)	48
Table 3.5	Oxide composition result of OPC used	49
Table 3.6	Physical and chemical characteristics of cement used	50
Table 3.7	Chemical composition of main compound of OPC used	51
Table 3.8	Specific gravity of Fine aggregate used	52
Table 3.9	Bulk density of fine aggregate	52
Table 3.10	Particle size distribution – fine aggregate	53
Table 3.11	Specific gravity of Crushed stone aggregate used	54
Table 3.12	Bulk density of crushed stone aggregate	55
Table 3.13	Particle size distribution – Coarse aggregate	55
Table 3.14	Crushed stone aggregate impact value	56
Table 3.15	Crushed stone aggregate crushing value	57
Table 3.16	Crushed stone aggregate abrasion value	58
Table 3.17	Crushed stone aggregate absorption capacity	59

Table 3.18	Crushed stone aggregate elongation index	60
Table 3.19	Crushed stone aggregate flakiness index	61
Table 3.20	Specific gravity of Coco nut shell aggregate used	63
Table 3.21	Bulk density of coconut shell aggregate	
Table 3.22	Particle size distribution- coconut shell aggregate	65
Table 3.23	Coconut shell aggregate impact value	65
Table 3.24	Coconut shell aggregate crushing value	66
Table 3.25	Coconut shell aggregate abrasion value	67
Table 3.26	Coconut shell aggregate absorption capacity	68
Table 3.27	Coconut shell aggregate elongation index	69
Table 3.28	Coconut shell aggregate flakiness index	70
Table 3.29	Physical characteristics of coarse and coconut shell aggregate	71
Table 3.30	Material proportion for the various mix ratios (coco nut shell concrete)	76
Table 3.31	Compressive Strength results for the coconut shell aggregate concrete	77
Table 4.1	Soundness of cement paste test results	79
Table 4.2	Cement sample setting time results	80
Table 4.3	Cement sample fineness compared with the standard	80
Table 4.4	Comparism of oxide composition results of Dangote cement Used with the standard	81
Table 4.5	Chemical composition of main compounds of OPC used	82

LIST OF FIGURES

Figure 2.1	The World Map of Coconut growing regions	25
Figure 2.2	Relationship between effective water cement ratio and compressive Strength of lightweight concrete	37
Figure 4.1	Particle size distribution of fine aggregate	86
Figure 4.2	Particle size distribution of coarse aggregate	87
Figure 4.3	Particle size distribution of coconut shell aggregate	88
Figure 4.4	Compressive strength development of coconut shell aggregate (1:1:1)	97
Figure 4.5	Compressive strength development of coconut shell concrete 1:2:2)	98
Figure 4.6	Compressive strength development of replacement of normal Aggregate with Coconut shell	99

LIST OF PLATES

Plate I	First bridge made from OPS	20
Plate II	Low cost house with OPS	20
Plate III	Coconut Shell waste dump	26
Plate IV	Typical coconut Tree	27
Plate V	An unopened coconut fruit	27
Plate VI	Coconut shell aggregate before crushing	62
Plate VII	Machine crushed coconut shell aggregate	62
Plate VIII	Segregation of mix ratio 1:2:4	72
Plate IX	Cubes from mix ratio 1:3:3	73
Plate X	Mix ratio 1:1:1 preparation	73
Plate XI	Mix ratio 1:1:1 specimen being casted in the mould	74
Plate XII	Coco nut shell cube from mix ratio 1:1:1	74
Plate XIII	Coco nut shell cube from mix ratio 1:2:2	75

CHAPTER ONE

INTRODUCTION

1.1 PREAMBLE

Global attention has been focused on environmental preservation due to alarming depletion of ozone layer as a result of pollution resulting from manufacturing processes. It was reported by Mehta (2001) that "cement production, coarse aggregate mining, processing and transportation operations accounts for about 7% of the global loading of carbon dioxide into the atmosphere due to considerable amount of energy consumed, thereby affecting the ecology of the forested areas and river beds.

In an attempt to reduce environmental degradation, close attention is now being paid to material recycling and the use of agricultural and industrial wastes in concrete production. In civil engineering practice and construction works, large volumes of coarse aggregates are usually used in the production of concrete.

Gambhir (2005) reported that coarse aggregate constitutes about 75% to 85% of the concrete matrix. Concrete being one of the major building materials that is used virtually in all aspects of construction and could be delivered to the job site, and be molded in situ or pre-cast to any form or shape, makes it a material of choice in construction. Hence the significance and relevance of coarse aggregate in concrete production in all areas of civil engineering practice and building construction cannot be ignored.

The basic constituents of concrete are cement, fine aggregate (sand), coarse aggregate (granite chipping) and water.

Nigeria being a developing country is faced with inadequate provision of physical infrastructure; shelter and related amenities, which are typical factors of under development that need to be addressed through provision of alternative, cheap and affordable materials. In these areas development require the use of cement and other related materials such as coarse aggregate. Technologies which can provide means of upgrading shelter within the scope of the socio economic and cultural environment need to be developed (Elinwa, 2003) .

Currently, research efforts have been geared towards sourcing, development and the use of local alternative construction materials including the possibility of using some agricultural wastes and residues as construction materials. Some investigations made shown that it is possible to produce concrete using agricultural, urban and industrial wastes material, (Gambhir, 2005). Hence the focus of this research is to investigate the use of coconut shell as an aggregate in concrete through experimental investigation.

1.2 STATEMENT OF RESEARCH PROBLEM

The use of wastes material as basic raw material in concrete production may provide foreseeable solution to the challenges of waste management. However, records have shown that industrial by-products such as sintered pulverized fuel ash (fly ash), formed or expanded blast-furnace slag and other material of plant origin which are considered as wastes have been used in concrete; these include wood saw dust, coconut pitch, rice husk, wheat husk, groundnut husk, etc. Coconut shell which is referred to as endocarp may be useful as aggregate for concrete production. However, the concrete produced using coconut shell as either main aggregate or

partially replacing the normal aggregate must have the necessary engineering performance characteristics (workability, consistency, compressive strength, etc) to meet the standard code of practice specifications. Hence the need for the investigation of the suitability of coconut shell aggregate in concrete. Other conditions that need to be addressed are the issue of environmental impact and the effect on health. Finally, the relevant code requirements and required test methods must be used to assess these waste materials.

The focus of this research is to tackle the following questions:

(i) Can coconut shell be used in concrete production?

(ii) If yes, is it environmental friendly?

(iii)What positive or negative impact does it have on concrete production?

1.3 SCOPE OF WORK

The scope of this work is limited to the following:

i. To determine the optimum percentage replacement of the coconut shell in concrete without compromising the strength.

ii. The mechanical properties of coconut shell.

iii. Test of the compressive strength of coconut shell concrete.

iv. The engineering properties of other aggregates used in the concrete (stone and fine aggregate)

v. The chemical properties of the binder used (ordinary Portland cement)

vi. Test of compressive strength of cubes with partial replacement of normal Stone aggregate with coconut shell.

vii. The analysis of the results obtained from the tests and drawing conclusions from the results.

1.4 AIM AND OBJECTIVE OF THE STUDY

The aim of this research is to investigate the use of coconut shell as coarse aggregate in concrete, through:

i. Characterization of the materials used for the works.

ii. Experimental determination of the mechanical properties of the concrete.

1.4 JUSTIFICATION OF THE STUDY

The availability and the cost of stone crushed coarse aggregate in Nigeria varies from the North to the South. The availability in the rural setting is a worrisome scenario. Although, coconut shells are often dumped as agricultural wastes, it is not commonly used in the construction industry.

However, with the quest for affordable housing system for both rural and urban population in Nigeria, locally available material will help in cutting down spending on conventional building material. One of the forefront suggestions has been the sourcing, development and use of available local materials such as agricultural wastes and residues as construction materials. Therefore, the research is designed to produce experimental results which can be used to establish the properties of concrete produced from coconut shell aggregate. It will also help to establish the level of percentage replacement of normal stone crush aggregate in concrete. The experimental results will be useful in making appropriate recommendation of the material in design and construction of concrete from coconut shell aggregate concrete.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

The growing concern of resource depletion and global pollution has challenged many engineers to seek and develop new materials relying on renewable resources (Teo et. al, 2006). These include the use of by-products and waste materials in building construction. In developing countries where abundant agricultural and industrial wastes are discharged, these wastes can be used as potential material or replacement material in the construction industry. This will have the double advantage of reduction in the cost of construction material and also as a means of disposal of wastes. Many of these by-products are used as aggregate for the production of concrete. Although, there has been much research conducted on the structural performance of normal stone aggregate concrete, these are mostly confined to naturally occurring aggregates, manufactured aggregates, and aggregates from industrial by-products. Coarse aggregate in concrete production will continue to play a significant role as a construction material in long time to come.

Mehta (2001) reported that ordinary concrete typically contains about 12% cement and 80% aggregate by mass. This means that globally for concrete making sand, gravel and crushed stone are being consumed at the rate of 10 to 11 billion tons every year. He further said that the mining, processing, and the transportation operations involving such large quantities of aggregates consume considerable amounts of energy and adversely affects the ecology of forested areas and river beds. This large amount of energy consumption in aggregate production contributes to the global loading of carbon dioxide into the atmosphere and subsequently the

green house effect. Therefore, the use of alternative materials to normal aggregate in concrete is of paramount importance. Hence the agricultural and industrial wastes which constitutes nuisances both to our health and environment can be converted into useful materials by either burning them into ashes, converting them from the original state and used in various proportions with cement, and thus reduce the cost for concrete works (Elinwa, 2003).

Gambhir (2005) stated that the forms in which waste materials are used are wide and varied, they may be used as binder material and as partial replacement of conventional Portland Cement.
Tay (1990) and Toress et. al (1999) also reported that waste materials generated from industrial and agricultural activities can be recycled into new building materials, because they reduce carbon dioxide (CO_2) emission and used less energy consumption in processing or they can be used directly as aggregate in their natural or processed states.
Payam et. al, (2010) observed that to build environmentally sustainable structures, especially in developing countries, the possibility of using some agricultural wastes and industrial by-products from different industries as construction materials will be highly desirable and has several practical and economical advantages.
Delsye et. al (2006) reported that exploitation of waste material from agricultural source lead to sustainable building material in construction industry which will help in preserving the natural resources and also helps maintain ecological balance.

Gambir (2005) Classified waste materials into three categories.

i) Organic wastes (agro wastes)

ii) Inorganic wastes (urban waste)

iii) Industrial wastes.

The focus of this Dissertation is organic waste material from the agricultural origin.

The waste materials categorized as organic wastes are of plant origin, namely wood saw dust, coconut pitch, coconut shell, palm kernel shell, rice husk, wheat husk, groundnut husk, plant fibre, etc. It must be appreciated that development of concrete using coconut shell as aggregates is still in early stages and published data are limited. Gambhir (2005) suggested that before using organic wastes on a large scale as constituents in concrete, careful investigations regarding their properties and durability need to be carried out.

Madakson et. al (2012) worked on characterization of coconut shell ash for potential utilization in metal matrix composites for automobile applications. Their research centered on the identification of characteristic of coconut shell ash using spectroscopic and microscopic analysis, density, and particles size, refractories SEM, XRD, and FHR spectroscopic methods were used for the characterization of the coconut shell ash. The result shows that the coconut shell ash possesses nearly same chemical phases and other functional groups as reinforcement bagasse ash that has been in metal matrix composites specifically for automobile application. They concluded that coconut shell ash can be used as a low cost reinforcement in metal matrix composites.

Faisal et. al (2011) researched on the "effect of maleic anhydride polypropylene on the properties of coconut shell filled thermoplastic elastometric Olafin composites". They described coconut shell as an agro wastes material which has high natural liqno cellulosics content. This they said provides a potential resource as reinforcement agent in thermoplastic elastometric Olafin. The effect of coconut shell loading and maleic anhydride poly propylene as compatibilizer on

mechanical properties, morphology and thermal properties were studied and the results show that the increases of coconut shell loading has increased the tensile strength, elongation at break and young modulus of thermoplastic elastometric Olafin/coconut shell composites.

George and Vinaya (2002) published a report on "Phito acoustic evaluation of the thermal diffusivity of coconut shell" using laser induced photo acoustic technique. It was found that laser induced heating of the coconut shell results in a thermo elastic bending of the sample. However, taking into account this effect, an appropriate modification of Rosencwaig-Gersho theory for the photo elastic effect was made, for the calculation of thermal diffusivity. The final investigation shows that coconut shell possesses a larger thermal diffusivity than ordinary wood.

Sukarton et. al (2011) reported the incorporation of coconut shell in Bio char as a way of overcoming soil fertility problems. They described Bio char as carbon rich products obtained when organic biomass is heated under limited or without oxygen condition. Bio char produced from coconut shell had higher carbon with typically less ash and it contains mineral nutrients compound compare with Bio char produced from cattle dung.

Gimba et. al (2008) worked on the "optimum conditions for carbonization of coconut shell". Carbonization is the production of charred carbon from a source material. The process is generally accomplished by heating the source material usually in the absence or limited amount of air to a temperature sufficiently enough to dry and volatilize substances in the carbonaceous material (Hassher, 1963).

It was reported by Gimba (2001) that coconut shell contains about 65 – 75% volatile matter and moisture which are removed largely during the carbonization process. This study addressed determination of yield, rate of weight loss, optimum temperature as well as determination of ash and moisture contents of the carbonized carbon and suitable resident time for carbonization. The result shows a maximum yield of 27% of carbonized product. The characteristic particle size of 500µ mm, carbonization temperatures of 500 – 600^{O}C at resident time of 5 minutes were the optimum production conditions.

Imoisilli et. al (2012) investigated the "Effect of concentration of coconut shell ash on the tensile properties of Epoxy composites". Having experimented with five filler concentrations (5 – 25% by weight) the test reports show that tensile strength, elastic modulus and micro hardness of the composite increase with increase in filler concentration, while percentage elongation and load at break decreases with increase in filler concentration. He concluded that coconut shell ash can be used as reinforcing filler in epoxy composites.

Rathanak and Ranat (2005) reported the great potential of coconut shell powder as a filler in producing biodegradable plastic composite in future. They studied the mechanical properties and bio degradability study of coconut shell powder filled low density polyethylene filler. The parameters tested include mechanical testing, tensile, and burst test. While the biodegradable test was carried out using microbes, Pseudomonas and E. Coli. It was concluded that the integration of coconut shell powder resulted in increment in modulus of elasticity burst strength and biodegradability, but reduction of tear strength, tensile strength and elongation at break. This is due to poor adhesion between the polymer and fiber.

Sapuan and Hurimi (2003) also reported their findings on mechanical properties of epoxy/coconut shell filler particle composites. The parameters tested were the tensile and flexural properties of composites made from coconut shell filler particles and epoxy resin. The tensile and flexural tests composites based on coconut shell filler particles at three different filler contents viz 5%, 10% and 15% were carried out using universal tensile testing machine according to ASTM D 3039/D, 3039 M – 95a and ASTM D 790 – 90 respectively. The experimental results show that tensile and flexural properties of the composites increased with the increase of the filler particle contents. It was also reported that the composite materials demonstrate somewhat linear behaviour and sharp fracture for tensile and slight non-linear behaviour and sharp fracture for flexural testing. The relation between stress and percentage of filler for tensile and flexural test were found to be linear with correlation factors of 0.9929 and 0.9973 respectively. The relation between the modulus and percentage of filler for tensile and flexural tests, it was found to be a quadratic relation with the same correlation factor approximated to 1.

Husseinsyah and Mustapha (2011) researched on the effect of filler content on properties of coconut shell filled polyester composites. In the study, coconut shell was used as filler in polyester composites. Polyester composite was prepared by incorporating coconut shell at different contents (0, 15, 30, 45, 60%) into polyester matrix. A catalyst butanox M - 60 was used to initiate he polymerization reaction. The effect of coconut shell content on the mechanical, water absorption and morphological properties were studied. The results revealed that increase in coconut shell content have increased the tensile strength, Young’s modulus and water absorption,

but reduced the elongation at break. The result from scanning electron microscopy (SEM) showed that increase in filler content, increased the tendency of filler – matrix interaction.

Bhaskar et. al (2012) reported their research work on water absorption and compressive properties of coconut shell particles reinforced epoxy composite. Coconut shell particles reinforced composites were fabricated by reinforcing shell particles (size between 200 – 800μmm) by weight % of 20, 25, 30 and 35 into epoxy matrix. The experimental results showed that water absorption increased with increase of weight % of particle, but compressive properties increased up to 30 weight % of particle approaches to actual compressive strength of epoxy.

Agunsoye et. al (2012) studied the mechanical behavior of coconut shell reinforced polymer matrix composite. The focus of the study was the evaluation of the morphology and mechanical properties of coconut shell reinforced polyethylene composite to establish the possibility of using it as a new material for engineering applications. Coconut shell reinforced composite was prepared by compacting low density polyethylene matrix with 5% - 25% volume fraction coconut shell particles and the effect of the particles on the mechanical properties of the composite produced was investigated. The result shows that the hardness of the composite increased with increase in coconut shell content though the tensile strength, modulus of elasticity impact energy and ductility of the composite decreased with increase in the particle content, while the Scanning Electron Microscopy (SEM) of the composites (with 0% - 25% particles) surfaces indicates poor interfacial interaction between the coconut shell particles and the low density polyethylene matrix. It was concluded that coconut shell particles improved the hardness

property of the polyethylene matrix composite, which is an added requirement for automobile interior.

Chanap (2012) on the mechanical and flexural properties of coconut shell ash reinforced epoxy composites. Carbonization method was used to prepare the coconut shell ash by heat-treating the crushed coconut shell at a temperature of 600 and 800^{oc}, density, particle size and X – Ray diffractometer methods were used for the characterization of coconut ash shell. The coconut shell ash epoxy composites were prepared by different filler concentration using hard layup technique. It was observed that at 20% of filler content, coconut shell ash which was heat treated at 800^{oc} gives the best results for micro hardness, flexural strength and tensile strength properties of the composite under consideration.

Faisal (2010) presents research reports on the "Effect of Acetic acid on properties of coconut shell filled low density polyethylene composites. He referred to coconut shell as the ligno cellosic material. In the study coconut shell was used as fillers in Low Density Polyethylene (LDPE) composites. The effects of surface treatment of coconut shell with acetic acid (acetylation) on mechanical properties, thermal properties and morphology were studied. It was reported that acetylation treatment has improved the tensile strength, elongation at break and Young modules of LDPE/CS composites. The thermogravimetric analysis (IGA) results show that the acetylated composites has better thermal stability compared to untreated composites at 600^{0C}. Differential scanning calorimetry analysis showed that the esterification treatment increases the crystallinity of LDPE/CS composites. It was also found that coconut shell acts as a nucleation agent in the presence of acetylic acid. The scanning electron microscopy (SEM) study

of the tensile fracture surface of acetylated composites indicates that the presence of acetic acid increased the interfacial interaction.

Ganapathy and Natarajan (2009) studied the pyrolysis of coconut shell, he described pyrolysis as one of the thermo chemical process which converts the solid biomass into liquids (bio oil), gas and solid. The optimum process conditions for maximizing the liquid yield from the coconut shell pyrolysis in a fixed bed reactor cover was identified. The highest liquid yield was obtained at a pyrolysis temperature of 550^{0C} particle size of 1.18 – 1.80mm, with a heating rate of 60^{0C}/mm in a 200mm length reactor. The results indicate that the effects of pyrolysis temperature and particle size on the pyrolysis yield are more significant than that of heating rate and residence times.

Olontser et. al (2010) also researched on the pyrolysis of coconut shell for the manufacture of carbon sorbents. They described pyrolysis as the currently workable methods for the thermal processing of organic fuels. The yield and the character of the resorting pyrolysis products depend on the molecular structure of the organic matter, the degree of metamorphism, the rate of heating, the removal of volatile substances and the intensity and time of thermal action. He concluded that it is reasonable to perform the pyrolysis of coconut shells without preliminary crushing.

Singhapura et. al (2012) carried out investigation on compressive strength of masonry blocks manufactured using crushed coconut shells. Solid masonry blocks having the size of 360mm x 100mm x 70mm were casted with the mixed proportion of 1:5cement: sand ratios.

Coconut shells were crushed, sieved and added to the mixture in different proportions to determine its optimum percentage utilization. The blocks were experimented for 7, 14 and 28 day compressive strength. Compressive strength of crushed coconut shell based sand cement blocks with 20%, 25%, 30% (volume basis) of crushed coconut shell was experimented to determine if crushed coconut shell aggregate can be used as full replacement of coarse aggregates and its optimum percentage. It was reported that the structural performance of crushed coconut shell based sand cement blocks were compared with some percentage of coarse aggregate sand cement blocks (i.e control blocks).

Water absorption capacity was also investigated for the crushed coconut shell based masonry blocks and was also compared with the conventional cement/sand block with coarse aggregate. The water absorption capacity was below 12% which is the maximum water absorption allowable for masonry blocks.

Sarkar et. al (2011) examined "the behaviour of reinforced concrete beams with coconut shell as coarse aggregate". The experiments were conducted on a loading frame of capacity of 400KN. The beams were tested as a simply supported beam with a clear span of 2500mm and it is subjected to two points loading. It was reported that specimen with 25%coconut shell aggregate shows initial crack at 25kN loading while the control experiment shows an initial crack at 35kN loading. The 50% and 75% coconut shell replacement shows initial cracks at 30kN and 35kN loading respectively.

Oyelade (2011) investigated coconut husk ash as a partial replacement of cement in sandcrete block production. The coconut husk ash was replaced at 0% to 30% levels using mix ratio 1:8

and specimen were tested at 7, 14, 21 and 28 days. He reported 2.1N/mm^2 maximum compressive strength at 5% replacement at 28 days. The compressive strength of the ordinary Portland cement/coconut husk ash sandcrete blocks generally decreases as the percentage of coconut husk ash content is increases. The maximum 2.10N/mm^2 for the 5% replacement level was found suitable because it is slightly higher than the values specified in the Nigerian National Building Code (2006) for loaded bearing walls.

Olugbenga et. al (2010) also investigated the "Potentials of coconut shell and husk ash on the geotechnical properties of lateritic soil for road works". Soil samples were collected from three barrows pits meant for road construction works, preliminary tests were performed on them for identification and classification purposes. Engineering properties tests such as compaction, California bearing ratio (CBR) and triaxial were done on both the stabilized and unstabilized states with the additions of 2, 4, 6, and 8% coconut shell and husk ash contents. The results show that the engineering properties of the samples were further improved with the addition of 4% coconut shell husk ash contents. The investigation revealed that there was a reduction in the plasticity index of the samples A and C from 20.43 to 16.74% and 29.51 to 15.67% respectively and reduction at 2% of C8HA in sample B. the maximum mixture dry density and shear strengths at 4% CSHA stabilization. The subsequent addition of CSHA increased the values of shear strengths to 136.32, 146. 91 and 127.96N/mm^2, whereas MDD increased to 1939.00, 1749.86 and 2080.25Kg/m^2 respectively in samples A, B and C. It was concluded that coconut shell and husk ash has a good potential for improving the geotechnical properties of lateritic soils.

Okenyi (2004) worked on the use of Coconut shell fibers in Cement/Concrete composites. Coir is position beneath the outer covering of the fruit and envelops the kernel or coconut shell. Coir is obtained from the husk or mesocarp, which is removed in the preparation of copra. The husk are broken by hand or by the use of a bursting machine. The extraction of the fibres involves retting at the edges and also in the pits or in modern operations in concrete tanks. The retted husks are beaten with sticks to remove extraneous matter and the dried fibre is suitable for spinning. Rougher fibre require less retting and the fibres are extracted from the husks mechanically. In his findings coconut husk fiber has an average length of 103mm, average diameter of 0.029mm and relative density of 0.9 as shown in Appendix I (a). He also observed that the composite plates produced shows that flexural and tensile strength of concrete can be improved by twice of its value when reinforced with coconut shell fiber as indicated in Appendix I (b). And the impact resistance of the composite plates improves with the coconut husk fibre as shown in Appendix I (c). He concluded that coconut fiber is a suitable vegetable fiber for the reinforcement of concrete for various concrete uses like roofing tiles, reinforcement in structural members in kerbs and chutes and underground concrete pipes for water distribution. He recommended that:

i. Coconut shell fiber is a suitable vegetable fiber for the reinforcement of concrete for various concrete uses like roofing tiles, and as reinforcement in structural members and in kerbs and chutes, underground concrete pipes for water distribution and many other concrete uses.

ii. The 1:3 mix ratio (cement-sand) is noticeably better when reinforced with coconut shell fibres than the 1:4 mix as used in concrete roofing tiles probably due to its richer cement composition which fills the voids making it less permeable to water and other liquids.

iii. The impact resistance of concrete improved when reinforced with coconut shell fibres, and therefore the fear of damage when it is being handled is reduced.

iv. The adhesive property (frictional force) offered penetrating nails and lack of cracks even when the nails penetrate the reinforced concrete is an advantage the fiber reinforced plates have in roofing tiles which have to be fastened by concrete nails and screws.

v. Plain concrete being a brittle material with low tensile strength and strain can have these properties of low tensile strength and strain improved by the coconut reinforcement for use as underground pipes for water distribution which carry loads from soil and internal pressure from the water being carried.

vi. The strength of the plates increase with time.

vii. Coconut fiber reinforced concrete improves the tensile strength of concrete helping concrete to withstand tensile stress in concrete members, which may occur due to restraint to contraction due to drying or temperature variation.

viii. Coconut fibre reinforced concrete can be used in road pavements and run ways.

Another agricultural waste which is being used in concrete is palm kernel shell which is a by-product from the processing of palm fruits. They are derived from the oil palm tree (elaeis guineensis). It is an economically valuable tree and native to Western Africa and wide spread through the tropics.

Basri et. al, (1999) described palm kernel shell as hard in nature and does not deteriorate easily once bound in concrete and therefore it does not contaminate or leach to produce toxic substances.

Owens (1993) reported that OPS aggregate has a unit weight of 500-600 kg/m^3 and this is approximately 60% lighter compared to the conventional crushed stone aggregates. Earlier investigations showed that OPS can be used as coarse aggregate in concrete (Mannan and Ganapathy, (2004) and Teo et al., 2005). The behaviour of OPS concrete in a marine environment was also previously studied (Mannan and Ganapathy, 2001).

Peter (2008) also investigated the performance of palm kernel shell as a partial replacement of coarse aggregate in asphalt concrete. He observed that palm kernel shell can be used to replace coarse aggregate up to 30% before drastic reduction in strength becomes noticeable. He therefore recommended that for heavily trafficked roads, palm kernel shells up to 10% can be used for the replacement while even 100% replacement is possible for lightly trafficked roads in rural settings. He presented the physical properties of palm kernel shell as in shown in Appendix I (d). and for the marshal stability and flow in appendix I (e). He concluded that:

i. Palm kernel shells can serve as partial replacement of coarse aggregate up to 10% for trafficked roads and 5% for light trafficked roads.

ii. For the very lightly trafficked roads in the rural communities palm kernel shells can be used as full replacement for the coarse aggregate. This will go along way into reducing construction and maintenance costs of these needs.

iii. The quest by government in developing countries especially those in Africa South of the Sahara for use of locally available materials in infrastructure development will be met with the use of palm kernel shells as a road construction materials.

iv. The economic power of the rural dwellers will be enhanced, if they are encouraged to plant palm trees from where these shells could be gotten.

Ndoke (2006) also investigated the suitability of Palm kernel shell as a dust control palliative on unpaved road. He reported that palm kernel shells were able to reduce the quantity of dust generated from the road to about 75% a few days after the application. It was then suggested that with the absence of funds for road maintenance works organic materials like palm kernel shells could be used as palliatives. He suggested that

i. Palm kernel shells could be used as a dust control palliative as this will reduce the quantity of dust generated from the road surface.
ii. The use of the shells will go a long way in reducing impact of dust on dust-sensitive vegetation, vehicular action, respiratory problems, complain from public road users and sedimentation in water bodies.
iii. Immediate application of palm kernel shells reduced the dust produced from the road at some speeds to zero. The rate of preservation of materials was between 75 and 100%.
iv. Daily monitoring of the effectiveness of the palm kernel shells showed that vehicular compactive action which led to the embedding of some of the shells exposed the surface which released some more dust. More shells should be placed on the exposed surface.
v. With the paucity of funds in developing countries for construction purposes, use of these natural materials can be encouraged as these are readily available.

Previous studies by Ogedengbe (1985), Nuhu-Koto (1999), Olateju (1992), Falade (1992), Omange (2001) and Ayangade (2004) have shown that palm kernel shell is suitable as granular fitter for water treatment, and as aggregate in plain light and dense concrete. In the University of Malaysia located at Sabah a small foot bridge of about 2m in span was constructed in May 2001 with oil palm shell as shown in plate I. In the year 2003 period a low cost house with floor area of about $59m^2$ was also built the picture is as depicted in plate II (Teo et. al 2006).





Plate I: Foot bridge made from OPS and Plate II: Low cost House with OPS

Adewuyi and Ola (2008) carried out an exploratory study of periwinkle shells as coarse aggregate in concrete work. Perinwinkle shells (*Nodilittorina radiatta*) are small greenish blue marine snails with spiral conical shell and round aperture. They are common in the riverine areas and coastal regions where they are used for food. They reported that the hard shells which are regarded as wastes and ordinarily posed environmental nuisance in terms of its unpleasant odour and unsightly appearance in open dump sites and located at strategic places was considered as full or partial replacement of normal aggregate in concrete. Their investigation focused on the physical properties of periwinkle shell, the compressive strength of specimen produced from the shells to determine the optimum percentage replacement without compromising the strength. They carried out experimental exercises on 300 concrete cubes of size 150 x 150 x150mm^3 with different percentages by weight of crushed granite to periwinkle shells as coarse aggregate in order of 100:0, 75:25, 50:50, 25:75, and 0:100. They investigated the physical and the mechanical properties of the specimen. The compressive strength tests showed that 35.4% and 42.5% of the periwinkle shells in replacement for the granite was quite satisfactory with no compromise in compressive strength requirements for mix ratios 1:2:4 and 1:3:6 respectively. It was reported that there is a saving of 14.8% and 17.5% for the two mixes respectively by adopting 35.4% and 42.5% periwinkle inclusion. The result of the workability of the concrete batches using slump test is as shown in Appendix I (f).

Tay (1990) reported that oil palm ash is obtained when shell and fibre are used for fuel for the production of steam in the palm oil mills as a means of waste disposal and energy recovery. At the end of the combustion about 5 percent ashes by weight of shell and fibre is produced. Palm oil fuel ash has also been found to have a good potential in concrete construction. According to his reports it has been possible to use palm oil fuel ash up to 40 percent in concrete without

adverse effects on workability and strength. Exposure to the marine environment also produced very encouraging results in terms of durability. Palm oil fuel ash was found to be able to suppress aggregate sulphate reaction (Abdul et. Al, 1996). The enhanced durability of concrete containing palm oil fuel ash was attributed to calcium hydroxide depletion a long term benefit, associated with pozzolanic reactions. The physical and chemical properties of fibre ash are given in Appendix I (g).

Tay (1990) used a mix ratio of 1: 2: 4 (cement: sand: coarse aggregate) with a water/cement ratio of 0.6 to evaluate the use of shell and fibre ash in blending Portland cement. The ash was used in the proportion of 10 percent, 20 percent, 30 percent, 40 percent and 50 percent, to replace cement and cubes of 100mm x 100mm x 100mm made and cured for 3, 7, 14, and 28 days. Some of his findings are as follows:

i. The workability of all the fresh concrete samples was good, as the slump value was 120mm and above, and the compacting factor was more than 0.950. For concrete values without ash, the slump and compacting factor are 150mm and 0.975, respectively. However, at 50 percent of ash added, the slump decreases to about 120mm and compacting factor drops to 0.950.

ii. The initial setting times for the concrete samples with various percentages of ash ranged from 2hr 10min to 2hr 40min, which was higher than the setting times for the control cubes. The final setting times for the concrete samples with various percentages of ash were also higher than the reference concrete cubes; they ranged from 3hr 30min to 4hr 40min, compared with 3hr 15min for the control. The initial and final setting times were well within the requirements of both American and British standards.

iii. Tests on blended cements up to 50 percent ash replacement showed no significant effects on the segregation, shrinkage, water absorption etc of the concrete.

Research efforts have been intensified in investigating the suitability of wood ash in concrete production. The results indicated that the wood ash is slightly pozzolanic, water demand increases as the ash content increases and the setting time of the paste increases as the ash content increases. Abdullahi (2003) also reported that compressive strength of wood ash/ordinary Portland cement concrete increases with age at optimum replacement of cement by wood ash to 20%. Some steady progress has been made in the utilization of wood sawdust in the production of some building materials this includes the manufacture of particle boards.

2.1 COCO NUT SHELL

Coconut shell is one of the by-products from the processing of coconut, it is organic in nature and similar to hard woods in chemical composition though lignin content is higher and cellulose content is lower (*www.reade.com*). The shell composition is shown in Table 2.1.

Table 2.1: Chemical composition of Coconut Shell

COCONUT SHELL COMPOUND (Dry basis)	
COMPOUND	PERCENT
CELLULOSE	33.61
LIGNIN	36.51
PENTOSANS	29.27
ASH	0.61

Source: Jasper Guy woodroof (1979 "Coconuts: Production, processing, products" 2nd ed AVI publishing Co. Inc

Coconut tree from which coconut shell is a by-product is often referred to as the "Tree of Life" because of the endless lists of products and by-products derived from its various parts. It serves as food, shelter and fuel.(*www.pca.da.gov.ph/to1.htm1)*

Therefore, considering the high cost of conventional building materials in the country which affects housing delivery, concrete using coconut shell as coarse aggregate can be useful as a structural lightweight concrete. This will enhance the quest for low cost housing system for both the rural, urban population in Nigeria and in the developing countries. The use of the waste generated will also contribute toward a cleaner environment. These waste materials however must be tested to ascertain their properties – chemical, mechanical and their suitability for constructional purposes. According to Gambhir (2005) the suitability of a particular lightweight concrete is determined by the specified compressive strength and the density of concrete. Burkill (1966) describes the Coconut palm as one of nature's greatest gifts to man. Corner (1966) says that Coconut palm "displays the whole range of human dependence on palm product". Its uses are legion. Its greatest multiplicity of uses found on tropical Islands in the Pacific, where it provides the inhabitants with almost every requisite; human life would be intolerable, and sometimes impossible, without it. It provides food, drinks, oil, medicine, fiber timber, thatch, mats, fuel and domestic utensils. The oil is used for cooking, anointing the body, illumination, lubrication and making soap. It is not surprising that it has been called the "tree of life" and mankind's greatest provider in the tropics. Coconut tree or palm *(coco nufera)* is a member of the family *Arecaceae (palm family)* It is the only species in the *genus* coco, and is a large palm, growing to 30m tall, with pinnate leaves 4-6m long, pinnae 60-90cm long, old leaves break away cleanly leaving the trunk smooth. (*www.en.wikipedia.org/wiki/coconut*)

Coconut tree as an agricultural crop is widely grown in the tropics, for decoration as used as for many culinary and non-culinary uses (Thampan, 1981). Traditionally found around hamlets in small stands. Although in the last century in larger plantations especially in the pacific, Asia, Caribbean and Africa. Plate III shows the regions where coco nut trees are predominantly grown.

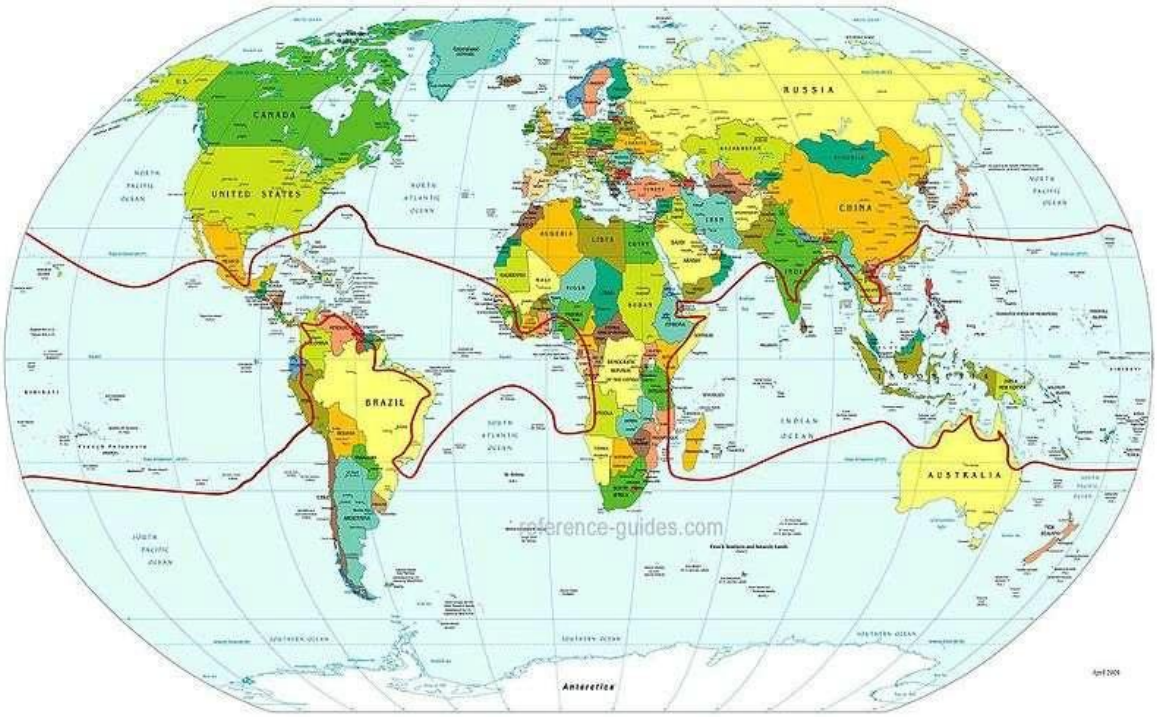


Figure 2.1: The world map of Coco nut growing regions

In Nigeria coconut trees are found in abundance in the West, East, Mid-West and part of middle belt region. Coconut trees are available in larger quantities and its supply is renewable compared with other materials.



Plate III: Coco nut shell waste dump

Adewuyi et. al (2008) reports that Coconut plantation is gaining prominence in the Southern, Eastern and Western part of Nigeria, because of the economic importance to the rural dwellers. One of the significance problem according to his report is the large amount of waste generated in the processing of Coconut, which includes fibre and shell. It's in an attempt to find possible usage of this waste that this research has been embarked upon to see the possibility of using coconut shell as aggregate for the production of lightweight concrete. The following questions then arise as to what is the appropriate mix ratio for coconut shell concrete, what quantity of coconut shell could be used as replacement for natural coarse aggregate, what are the mechanical properties of coconut shell, what are the likely resultant compressive strength and other characteristics of concrete produced from coconut shell aggregate. These are the questions this research seeks to proffers answer to. Although a bag of cement is sold at relatively uniform price in Nigeria with slight variation from every state in the federation. Usually fine aggregates are commonly available although varied in quality. The coarse aggregate which is derived from

stone crushed or local gravels varies in cost from the Northern to Southern part of Nigeria, the reason for high cost of construction in the Niger delta area.

2.1.1 ANATOMY OF COCONUT FRUIT



PLATE IV: COCONUT TREE



PLATE V: AN UNOPENED COCONUT FRUIT

In addition exploiting this waste materials will not only maximizes the use of coconut shell but also helps preserve natural resources and ecological balance. This may also be a solution to the growing concern of resources depletion and global pollution which has being a challenge to many researchers and engineers. Although, concerted efforts to seek and develop new materials relying on renewable resources are attracting the attention of researchers. These include the use of by-products and waste materials in building construction. Some of these by products are used as aggregate for the production of concrete. Although, there has been much research conducted on the structural performance of stone aggregate concrete, those are mostly confined to naturally occurring aggregates, manufactured aggregates and aggregates from industrial by products. By reason of current increase in demand for low cost houses in Nigeria and the global

economic recession coupled with the market inflationary trends, the constituent materials used for these structures had led to a very high cost of construction. Hence the usage of coconut shell as an alternative to the conventional aggregates in the area where there is an abundance of these wastes will be a way forward in fulfilling the housing demand for the masses.

Owen (1993) stated that usually aggregates which have dry weights (of less than) 1200kg/m3 are classified as light weight aggregates. Coconut shell aggregates has a unit weight of 500-650kg/m^3 and this is approximately 60% lighter compared to the conventional crushed stone aggregates. Consequently, the resulting concrete will be light weight.

Nimityongskul et. Al, (1995) reported success in the partial replacement of coarse aggregates with cow bone ash, palm kernel shells, fly ash, rice husk and rice straw as pozzolanic materials. The use of coconut husk ash, corn cob ash and peanut shell ash as cement replacement has also been researched on.

Adegoke et. al (2008) reported that numerous achievements have been made in researching in to the usage of local material which has attracted attention due to it's functional benefit of waste reusability and sustainable development. Reduction in construction costs and the ability to produce lightweight are added advantages.

One of the disadvantages of conventional concrete is the high self weight of concrete (Shetty, 2006). This heavy self weight will make it to some extent an uneconomical structural material. Attempts have been made in the past to reduce the self weight of concrete to increase the efficiency of concrete as a structural material. The density of normal concrete ranges from 2200kg/m^3 to 2600kg/m^3, while that of lightweight lies within 300 to 2000kg/m^3. According to Shetty (2006) there are many advantages of having low density, this includes:

i. Reduction in dead load

ii. Increase the progress of building

iii. Lowers haulage and handling costs

iv. Low thermal conductivity, a property which improves with decreasing density

Postacioglu and Yaganoglu (1999) reported that to provide adequate comfort condition in building at the present time, the most costly component is energy. He now recommended that the future material component of building construction should focus on heat isolation, which is best provided by using lightweight concrete.

Gambir (2005) stated that due to reduction in the weight of the concrete produced by using light weight aggregate this will enhance better thermal insulation and thereby improves the fire resistance of the structure.

Teo et. al (2006) stated that by reducing the weight of the structure, catastrophic earthquake forces and inertia forces that influence the structures can also be ultimately reduced, as these forces are proportional to the weight of the structure

Rossignolo and Agnesini,(2001). Reported from their investigation that lightweight concrete production produces low unit weight concrete elements which are preferred as heat isolation materials. By this comfort temperature values can be provided with lower energy consumption. They concluded that because of the advantages of lightweight concrete in providing heat isolation, the production has increased from early 1980's until present day and an important industry has developed from it.

Short et. al (1978) and Bhatty et. al (1989), classified light weight concrete according to density, into three groups. They are low density concrete commonly used in heat isolations, middle density concretes which are used for briquette producing and the carrier light weight concrete have the opportunities to be used for construction of foundations and supporting parts.

According to Gupta et al (2005) workability of light weight aggregate concrete needs special attention, as for equal workability light weight aggregate concrete gives a lower slump and a lower compacting factor than the normal weight aggregate concrete as work done by gravity is smaller in case of light weight aggregate concrete. He further said that if a higher workability is kept, there will be a higher tendency of segregation. In case of higher slump and over vibrations, the mortar goes down and aggregate tends to float, which is a reverse phenomenon that of normal weight aggregate concrete. In such conditions the finishing operations of deck slab and floors will be difficult.

To overcome this difficulty, usually the maximum slump is restricted to 100 mm. Due to the porous nature of light weight aggregates they have high and rapid water absorption. If the aggregate is dry at the time of mixing, it will absorb water rapidly and the workability decreases quickly. This problem can be overcome by mixing the aggregate with at least one half of the mixing water before adding cement to it. However this procedure will increase the density and decrease its thermal insulation. The light weight aggregate mixes tend to be harsh, which can be reduced by air entrainment. Air entrainment reduces water requirements and also the tendency of segregation and bleeding. The usual total amount of air content by volume is 4 to 89% for 20 mm maximum size of aggregate and 5 to 9% for 10 mm, maximum size of aggregate. Light weight aggregate concrete exhibits higher moisture movement than the normal weight concrete. The wet concrete swells more while dry concrete shrinks more. Due to the higher drying shrinkage and

lower tensile strength, the light weight aggregate concrete develops shrinkage cracks. The coefficients of thermal expansion of light weight aggregate concrete is much lower than ordinary concrete. Typical values are shown in Table 2.2.

Table 2.2. Coefficient of thermal expansion of light weight aggregate concrete

	Concrete with the light weight aggregate	Linear cofff. of thermal expansion determined over *c.* \ range of -22"C 52° C in 10^ per ^{C}C
1.	Cinders	About 3.8
2.	Expanded shale	6. 5 to 8.0
3.	Expanded slag	7.0to 11.2
4.	Perlite	7.6 to 11.0
5.	Vermiculite	8.3 to 14.2
6.	Pumice	9. 4 to 10.8

(Gupta et. Al, 2005)

Gupta et. Al, (2005) enumerated the following as the important characteristics of light weight concrete:

i. Low density. The density of this concrete varies from 300 to 1200 kg/m^3. The lightest variety is suitable for insulation purposes while the heavier variety is used for structural purposes. The low density of cellular concrete makes it suitable for pre cast roofing and floor units. These units being

lighter are easy to handle and transport from factory to the site.

ii. High strength. The compressive strength of cellular concrete is high in relation to its density. The compressive strength of such concrete has been found to increase with the increase in its density. The tensile strength of cellular concrete is about 15 to 20% of its compressive strength. The strength to mass ratio of cellular concrete is much higher

than normal concrete. Thus the weight of roof slab and floor of the cellular concrete arc about 25% of the normal reinforced concrete.

iii. Durability. Aerated concrete is slightly alkaline. Due to its porosity and low alkalinity it does not provide any protection to the steel reinforcement as provided by the dense compacted concrete. Thus the reinforcement used in cellular concrete needs special treatment for the protection against corrosion.

iv. Thermal insulation. The insulation value of light weight concrete is about 3 to 4 times more than that of bricks and about 10 times that of concrete. The degree of insulation of *20* cm thick wall of aerated concrete of density of 800 kg/m^3 is the. same as that of 40 cm thick brick wall of 1600 kg/m^3 density.

v. Fire resistance. The fire resistance properties of light weight concrete are excellent. Its low thermal conductivity makes it suitable for the protection of other structures from the effect of fire.

vi. Sound insulation. The sound insulation of cellular concrete is not as good as that of dense concrete.

vii. Shrinkage. The shrinkage of light weight concrete is small. The autoclaving of cellular concrete reduces its dry shrinkage to 20% of that occurring during air curing.

viii. Repairability. The light weight concrete products can be easily cut, drilled, nailed and sawn. This property makes the construction easier. The local repair of the structure can be attended as and when required without affecting the rest of the structure.

ix. Speed of construction. By adopting prefabrication of units, the structure can be designed on the concept of modular coordination, which ensures a faster rate of construction.

x. Economy. Due to the high ratio of strength to muss and light weight of cellular concrete products, their use results in lesser consumption of steel. Composite floor construction using precast unreinforced cellular concrete blocks and reinforced concrete grid beams results in appreciable saving in the consumption of cement and steel. This reduces the cost of construction of roofs and floors considerably. Using this type of construction a saving of about 15-20% can be effected in the construction of roofs and floors in comparison to conventional construction.

xi. Quality control. With the use of light weight concrete products a better-quality control can be exercised as these units are factory made.

The followings are some of the other properties of light weight aggregate concrete as compared to normal weight concrete.

i. For the same strength, the modulus of elasticity of light weight concrete is lower by 25 to 50% than normal concrete. Hence its deflections are greater.

ii. Its resistance to freezing and thawing is greater than normal weight Concrete due to the greater porosity of light weight aggregate, provided the aggregate is not saturated before mixing.

iii. Its fire resistance is greater as light weight aggregate have a lesser tendency to spall. Thus concrete suffers a lesser loss of strength due to rise in temperature.

iv. It is easy to cut to fix desired attachments.

v. For the same compressive strength us shear strength is lower by 15 to 25% and bond strength is lower by 20 to 50%. Thus in the design of reinforced concrete beams these differences have to be taken into account.

vi. The tensile strain capacity of light weight aggregate is greater than normal weight aggregate. Thus the tensile strain capacity of light weight aggregate concrete is about 50% greater than normal weight concrete. Hence the ability to withstand restraint to movement *i.e.* due to internal temperature gradient is greater for light weight concrete.

vii. For the same strength the creep of light weight aggregate concrete is about the same as that of normal weight concrete.

Light weight concrete can be used as follows:

i. As Load bearing masonry walls using cellular concrete blocks.

ii. As precast floor and roof panels in all types of buildings.

iii. As partition walls in all types of buildings as residential, industrial and institutional buildings.

iv. As insulating materials to exterior walls in all types of buildings, especially in office and industrial buildings.

v. As a filler in the form of precast reinforced wall panels in multi-storey buildings.

vi. As precast composite floor or wall panels etc.

Gambhir (2005) reports that due to large variations in the characteristics of light-weight; aggregates, it is difficult to seek a single approach to mix design for structural light-weight aggregate concrete. However, he suggested that the following points should be considered. As in case of normal weight concrete, the light-weight aggregate concrete can, attain the strength of mortar matrix only if the strength and stiffness of the aggregate are at least as high as those of the mortar. Below this limit, internal stress transfer takes place in the same way as in normal weight concrete. In this case concrete strength is approximately equal to the strength of mortar (Gambhir 2005). The *water-cement ratio* and mix proportions applicable to

ordinary concrete can be adopted, however instead of total water only the effective water must be taken into account. It is also possible to manufacture light-weight concretes with higher strength than the limit strength mentioned above by using a stronger mortar (having greater stiffness) with a higher density (Gambhir 2005). In this concrete the mortar matrix will transmit higher stress at the same deformation. For economic reasons, it is preferable to select a stronger aggregate such that the required concrete strength can be attained with (the mortar of lower strength. For a concrete of given compressive strength, a strong aggregate requires a low mortar strength and a weak aggregate requires a high mortar strength. Since aggregate strength and its modulus of deformation is not usually available, the suitability of a light-weight aggregate for a specific application is generally assessed by means of the particle density or bulk density. He recommended that for structural light-weight concrete, the maximum nominal size of the aggregate is limited to 10 mm since the modulus of deformation, strength and density of aggregate particles decrease as particle size increases. On the other hand a lower maximum size and a large proportion of fines may lead to higher strength but the concrete density will increase. The conventional *water-cement ratio* rule is not suitable for light-weight concrete. In light-weight concrete the water content to be taken into account for calculation of water-cement ratio is not the total quantity of water present only the effective or free water, because the relationship between strength and water cement ratio varies from aggregate to aggregate. The main problem of light-weight concrete mix design lies in the advance determination of effective water and air contents of cement matrix at the moment of completion of compaction of concrete. The prediction is difficult to make since throughout the mixing process the effective (free) water content is progressively reduced through absorption by aggregate, except when completely saturated aggregate is used.

The combined free-water and air contents can be approximately estimated as the *residual absolute volume,* when the density of fresh concrete, the mix proportions and particle density are known. The residual absolute volume, Vres, is obtained by subtracting the volume of the solid cement and aggregates from the total volume of concrete.

$$\mathbf{V_{res} = V_w + V_{air} = 1000\ (1 - C/S_c - A/S_a)} \ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(2.1)}$$

where, V_w and V_{air} are the free-water and air contents in litre/m3, respectively. C and A denote cement and aggregate contents in kg/m3 respectively. S_c *and* S_a are the density of cement and mean particle density of aggregates in kg/m3 respectively. In contrast to normal concrete the relationship between *residual absolute volume-cement ratio* and the strength of light-weight concrete vary from aggregate to aggregate. As the residual absolute volume-cement ratio decreases the concrete strength increases, however the increase is less than that for normal concrete. For every type of light-weight aggregate the compressive strength of the concrete bears a definite relationship to the residual absolute volume-cement ratio and to the cement strength. This characteristic can facilitate the design of light-weight concrete mixes. The *optimum cement content* may be determined by *trial mixes.* In general first trial, the cement content required for ordinary sand and gravel concrete may be used, but more cement is normally required for most light-weight aggregate concretes. There are several methods to determine the aggregate content. In this section a method using *effective water-cement ratio* for the calculation of aggregate content is described.

This method of light-weight aggregate concrete mix design which is based on water-cement rule and is an adaptation of the well-known British mix design method has been recommended.

The steps involved to obtain the mix proportions for the stipulated 28-day strength of concrete are the following.

(i) The target mean strength of the concrete is determined from the characteristic strength.

(ii) The water-cement ratio for the required target strength is read from the Figure 2.4

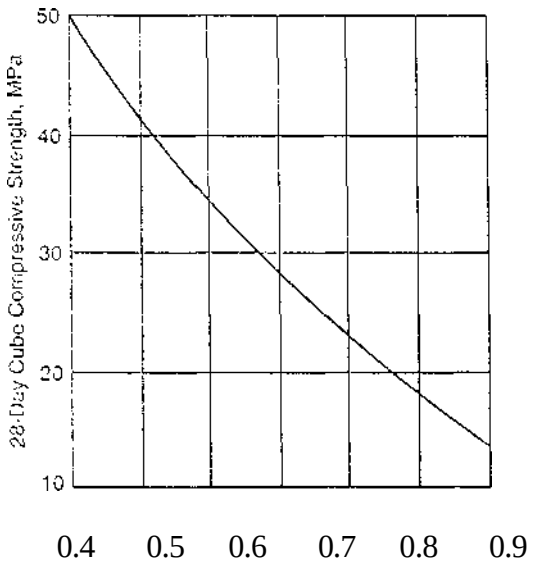


Fig. 2.4: Typical relationship between effective water-cement ratio and compressive strength of light-weight aggregate concrete

(iii) For the water-cement ratio determined in step (ii) aggregate-cement ratio (by volume), cement content in kg/m^3 and optimum percentage of fine aggregate for the desired workability.

(iv) The cement and aggregate volumes are converted to mass contents by multiplying with their dry bulk densities.

(v) The water content is adjusted for the absorption and moisture content of aggregates to obtain effective free-water content for the mix.

(VI) A trial mix is prepared and water content is adjusted to maintain the desired workability. The density of fresh wet compacted concrete is calculated and cement content checked. If it is not correct, minor corrections are made by adding or subtracting cement and subtracting or adding the same volume of fine aggregate as follows:

Volume of fresh concrete = Absolute volume of ingredients…… (2.2)

Gupta et al (2004) on the other hand established that the water/cement ratio has the same influence on the strength of light weight aggregate cone etc as that on normal aggregate concrete. Hence theoretically same procedure may be adopted for mix design as in the case of normal weight aggregate concrete. But in the absence of accurate values of absorption, specific gravity and free moisture content in the aggregate makes it difficult to apply the water/cement ratio law accurately for the mix proportion of light weight aggregate concrete.

Light weight aggregate produced artificially usually is bone dry if it is saturated before mixing the strength of the concrete will be lower by 5 to 10% than, dry aggregate is used for the same cement content and workability. In case of bone dry aggregate, some of the mixing water is absorbed after mixing, but before setting, reducing the effective wafer/cement ratio. The density of concrete made with saturated aggregate is higher, but the resistance to freezing and thawing is reduced. They recommended that if the aggregate with high absorption is used without pre soaking, it will be difficult to obtain workable and cohesive mix. In general, aggregate with more than 10% absorption should be pre soaked and air entrainment should be done. Thus the light weight concrete mix design usually is established by trial mixes. The proportion of fine to coarse *aggregate and* water and cement requirements are estimated on the previous experience with a

particular aggregate. The different degrees of absorption by different light weight aggregates is one of the main difficulty in the design of mix proportions.

Table 2.3 shows variation of cement content aggregate cement ratio, fine aggregate content with water-cement ratio for light weight aggregate concrete

Table 2.3: Variation of cement content aggregate cement ratio

Water cement ratio	*Degree of workability*					
	Medium compacting			*High compacting*		
	Cement	*Aggregate*	*F.A. %*	*Cement*	*Aggregate*	*F.A. %*
0.40	525	3.0	28	59!	2.65	27
0.45	468	3.5	30	533	3.03	28
0.50	419	4.04	32	474	3.50	30
0.55	372	4.63	35	425	4.01	32
0.60	332	5.35	40	383	4.55	34
0.65	293	6.05	49	342	5.23	38
0.70	260	6.83	58	306	5.99	44
0.75	230	8.02	69	273	6.75	53

2.2 Aggregates

Aggregates are the most important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. Aggregates were considered as chemically inert materials but now it has been recognized that some of the aggregates are chemically active and also that certain aggregates exhibit chemical bound at the interface of aggregate and paste. For the fact that the aggregates occupy 70 – 80 per cent of the value of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable. Its physical, thermal and chemical properties influence the performance of concrete to a great extent and provide better strength, stability and durability to the structure made from cement concrete than cement paste alone. To know more about the concrete, it is very essential that one should know more about the aggregates which constitutes major volume in concrete. Since other ingredients namely

water and aggregates are natural materials and can vary to any extent in many of their properties, hence the need for in depth range of studies that are required to be made in respect of aggregates to understand their widely varying effect and influence on the properties of concrete cannot be underrated.

2.3.1 Classification of Aggregates

The classification of the aggregates is generally based on their geological origin, size and unit weight.

2.3.1.1 Classification according to geological origin: The aggregates are usually derived from natural sources and may have been naturally reduced to size (e.g gravel or shingle) or may have to be reduced by crushing. This type of aggregates can be further sub-divided to natural and artificial aggregates. Examples of natural aggregates are aggregates obtained from natural deposits of Sand and gravel, or from quarries by cutting rocks. While the examples of artificial aggregate are clear broken bricks and air cooled fresh blast furnace–slag.

2.3.1.2 Classification according to size: According to size the aggregate is classified as fine aggregate, coarse aggregate and all in-aggregate. The maximum size of the aggregate may vary, but in each case it is to be so graded that the particle of different size fractions are incorporated in the mix in appropriate proportions.

2.3.1.3 Classification according to shape: It was reported by Gambir (2005) that the particle shapes of aggregates influence the properties of fresh concrete more than those of hardened concrete. Depending upon the particle shape the aggregate may be classified as rounded, irregular or partly round, angular or flaky.

2.3.1.4 Flaky and elongated aggregates: An aggregate is termed flaky when its least dimension (thickness) is less than three-fifth of its mean dimension. The main dimension of the aggregate is the average of the sieve size through which the particles pass and are retained respectively. An aggregate is said to be elongated when its greatest dimension (length) is greater than nine-fifth of its main dimension.

2.3.1.5 Classification based on unit weight: The aggregates can also be classified according to their unit weights as normal weight, heavy weight and light weight aggregates.

2.3.2 Light Weight Aggregate

The light weight aggregates having unit weight up to 12KN/m^3 and used in the manufacturing of structural concrete and masonry block for reduction of the self weight of the structure. These aggregates can be either natural such as diotomite, pumice, volcanic cinder or manufactured, such as bloated clays, sintered fly ash or foamed blast furnace slay. In addition to reduction in the weight, the concrete produced by using light weight aggregate provides better thermal insulation and improved fire resistance.

Light weight aggregates may be grouped in the following categories:

i) Naturally occurring materials which require further processing, such as y, shale and slate, etc.

ii) Industrial by-products, such as sintered pulverized fuel ash (fly ash), foamed or expanded blast-furnace slag.

iii) Naturally occurring materials, such as pumice, foamed lava, volcanic and porous limestone.

2.3.3 Aggregates Manufactured from Natural Raw Material

The artificial lightweight aggregates are mainly made from clay, shale, slate or pulverized fuel ash, subject to a process of either expansion (bloating) or agglomeration. During the process of expansion the material is heated to fusion temperature at which point pyroplasticity of material occurs simultaneously with the formation of gas. Agglomeration on the other hand occurs when some of the materials fuses (melts) and various particles are bonded together. Thus to achieve proper expansion a raw material should contain sufficient gas-producing constituents, and pyroplasticity should occur simultaneously with the formation of gas. The gas may form due to decomposition and combustion of sulphide and carbon compounds; removal of CCK from carbonates or reduction of Fe_20_3 causing liberation of oxygen. The common examples of natural minerals suitable for expansion are clay, shale, slate and perlite and exfoliated vermiculite. The production process are enumerated below.

(i) *Expanded or Bloated-clay:* Bloated-clay aggregates are made from a special grade of clay suitable for expansion. The ground clay mixed with additive which encourages bloating, is passed through a rotary or vertical shaft kiln fired by a mixture of pulverized coal and oil with temperature reaching about 1200^{oC}. The material produced consists of hard rounded particles with a smooth dense surface texture and honeycomb interior.

(ii) *Expanded – shale:* The crushed raw material such as colliery waste, blended with ground coal is passed over a sinter strand reaching a temperature of about 1200oC. At this temperature the

particles expand and fuse together trapping gas and air within the structure of the material with a porous surface texture.

(iii) *Expanded-slate* The crushed raw material is fed into a rotary kiln with temperature reaching 1200°C. The material produced is chemically inert and has a highly vitrified internal pore structure. This material is then crushed and graded.

(iv) *Exfoliated-vermiculite:* The raw material resembles mica in appearance and consists of thin flat flakes containing microscopic particles of waster. On being suddenly heated to a high temperature of about 700-1000oC; the flakes expand (exfoliate) due to steam forcing the laminates apart. The material produced consists of accordion granules containing many minute air layers.

2.3.3.1 Industrial by-product Light-weight Aggregate: These include sintered-pulverized fuel ash, foamed-blast-furnance slag and pelletized slag.

(i) *Sintered-pulverized fuel ash* The fly ash collected from modern power stations burning pulverized fuel, is mixed with water and coal slurry in screw mixers and then fed onto rotating pans, known as pelletizers, to form spherical pellets. The *green* pellets are then fed onto a sinter strand reaching a temperature of 1400°C. At this temperature the fly ash particles coagulate to form hard brick-like spherical particles. The produced material is screened and graded.

(ii) Fo*amed-blast-furnace slag: It is a* by-product of iron production formed by introducing water or steam into molten material. The material produced after annealing and cooling is angular in shape with a rough and irregular glassy texture, and an internal round void system.

2.3.3.2 Naturally Occurring Light-weight Aggregates: The common examples are pumice and diatomite. *Pumice,* is light and strong enough to be used in its natural state, but has variable qualities depending upon its source. It us chemically inert and usually has a relatively high silica content of approximately 75 per cent. Diatomite on the other hand is a semi-consolidated sedimentary deposit formed in cold water environment.

Production In India, raw light-weight aggregates are produced by using any of the following:

(i) bloated-clay aggregates by bloating suitable clays with or without additives,

(ii) sintered-fly-ash aggregates by sintering the fly-ash, and

(iii) light-weight aggregate from blast-furnace slag.

In one of the processes for manufacturing light-weight concrete, the cement and pulverized sand are first mixed in a certain proportion 1:1 for insulation and 1:2 for petitioning purposes. The mixture so formed is then made into slurn with the addition of a pre-determined quantity of water. The sand-cement slurry is next foamed to the extent of pre-determined volume with the help of a foaming compound. The foam product is thereafter poured into moulds. The moulded blocks are finally cured under elevated *hydrothermal conditions* in autoclaves which impacts strength, reduces drying shrinkage and gives the block a creamy colour. In another product, lime and sand are used as raw materials. Both arc first ground to fine powder in huge ball mills. The mixture is then made into slurry with the addition of water. Adding aluminum powder and gypsum to the slurry triggers a chemical reaction, and the hydrogen gas evolved gives the cellular concrete its lightness. After initial hardening it is cut into convenient sizes and the moulded blocks are finally cured under

elevated *hydrothermal conditions* (under a pressure of 12 atmospheres and temperature of 196 °C).

The suitability of a particular light-weight aggregate is determined by the specified compressive strength and the density of concrete.

CHAPTER THREE

3.00 MATERIALS AND METHODS

This chapter outlined the tests and results of experiments performed on the materials used in this work. The materials are ordinary Portland cement, river sand as fine aggregate, stone crushed aggregate and coconut shell aggregate.

3.1 Material tests

The tests carried out on these materials are presented below.

3.2 Cement: Ordinary portland cement

The physical as well as the chemical properties tests were carried out in accordance to Nigerian Industrial standard: NIS 11(1974); NIS 445(2003); NIS 446(2003); NIS 447(2003) and British standards, BS 4550 (1978) and BS 12 (1991) and EN 196-1: 1995 on dangote manufactured Portland cement used in this investigation. The chemical analysis test of the cement was done in Department of Chemistry Nigerian Defence Academy, Kaduna. The results are summarized below in tables 3.1 to 3.3. Table 3.1 shows the physical test results of dangote Portland cement used in accordance with BS 4550, Part 3, section 3.1, 1978. The Dangote Portland cement conformed with the standards.

3.2.1 Experiments

3.2.2 Soundness of cement paste;

The soundness test for the brand of ordinary Portland cement used was conducted using the ‘Le Chatelier’ method of measuring expansion in accordance to NIS 447(2003) and BS 4550 (1978). The results of the soundness tests are presented in table 3.1. The raw data is as shown Appendix I

TABLE 3.1: Soundness test results of ordinary Portland cement used.

OPC samples	Average Expansion (mm)	Total average Expansion
Specimen A	4.80	4.78
Specimen B	4.75	
Specimen C	4.80	

The average result shown in the table is an average of the three test results for each sample.

3.2.3 Setting times of cement paste;

The tests for determination of initial and final setting times of the OPC used were done using Vicat apparatus in accordance with NIS 447 (2003) and BS4550 (1978). The results of the tests are presented in Table 3.2. The average results of the samples are as show in the table.

Table: 3.2: Initial and Final setting time for the OPC used

Samples Of OPC	**Average initial setting time (mins)**	**Overall average initial setting time (mins)**	**Average final setting time**	**Overall average initial setting time (mins)**
Sample A	1hr. 42mins	1hr. 45mins	3hrs. 02mins	3hrs.05mins
Sample B	1hr. 45mins		3hrs. 08mins	
Sample C	1hr. 48 mins		3hrs.05mins	

3.2.4 Fineness Test;

The test was carried out in accordance with BS 12 (1991) and NIS 448, (2003). The test results are presented in table Table 3.3. The test was performed using the Blaine air permeability in accordance with NIS 11 1974 which provides an alternative test for fineness.

Table: 3.3: Fineness Test Result of OPC used

OPC Samples	Specific surface area (m^2/Kg)	Average Specific surface area (m^2/Kg)
Sample A	658	658
Sample B	659	
Sample C	657	

Table: 3.4: Fineness Test result of cement according to NIS 11 (1974)

Samples of OPC	% Passing sieve number 200(75µm)	Average % Passing sieve number 200(75µm)	% Retained on sieve number 200(75µm)	aAverage % Retained on sieve number 200(75µm)
Sample A	96.13	96.09	3.87	3.91
Sample B	96.15		3.85	
Sample C	96.00		4.00	

3.2.5 Chemical composition test of the OPC used.

The chemical composition test of the cement used in this research was performed at Chemistry Department of Nigerian Defence Academy, Kaduna. The results are presented in Table 3.5

Table 3.5: Oxide composition result of OPC (Dangote cement) used.

S/no	Oxide composition	Percentage of oxide composition
1.	CaO	64.45
2.	SiO_2	21.55
3.	Al_2O_3	5.28
4.	Fe_2O_3	3.95
5.	MgO	1.85
6.	SO_3	1.50
7.	Loss of Ignition	1.44
8.	Insoluble residue	0.65
	TOTAL	100.67

Table 3.6: Physical and chemical characteristics of the cement used

Soundness average expansion (mm)	**Average Initial Setting time**	**Average Final setting time**	**Cement fineness:** Average Specific surface area (m^2/Kg)	**Oxide composition**	**Percenage Oxide Composition**
4.8	1hr. 45mins	3hr. 05mins	658	CaO	64.45
				SiO_2	21.55
				Al_2O_3	5.28
				Fe_2O_3	3.95
				MgO	1.85
				SO_3	1.50
				Loss of Ignition	1.44
				Insoluble residue	0.65
				TOTAL	100.67

Table 3.7: chemical composition of main compounds of OPC used.

S/NO	Cement component	Percentage composition using boque equation
1.	C_3S	65.45
2.	C_2S	12.54
3.	C_3A	7.32
4.	C_4AF	12.01
5.	Lime saturation factor (L.S.F)	0.92

3.3 Aggregates

3.3.1 Fine aggregate

The fine aggregate (sand) was obtained from naturally occurring clean sand from River Kaduna, in Kawo area, located within latitude 10° 30´ N and longitude 7° 27´E. The tests carried out gave 2.66 as specific gravity, 1535.67 Kg/m^3 bulk density and the particle size distribution analysis shows that it is within Zone 1. These tests were performed in accordance to BS 812 part 2, 1995, BS 812 part 101, 1990 and BS 812 part 103, 1989 respectively. The results are shown in Table 3.7, 3.8 and 3.9.

Table 3.8 Specific gravity of fine aggregate (sand)

Samples	Sample 1	sample 2	sample 3
Specific gravity (S.G)	2.70	2.62	2.66
Average S.G	2.66		

(According to BS 812 part 101, 1990)

Table 3.9 Bulk density of fine aggregate

Samples	Nominal aggregate size (mm)	Bulk density Kg/m^3	Average bulk density Kg/m^3
A1	2.5mm	1530	1533
A2	2.5mm	1535	
A3	2.5mm	1534	
B1	2.5mm	1535	1538
B2	2.5mm	1538	
B3	2.5mm	1540	
C1	2.5mm	1536	1536
C2	2.5mm	1542	
C3	2.5mm	1531	

See appendix II for details

Table 3.10: particle size distribution – fine aggregate

Sieve size mm	5.00	3.35	2.36	1.18	0.60	0.30	0.15	0.075	Pan
% passing cumulative	99.23	96.72	90.18	81.16	60.16	25.99	17.28	5.20	0.00

See appendix III for details

3.3.2 Coarse aggregate

The coarse aggregate is a normal weight aggregate with a nominal size of 20mm. This was Sourced from Brono Prono Construction company quarry along Kaduna –Brinigwari road, Kaduna, the location is within latitude 10° 30´ N and longitude 7° 27´E**.** The tests performed on the coarse aggregate includes the specific gravity, bulk density, particle size distribution, aggregate impact value, aggregate crushing value, aggregate abrasion value, porosity/water absorption capacity, elongation index and flakiness index. All these tests were performed in accordance to BS 812, part 101, 1984, BS 812, part 101, 1990, BS 812, part 105.1, 1990, BS 812, part 105.2, 1990,BS 812, part 109, 1990,BS 812, part 110, 1990, BS 812, part 112, 1990, BS 812, part 113, 1990,and BS 1330, part 2, 1995. The results are presented in tables 3.10, 3.11, 3.12, 3.13, 3.14, 3.15, 3.16, 3.17 and 3.18

Table 3.11 Normal aggregate specific gravity value

Samples	Nominal aggregate size (mm)	Aggregate specific gravity value	Average aggregate specific gravity value
A1	13.5mm	2.65	2.65
A2	13.5mm	2.70	
A3	13.5mm	2.60	
B1	13.5mm	2.60	2.63
B2	13.5mm	2.75	
B3	13.5mm	2.55	
C1	13.5mm	2.65	2.63
C2	13.5mm	2.65	
C3	13.5mm	2.60	

See appendix I for details

Table 3.12: Normal aggregate bulk density

Samples	Nominal aggregate size (mm)	Bulk density Kg/m^3	Average bulk density Kg/m^3
A1	13.5mm	1365.00	1366.00
A2	13.5mm	1369.00	
A3	13.5mm	1364.00	
B1	13.5mm	1374.00	1369.00
B2	13.5mm	1368.00	
B3	13.5mm	1364.00	
C1	13.5mm	1365.00	1367.00
C2	13.5mm	1370.00	
C3	13.5mm	1366.00	

See appendix II for details

Table 3.13: particle size distribution- coarse aggregate (20mm)

Sieve size (mm)	20	14	10	6.30	5.0	3.35	Pan
% passing cumulative	84.17	14.17	1.8	0.43	0.17	0.13	0.00

See appendix III for details

Table 3.14: Normal aggregate impact value

Samples	Aggregate impact value %	Average Aggregate impact value %
A1	20.00	19.48
A2	19.50	
A3	18.95	
B1	17.85	19.15
B2	19.30	
B3	20.29	
C1	19.00	19.06
C2	18.90	
C3	19.29	

See appendix IV for details

Table 3.15: Normal aggregate crushing value

Samples	Single aggregate size (mm)	Aggregate crushing value %	Average aggregate crushing value %
A1	10mm	24.00	25.00
A2	10mm	26.00	
A3	10mm	25.00	
B1	10mm	26.00	26.67
B2	10mm	27.00	
B3	10mm	27.00	
C1	10mm	26.00	25.33
C2	10mm	24.00	
C3	10mm	26.00	

See appendix V for details

Table 3.16: Normal aggregate abrasion value

Samples	Single aggregate size (mm)	Aggregate abrasion value %	Average aggregate abrasion value %
A1	16mm	26.00	26.00
A2	16mm	25.00	
A3	16mm	27.00	
B1	16mm	29.00	28.00
B2	16mm	28.00	
B3	16mm	27.00	
C1	16mm	29.00	29.00
C2	16mm	30.00	
C3	16mm	28.00	

See appendix VI for details

Table 3.17: Normal aggregate absorption capacity

Samples	Single aggregate size (mm)	Absorption capacity %	Average absorption capacity %
A1	13.5mm	1.10	1.13
A2	13.5mm	1.10	
A3	13.5mm	1.20	
B1	13.5mm	1.30	1.30
B2	13.5mm	1.20	
B3	13.5mm	1.40	
C1	13.5mm	1.25	2.98
C2	13.5mm	1.30	
C3	13.5mm	1.30	

See appendix VII for details

Table 3.18: Normal aggregate Enlongation index

Samples	Single aggregate size (mm)	Enlongation index %	Average enlongation index %
A1	13.5mm	9.00	8.33
A2	13.5mm	8.00	
A3	13.5mm	8.00	
B1	13.5mm	7.00	8.00
B2	13.5mm	8.00	
B3	13.5mm	9.00	
B1	13.5mm	10.00	10.00
B2	13.5mm	9.00	
B3	13.5mm	11.00	

See appendix VIII for details

Table 3.19 Normal aggregate Flakiness index

Samples	Single aggregate size (mm)	Flakiness index %	Average Flakiness index %
A1	13.5mm	35.00	36.00
A2	13.5mm	37.00	
A3	13.5mm	36.00	
B1	13.5mm	38.00	37.00
B2	13.5mm	36.00	
B3	13.5mm	37.00	
C1	13.5mm	38.00	37.67
C2	13.5mm	36.00	
C3	13.5mm	39.00	

See appendix IX for details

3.3.3 Coconut shell aggregate

The coconut shell aggregate was obtained from the local hawkers of coconut (popularly called in Hausa "Kwakwa") in the central market area, Kaduna, located within latitude 10° 30´ N and longitude 7° 27´E. It was sun dried for two months before being crushed in the quarry. The crushed Coconut shell material was later transported to the laboratory where they were thoroughly cleaned and washed, then allowed to dry under ambient temperature. The coconut shells were available in various shapes, such as curved, flaky, elongated, roughly parabolic and other irregular shapes as shown in Plate VI and VII. The sizes shown below were obtained

before crushing. In order to ascertain the properties of coconut shell aggregate the following tests was carried out which includes the specific gravity, bulk density, particle size distribution, aggregate impact value, aggregate crushing value, aggregate abrasion value, , porosity/water absorption capacity, elongation index and flakiness index. All these tests were performed in accordance to BS 812, part 101, 1984, BS 812, part 101, 1990, BS 812, part 105.1, 1990, BS 812, part 105.2, 1990,BS 812, part 109, 1990,BS 812, part 110, 1990, BS 812, part 112, 1990, BS 812, part 113, 1990 and BS 1330, part 2, 1995. The results are presented in tables 3.19, 3.20, 3.21, 3.22, 3.23, 3.24, 3.25, 3.26 and 3.27.



Plate VI: Coconut shell aggregate before crushing.



Plate VII. Machine crushed Coconut shell aggregate.

Plate VIII shows coconut shell aggregates after crushing from the quarry mill. The particle size distribution analysis of the coconut shell was carried out in accordance with BS 812 Part 101, 1984 as shown in Table 3.21.

Table 3.20 Coconut shell aggregate specific gravity value

Samples	**Nominal aggregate size (mm)**	**Aggregate specific gravity value**	**Average aggregate specific gravity value**
A1	13.5mm	1.35	1.35
A2	13.5mm	1.33	
A3	13.5mm	1.37	
B1	13.5mm	1.31	1.30
B2	13.5mm	1.30	
B3	13.5mm	1.29	
C1	13.5mm	1.29	1.29
C2	13.5mm	1.31	
C3	13.5mm	1.27	

See appendix I for details

Table 3.21 Coconut shell aggregate bulk density

Samples	Nominal aggregate size (mm)	Bulk density Kg/m^3	Average bulk density Kg/m^3
A1	13.5mm	639.45	639.45
A2	13.5mm	639.48	
A3	13.5mm	639.42	
B1	13.5mm	625.00	625.00
B2	13.5mm	622.00	
B3	13.5mm	628.00	
C1	13.5mm	629.00	626.00
C2	13.5mm	623.00	
C3	13.5mm	626.00	

See appendix II for details

Table 3.22: particle size distribution- coconut shell aggregate (16mm)

Sieve size mm	28	20	14	10	6.30	5.0	3.35	Pan
% passing cumulative	99.50	96.86	17.36	2.06	0.84	0.52	0.26	0.00

See appendix III for details

Table 3.23: Coconut shell aggregate impact value

Samples	**Aggregate impact value %**	**Average aggregate impact value %**
A1	1.32	1.32
A2	1.31	
A3	1.33	
B1	1.29	1.29
B2	1.30	
B3	1.29	
C1	1.31	1.30
C2	1.30	
C3	1.29	

See appendix IV for details

Table 3.24: Coconut shell aggregate crushing value

Samples	Single aggregate size (mm)	Aggregate crushing value %	Average aggregate crushing value %
A1	10mm	1.159	1.157
A2	10mm	1.158	
A3	10mm	1.153	
B1	10mm	1.169	1.162
B2	10mm	1.158	
B3	10mm	1.160	
C1	10mm	1.158	1.157
C2	10mm	1.154	
C3	10mm	1.159	

See appendix V for details

Table 3.25: Coconut shell aggregate abrasion value

Samples	Single aggregate size (mm)	Aggregate abrasion value %	Average aggregate abrasion value %
A1	16mm	2.26	2.26
A2	16mm	2.25	
A3	16mm	2.27	
B1	16mm	2.24	2.24
B2	16mm	2.26	
B3	16mm	2.22	
C1	16mm	2.19	2.19
C2	16mm	2.16	
C3	16mm	2.22	

See appendix VI for details

Table 3.26: Coconut shell aggregate absorption capacity

Samples	Single aggregate size (mm)	absorption capacity %	Average absorption capacity %
A1	13.5mm	23.72	23.72
A2	13.5mm	23.69	
A3	13.5mm	23.75	
B1	13.5mm	23.78	23.78
B2	13.5mm	23.80	
B3	13.5mm	23.76	
C1	13.5mm	23.67	23.67
C2	13.5mm	23.65	
C3	13.5mm	23.69	

See appendix VII for details

Table 3.27: Coconut shell aggregate Enlongation index

Samples	Single aggregate size (mm)	Enlongation index %	Average enlongation index %
A1	13.5mm	26.69	26.69
A2	13.5mm	26.71	
A3	13.5mm	26.67	
B1	13.5mm	26.66	26.66
B2	13.5mm	26.64	
B3	13.5mm	26.68	
B1	13.5mm	26.78	26.72
B2	13.5mm	26.66	
B3	13.5mm	26.72	

See appendix VIII for details

Table 3:28 Coconut shell aggregate Flakiness index

Samples	Single aggregate size (mm)	Flakiness index %	Average Flakiness index %
A1	13.5mm	86.11	86.11
A2	13.5mm	86.14	
A3	13.5mm	86.09	
B1	13.5mm	86.13	86.13
B2	13.5mm	86.10	
B3	13.5mm	86.16	
C1	13.5mm	86.15	86.12
C2	13.5mm	86.09	
C3	13.5mm	86.12	

See appendix IX for details

Table 3.29: Physical characteristics of the coarse and coco nut shell aggregates

Physical characteristics	Coarse aggregates	Coconut aggregates
Specific gravity	**2.64**	**1.31**
Bulk density Kg/m^3	**1367.33**	**630.15**
Impact value %	**19.23**	**1.30**
Aggregate crushing value %	**25.67**	**1.16**
Abrasion value %	**27.67**	**2.23**
Absorption capacity %	**1.8**	**23.72**
Elongation index %	**8.78**	**26.69**
Flakiness index %	**36.89**	**86.12**

3.4 Water

Water used for all the investigation was obtained from the laboratory and it is portable water adequate for drinking. Thus, it is assumed good for making concrete.

3.5 Trial mixes

Ten trial mixes were performed before arriving at a reasonable mix ratio. The trial mixes include the following (1:2:4, 1:2:3, 1:3:3, 1:1½:3, 1:2½:3, 1:3:4, 1:4:4, 1:1½:1, 1:1:1 and 1:2:2). Using mix ratio 1:2:4 as an example it means that one part of cement to two part of sand and to four part of coarse aggregate. After carrying out mix ratio 1:2:4, it was observed that it failed on removing the mould (See Plate IX). Similarly mix ratio 1:2:3, 1:3:3, 1:1½:3, 1:2½:3, 1:3:4 and 1:4:4 failed on removing the mould after 24 hours. One of the photos is shown in plate X.

However, mix ratio 1:1:1 and 1:2:2 did not collapse and the results for different ages are shown in tables 3.29 to 3.32. The water - cement ratio and aggregate - cement ratio of 0.5 and 2 was respectively adopted for all the mixes. However, before the trial mixes were conducted the coconut shells were pre soaked for 24hrs and subsequently air dried under normal laboratory condition. This is because the coconut shell has high absorption capacity thereby reducing the available water for workability of the concrete.



Plate VIII: Showing segregation of mix ratio 1:2:4



Plate IX: Showing the cubes from mix ratio 1:3:3

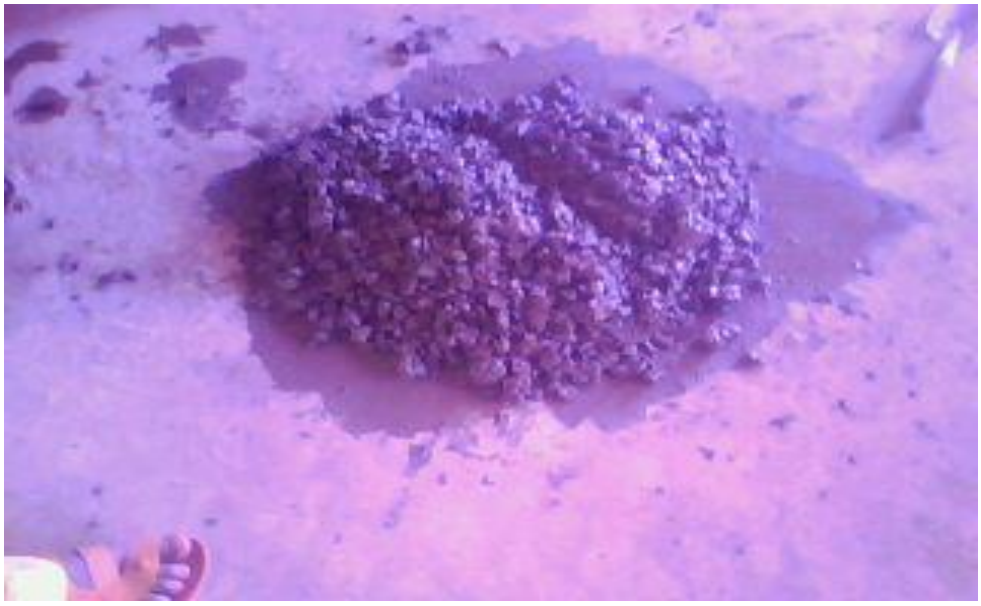


Plate X: Showing mix ratio 1:1:1 preparation in progress.



Plate XI: Showing specimen being casted into mould for mix ratio 1:1:1



Plate XII: Showing Coconut shell concrete cube for mix ratio 1:1:1 after test 28 day.

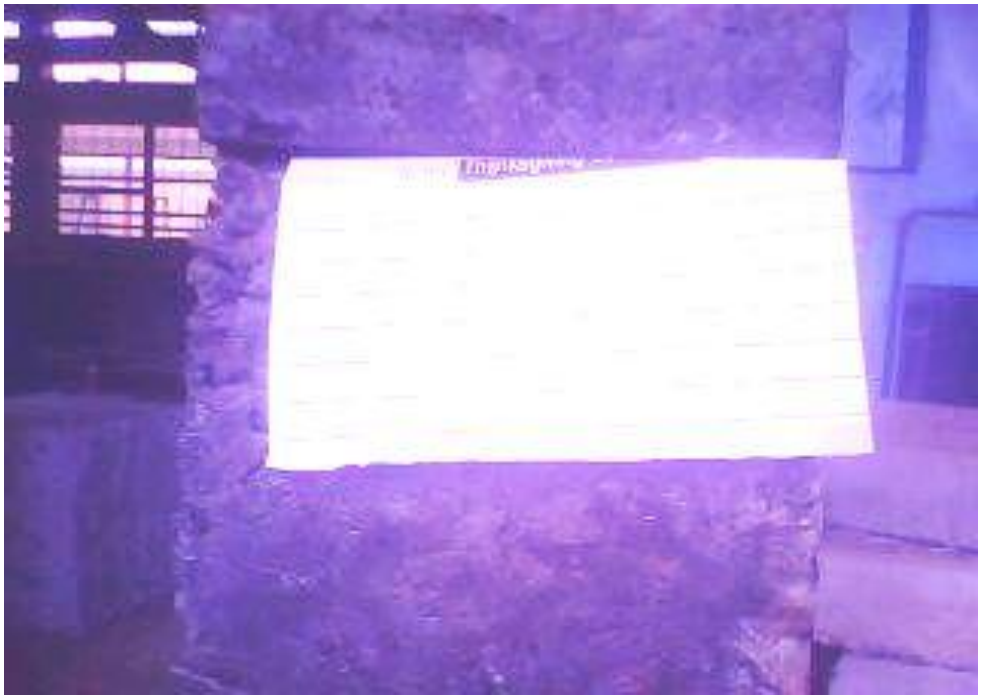


Plate XIII: Showing the cube produced for mix ratio 1:2:2

3.6 Mix design

The mix design for the ratios 1:1:1 and 1:2:2 was based on the properties of the fine and coarse aggregate adopted. The mix proportion was established using the absolute volume method shown below:

$$\frac{w}{1000} + \frac{C}{1000\rho c} + \frac{A1}{1000\rho A} = 1\text{m}3$$

W= water (kg/m^3), C= cement (kg/m^3), A= aggregate (kg/m^3), ρc= specific gravity of cement, $and\ \ \rho A$ = specific gravity of aggregates.

The water cement ratio ($^{W}/_{C}$) and aggregate cement ratio ($^{Ag}/_{C}$) were taken as 0.5 and 2

respectively. The water cement ratio was adequate for the workability of the resulting concrete. The results of the computation gave the various constituents of coconut shell concrete as shown in Table 3.26 below. That is for mix ratio 1:1:1 and 1:2:2.

Table 3.30. Material proportion for the various mix ratios (coconut shell concrete)

s/no	mix ratio	w/c ratio	agg/c ratio	cement kg/m^3	Fine Agg kg/m^3	Coconut Shell aggregate kg/m^3
1.	1:1:1	0.5	2.0	425	425	425
2.	1:2:2	0.5	2.0	424	849	849

The coconut shell aggregate used was mixed at saturated surface dry condition based on 24hr submersion in portable water. The major experiment is to determine the best mix ratio using coconut shell aggregate concrete. And to determine the strength development of the partial replacement of coconut shell in normal coarse aggregate concrete. Cast iron mould of size 150 x 150 x $150mm^3$ was used for the production of samples. The specimens were made in accordance with BS 1881 Part 108 (1983). The molded concrete cubes were given 24 hours to set before demoulding. The preparation of the specimen was carried out in the Concrete Laboratory Department of Civil engineering Kaduna Polytechnic. They were then immersed into curing tank, to promote increase in strength, hydration, eliminate shrinkage and absorb heat of hydration until the age of test. The cubes prepared were cured for 3 days, 7 days, 14 days and 21 days and 28days. The cubes were weighted before testing and the densities of the cubes at different time

of testing were measured. Prior to testing, the specimen were brought out of the curing tank, left inside in the open air for about 2 hours before crushing. The compressive strengths of the cubes were tested in accordance to BS 1881 Part 116 (1983) using universal testing machine. The results are shown in tables 3.29 to 3.31 for different size of aggregate for mix 1:1:1.

Table 3.31: Compressive strength results for the Coconut shell aggregate

Mix proportion	Aggregate size	Average compressive strength				
		3day	7day	14day	21day	28day
1:1:1	10mm	1.6	3.29	5.63	8.82	11.11
	12mm	1.70	3.36	6.48	10.53	13.25
	16mm	2.41	4.67	8.18	12.47	16.00
1:2:2						
	16mm	1.15	2.32	3.81	6.30	7.71

3.6 Partial replacement of normal aggregate with coconut shell aggregate.

Having established the fact only a mix ratio of 1:1:1 and 2:2:2 are the only possible ratios for coconut shell concrete an experiment of partial replacement was embarked upon, using zero percentage as a control for the aggregate replacement. The normal aggregate was replaced with coconut shell in the following percentages, 25%, 50% and 75%. These percentages were mixed and cured for various ages as the results are shown in tables 3.33 to 3.37. For each percentage, 3 cubes were tested and the average values as shown in the tables mentioned above. The rest details are in the appendix III.

T**able 3.32: Compressive Strength test results for the various aggregate replacement (1:2:4)**

Mix proportion	Aggregate size	Replacement %	Average compressive strength N/mm2 at the age of test.				
	16mm for coconut shell and 20mm for stone crush aggregate		3 day	7 day	14 day	21day	28 day
1:2:4		0%	8.10	17.00	21.00	24.00	27.00
		25%	6.90	14.00	18.00	20.00	23.00
		50%	6.00	12.00	14.00	16.00	20.00
		75%	5.10	11.00	12.00	15.00	17.00
		100%	4.50	10.00	11.00	14.00	15.00

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

Following the tests carried out in chapter three and the result presented, this chapter analyses and discusses the result to arrive at a reasonable conclusion recommendation.

4.1 Ordinary Portland cement (OPC) Test

4.1.1 Cement Soundness

The test results are presented in table 3.1 of Chapter 3 and compared with standard specification as shown below in Table 4.1

Table 4.1: **S**oundness of cement paste test results.

OPC samples	Average expansion (mm)	Code Specification BS 4550, NIS 447 RECOMMENDATION
A	4.8	≤10 mm
B	4.75	
C	4.80	

The cement samples satisfied the code of practice in terms of expansion.

4.1.2 Setting Time Of Cement Paste

The results of the setting time of the cement used were presented in table 3.2 of chapter 3 and the results are compared with the standard requirement as shown in Table 4.2 below.

Table 4.2: Cement Sample Setting Time Results

Samples	Initial setting time	Final setting time
A	1hr 2mins	3hrs 03mins
B	1hr 45mins	3hrs 08mins
C	1hr 45mins	3hrs 05mins
Standard requirements (mins)	≥45	≤600

From the results above the cement samples satisfied the code provision of setting time requirement. The lowest initial setting time being 1hr 2mins and the highest final setting time was 3hrs 08mins. Similarly, provisions of 45mins in European standards EN 196-1:1983 and EN 196-6 with respect to initial setting time was satisfied. Therefore, the Dangote cement used in the experiment satisfied the codes specification for ordinary Portland cement from the initial setting.

4.1.3 Cement Fineness

Fineness is an important property of cement and need to be carefully checked and controlled. The results of the test were presented in TableS 3.3 and 3.4 of chapter 3 and compared with standard as shown in Table 4.3.

Table 4.3: Cement Sample Fineness Compared with the Standard

Samples	Specific surface (m^2/kg)	Percentage retained on 200 sieve
A	658	3.87
B	659	3.85
C	657	4.0
Standard requirement (BS12, NIS 448)	≥225	≤10

All the samples tested were satisfactory in terms of fineness.

4.1.4 Chemical composition of the OPC used.

The chemical composition of OPC (Dangote cement) used is presented in table 3.5 of chapter 3.

The results were compared with the standard specifications as shown in Table 4.4.

Table 4.4: Comparism of Oxide composition results of Dangote cement used with standard

S/NO	OXIDE Composition	Percentage (%) of oxide composition	Standard requirement
1.	CaO	64.45	60-67
2.	SiO_2	21.55	17-25
3.	Al_2O_3	5.28	3.0-8.0
4.	Fe_2O_3	3.95	0.5-6.0
5.	MgO	1.85	0.1-4.0
6.	SO_3	1.50	1.0-3.0
7.	Loss of Ignition	1.44	≤ 3.0
8.	Insoluble	0.65	≤ 1.5

The oxide content of the cement compared with standard shows compliance. The calcium oxide (CaO) fell within the range, while silicate oxide (SiO_2) was also within the range. The rest oxide compositions are within the range specified using Boque's equation given below.

$C_3S = 4.07(CaO) - 7.60(SiO_2) - 6.72(Al_2O_3) - 1.43(Fe_2O_3) - 2.85(SO_3)$…… (i)

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

$C_3A = 2.65(Al_2O_3) - 1.69(Fe_2O_3)$ …….. (iii)

$C_4AF = 3.04(Fe_2O_3)$…… (iv)

Where

C_3S = Tricalcium Silicate

C_2S = Dicalcium Silicate

C_3A = Tricalcium Aluminate

C_4AF = Tetra Calcium Aluminoferite

The chemical compound compositions were determined and the result was given in Table 3.3 and is summarized in Table 4.5 below.

Table 4.5: chemical composition of main compounds of OPC used.

S/No	Cement component	Using Boque equations composition of typical OPC %
1.	C_3S	65.45
2.	C_2S	12.54
3.	C_3A	7.32
4.	C_4AF	12.01
5.	Lime saturation factor (L.S.F)	0.92

(Using Boque equation)

Compound composition of the cement is of good quality, it agrees with the standards (European standards EN 196-1:1987 and EN 196-6: 1989) which recommends that the summation of tricalcium silicate (C_3S) and dicalcium silicate (C_2S) content should not be less than 70%, the above Table 4.5 Shows the compliance with this provision. Therefore the cement is adequate as ordinary Portland cement.

4.2 Mechanical properties of the aggregates

4.2.1 Specific gravity of aggregates

The specific gravity of an aggregate is of importance in the calculation of the quantity of aggregate required for a given volume of concrete. The results of specific gravity of fine, coarse and coconut shell aggregate are presented in Tables 3.11 and 3.20 of chapter 3. This was conducted in accordance to BS 1330: Part 2: 1995. The specific gravity adopted in this research is the apparent specific gravity. The apparent specific gravity is the ratio of the mass of the aggregate dried in an oven at 100 to 110°c for 24 hours to the mass of water occupying a volume equal to that of the solid including the impermeable pores. It is worthy of note that the apparent specific gravity of an aggregate depends on the specific gravity of the minerals of which the aggregate is composed and also on the amount of voids. The British standard BS 1330: part 2: 1995 stipulates the procedure for determining the specific gravity of an aggregate. It also gave the specific gravity of majority of natural aggregate to be between 2.6 and 2.7.

4.2.1.1 Specific gravity: Fine aggregate

The fine aggregates results is presented in Table 3.8, the results shows that the fine aggregate having average specific gravity of 2.66 which agreed with BS 812 part 101, 1990.

4.2.1.2 Specific gravity: Coconut shell aggregate

The results of the specific gravity tests carried out are as shown in table 3.20 of chapter 3. The results showed that coconut shell has an average specific gravity of 1.31. The average specific gravity value of 1.31 for coconut shell aggregate is about 50 percent lower than the specific gravity of naturally occurring aggregate as stated above. This implies that more aggregate is needed for concrete mix.

4.2.1.3 Specific gravity: Normal crushed stone aggregate

The specific gravity results for the normal crushed stone aggregate is presented in

Table 3.11.The results indicated that the normal crushed stone aggregate used has specific gravity of 2.64which is within the stipulated range of 2.6 to 2.7 by BS 1330: Part 2: 1995.

4.2.2 Aggregate bulk density

The bulk density gives information in respect of shape and grading of the aggregate. This is test was performed in accordance to BS 812: Part 2: 1990. The detail results are shown in Tables 3.9, 3.12 and 3.21 of chapter 3.

4.2.2.1 Fine aggregate bulk density

From Table 3.9 of chapter three, the value of bulk density of fine aggregate ranges between 1530kg/m^3 and 1542kg/m^3 the result conformed with BS 812: Part 2: 1990.

4.2.2.2 Coconut shell aggregate bulk density

The coconut shell bulk density also ranges from 622kg/m^3 to 639.48kg/m^3 as shown in Table 3.21. This value is within the limit specified for light weight aggregate. The result shows that coconut shell aggregate have about 50% less weight compare with that of both fine and normal stone aggregate making it light weight aggregate.

4.2.2.3 Normal stone crushed aggregate bulk density

The average bulk density for the normal coarse aggregate from the test results is 1365 kg/m^3 as shown in table 3.11 of chapter 3.

4.2.3 Aggregate particle size distribution analysis

The sieve analysis is conducted to determine the particle size distribution in a sample of aggregate, often referred to as gradation. A good aggregate particle size distribution implies that a sample of aggregates contains all standard fractions. That is aggregate in required proportion, such that the sample contains minimum voids. The essence of particle size distribution analysis is to have well graded aggregate which have direct influence on producing workable concrete.

4.2.3.1 Fine aggregate particle size distribution analysis

The particle size distribution test result for fine aggregates is presented in Table 3.10 of chapter three. This was carried out in accordance with BS 812: Part 103, 1989. The particle size distribution graph is shown in figure 4.1. This shows that the fine aggregate is in zone 2. The sand is also uniformly graded.

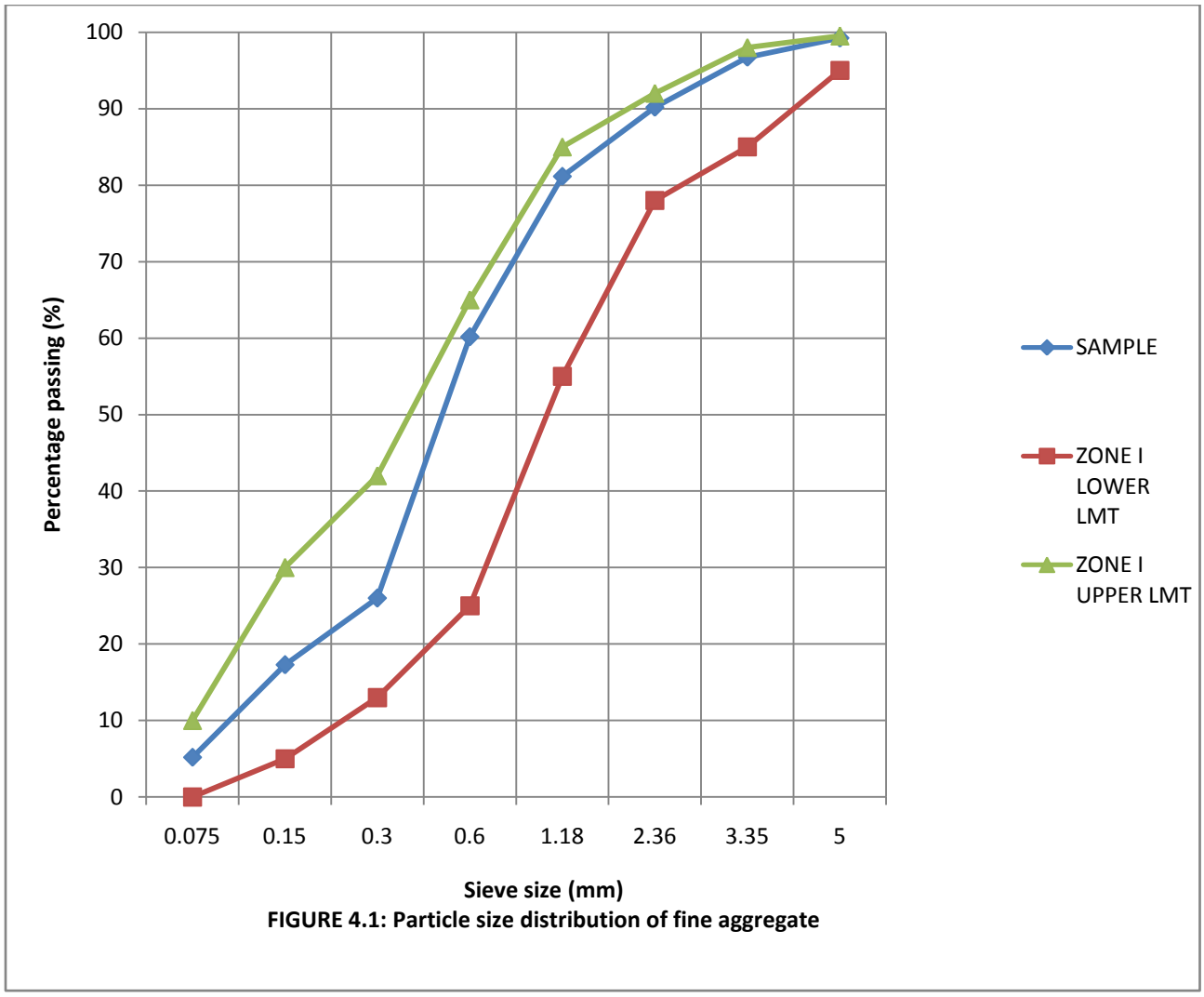


FIGURE 4.1: Particle size distribution of fine aggregate

4.2.3.2 Normal crushed stone aggregate particle size distribution analysis

A single size coarse aggregate of nominal size 20mm was used. The particle size distribution was carried out on the sample. The coarse aggregate particle size distribution is of great importance in achieving good concrete workability and compactibility. The results is presented in Table 3.13 of chapter 3, while the graph showing the particle size grading distribution is as shown in Figure 4.2.

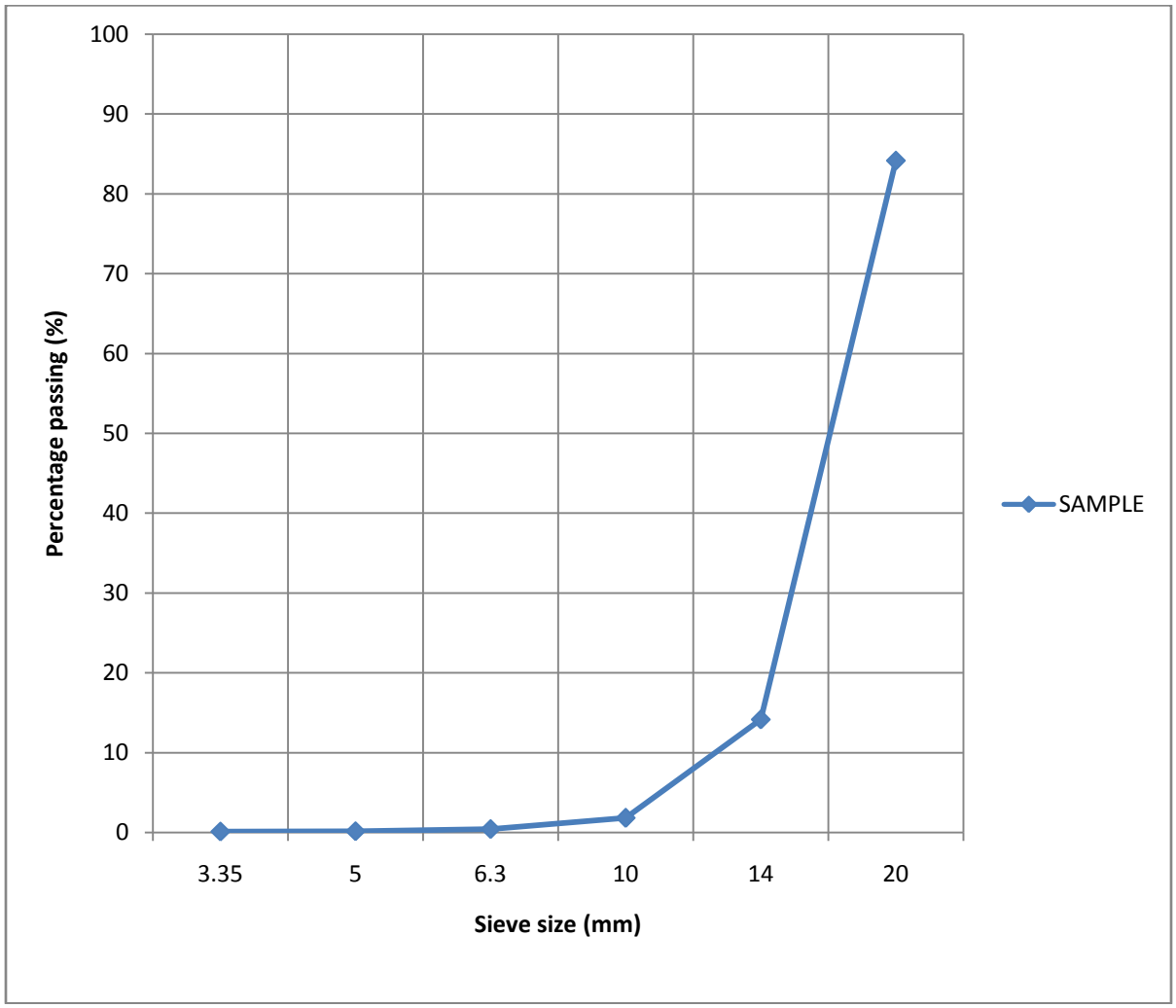


FIGURE 4.2: Particle size distribution of coarse aggregate

4.2.3.3 Coconut shell aggregate particle size distribution

The particle size distribution analysis was carried to ensure that the resulting concrete is workable, since good grading of aggregates is one of the factors in producing good concrete. The results are shown in Table 3.22 of chapter 3, while the graph showing the percentage passing against the various sieve sizes is shown in figure 4.3. The single aggregate size used in the analysis is reflected, as the highest percentage of the aggregate passing fell between size 14-20mm.

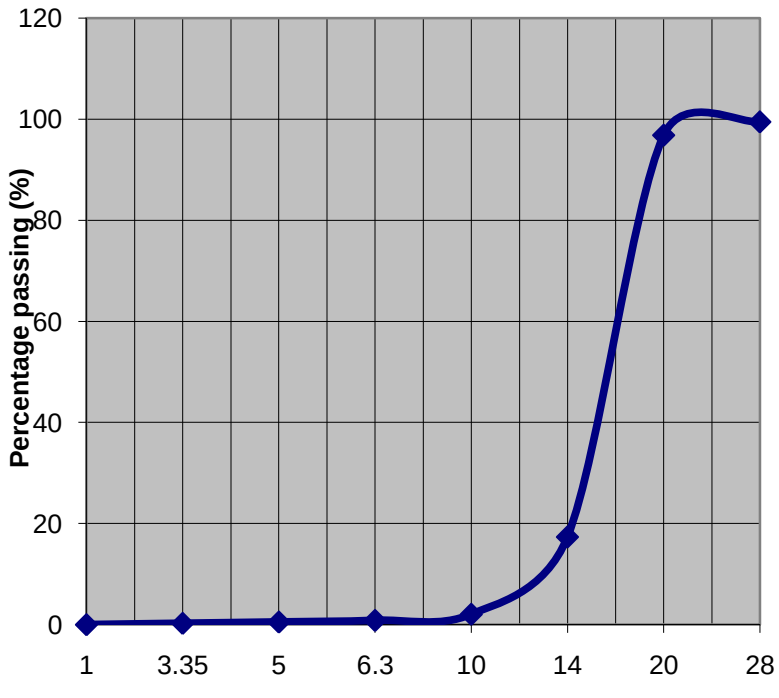


Figure 4.3: Particle distribution of Coconut shell aggregate

4.2.4 Aggregate impact value

The aggregate impact value test results are presented in Tables 3.14 and 3.23 of chapter 3. This was done in accordance with BS 812: Part 112: 1990. The aggregate Impact value can be described as a standard hammer falling 15 times under its own weight upon the aggregate in a cylindrical container. This results in fragmentation in manner similar to that produced by the pressure of the plunger in aggregate crushing value. The British standard (BS 812: Part 112:1990 and BS 882: 1992) specified maximum value of 25 percent when the aggregate is to be used in heavy duty floors; 30 percent when the aggregate is to be used in concrete for wearing surfaces and 45 percent when it is to be used in the other concrete. Resistance to wear is an important property of concrete used in pavements, and in floor surfaces subjected to heavy traffic.

4.2.4.1 Coconut shell aggregate impact value

From Table 3.23 of chapter 3, the impact values for coconut shell aggregate ranges from 1.29 to 1.32 percent. This means that coconut shell aggregate is resistance to wear. Hence it can be used for all types of light weight concrete. The average impact value for Coconut shell aggregate is 1.32 percent which is far less than 25 percent allowed in BS 812: Part 112:1990 and BS 882: 1992. The Coconut shell aggregate impact value indicates that it can also be used for construction material.

4.2.4.2 Normal Crushed stone aggregate impact value

The normal aggregate impact values ranges from 17.85% to 20.29%, as shown in Table 3.14 this is also within the allowable range specified in the code BS 812: Part 112:1990 and BS 882: 1992.

4.2.5 Aggregate crushing value

This test was carried out in accordance with BS 812: Part 110: 1990. The details of the results are presented in Tables 3.15and 3.24 of chapter 3. The test of aggregate crushing value is a measure of aggregate resistance to pulverization. The British standard code of practice BS 812: part 110: 1990 specified that aggregate crushing value should not be more than 45% for aggregate used for concrete other than for wearing surfaces and 30% for concrete used for wearing surface such as runways, roads and air field pavements.

4.2.5.1 Coconut shell aggregate crushing value

From Table 3.24 of chapter three the crushing value of coconut shell aggregate ranges from 1.153% to 1.169%. Hence the coconut shell aggregate can be used for other concrete work other than the ones mentioned above. The average of coconut shell aggregate crushing value is 1.16% which is lower than 30% maximum specified in the code. Therefore, the coconut shell aggregate crushing value shows that the material can be used as alternative construction material.

4.2.5.2 Normal crushed stone aggregate crushing value

The results of normal stone aggregate crushing value is shown in Table 3.15. The aggregate crushing value ranges from 24% to 27%.This result shows that the aggregate is adequate for any concrete work. The disparity between their crushing values of both coconut shell and the normal

stone aggregate may be connected to their origin. The Coconut shell is of plant origin while the crushed stone aggregate is of geological origin.

4.2.6 Aggregate abrasion value

The aggregate abrasion value test results carried out are presented in Tables 3.16 and 3.25 of chapter 3. The abrasion value test on aggregate particles was done as prescribed by BS 812: part 113:1990. The aggregate abrasion value is defined in terms of the percentage loss in mass on abrasion. The aggregate sample is subjected to abrasion in a standard machine, the grinding lap being turned 500 revolutions. High aggregate abrasion value denotes a low resistance to abrasion. The aggregate abrasion test is of great importance if the aggregate is to be used for road construction, warehouse floors and pavement constructions. The code specified that for aggregates to be used for above type of construction should have max abrasion value between 30% - 50%.

4.2.6.1 Coconut shell aggregate abrasion value

The coconut shell abrasion value ranges between 2.19 to 2.26 percent as shown in Table 3.25 of chapter 3. While the average abrasion value is 2.23% this is far less than 30%. Hence the coconut shell aggregate is a suitable material for construction as it satisfied the abrasion provision in the code. The implication of this result is that coconut shell aggregate have high resistance to wear.

4.2.6.2 Normal stone aggregate abrasion value

The crush stone aggregate abrasion value results are presented in Table 3.16 of chapter 3. The abrasion values ranges from 25% to 30% and an average of 27%. This is within the specified range of 30%-50%.Therefore, the aggregate is satisfactory.

4.2.7 Aggregate porosity /water absorption capacity

The standard procedures for assessing the porosity and water absorption of aggregate is prescribed in BS 812: Part 2: 1975 and BS 812: part 109: 1990. The presence of internal pores in the aggregate particles and the characteristics of these pores are of paramount importance in the study of its properties. The porosity of aggregate, the permeability and the absorption influences such properties of aggregate as the bond between it, the hydrated cement paste, the resistance of concrete to freezing and thawing as well as its chemical stability and resistance to abrasion. Since aggregate represents three-quarters of the volume of concrete, it is clear that the porosity of aggregate materially contributes to the overall porosity of concrete. The water absorption of aggregate is determined by measuring the increase in mass of an oven dried sample when immersed in water for 24 hours. The ratio of the increase in mass to the mass of the dried sample expressed as a percentage is termed absorption.

4.2.7.1 Coconut shell aggregate porosity /water absorption capacity

The coconut shell aggregate porosity/water absorption capacity test results are presented in Table 3.26 of chapter 3. The value of coconut shell absorption capacity ranges from 23.65% to 23.80%. While the average coconut shell absorption capacity is approximately 24%. This value is within the range for absorption capacity of light weight aggregates as stipulated by Portland cement

association, which is between 5% and 30%. Hence the coconut shell aggregate can also be used or classified as light weight aggregate.

4.2.7.2 Normal stone aggregate porosity /water absorption capacity

The absorption capacity of crush stone aggregate is presented in Table 3.17 of chapter 3. The results indicated that the absorption capacity of crushed stone aggregate ranges from 1.10% to 1.40%. This is an indication that the aggregate is not porous and adequate for any concrete work.

4.2.8 Aggregate elongation index

The test results are presented in Tables 3.18 and 3.27 of chapter three and it was carried out in accordance with BS 812 section 105.2: 1990. and 9% elongation index respectively. Although BS 812 section 105.2: 1990 have no recognized limits but this result is acceptable for a light weight aggregate.

4.2.8.1 Coconut shell aggregate elongation index

The result shows that coconut shell aggregate have approximately 27%. Although, there is no recognized limits laid down, the presence of elongated particles in excess of 10 to 15% of the mass of coarse aggregate is generally considered undesirable.

4.2.8.2 Normal crush stone aggregate elongation index

The results are presented in table 3.18 of chapter 3, the normal crushed stone Aggregate has an average elongation index of 9% which is within the desirable limits of 10-15%.

4.2.9 Aggregate flakiness index

The results of the flakiness index tests are shown in Tables 3.19 and 3.28 of chapter three. The flakiness index of an aggregate is the percentage by weight of particles whose least dimension (thickness) is less than three fifths of their mean dimension.

4.2.9.1 Coconut shell aggregate flakiness index

The coconut shell flakiness index test ranges from 86.09% to 86.16% as shown in Table 3.28. The result shows that coconut shell aggregate is a flaky material, based on BS 882:1992 which limits the flakiness index of the coarse aggregate to 50% for natural gravel and 40% for crushed coarse aggregate.

4.2.9.2 Normal crushed stone aggregate flakiness index

The results of the crushed stone aggregate flakiness index are presented in Table 3.19 of chapter 3. The flakiness index ranges from 35% to 39%.This is within the limits laid down in BS 882:1992.

4.3 Compressive strength test results

The compressive strength test results of coconut shell aggregate concrete produced from the various sizes of coconut shell aggregates (10mm, 12mm and 16mm) and different mix ratios (1:1:1 and 1:2:2) are presented in tables 3.29 to 3.32 of chapter 3. While the results obtained for the partial replacement of normal coarse aggregate with coconut shell aggregate is also presented in Table 3.32 of the same chapter 3.

4.3.1 Compressive strength test results of coconut shell aggregate (size 10mm)

The results of the compressive strength test for coconut shell aggregate size 10mm is presented in Table 3.31 of chapter 3 with mix ratio 1:1:1. The result shows minimum of 1.64N/mm^2 and maximum of 11.11N/mm^2 compressive strength development for 3day and 28day respectively. That is there is progressive strength development as the age and curing continued. This is shown in figure 4.4.

4.3.2 Compressive strength test results of coconut shell aggregate (size 12mm)

The results of the compressive strength test for coconut shell aggregate size 12mm is presented in Table 3.31 of chapter 3 with mix ratio 1:1:1. The result shows minimum of 1.70N/mm^2 and maximum of 13.25N/mm^2 compressive strength development for 3day and 28day respectively. The strength development shows progression as the age and curing continued. This is shown in figure 4.4.

4.3.3 Compressive strength test results of coconut shell aggregate (size 16mm)

The results of the compressive strength test for coconut shell aggregate size 16mm is presented in Table 3.32 of chapter 3 with mix ratio 1:1:1. The result shows minimum of 2.41N/mm^2 and maximum of 16.00N/mm^2 compressive strength development for 3day and 28day respectively. This result is an indication that the aggregate nominal size 16mm produces the highest compressive strength development as the age and curing continued. This is shown in figure 4.4.

4.3.4 Compressive strength test results of coconut shell aggregate (size 16mm) with mix ratio 1:2:2

The results of the compressive strength test for coconut shell aggregate size 16mm is presented inT able 3.31 of chapter 3 with mix ratio 1:2:2. The result shows minimum of 1.15N/mm^2 and

maximum of 7.71.00N/mm^2 compressive strength development for 3day and 28day respectively. This result indicates that mix ratio 1:1:1 produced higher compressive strength development as the age and curing continued. This is shown in figure 4.5.

4.4 Partial replacement of normal aggregate with coconut shell aggregate

The results obtained from the partial replacement of normal coarse aggregate with coconut shell aggregate are shown in Table 3.32.The percentage of coarse aggregate replacement adopted are 0%, 25%, 50%, 75% and 100% using mix ratio 1:2:4. The results show that the compressive strength decreases with percentage increase in the coconut shell aggregate content. But with 25% to 50% of coconut shell replacement of normal aggregate in concrete, compressive strength of 23N/mm^2 and 20N/mm^2 can be achieved after 28day curing. This strength is adequate for any structural element that is not subjected to excessive load. Figure 4.6 presents the compressive strength development of the concrete cubes produced with different percentages replacement of normal aggregate with coconut shell.

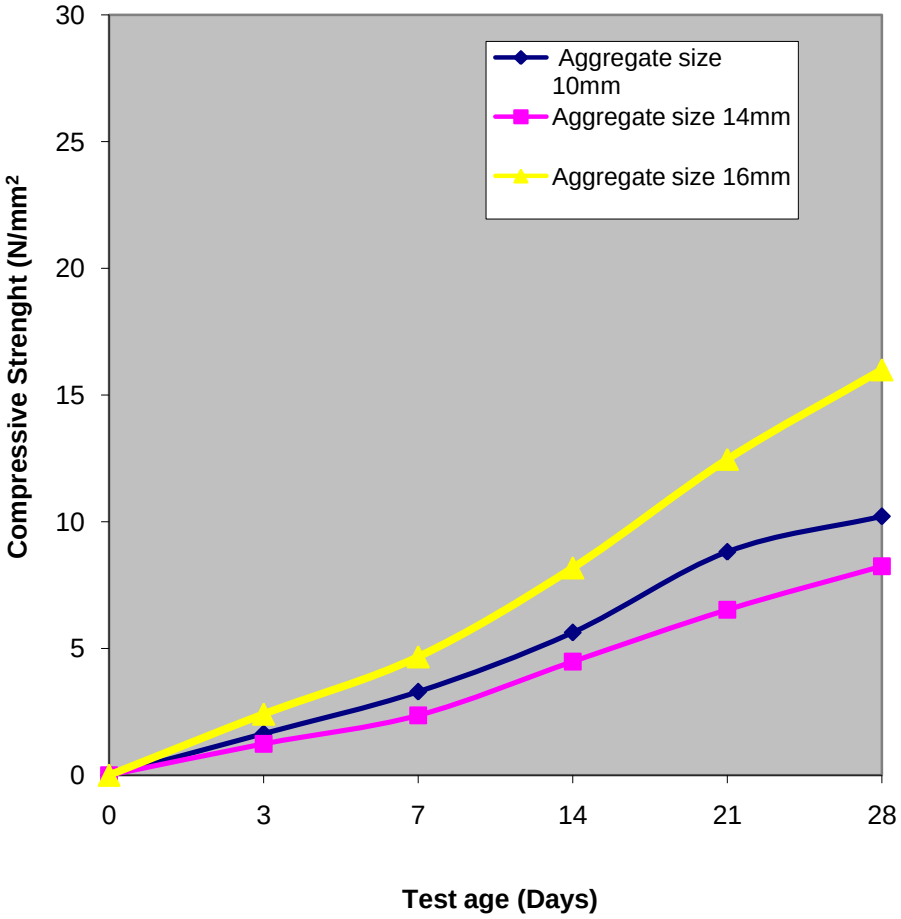


Figure 4.4: Compressive strength development of coconut shell aggregate (mix ratio 1:1:1)

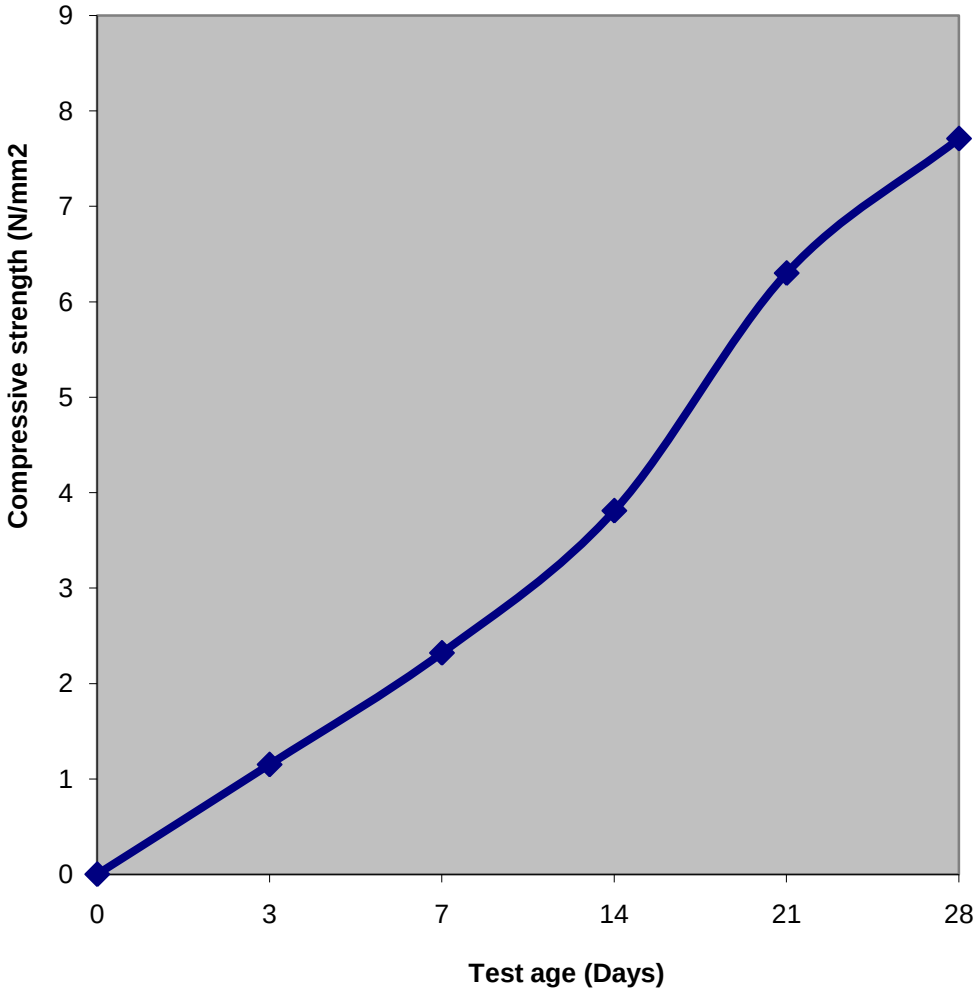


Figure 4.5: Compressive strength development of coconut shell concrete with mix ratio 1:2:2 (16mm)

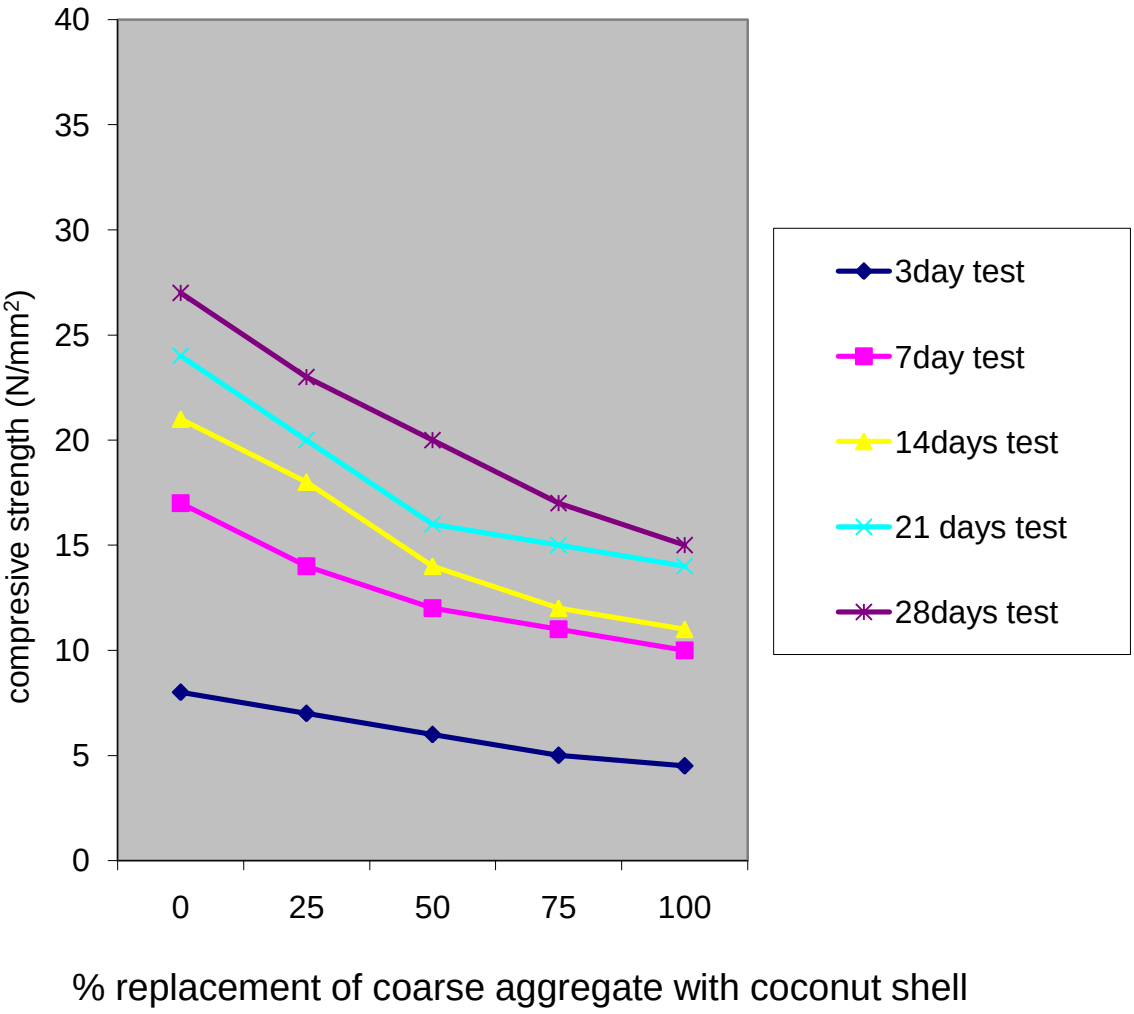


Figure 4.6: Compressive strength development of partial replacement of normal aggregate with coco nut shell.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The study of the properties of coconut shell aggregate concrete has been carried out through experimentations, analysis and discussions of the suitability of coconut shell aggregate. Therefore from the experimental results coconut shell has good potential as coarse aggregate in lightweight concrete as well as a partial replacement of conventional coarse aggregate in concrete. Therefore, based on investigation the following conclusion can be drawn:

i. The compressive strength of the coconut aggregate concrete shows sensitivity to the size of coco nut aggregate used. The concrete cubes produced from 16mm aggregate size gave high compressive strength compared with that of 10mm and 12mm respectively.
ii. The compressive strength of coconut shell aggregate concrete at 28 day test was 16N/mm^2 which satisfied the requirement of lightweight concrete.
iii. The coconut shell aggregate concrete has a density ranging from 1542 Kg/m^3 to 1782Kg/m^3 which is within the lightweight concrete density as shown Appendix XI
iv. In all cases the density of the concrete produced decreased with increase in the percentage replacement of conventional coarse aggregate with coconut shell aggregate as shown in Appendix XI.(e, f, g, h and j)
v. Concrete with 25% to 50% coconut shell inclusion can still give the minimum 28-day cube strength values of 23N/mm^2 and 20 N/mm^2 expected for concrete mix 1:2:4 respectively.

5.2 RECOMMENDATIONS

Based on the scope and the results of this research the following are the recommendation for further investigation.

i. A study of the shrinkage characteristics of Coconut shell concrete is recommended.

ii. A long term durability study of Coconut shell concrete should be investigated.

iii. There is the need to study the permeability of coconut shell concrete.

iv. The study of the development of the micro structure of the coconut shell concrete is important in predicting the long term behavior.

v. The use of coconut shell aggregate as a replacement in convectional concrete should be encourage in the locality where it is in abundance to enhance environmental cleanliness.

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APPENDICES

APPENDIX I

(a)

Values of length and diameter of sample of fibres

S/No.	Length	Diameter		
1	94	0.014	0.014	0.014
2	80	0.009	0.009	0.009
3	97	0.053	0.053	0.053
4	85	0.017	0.017	0.017
5	120	0.019	0.019	0.017
6	130	0.020	0.022	0.015
7	90	0.053	0.055	0.015
8	120	0.037	0.037	0.037
9	100	0.032	0.032	0.032
10	110	0.053	0.053	0.053

(Okenyi 2004)

(b) Density values fibre specimen

Weights (g)				Relative density of fibre
W1	W2	W3	W4	
593	1581	667	1572	0.9

(Okenyi 2004)

(C) Water absorption of the fibre

Wetting	Wt of dry fibers (g)	wt of water fiber (g)	Wt of water absorbed (g)	Percentage absorption (%) relative to dry
10	10	30	20	200
20a	10	35	25	250
30	10	35	25	250

(Okenyi 2004)

(d) Result of Flexural Strength Test on Plates produced

Mix Ration	Fibre content (%)	Breaking Load (kN)	Flexural strength (Nmm-2)
1:3	-	29.0	3.87
	0.5	72.0	9.60
1:4	-	24.5	3.27
	0.5	48.0	6.40

(Okenyi 2004)

L = 800mm, b = 150mm, d = 200mm

(e) IMPACT TEST RESULTS

Mix Ration	Water-cement ratio	Percentage fibre content	Drop height	Observation	Impact Energy (J)
1:3	0.50	-	300	No cracks	15
			500	No cracks	25
			700	No cracks	34
			900	Shatter on impact	44
	0.55	-	500	No cracks	25
			700	No cracks	34
			900	No cracks	44
			1000	Shatter on impact	49
1:3	0.50	0.5	700	No cracks	34
			900	No cracks	44
			1100	No cracks	54
			1300	Hair-like cracks appear	64
	0.55	0.5	700	No cracks	34
			900	No cracks	44
			1100	No cracks	54
			1300	Hair-like cracks appear	64
1:4	0.50	-	500	No cracks	25
			700	No cracks	34
			900	No cracks	44
			1100	Hair-like cracks appear	54
1:4	0.55	0.5	500	No cracks	25
			700	Shatters on impact	34
	0.55	0.5	700	No cracks	34
			900	No cracks	44
			1200	No cracks	59
			1400	Hair-like cracks	69
	0.55	0.5	700	No cracks	34
			900	No cracks	44
			1100	No cracks	54
			1300	No cracks	64
			1400	Hair-like cracks appear	69

(f) Water Absorption Test Result at 24 Hours

Mix Ratio	Water-Cement Ratio	Percentage Fiber Content (%)	Dry wt of Plates	Wt of Wet Plates (Kg)	Wt of Water Absorbed (Kg)	Percentage Absorption (%)
1:3	0.50 0.55	- -	3.826 3.741	3.901 3.995	0.075 0.254	2.0 6.7
1:3	0.50 0.55	0.5 0.5	3.734 3.633	3.974 3.845	0.240 0.212	6.4 5.8
1:4	0.50 0.55	- -	3.091 3.389	3.261 3.545	0.170 0.156	5.5 4.6
1:4	0.50 0.55	0.5 0.5	3.785 4.194	4.033 4.420	0.284 0.226	6.6 5.4

(Okenyi 2004)

(g) Summary of Porosity Test

Mix Ration	**Water-Cement ratio**	**Percentage fibre content (%)**	**Observation**
1:3	0.50	-	Damp underneath after 6 hours
	0.50	-	Damp underneath after 6 hours
1:3	0.50	0.5	No moisture underneath even after 48 hours
	0.55	0.5	No moisture underneath even after 48 hours
1:4	0.50	-	Water dripped through after six hours
	0.55	-	Water dripped through after six hours
1:4	0.50	0.5	Damp underneath after 24 hours
	0.55	0.5	Damp underneath after 24 hours.

(Okenyi 2004)

Table 2.8: Physical properties of the palm kernel shells.

Property	**Value**
Bulk dusting mg/m^3	0.74
Dry density mg/m^3	06.5
Void ratio	0.40
Porosity %	28
Water content %	9
Water absorption %	14
Specific gravity	1.62
Impact value %	4.5

(Peter, 2008)

Table 2.9: Strength characteristics of Asphalt concrete

Palm Kernel	**Impact Value %**	**Density kg/m^3**	**Water Absorption%**	**Marshal Stability (KN)**	**Flow (mm)**
0	20.64	2.40	0.2	14.44	3.42
10	16.60	2.28	1.2	13.45	3.71
30	12.43	1.90	6.3	11.96	3.78
50	11.20	1.87	8.2	11.10	3.80
70	10.60	1.85	8.6	10.90	4.10
100	4.50	1.70	14	7.78	4.32

(Peter, 2008)

Table 2.11: Workability of periwinkles concrete batches from slump test.

Periwinkle shell: granite	0:100	25:75	50:50	75:25	100:0
Slump 1:2:4 mix (mm)	18	15	10	8	5
Slump 1:3:6 mix (mm)	15	11	8	5	2

(Adewuyi, 2008)

TABLE 2.10: Physical and chemical properties of ash

Properties	**Range**	**Average**
Moisture content (%)	0.48 – 0.73	0.59
Specific gravity	1.78 – 1.87	1.84
Loss of ignition (%)	16.20 – 21.13	18.22
Loose bulk density (kg/m^3)	473 – 504	493
pH	9.35 – 9.70	9.50
Chemical Composition (gm/kg)		
Ca	34.0 – 39.9	37.8
Si	29.3 – 54.3	34.3
K	26.3 – 41.0	32.0
Al	20.7 – 32.7	24.6
Mg	20.3 – 22.0	21.1
Ee	11.4 – 20.3	14.9
Na	1.0 – 3.8	2.3
Mn	0.2 – 0.4	0.3
Zn	0.1 – 0.3	0.2
Ni	0.05 – 0.1	0.1
Cu	0.02 – 0.3	0.1
Cr	0.02 – 0.2	0.05
Pb	0.02 – 0.1	0.03

Table 2.12 : Chemical composition and physical properties of port land cement and timber industrial ash

Chemical composition (%w/w)	**Portland cement**	**Timber industrial ash**
Al_2O_3	7.16	2.8
CaO	60.00	0.1
Fe_2O_3	3.98	1.53
MgO	2.01	2.0
K_2O	0.55	0.53
SiO_2	18.58	67.70
Na_2O	0.33	0.60
SO_3	1.90	1.59
TiO_2	<0.001	<0.001
Physical properties		
Loss on ignition Fineness (m^2/g) Specific gravity	3.55 275 3.15	0.45 330 2.39

(Lee, 1999)

TABLE 2.13: Chemical analysis of Tanzanian and Vietnamese types of rice husk ash

Main oxide	**Vietnamese rice husk ash (% by weight)**	**Tanzanian rice husk ash (% by weight)**
SiO_2	96.7	88.9
Al_2O_3	0.08	0.30
Fe_2O_3	0.03	0.19
CaO	0.30	0.43
K_2O	0.73	3.67
MgO	0.16	2.07

(Biu, 1999)

TABLE 2.14: Specific surface of area of samples of rice husk ask

Max^{-m} Temperature (^{0}c)	**Duration (hours)**	**Specific surface area (m^2/g)**
350	24	102
400	20	76
500	6	57
600	10	120
900	15	104

(Biu, 1999)

Table 2.15: Compressive Strength of Rice husk ash/ Portland cement mortar cubes

Ratio of Ash to cement content	**Compressive Strength (N/mm^2)**			
	3 days	**7 days**	**28 days**	**90 days**
70:30	31.9	45.5	58.7	63.9
50:50	26.1	39.0	57.6	60.7
30:70	24.0	35.4	42.7	50.1
0:100	22.4	32.5	42.4	47.7

(Mehta, 1977) %.

TABLE 2.61: Chemical composition of sugarcane bagasse ash (SCBA) compared with OPC and RHA (Ahmad et al 1992)

Composition	**Sugar cane bagasse ash (%)**		**Rice husk ash (%)**	**Oil palm ash (%)**
	Sample M	**Sample F**		
SiO_2	60.28	63.89	92.05	20.90
Al_2O_3	9.29	8.95	0.94	5.20
Fe_2O_3	1.72	3.49	0.81	4.10
CaO	7.98	7.21	0.27	63.70
MgO	2.40	3.03	0.27	1.80
Na_2O	2.84	1.46	0.06	0.14
K_2O	8.15	8.34	1.72	0.71
SO_3	1.01	0.28	0.31	2.30
Loss of Ignition	5.11	2.52	3.19	1.00
Specify gravity	2.37	2.44	2.09	2.09
Fitness: wet sieving finer than sieve No. 325	88	96	93	84
-Blaine, cm^2/g	Nil	Nil	14300	3000

(Ahmad, 1992)

Table 2.17: The chemical analysis of Bagasse ash from different Sources.

Constituents	% Composition					
	Uteene *	**Report ***	**Paturan ***	**Li Pin Yaen ***	**Dundee Hopper**	**Dundee Crate**
SiO_2	74.2	75.0	71.4	73.07	50.19	57.61
Al_2O_3	12.12	3.6	1.6	12.00	10.12	10.11
Fe_2O_3	12.12	2.7	1.9	12.00	15.75	10.79
CaO	3.93	3.9	4.3	4.3	4.94	4.58
MgO	0.32	4.1	3.8	2.66	8.14	5.31
K_2O	1.67	7.1	11.0	2.65	5.56	6.22
Na_2O	0.36	0.2	0.08	0.16	0.41	0.29
P_2O_5	5.58	2.3	3.4	2.57	2.09	2.38
SO_3	0.20	0.3	Nil	0.23	Nil	Nil
Cl_2	0.07	Nil	Nil	0.01	Nil	Nil
MnO	Nil	Nil	Nil	Nil	0.26	0.29
TiO_2	Nil	Nil	Nil	Nil	1.57	1.46
L.O.I	1.63	1.65	Nil	1.20	1.23	1.24

(Baguant, 1992)

TABLE 2.18: Consistency of OPC paste and SCBA paste

PROPORTION OPC: SCBA	NORMAL CONSISTENCY (%)
100:00	27.0
90:10	28.5
85:15	29.0
80:20	29.0
75:25	29.5
70:30	29.5

(Ahmad, 1992)

Table 2.19: Strength Development with time

Age (Days)	Compressive strength					
	Normal Concrete N/mm^2 %		Hopper ash concrete N/mm^2 %		Grate ash N/mm^2 %	
3	19.9	48.3	21.5	48.5	20.1	46.9
7	30.3	73.5	30.9	69.7	29.9	68.7
28	41.2	100.0	44.3	100.0	43.5	100.0
90	45.4	110.2	50.1	113.1	47.8	109.9
180	45.2	109.7	50.7	114.1	48.4	111.3
365	45.90	111.4	51.5	116.2	51.5	118.4

(Buguant, 1990)

Table 2.20: Batching mix

S/No	Sample	Batch No	Proportion OPC: SCBA (% by weight)
1	M	MA	90:10
		MB	85:15
		MC	80:20
		MD	75:25
		ME	70:30
2	F	FA	90:10
		FB	85:15
		FC	80:20
		FD	75:25
		FE	70:30
3	Control Batch	C	100:00

(Ahmad, 1992)

Table 2.21: Compressive strength requirements of blended cements

	Compressive strength requirements as per ASTM C595 (N/mm^2)		
	3 days	7 days	28 days
Type S	Nil	4.1	10.3
Type IS	12.4	19.30	24.1
Type P	Nil	10.30	20.7
Type IP	12.4	19.30	24.1

(Ahmad , 1992)

Table 2.22: Physical properties of groundnut husk ash

Property	**Range**	**Average**
Moisture content (%)	2 – 3	2.5
Specific gravity	2.38 – 2.44	2.41
Loose bulk density (kg/m^2)	431.1 – 435.7	435
pH	11.25 – 11.30	11.28
Loss of ignition (%)	4	4

(Elinwa , 2001)

Table 2.23: chemical analysis of groundnut – husk ash

Constituents	Percentage by weight
SiO_2	42.30
Al_2O_3	20.02
Fe_2O_3	6.11
CaO	9.78
MgO	10.03
MnO	Nd
Na_2O_3	0.17
K_2O	0.06
P_2O_3	Nd
SO_3	11.56

(Elinwa , 2001)

Table 2.24: Setting time of OPC with GHA mix

Initial setting time (min)	Ash content (%)	Final setting time (Min)	Water/Cement
157	0	1285	0.36
178	5	245	0.38
195	10	258	0.41
210	15	275	0.,44
228	20	310	0.46
235	25	330	0.47

(Elinwa, 2001)

Table 2.25: Compressive strength of groundnut – husk ash/portland cement concrete

Ash (%)	Compressive Strength (N/mm^2)			
	3 days	**7 days**	**14 days**	**28 days**
0	12.71	15.40	17.78	21.78
5	10.04	12.65	14.20	19.91
10	9.61	10.76	13.10	18.40
15	8.41	10.00	12.67	16.54
20	7.31	8.22	11.37	14.67
25	6.31	7.50	9.31	12.67
30	4.22	5.78	7.50	11.40

(Elinwa, 2001)

APPENDIX II

SPECIFIC GRAVITY OF COCO NUT SHELL

(a) First test

Total weight of the sample = 17.80g

	First test		
SECIMEN	**A1**	**A2**	**A3**
Wt of pycometer (g) W_1	**27.70**	**27.70**	**27.70**
Wt of pycometer + sample (g) W_2	**45.50**	**45.50**	**45.50**
Wt of pycometer + sample + water (g) W_3	**81.75**	**87.74**	**89.74**
Wt of pycometer + Water (g) W4	**77.45**	**77.45**	**77.45**
Specific gravity = $\frac{W2}{W2-(W3-W4)}$	**1.35**	**1.33**	**1.37**
Average specific gravity	**1.35**		

{b) Second test

Total weight of the sample = 17.80g

	Second test		
SECIMEN	**B1**	**B2**	**B3**
Wt of pycometer (g) W_1	**27.70**	**27.70**	**27.70**
Wt of pycometer + sample (g) W_2	**45.50**	**45.50**	**45.50**
Wt of pycometer + sample + water (g) W_3	**88.22**	**87.95**	**87.68**
Wt of pycometer + Water (g) W4	**77.45**	**77.45**	**77.45**
Specific gravity = $\frac{W2}{W2-(W3-W4)}$	**1.31**	**1.30**	**1.29**
Average specific gravity	**1.30**		

(C) Third Test

Total weight of the sample = 17.80g

	Third test		
SECIMEN	**C1**	**C2**	**C3**
Wt of pycometer (g) W_1	**27.70**	**27.70**	**27.70**
Wt of pycometer + sample (g) W_2	**45.50**	**45.50**	**45.50**
Wt of pycometer + sample + water (g) W_3	**87.68**	**88.22**	**87.12**
Wt of pycometer + Water (g) W4	**77.45**	**77.45**	**77.45**
Specific gravity = $\frac{W2}{W2(W3-W4)}$	**1.29**	**1.31**	**1.27**
Average specific gravity	**1.29**		

SPECIFIC GRAVITY OF COARSE AGGREGATE (CRUSHED STONE AGGREGATE)

(a) First test

Total weight of the sample = 776.00g

	First test		
SECIMEN	**A1**	**A2**	**A3**
Wt of jar (g) W_1	**585.00**	**585.00**	**585.00**
Wt of jar + sample (g) W_2	**1361.00**	**1361.00**	**1361.00**
Wt of jar + sample + water (g) W_3	**2245.15**	**2437.85**	**2449.92**
Wt of jar + Water (g) W4	**1656.00**	**1656.00**	**1656.00**
Specific gravity = $\frac{W2}{W2-(W3-W4)}$	**2.38**	**2.35**	**2.40**
Average specific gravity	**1.35**		

Second test

Total weight of the sample = 776.00g

	Second test		
SECIMEN	**B1**	**B2**	**B3**
Wt of jar (g) W_1	**585.00**	**585.00**	**585.00**
Wt of jar + sample (g) W_2	**1361.00**	**1361.00**	**1361.00**
Wt of jar + sample + water (g) W_3	**2437.85**	**2425.26**	**2472.60**
Wt of jar + Water (g) W4	**1656.00**	**1656.00**	**1656.00**
Specific gravity = $\frac{W2}{W2-(W3-W4)}$	**2.35**	**2.30**	**2.50**
Average specific gravity	**2.38**		

Third test

Total weight of the sample = 776.00g

	Third test		
SECIMEN	**C1**	**C2**	**C3**
Wt of jar (g) W_1	**585.00**	**585.00**	**585.00**
Wt of jar + sample (g) W_2	**1361.00**	**1361.00**	**1361.00**
Wt of jar + sample + water (g) W_3	**2449.92**	**2437.85**	**2493.54**
Wt of jar + Water (g) W4	**1656.00**	**1656.00**	**1656.00**
Specific gravity = $\frac{W2}{W2-(W3-W4)}$	**2.40**	**2.35**	**2.60**
Average specific gravity	**2.45**		

APPENDIX III

BULK DENSITY

(a) Coconut shell aggregate bulk density

Aggregate size = 2.5mm, using 500ml capacity of cylinder

	First test		
Specimen	**A1**	**A2**	**A3**
Mass (kg) =M	**0.390**	**0.390**	**0.390**
Volume=$\frac{\pi d^2}{4} H$	**6.10×10^{-4}**	**6.10×10^{-4}**	**6.10×10^{-4}**
Bulk density= $\frac{Mass}{Volume}$ Kg/m^3	**639.00**	**639.00**	**639.00**

Second Test: Coconut shell bulk density

	Second test		
Specimen	**B1**	**B2**	**B3**
Mass (kg) =M	**0.390**	**0.390**	**0.390**
Volume=$\frac{\pi d^2}{4} H$	**6.24×10^{-4}**	**6.27×10^{-4}**	**6.21×10^{-4}**
Bulk density= $\frac{Mass}{Volume}$ Kg/m^3	**625.00**	**622.00**	**628.00**

Third Test: Coconut shell bulk density

	Third test		
Specimen	**C1**	**C2**	**C3**
Mass (kg) =M	**0.390**	**0.390**	**0.390**
Volume=$\frac{\pi d^2}{4} H$	**6.20×10^{-4}**	**6.26×10^{-4}**	**6.23×10^{-4}**
Bulk density= $\frac{Mass}{Volume}$ Kg/m^3	**629.00**	**623.00**	**626.00**

(b) Bulk density of fine aggregate

Samples	Nominal aggregate size (mm)	Bulk density Kg/m^3	Average bulk density Kg/m^3
A1	**2.5mm**	**1530**	**1533**
A2	**2.5mm**	**1535**	
A3	**2.5mm**	**1534**	
B1	**2.5mm**	**1535**	**1538**
B2	**2.5mm**	**1538**	
B3	**2.5mm**	**1540**	
C1	**2.5mm**	**1536**	**1536**
C2	**2.5mm**	**1542**	
C3	**2.5mm**	**1531**	

(c) Normal aggregate bulk density

Samples	Nominal aggregate size (mm)	Bulk density Kg/m^3	Average bulk density Kg/m^3
A1	13.5mm	1365.00	1366.00
A2	13.5mm	1369.00	
A3	13.5mm	1364.00	
B1	13.5mm	1374.00	1369.00
B2	13.5mm	1368.00	
B3	13.5mm	1364.00	
C1	13.5mm	1365.00	1367.00
C2	13.5mm	1370.00	
C3	13.5mm	1366.00	

APPENDIX IV

(a) PARTICLE SIZE DISTRIBUTION – FINE AGGREGATE

SIEVE SIZE (mm)	Wt Retained (g)	% Retained	Cummulative % Retained	% Passing
5.00	3.85	0.77	0.77	99.23
3.35	12.55	2.51	3.28	96.72
2.36	32.70	6.54	9.82	90.18
1.18	45.14	9.02	18.84	81.16
0.60	105.00	21.00	39.84	60.16
0.30	170.84	34.17	74.01	25.99
0.15	43.54	8.71	82.72	17.28
0.075	60.36	12.07	94.80	5.20
Pan	26.02	5.20	100.00	0.00

(b) PARTICLE SIZE DISTRIBUTION- COARSE AGGREGATE (20mm)

SIEVE SIZE	WEIGHT RETAINED (g)	WEIGHT PASSING (g)	% RETAINED	CUMULATIVE % RETAINED	% PASSING
20mm	475	2525	15.83	15.83	84.17
14mm	2100	425	70.00	85.83	14.17
10mm	370	55	12.33	98.16	1.83
6.30	42	13	1.40	99.56	0.43
5.0	8	5	0.27	99.83	0.17
3.35	4	1	0.13	99.96	0.13
Pan	1	0	0.03	100.00	0.00

(c) PARTICLE SIZE DISTRIBUTION- COCONUT SHELL

AGGREGATE (16mm)

SIEVE SIZE	WEIGHT RETAINED (g)	% RETAINED	CUMULATIVE % RETAINED	% PASSING
28mm	25	0.50	0.50	99.50
20mm	132	2.64	3.14	96.86
14mm	3975	79.50	82.64	17.36
10mm	765	15.30	97.94	2.06
6.30	61	1.22	99.16	0.84
5.0	16	0.32	99.48	0.52
3.35	13	0.26	99.74	0.26
Pan	13	0.26	100	0.00

APPENDIX V

Coconut shell aggregate impact value

(a) First test

	First test		
SPECIMEN	**A1**	**A2**	**A3**
Wt of cylinder (g) W_1	**2000**	**2000**	**2000**
Wt of sample W_2	**228**	**228**	**228**
$W_1 + W_2$ (g)	**2228**	**2228**	**2228**
Wt of sample that passes sieve 2.36mm (g) W_3	**2.94**	**3.00**	**3.03**
AIV= $\frac{W_3}{W_2}$ X 100%	**1.32**	**1.31**	**1.33**

(b) Second test

	Second test		
SPECIMEN	**B1**	**B2**	**B3**
Wt of cylinder (g) W_1	**2000**	**2000**	**2000**
Wt of sample W_2	**228**	**228**	**228**
$W_1 + W_2$ (g)	**2228**	**2228**	**2228**
Wt of sample that passes sieve 2.36mm (g) W_3	**2.96**	**2.94**	**3.00**
AIV= $\frac{W_3}{W_2}$ X 100%	**1.30**	**1.29**	**1.31**

(c) Third test

	Third test		
SPECIMEN	**C1**	**C2**	**C3**
Wt of cylinder (g) W_1	**2000**	**2000**	**2000**
Wt of sample W_2	**228**	**228**	**228**
$W_1 + W_2$ (g)	**2228**	**2228**	**2228**
Wt of sample that passes sieve 2.36mm (g) W_3	**3.00**	**2.96**	**2.94**
AIV= $\frac{W_3}{W_2}$ X 100%	**1.31**	**1.30**	**1.29**

AGGREGATE IMPACT VALUE FOR CRUSHED STONE

(a) First test

	First test		
SPECIMEN	**A1**	**A2**	**A3**
Wt of cylinder (g) W_1	**2000**	**2000**	**2000**
Wt of sample W_2	**228**	**228**	**228**
$W_1 + W_2$ (g)	**2228**	**2228**	**2228**
Wt of sample that passes sieve 2.36mm (g) W_3	**2.94**	**3.00**	**3.03**
AIV= $\frac{W_3}{W_2}$ X 100%	**1.32**	**1.31**	**1.33**

(b) Second test

	Second test		
SPECIMEN	**B1**	**B2**	**B3**
Wt of cylinder (g) W_1	**2000**	**2000**	**2000**
Wt of sample W_2	**228**	**228**	**228**
$W_1 + W_2$ (g)	**2228**	**2228**	**2228**
Wt of sample that passes sieve 2.36mm (g) W_3	**2.96**	**2.94**	**3.00**
AIV= $\frac{W_3}{W_2}$ X 100%	**1.30**	**1.29**	**1.31**

(a) Third test

	Third test		
SPECIMEN	**C1**	**C2**	**C3**
Wt of cylinder (g) W_1	**2000**	**2000**	**2000**
Wt of sample W_2	**228**	**228**	**228**
$W_1 + W_2$ (g)	**2228**	**2228**	**2228**
Wt of sample that passes sieve 2.36mm (g) W_3	**3.00**	**2.96**	**2.94**
AIV= $\frac{W_3}{W_2}$ X 100%	**1.31**	**1.30**	**1.29**

APPENDIX VI

AGGREGATE CRUSHING VALUE

(a) Coconut shell

(i) First test

	First test		
SPECIMEN	**A1**	**A2**	**A3**
Wt of sample W_1 (g)	**1300**	**1300**	**1300**
Wt of sample that passes sieve 2.36mm (g) W_2	**15.07**	**15.05**	**14.99**
AIV= $\frac{W_2}{W_1}$ X 100%	**1.159**	**1.158**	**1.153**

(ii) Second test

	Second test		
SPECIMEN	**B1**	**B2**	**B3**
Wt of sample W_1 (g)	**1300**	**1300**	**1300**
Wt of sample that passes sieve 2.36mm (g) W_2	**15.20**	**15.05**	**15.08**
AIV= $\frac{W_2}{W_1}$ X 100%	**1.169**	**1.158**	**1.160**

(i) Third test

	Third test		
SPECIMEN	**C1**	**C2**	**C3**
Wt of sample W_1 (g)	**1300**	**1300**	**1300**
Wt of sample that passes sieve 2.36mm (g) W_2	**15.05**	**15.00**	**15.06**
AIV= $\frac{W_2}{W_1}$ X 100%	**1.158**	**1.154**	**1.159**

(b) Crushed stone aggregate crushing value

(i) First test

	First test		
SPECIMEN	**A1**	**A2**	**A3**
Wt of mould (g) W_1	**10450**	**10450**	**10450**
W_1 + sample (g) W_2	**13850**	**13850**	**13850**
Wt of sample (g) W_3	**3400**	**3400**	**3400**
Wt of sample that passes sieve 2.36mm (g) W_4	**800**	**884**	**850**
ACV= $\frac{W_4}{W_3}$ X 100%	**24%**	**26%**	**25%**

(ii) Second test

	Second test		
SPECIMEN	**B1**	**B2**	**B3**
Wt of mould (g) W_1	**10450**	**10450**	**10450**
W_1 + sample (g) W_2	**13800**	**13800**	**13800**
Wt of sample (g) W_3	**3350**	**3350**	**3350**
Wt of sample that passes sieve 2.36mm (g) W_4	**871**	**905**	**905**
ACV= $\frac{W_4}{W_3}$ X 100%	**26%**	**27%**	**27%**

(iii) Third test

	Third test		
SPECIMEN	**C1**	**C2**	**C3**
Wt of mould (g) W_1	**10450**	**10450**	**10450**
W_1 + sample (g) W_2	**13800**	**13800**	**13800**
Wt of sample (g) W_3	**3400**	**3400**	**3400**
Wt of sample that passes sieve 2.36mm (g) W_4	**900**	**816**	**900**
ACV= $\frac{W_4}{W_3}$ X 100%	**26%**	**24%**	**26%**

APPENDIX VII

AGGREGATE ABRASION VALUE

(a) Coco nut shell aggregate

(i) First test

SPECIMEN	**A1**	**A2**	**A3**
Initial wt of sample (g) W_1	**500**	**500**	**500**
Final wt of sample (g) W_2	**488.70**	**488.70**	**488.65**
AAV= $\frac{W_1 - W_2}{W_1}$ X 100%	**2.26%**	**2.25%**	**2.27%**

(ii) Second test

SPECIMEN	**B1**	**B2**	**B3**
Initial wt of sample (g) W_1	**500**	**500**	**500**
Final wt of sample (g) W_2	**488.80**	**488.70**	**488.90**
AAV= $\frac{W_1 - W_2}{W_1}$ X 100%	**2.24%**	**2.26%**	**2.22%**

(iii) Third test

SPECIMEN	C1	C2	C3
Initial wt of sample (g) W_1	500	500	500
Final wt of sample (g) W_2	489.05	489.20	488.90
AAV= $\frac{W_1 - W_2}{W_1}$ X 100%	2.19%	2.16%	2.22%

(b) Crushed stone aggregate crushing value

(i) First test

SPECIMEN	A1	A2	A3
Initial wt of sample (g) W_1	500	500	500
Final wt of sample (g) W_2	370.00	375.00	365.00
AAV= $\frac{W_1 - W_2}{W_1}$ X 100%	26.00%	25.00%	27.00%

(ii) Second test

SPECIMEN	A1	A2	A3
Initial wt of sample (g) W_1	500	500	500
Final wt of sample (g) W_2	355.00	360.00	365.00
AAV= $\frac{W_1 - W_2}{W_1}$ X 100%	29.00%	28.00%	27.00%

(i) Third test

SPECIMEN	C1	C2	C3
Initial wt of sample (g) W_1	500	500	500
Final wt of sample (g) W_2	355.00	350.00	360.00
AAV= $\frac{W_1 - W_2}{W_1}$ X 100%	29.00%	30.00%	28.00%

APPENDIX VIII

AGGREGATE ABSORPTION CAPACITY

(a) Coconut shell aggregate absorption capacity

(i) First test

SPECIMEN	**A1**	**A2**	**A3**
Wt of sample soaked (g)	**1100**	**1100**	**1100**
Wt of surface dry sample (g) W_1	**1210.00**	**1209.69**	**1210.28**
Wt of oven dry sample (g) W_2	**978.00**	**978.00**	**978.00**
Water absorption capacity= $\frac{W_1 - W_2}{W_2}$ X 100%	**23.72%**	**23.69%**	**23.75%**

(ii) Second test

SPECIMEN	**B1**	**B2**	**B3**
Wt of sample soaked (g)	**1100**	**1100**	**1100**
Wt of surface dry sample (g) W_1	**1210.57**	**1209.76**	**1210.37**
Wt of oven dry sample (g) W_2	**978.00**	**978.00**	**978.00**
Water absorption capacity= $\frac{W_1 - W_2}{W_2}$ X 100%	**23.78%**	**23.80%**	**23.76%**

(iii) Third test

SPECIMEN	**C1**	**C2**	**C3**
Wt of sample soaked (g)	**1100**	**1100**	**1100**
Wt of surface dry sample (g) W_1	**1209.49**	**1209.30**	**1210.69**
Wt of oven dry sample (g) W_2	**978.00**	**978.00**	**978.00**
Water absorption capacity= $\frac{W_1 - W_2}{W_2}$ X 100%	**23.67%**	**23.65%**	**23.69%**

(b) Crushed stone aggregate absorption capacity

(i) First test

SPECIMEN	**A1**	**A2**	**A3**
Wt of saturated sample (g) W_1	**100.65**	**100.65**	**100.72**
Wt of oven dry sample (g) W_2	**99.53**	**99.53**	**99.53**
Water absorption capacity= $\frac{W_1 - W_2}{W_2}$ X 100%	**1.10%**	**1.10%**	**1.20%**

(ii) Second test

SPECIMEN	**B1**	**B2**	**B3**
Wt of saturated sample (g) W_1	**100.82**	**100.72**	**100.92**
Wt of oven dry sample (g) W_2	**99.53**	**99.53**	**99.53**
Water absorption capacity= $\frac{W_1 - W_2}{W_2}$ X 100%	**1.30%**	**1.20%**	**1.40%**

(iii) Third test

SPECIMEN	**C1**	**C2**	**C3**
Wt of saturated sample (g) W_1	**100.77**	**100.82**	**100.82**
Wt of oven dry sample (g) W_2	**99.53**	**99.53**	**99.53**
Water absorption capacity= $\frac{W_1 - W_2}{W_2}$ X 100%	**1.25%**	**1.30%**	**1.30%**

APPENDIX IX

AGGREGATE ELONGATION INDEX

(a) Coconut shell aggregate

(i) First test

	First test		
SPECIMEN	**A1**	**A2**	**A3**
Wt of sample (g) M_1	**281**	**281**	**281**
The sum of fractions that have a mass greater than 3% of total mass (g) M_2	**10.15**	**10.14**	**10.16**
The mass of all the elongated particles (g) M_3	**271**	**271**	**271**
AEI= $\frac{M_3}{M_2}$ X 100%	**26.69%**	**26.71%**	**26.67%**

(ii) Second test

	Second test		
SPECIMEN	**B1**	**B2**	**B3**
Wt of sample (g) M_1	**281**	**281**	**281**
The sum of fractions that have a mass greater than 3% of total mass (g) M_2	**10.16**	**10.17**	**10.15**
The mass of all the elongated particles (g) M_3	**270.84**	**270.83**	**270.85**
AEI= $\frac{M_3}{M_2}$ X 100%	**26.66%**	**26.64%**	**26.68%**

(iii) Third test

	Third test		
SPECIMEN	**C1**	**C2**	**C3**
Wt of sample (g) M_1	**281**	**281**	**281**
The sum of fractions that have a mass greater than 3% of total mass (g) M_2	**10.12**	**10.16**	**10.14**
The mass of all the elongated particles (g) M_3	**270.88**	**270.84**	**270.86**
AEI= $\frac{M_3}{M_2}$ X 100%	**26.78%**	**26.66%**	**26.72%**

(b) Crushed stone aggregate elongation index

(i) First test

	First test		
SPECIMEN	**A1**	**A2**	**A3**
Wt of sample (g) M_1	**281**	**281**	**281**
The sum of fractions that have a mass greater than 3% of total mass (g) M_2	**28.10**	**31.22**	**31.22**
The mass of all the elongated particles (g) M_3	**252.90**	**249.78**	**249.78**
AEI= $\frac{M_3}{M_2}$ X 100%	**9.00%**	**8.00%**	**8.00%**

(ii) Second test

	Second test		
SPECIMEN	**A1**	**A2**	**A3**
Wt of sample (g) M_1	**281**	**281**	**281**
The sum of fractions that have a mass greater than 3% of total mass (g) M_2	**35.13**	**31.22**	**28.10**
The mass of all the elongated particles (g) M_3	**245.87**	**249.78**	**252.90**
AEI= $\frac{M_3}{M_2}$ X 100%	**7.00%**	**8.00%**	**9.00%**

(iii) Third test

	Third test		
SPECIMEN	**C1**	**C2**	**C3**
Wt of sample (g) M_1	**281**	**281**	**281**
The sum of fractions that have a mass greater than 3% of total mass (g) M_2	**25.55**	**28.10**	**23.42**
The mass of all the elongated particles (g) M_3	**255.45**	**252.90**	**257.58**
AEI= $\frac{M_3}{M_2}$ X 100%	**10.00%**	**9.00%**	**11.00%**

APPENDIX X

AGGREGATE FLAKINESS INDEX

(a) Coconut shell aggregate

(i) First test

	First test		
SPECIMEN	**A1**	**A2**	**A3**
Wt of sample (g) W_1	**281**	**281**	**281**
Total weight of the material passing the selected metal guage (g) W_2	**241.97**	**242.05**	**241.91**
AFI= $\frac{W_2}{W_1}$ X 100%	**86.11%**	**86.41%**	**86.09%**

(i) Second test

	Second test		
SPECIMEN	**B1**	**B2**	**B3**
Wt of sample (g) W_1	**281**	**281**	**281**
Total weight of the material passing the selected metal guage (g) W_2	**242.03**	**241.94**	**242.11**
AFI= $\frac{W_2}{W_1}$ X 100%	**86.13%**	**86.10%**	**86.16%**

(iv) Third test

	Third test		
SPECIMEN	**C1**	**C2**	**C3**
Wt of sample (g) W_1	**281**	**281**	**281**
Total weight of the material passing the selected metal guage (g) W_2	**242.08**	**241.92**	**242.00**
AFI= $\frac{W_2}{W_1}$ X 100%	**86.15%**	**86.09%**	**86.12%**

(b) Crushed stone aggregate Flakiness index

(i) First test

	First test		
SPECIMEN	**A1**	**A2**	**A3**
Wt of sample (g) W_1	**281**	**281**	**281**
Total weight of the material passing the selected metal guage (g) W_2	**98.35**	**103.97**	**101.16**
AFI= $\frac{W_2}{W_1}$ X 100%	**35.00%**	**37.00%**	**36.00%**

(ii) Second test

	Second test		
SPECIMEN	**A1**	**A2**	**A3**
Wt of sample (g) W_1	**281**	**281**	**281**
Total weight of the material passing the selected metal guage (g) W_2	**106.78**	**101.16**	**103.97**
AFI= $\frac{W_2}{W_1}$ X 100%	**38.00%**	**36.00%**	**37.00%**

(iii) Third test

	Third test		
SPECIMEN	**A1**	**A2**	**A3**
Wt of sample (g) W_1	**281**	**281**	**281**
Total weight of the material passing the selected metal guage (g) W_2	**106.78**	**101.16**	**109.59**
AFI= $\frac{W_2}{W_1}$ X 100%	**38.00%**	**36.00%**	**39.00%**

APPENDIX XI

(a) Compressive strength results for the aggregate size 10mm mix ratio 1:1:1

ID No	Age (Days)	Weight (Kg)	Density (Kg/m^3)	Applied load (KN)	Compressive strength test (N/mm^2)	Average Compressive Strength (N/mm^2)
A1	3	5.20	1541	38.00	1.67	1.64
A2	3	5.21	1544	37.00	1.65	
A3	3	5.24	1553	36.00	1.60	
B1	7	5.50	1630	74.00	3.30	3.29
B2	7	5.44	1612	73.00	3.25	
B3	7	5.30	1570	75.00	3.32	
C1	14	5.53	1639	125.00	5.55	5.63
C2	14	5.55	1644	126.00	5.60	
C3	14	5.56	1647	129.00	5.75	
D1	21	5.70	1689	198.00	8.80	8.82
D2	21	5.65	1674	200.00	8.90	
D3	21	5.48	1624	197.00	8.75	
E1	28	6.40	1896	250.00	11.11	11.11
E2	28	5.95	1763	200.00	8.89	
E3	28	6.30	1867	240.00	10.67	

(c) Compressive strength results for the aggregate size 14mm mix ratio 1:1:1

ID No	Age (Days)	Weight (Kg)	Density (Kg/m^3)	Applied load (KN)	Compressive strength test (N/mm^2)	Average Compressive Strength (N/mm^2)
F1	3	5.60	1659	28.00	1.25	1.24
F2	3	5.55	1644	29.00	1.23	
F3	3	5.58	1653	28.00	1.23	
G1	7	5.65	1674.	54.00	2.40	2.36
G2	7	5.63	1668	50.00	2.20	
G3	7	5.68	1683	56.00	2.48	
H1	14	5.70	1689	101.00	4.50	4.48
H2	14	5.68	1683	99.00	4.40	
H3	14	5.60	1659	105.00	4.55	
J1	21	5.65	1674	147.00	6.55	6.53
J2	21	5.63	1668	145.00	6.45	
J3	21	5.67	1680	148.00	6.58	
K1	28	6.10	1807	190.00	8.45	8.25
K2	28	5.88	1742	187.00	8.30	
K3	28	6.00	1778	180.00	8.00	

(d) Compressive strength results for the aggregate size 16mm mix ratio 1:1:1

ID No	Age (Days)	Weight (Kg)	Density (Kg/m^3)	Applied load (KN)	Compressive strength test (N/mm^2)	Average Compressive Strength (N/mm^2)
L1	3	5.65	1670	54.00	2.40	2.41
L2	3	5.80	1719	54.00	2.38	
L3	3	5.72	1695	55.00	2.45	
M1	7	5.60	1659	108.00	4.80	4.67
M2	7	5.68	1683	102.00	4.53	
M3	7	5.55	1644	105.00	4.68	
N1	14	5.63	1668	182.00	8.10	8.18
N2	14	5.45	1615	184.00	8.18	
N3	14	5.58	1653	186.00	8.25	
P1	21	6.10	1807	288.00	12.80	12.47
P2	21	5.63	1668	268.00	11.90	
P3	21	5.70	1689	286.00	12.70	
Q1	28	6.15	1822	400.00	17.78	16.00
Q2	28	5.65	1674	340.00	15.11	
Q3	28	5.95	1763	340.00	15.11	

(e) Compressive strength results for the aggregate size 16mm mix ratio 1:2:2

ID No	Age (Days)	Weigh t (Kg)	Density (Kg/m^3)	Applied load (KN)	Compressive strength test (N/mm^2)	Average Compressive Strength (N/mm^2)
R1	3	5.15	1526	26.00	1.15	1.15
R2	3	5.10	1511	25.00	1.10	
R3	3	5.13	1520	27.00	1.20	
S1	7	5.00	1481	51.00	2.25	2.32
S2	7	4.95	1467	52.00	2.31	
S3	7	5.33	1579	54.00	2.40	
T1	14	5.30	1570	86.00	3.80	3.81
T2	14	5.28	1564	87.00	3.85	
T3	14	5.30	1570	85.00	3.78	
W1	21	5.10	1511	138.00	6.15	6.30
W2	21	5.40	1600	143.00	6.35	
W3	21	5.35	1585	144.00	6.40	
X1	28	5.55	1644	220.00	9.78	7.71
X2	28	5.25	1556	150.00	6.67	
X3	28	5.60	1659	150.00	6.67	

(e) Compressive Strength test results at age 3day for the various % of normal aggregate replacement (1:2:4)

ID No	Age (Days)	Weight (kg)	Density Kg/m^3	Applied load (KN)	Compressive Strength test (N/mm^2)	% Coarse aggregate replacement	Average Compressive Strength (N/mm^2)
A4	3	2.81	833	203.00	9.00	0%	8.00
A5	3	2.19	649	158.00	7.00		
A6	3	2.50	741	180.00	8.00		
B4	3	2.50	741	180.00	8.00	25%	7.00
B5	3	2.19	649	158.00	7.00		
B6	3	1.88	557	135.00	6.00		
C4	3	1.88	557	135.00	6.00	50%	6.00
C5	3	1.56	462	113.00	5.00		
C6	3	2.19	649	158.00	7.00		
D4	3	1.56	462	113.00	5.00	75%	5.00
D5	3	1.88	557	135.00	6.00		
D6	3	1.25	370	90.00	4.00		
E4	3	1.56	462	113.00	5.00	100%	4.50
E5	3	1.41	418	101.00	4.50		
E6	3	1.25	370	90.00	4.00		

(f) Compressive Strength test results at age 7days

for the various % of normal aggregate replacement (1:2:4)

ID No	Age (Days)	Weight (kg)	Density Kg/m^3	Applied load (KN)	Compressive Strength test (N/mm^2)	% Coarse aggregate replacement	Average Compressive Strength (N/mm^2)
F4	7	5.31	1573	382.50	17.00	0%	17.00
F5	7	5.94	1760	427.50	19.00		
F6	7	4.69	1390	337.50	15.00		
G4	7	3.75	1111	270.00	12.00	25%	14.00
G5	7	4.38	1298	315.00	14.00		
G6	7	5.00	1481	360.00	16.00		
H4	7	3.13	927	225.00	10.00	50%	12.00
H5	7	3.44	1019	247.50	11.00		
H6	7	4.38	1298	315.00	14.00		
J4	7	3.44	1019	247.50	11.00	75%	11.00
J5	7	3.75	1111	270.00	12.00		
J6	7	3.13	927	225.00	10.00		
K4	7	2.81	833	202.50	9.00	100%	10.00
K5	7	3.44	1019	247.50	11.00		
K6	7	3.12	924	225.00	10.00		

(g) Compressive Strength test results at age 14day for the various % of normal aggregate replacement (1:2:4)

ID No	Age (Days)	Weight (kg)	Density Kg/m^3	Applied load (KN)	Compressive Strength test (N/mm^2)	% Coarse aggregate replacement	Average Compressive Strength (N/mm^2)
L4	14	6.88	2039	495.00	22.00	0%	21.00
L5	14	6.56	1944	473.00	21.00		
L6	14	6.25	1852	450.00	20.00		
M4	14	5.62	1665	405.00	18.00	25%	18.00
M5	14	6.25	1852	450.00	20.00		
M6	14	5.00	1481	360.00	16.00		
N4	14	4.06	1203	293.00	13.00	50%	14.00
N5	14	4.69	1390	338.00	15.00		
N6	14	4.38	1298	315.00	14.00		
P4	14	3.44	1019	248.00	11.00	75%	12.00
P5	14	3.44	1019	248.00	11.00		
P6	14	4.38	1298	315.00	14.00		
Q4	14	2.81	833	203.00	9.00	100%	11.00
Q5	14	3.75	1111	270.00	12.00		
Q6	14	3.44	1019	247.00	11.00		

(h) Compressive Strength test results at age 21day for the various % of normal aggregate replacement (1:2:4)

ID No	Age (Days)	Weight (kg)	Density Kg/m^3	Applied load (KN)	Compressive Strength test (N/mm^2)	% Coarse aggregate replacement	Average Compressive Strength (N/mm^2)
R4	21	8.13	2409	585.00	26.00	0%	24.00
R5	21	7.19	2130	518.00	23.00		
R6	21	7.19	2130	518.00	23.00		
S4	21	6.56	1944	473.00	21.00	25%	20.00
S5	21	5.94	1760	428.00	19.00		
S6	21	6.25	1852	450.00	20.00		
T4	21	5.00	1481	360.00	16.00	50%	16.00
T5	21	5.00	1481	360.00	16.00		
T6	21	5.00	1481	360.00	16.00		
W4	21	4.38	1297	315.00	14.00	75%	15.00
W5	21	5.00	1481	360.00	16.00		
W6	21	4.69	1390	338.00	15.00		
X4	21	4.69	1390	338.00	15.00	100%	14.00
X5	21	4.38	1297	315.00	14.00		
X6	21	4.06	1203	293.00	13.00		

(j) Compressive Strength test results at age 28days

for the various % of normal aggregate replacement (1:2:4)

ID No	Age (Days)	Weight (kg)	Density Kg/m^3	Applied load (KN)	Compressive Strength test (N/mm^2)	% Coarse aggregate replacement	Average Compressive Strength (N/mm^2)
AA1	28	8.43	2498	608.00	27.00	0%	27.00
AA2	28	7.81	2314	563.00	25.00		
AA3	28	9.06	2684	653.00	29.00		
BB1	28	6.88	2038	495.00	22.00	25%	23.00
BB2	28	7.50	2222	540.00	24.00		
BB3	28	7.76	2299	518.00	23.00		
CC1	28	6.56	1944	473.00	21.00	50%	20.00
CC2	28	5.94	1760	428.00	19.00		
CC3	28	7.09	2100	450.00	20.00		
DD1	28	5.76	1707	360.00	16.00	75%	17.00
DD2	28	6.48	1920	405.00	18.00		
DD3	28	5.76	1707	360.00	16.00		
EE1	28	5.40	1600	338.00	15.00	100%	15.00
EE2	28	5.04	1493	315.00	14.00		
EE3	28	5.76	1707	360.00	16.00		