THE USE OF PALM KERNEL SHELL AS AGGREGATE FOR CONCRETE

BY

NUHU-KOKO, MUHAMMAD KABIR

A Thesis submitted to the Postgraduate School, Ahmadu Bello University, Zaria in partial fulfillment of the requirements for the award of the degree of MASTER OF SCIENCE (CONSTRUCTION TECHNOLOGY).

Department of Building,
Faculty of Environmental Design,
Ahmadu Bello University,
Zaria.

November, 1988

DECLARATION

I, Nuhu-Koko, M.K., declare as follows:

That this thesis is the record of investigation actually carried out by me.

That, to the best of my knowledge, this work has not been presented, anywhere for a degree.

That all materials and information used from other sources have been duly acknowledged.

.....
Nuhu-Koko, Muhammadu Kabir

.....
Date

APPROVAL STATEMENT

This thesis entitled: "THE USE OF PALM KERNEL SHELL AS AGGREGATE FOR CONCRETE" by Muhu-Koko, Muhammadu Kabir meets the regulations governing the award of the degree of Master of Science (Construction Technology) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

.....	.....
Dr. A.A. Huseini Chairman, Supervisory Committee	Date
.....	.....
Mr. Sani Nelson Member, Supervisory Committee	Date
.....	.....
Mr. U.K. Aimiuwu Member, Supervisory Committee	Date
.....	.....
Dr. T.O. Mosaku Head of Department of Building	Date
.....	.....
Dean, Post-graduate School	Date

DEDICATION

TO BASHIR.

That you may grow up to
achieve greater heights
than your father

ACKNOWLEDGEMENT

I wish to register my indeptedness to Dr. A.A. Husseini for his guidance and constructive criticism at every stage during the compilation of this work. I am also grateful to Messrs Nelson Sani and Kennedy Aimiuwu for their brotherly advice. I am grateful to Dr. T.O. Mosaku for his fatherly advice.

I am grateful to my father, Alhaji Nuhu Koko, to my mother, Hajiya Lamishi Nuhu Koko, and to the entire Nuhu-Koko family for their love and understanding. I am especially grateful to my wife, Rabi for her patience during the course of this work.

I wish to acknowledge my gratitude to Dr. G. Oduma, the Director of Public Buildings, Federal Ministry of Works and Housing, Lagos for giving me the opportunity to undertake this course. I am grateful to Arc. Denis Ayo, the Controller, Federal Ministry of Works and Housing, Sokoto, Mr. A.K. Oyekunle, former Controller, Federal Ministry of Works and Housing, Sokoto, to Arc. Umar Marnai Saulawa, the Resident Architect, Mr. Odeleye, Chief Resident Engineer (Highways) and to the entire members of staff of the Federal Ministry of Works and Housing, Field Headquarters, Sokoto for their moral support and understanding.

I wish to particularly, express my gratitude and appreciation to Mrs. S.E. Atta of the Niger Basin Authority, Minna, for her moral support, encouragement and understanding which were critical to the successful completion of this work.

I am grateful to my friends and classmates for their encouragement.

I am also grateful to the following staff of the building laboratory for their help; Mr. Igbi, Mr. George Nnabugwu, Mr. Abubakar Aliyu and Salisu Rilwanu Audi.

I wish to express my gratitude to Dr. Ataga and Dr I.S. Orewa of the Nigerian Institute for Oil Palm Research, Benin, for their help in providing the information on oil palm.

This acknowledgement would not be complete without thanking Mr. Ochuko Akpomuje and the entire Olori family of Ughelli Bendel State for helping me with the palm kernel shells used in this research work.

I am grateful, too, to Messrs A.R.O. Bello and M.A. Shonibare of the concrete laboratory of the Civil Engineering Department, Ahmadu Bello University, Zaria.

Finally, I am grateful to Mr. Lasisi Gbadamoshi for so enthusiastically accepting to type my manuscript but which he had to abandon to Miss. Florence Mmambiko to complete, due to illness.

I thank you all. May Allah be with you all, amin.

Nuhu-Koko, M.K.
A.B.U.,
Zaria.

November 1988

ABSTRACT

Building materials and components constitute about 50 to 60 per cent of the total cost of a building. However, this high cost can be reduced by the use of alternative building materials that are cheap, affordable and bring about a reduction in the dead weight of the building as a whole.

The environment is becoming in undated with industrial and agricultural bye-products. Some of these waste materials can be gainfully used as building materials.

In this research work palm kernel shell is used as a substitute to coarse aggregate for the making of lightweight concrete.

The physical properties of palm kernel are investigated for both the crushed shell and the uncrushed nut.

Preliminary mixes of ratio 1:8 and 1:2:4 are made for each of the crushed shell and the nut. Further mixes are designed using only the crushed shell applying the CP 114 and AC I methods of design.

Cubes and cylinders produced are cured in water at room temperature and pressure. The cubes are crushed at 7 and 28 days. The cylinders are used for the modulus of elasticity and split tensile tests.

From the results obtained it is found that the strength of concrete made with palm kernel shell (0.5 N/mm^2 to 22 N/mm^2) covers the range of lightweight concretes for both structural and non-structural uses. Indeed the strength is comparable to some categories of dense structual concrete.

Table of Contents

Topic		Page
Title Page		i
Declaration		ii
Approval Statement		iii
Dedication		iv
Acknowledgements		v
Abstracts		vii
Table of Contents		viii
List of Tables		xiv
List of Figures		xvi
List of Plates		xvii
List of Appendices		xviii
Definition of Statistical Terms		xix
1.	Chapter One: Introduction	1
	1.1.0. Background	1
	1.2.0. Objectives	2
	1.3.0. Methodology	2
	1.4.0. Scope and Limitations	4
2.	Chapter Two: Literature Review	5
	2.1. Historical Background	5
	2.2. Characteristics of Lightweight Concrete	6
	2.3.0. Chemistry of Lightweight Concrete	13
	2.3.1. The Process of Hydration in Lightweight Concrete	13
	2.3.2. Pozzolanas in Lightweight Concrete	15
	2.3.3. Carbonation in Lightweight Concrete	15
	2.3.4. Additives in Lightweight Concrete	15
	2.4.0. Curing of Lightweight Concrete	16

2.4.1.	Air Curing	17
2.4.2.	Low-Pressure Steam-Curing	17
2.4.3.	High-Pressure Steam-Curing	18
2.5.0.	Drying Shrinkage and Cracking	20
2.6.0.	Creep of Lightweight Concrete	21
2.7.0.	Functional Properties of Lightweight Concrete	21
2.7.1.	Thermal Insulation	21
2.7.2.	Thermal Expansion/Conductivity	23
2.7.3.	Fire Resistance/Protection	24
2.7.4.	Durability of Lightweight Concrete	26
2.7.5.	Water Absorption of Lightweight Concrete	27
2.7.6.	Acoustic Properties of Lightweight Concrete	27
2.7.7.	Rain Penetration of Lightweight Concrete	28
2.8.	Aerated Concrete	28
2.8.1.	Gas Concrete	28
2.8.2.	Foamed Concrete	29
2.8.3.	Uses of Aerated Concrete	29
2.9.0.	"No-Fines" Concrete	30
2.9.1.	Density of "No-Fines" Concrete	31
2.9.2.	Compaction, Placing and Elastic Modulus of "No-Fines" Concrete	32
2.9.3.	Shrinkage of No-Fines Concrete	33
2.9.4.	Thermal Expansion of No-Fines Concrete	33
2.9.5.	Forst Resistance of "No-Fines" Concrete	33
2.9.6.	Water Absorption of "No-Fines" Concrete	34
2.9.7,	Reinforcement of "No-Fines" Concrete	34
2.10.0.	Saw Dust Concrete	34
2.10.1.	Uses of Saw-Dust Concrete	34

2.10.2.	Properties of Saw-Dust Concrete	35
2.10.3.	Other Organic Aggregate Lightweight Concrete	35
2.11.0.	Cork Lightweight Concrete	35
2.11.1.	Physical Properties of Cork	35
2.11.2.	Uptimum Water/Cement Ratio for Cork Lightweight Concrete	36
2.11.3.	Compaction of Cork-Lightweight Concrete	37
2.11.4.	Methods of Curing	37
2.11.5.	Compressive Strength of Cork Lightweight Concrete	38
2.11.6.	Bond Strength of Cork Lightweight Concrete	38
2.11.7.	Properties of Cork Lightweight Concrete	39
2.11.8.	Uses of Cork Lightweight Concrete	40
2.12.0.	Testing of Hardened Concrete	40
2.12.1.1.	Factors Affecting Tests on Hardened Concrete	40
2.12.1.2.	End Condition	41
2.12.1.2.	Moisture Condition	42
2.12.1.3.	Influence of Rate of Load Application	43
2.12.1.4.	Effects of Characteristics of Concrete	44
2.12.1.5.	Age and Other Factors	44
2.12.2.0.	Compressive Test	44
2.12.2.1.	Cube Test	45
2.12.2.2.	Ratio of 7-day to 28-day Strengths	46
2.12.3.0.	Modulus of Elasticity Test	46
2.12.3.1.	Methods of Determining Moduli of Elasticity	47
2.12.3.2.	Relation of Modulus of Elasticity to Strength	49
2.12.4.0.	Tensile Test	50
2.12.4.1.	The Split Tensile Test	50
2.12.4.2.	Relation Between Compressive Strength and Tensile Strength	51

2.13.0.0	Palm Kernel	52
2.13.1.	Historical Background	52
2.13.2.	Recent Research and Development	54
2.13.3.	Production Potential	55
2.13.4	Availability of Palm Kernel Shell	55
2.14.0.	Other Uses of Palm Kernel	56
2.14.1.	Palm Oil	57
2.14.2.	Palm Kernel Oil	57
2.14.3.	Palm Wine	58
2.14.4.	Shells and Fibres	58
2.14.5.	Leaves	58
2.14.6.	Trunk and Bunch Refuse	58
3.	Chapter Three: Physical Properties of Palm Kernel Aggregate	60
3.1.0.	Specific Gravity of Palm Kernel Aggregate	60
3.1.1.	Procedure of Determining the Specific Gravity	60
3.1.2.	Specific Gravity of Palm Kernel Shell	61
3.1.3.	Specific Gravity of Palm Kernel Nut	61
3.2.0.	Bulk Density of Palm Kernel Aggregate	64
3.3.0.	Voids Ratio of Palm Kernel Aggregate	66
3.4.0.	Porosity of Palm Kernel Aggregate	67
3.5.0.	Absorption of Palm Kernel Aggregate	68
3.6.0.	Moisture Content of Palm Kernel Aggregate	71
3.7.0.	Sieve Analysis of Palm Kernel Aggregate	73
3.7.1.	The Sieving Process	74
3.7.2.	Grading Curves for Palm Kernel Aggregate	78
3.7.3.	Grading Requirements	80
3.7.4.	Fineness Modulus of Palm Kernel	81

4. Chapter Four: Mix Design 83

4.1.0. Introduction 83

4.2.0. Objectives of Mix Design 83

4.3.0. Factors To Be Considered in Mix Design 84

4.3.1. Water-Cement Ratio 84

4.3.2. Cement Content 85

4.3.3. Grading of Aggregate 86

4.3.4. Workability 87

4.3.5. Curing Condition 88

4.3.6. Design Strength 88

4.4.0. Mixing of Palm Kernel Lightweight Concrete 89

4.5.0. Mix Design Procedure 90

4.5.1. Palm Kernel Shell "No-Fines" 91

4.5.2. Palm Kernel Nut "No-Fines" 92

4.5.3. Palm Kernel Shell Concrete 93

4.5.4. Palm Kernel Nut Concrete 94

4.5.5. Palm Kernel Shell Concrete 1:1½:3 95

4.5.6. Palm Kernel Shell Concrete 1:2:4 96

4.5.7. Palm Kernel Shell Concrete Designed to ACI Standards 98

5. Chapter Five: Properties of Palm Kernel Concrete 100

5.1.0. Introduction 100

5.2.0. Workability of Palm Kernel Concrete 100

5.3.0. Slump Test on Palm Kernel Concrete 102

5.4.0. Compacting Factor for Palm Kernel Concrete 103

5.4.1. Compacting Factor for Palm Kernel Shell "No-fines" 103

	5.4.2.	Compacting Factor for Palm Kernel Nut "No-fines"	104
	5.4.3.	Compacting Factor for Palm Kernel Shell Concrete	105
	5.4.4.	Compacting Factor for Palm Kernel Nut Concrete	106
	5.4.5.	Compacting Factor Range	107
6.	Chapter Six: Properties of Hardened Palm Kernel Lightweight Concrete		109
	6.1.0.	Compressive Strength of Hardened Palm Kernel Lightweight Concrete	109
	6.1.1.	Preliminary Mix Design Strength	110
	6.1.2.	Compressive Strength of Mix 1: 1½: 3	111
	6.1.3.	Compressive Strength of Mix 1: 2: 4	114
	6.1.4.	Compressive Strength of ACI Mix	117
	6.1.5.	Summary and Analysis of Compressive Test Results	120
	6.2.0.	Modulus of Elasticity	122
	6.2.1.	Modulus of Elasticity of Mix 1:1½:3	122
	6.2.2.	Modulus of Elasticity of Mix 1:2:4	125
	6.2.3.	Modulus of Elasticity of ACI Mix	125
	6.2.4.	Summary of Modulus of Elasticity Test Results	127
	6.3.0.	Split Tensile Test	128
	7.0.	Conclusion and Recommendations	131
	7.1.	Recommendations for Future Work	132
		References	134

List of Tables

Table		Page
2.1.	A.S.T.M.C. 330-69 Grading Requirements for Lightweight Aggregates for Structural Concrete	9
2.2.	BS.3797:1964 Grading Limits of Coarse Lightweight Aggregate	10
2.3.	BS.3797:1964 Grading Zones of Fine Lightweight Aggregates	11
2.4.	Typical Properties of Lightweight Concretes	12
2.5.	Coefficient of Thermal Expansion of Concretes Made with Lightweight Aggregates	24
2.6.	Estimated Figure Resistance of Hollow Masonry Walls	25
2.7.	Typical Data for 9.5 - 19mm No-Fines Concrete	31
2.8.	Relation Between Modulus of Elasticity and Strength	33
2.9.	Physical Properties of Cork Granules	36
2.10.	Properties of Cork Lightweight Concrete	39
2.11.	Oil Yield Component of Nifor Elite Tenera Compared with the Improved and Unimproved Dura	54
3.1.	Specific Gravities of Palm Kernel	62
3.2.	Apparent Specific Gravity of Different Rock Groups	63
3.3.	Bulk Densities of Palm Kernel	65
3.4.	Percentabe Porosities of Palm Kernel Aggregate	67
3.5.	Porosity of Some Common Rocks	68
3.6.	Absorption Palm Kernel Aggregate Before Heating	69
3.7.	Absorption of Palm Kernel Aggregate After Heating	69
3.8.	Moisture Content of Palm Kernel Aggregate Before Heating	72
3.9.	Moisture Content of Palm Kernel Aggregate After Heating	73
3.10.	Sieve Analysis of Palm Kernel Shell	75
3.11.	Sieve Analysis of Palm Kernel Nut	75
4.1.	Approximate Relationship Between Strength of Lightweight Aggregate Concrete and Cement Content	86

4.2.	CP110:1972: Minimum Strengths of Concrete for Various Uses	88
5.1.	Compacting Factor for Palm Kernel Shell "No-Fines"	104
5.2.	Compacting Factor for Palm Kernel Nut "No-Fines"	105
5.3.	Compacting Factor for Palm Kernel Shell Concrete	106
5.4.	Compacting Factor for Palm Kernel Nut Concrete	107
6.1.	Summary of Preliminary Mix Design Data	110
6.2.	Summary of Results for Mix 1:1½:3	114
6.3.	Summary of Results for Mix 1:2:4	114
6.4.	Summary of Results for ACI Mix	117
6.5.	Summary of Test Results	120
6.6.	Summary of Modulus of Elasticity Test Results	127
6.7.	Results of Split Tensile Tests	130
6.8.	Ratio of Tensile Strength to Compressive Strength	130

List of Figures

Figures		Page
2.1.	Typical Ranges of Densities of Concrete Made with Various Lightweight Aggregates	8
2.2.	Relationship Between Strength and Density of High-Pressure Steam -Cured Aerated Concrete	30
2.3.	Relationship Between Water-Cement Ratio and Compressive strength	36
2.4.	Influence of Compaction Methods on Compressive Strength	37
2.5.	Influence of Water-Cement Ratio on Bond Strength for Various Mixes	38
2.6.	Typical Stress-Strain Curve for Concrete and Various Moduli of Elasticity	48
2.7.	Split Tensile Test	51
3.1.	Grading Curve for Palm Kernel Shell	76
3.2.	Grading Curve for Palm Kernel Nut	77
6.1.	Normal Distribution Curve: Mix 1:1½:3 7 day Strength	112
6.2.	Normal Distribution Curve: Mix 1:1½:3 28-day Strength	113
6.3.	Normal Distribution Curve: Mix 1:2:4 7-day Strength	115
6.4.	Normal Distribution Curve: Mix 1:2:4 28-day Strength	116
6.5.	Normal Distribution Curve: ACI Mix 7-lay Strength	118
6.6.	Normal Distribution Curve: AC Mix 28-Day Strength	119
6.7.	Modulus of Elasticity: Mix 1:1½:3	123
6.8.	Modulus of Elasticity Mix 1:2:4	124
6.9.	Modulus of Elasticity: ACI Mix	126

List of Plates

Plate		Page
I	Particle Sizes of Palm Kernel Shell	79
II	Particle Sizes of Palm Kernel Nut	79
III	Compressive Strength Test on Palm Kernel Lightweight Concrete	109
IV	Modulus of Elasticity Test on Palm Kernel Lightweight Concrete Cylinder	127
V	Split Tensile Test on Palm Kernel Shell Lightweight Concrete	129
VI	Crushed Palm Kernel Shell Lightweight Concrete Cylinders	129

List of Appendices

Appendix		Page
A	Preliminary Design Mixes: Cube Strength for 7 Days	131
B	Preliminary Design Mixes: Cube Strength for 28 Days	132
C	Statistical Analysis for Mix 1:1½:3	133
D	Statistical Analysis for Mix 1:2:4	136
E	Statistical Analysis for ACI Mix	139
F	Modulus of Elasticity for Mix 1:1½:3	142
G	Modulus of Elasticity for Mix 1:2:4	143
H	Modulus of Elasticity for ACI Mix	144

Definition of Statistical Terms

$\bar{x}$ = average strength

x = value of strength of all specimens

u = Arithmetic means

for = required average strength

fc' = specified design strength

c = cell size or range in strength encompassed by each cell

n = number of specimens

STANDARD DEVIATION

The dispersion of strength about the mean is a fixed function of the standard deviation. It is called the root-mean-square deviation and is given by:

A small value of standard deviation indicates good results.

Coefficient of Variation

Significant comparison of dispersions is made by the use of a variation expressed as a ratio or percentage. This is referred to as the coefficient of variations, v.

$$v = \frac{\quad}{\bar{x}} \times 100$$

The smaller the coefficient of variation the better the uniformity of the test results. A variation of 10 per cent indicates good control, 15 per cent is considered fair and anything above that is poor.

Equations of the Gaussian Curve

The Normal curve is plotted by computing the ordinates at $\bar{x}$, at $\bar{x} \pm$ and at $\bar{x} \pm$. A smooth curve is drawn through these points with the points of inflection at $\bar{x} \pm$.

at $\bar{x}$:

$$y = 0.3989 \ nc$$

$\bar{x} \pm$:

$$y = 0.242 \ nc$$

$\bar{x} \pm 2$:

$$y = 0.054 \ nc$$

CHAPTER ONE

INTRODUCTION

KASHIM IBRAHIM LIBRARY
AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA.

1.1.0. Background

Nigeria has formulated various policies and programmes to grapple with the problem of shelter for the people from colonial era to date with limited success. Many reasons can be adduced for this dismal failure. One common feature of these policies is the low priority given to local sourcing of building materials.

Hitherto, all government and private sector designs lay heavy emphasis on the traditional building materials (i.e. cement, steel, gravel, sand, etc.). These materials are either imported or the machinery to produce them is imported. The cost of these materials is made exorbitant by the attendant imported inflation, handling and hauling costs, over head charges, over invoicing, etc.

Another problem that has recently commanded the attention of the various governments in the country is the deteriorating environment. Due to the increasing industrial and agricultural activities tonnes of waste materials are deposited into the environment. Some of these materials are not easily decomposed and their accumulation is a threat to the environment. Examples of these waste materials are rice husks, maize comb, saw dust, perm kernel shell, etc.

To overcome the environmental hazards caused by these waste materials they can be used as construction materials. Research work done by Parker (1947) on saw dust, Aziz et. al. (1978) on cork, Slate (1976) on coconut fibre and Aziz (1973) on rice-husk has shown that these materials can be used to produce lightweight concretes.

This research work is aimed at investigating the use of palm kernel shell as an aggregate for producing lightweight concrete.

1.2.0. Objectives

The objectives of this research work are to investigate:

(i) The possibility of using palm kernel shell to produce concrete.

(ii) The properties of palm kernel shell as an aggregate for concrete.

(iii) The properties of palm kernel shell lightweight concrete.

(iv) The application of palm kernel shell lightweight concrete in construction.

(v) The availability of palm kernel shell in commercial quantities for concrete production.

1.3.0. Methodology

There is no published literature on palm kernel shell lightweight concrete. It is therefore considered necessary to begin this research work with the determination of the physical properties of palm kernel (the crushed shell and the uncrushed nut).

The following properties are determined: Specific gravity, bulk density, voids ratio, porosity, absorption, moisture content and sieve analysis.

Preliminary tests are carried out with the following trial mixes:

(i) Crushed shell "no-fines"; 1:8 cement; shell w/c = 0.45.

(ii) Uncrushed nut "no-fines"; 1:8 cement: Nut w/c = 0.45.

(iii) Crushed shell concrete; 1:2:4 cement: Sand:Shell
w/c = 0.78.

(iv) Uncrushed nut concrete; 1:2:4 cement: Sand: Nut
w/c = 0.75.

The fresh concrete mixes are tested for workability, slump test and compacting factor. Cubes are cast. After 24 hours the cubes are demoulded and cured in water. The cubes are crused at 7 and 28 days.

Further tests are carried out on only the crushed shell light-weight concrete using two methods of mix design. The first method is the CP 114 with which two mixes are made viz: 1:1½:3 and 1:2:4. The second method is the ACI committee standard 211.1-70.

The objective here is not to test the efficacy of the two methods of design. Rather the simplicity of the CP114 method and its wide-spread use in Nigeria informed its use in the first two mixes. However, the strength developed by those mixes was far below the strength of structural lightweight concrete. Therefore a third mix was designed using the ACI method. With this method the strength and other characteristics of the concrete can be predetermined.

Thirty cubes and six cylinders of each mix are cast. The curing is done in water at room temperature and pressure. The cubes are crushed at 7 and 28 days. The cylinders are tested at 28 days. The tests carried out are: compressive strength, split tensile test and modulus of elasticity test.

1.4.0 Scope and Limitation

The scope of this study is limited to the determination of the physical properties of palm kernel and the strength characteristics of palm kernel shell lightweight concrete.

Due to time limitation the curing of the concrete cannot be extended beyond 28 days. It was therefore not possible to monitor the strength development at six months, one year, three years, etc.

Only seven mixes were tested in this study. This is because of the difficulty in the transportation of the raw materials from Bendel State to Zaria. As a result of this it was not possible to try out all possible mixes with varying water/cement ratios to arrive at the most suitable mix.

Certain tests could not be carried out due to financial constraints, time limitation and lack of necessary equipment. Such functional properties of palm kernel shell lightweight concrete as thermal insulation, fire protection, water absorption, rain penetration, thermal conductivity, thermal diffusivity, coefficient of thermal expansion and acoustic properties could not be determined due to these constraints.

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Historical Background

Lightweight concrete is not a new building material per se. The Romans were known to have used lightweight concrete as far back as the second century A.D. According to Short and Kinniburgh (1963), the 43.6m diameter dome of the Pantheon in Rome was built using cast in situ pumic aggregate concrete. Clinker (cinder) concrete was first used by the British and the Americans in the late nineteenth century.

During the First World War The Emergency Fleet Building Corporation of America built ships and barges using reinforced lightweight concrete made from expanded clay aggregate (Portland Cement Association; (1975).

Apart from the initial limited uses of lightweight concrete, it was not until after the Second World War that the Europeans developed interest in it as a construction material. Foamed blast furnace slag was introduced into Britain in the mid 1930s. By 1929 the Swedes were using aerated concrete in the manufacture of blocks. With subsequent improvement through research, reinforced aerated concrete is now widely used in Sweden. (Short and Kinniburgh, 1963).

In general the renewed interest in lightweight concrete in Europe and America was engendered by the desire to construct cheap and affordable houses for the population resulting from the post World War II baby boom. In America and the Soviet Union, where construction materials have to be hauled over long distances, resort was made to lightweight aggregate so as to reduce the cost of haulage. (Short and Kinniburgh, 1963).

At the initial stage, there was a reluctance to embrace lightweight concrete in home construction. But this fear is now largely allayed by the research efforts of scientists both in Europe and America. The Building Research Station of England has made tremendous strides in this direction.

Over the last three decades large estates have been erected using lightweight concrete. According to the Portland Cement Association, the following structures were all made up of lightweight concrete:

(1) The thin-shell roof of the TWA terminal building at Kennedy International Airport, New York

(2) Floor slabs and beams of Marina Towers and Lake point Tower, Chicago.

(3) The Broadmoor Hotel's International Centre, Colorado Springs.

(4) The Assembly Hall at the University of Ilinois, Urbana.

(5) One shell plaza, Houston.

(6) The park Plaza Hotel in St. Louis.

(7) The San Francisco-Oakland Bay Bridge.

2.2. Characteristics of Lightweight Concrete

Short and Kininburgh (1963) describe lightweight concrete as concrete that has been made light by one way or another. There are three methods of producing lightweight concrete (Neville, 1977).

(a) By the elimination of fine aggregate in the mix. Normal coarse aggregate and cement are used to produce the so-called "No-fines" concrete.

(b) By the introduction of voids in the concrete matrix to produce cellular, aerated, foamed or gas concrete.

(c) By using porous lightweight aggregate of low apparent specific gravity.

Neville (1977) has suggested that lightweight concrete can be defined according to the purpose for which it is to be used. Hence there is structural lightweight concrete and insulation lightweight concrete. It is however preferable to describe lightweight concrete in terms of density and compressive strength. The ACI COMMITTEE 213 on the use of structural lightweight aggregate concrete defines it as the concrete having a 28-day strength of not less than 17 N/mm^2 and air-dry unit weight of less than 1850 Kg/m^3.

Insulating concrete generally has a density lower than 800 Kg/m^3 and a strength of between 0.7 and 7 N/mm^2.

In general, the strength of lightweight concrete ranges from 0.3 to 60 N/mm^2. For a strength of 20 N/mm^2 lightweight concrete may require between 240 and 400 kg of cement per cubic metre. For a strength of 30 N/mm^2 the cement content is between 330 to 500 Kg/m^3. Generally, the cement content of lightweight concrete is several times more than that for ordinary concrete of the same strength (Neville, 1977).

Density ranges of concretes made with various lightweight aggregates is shown in Fig. 2.1. These are based on the ACI classification.

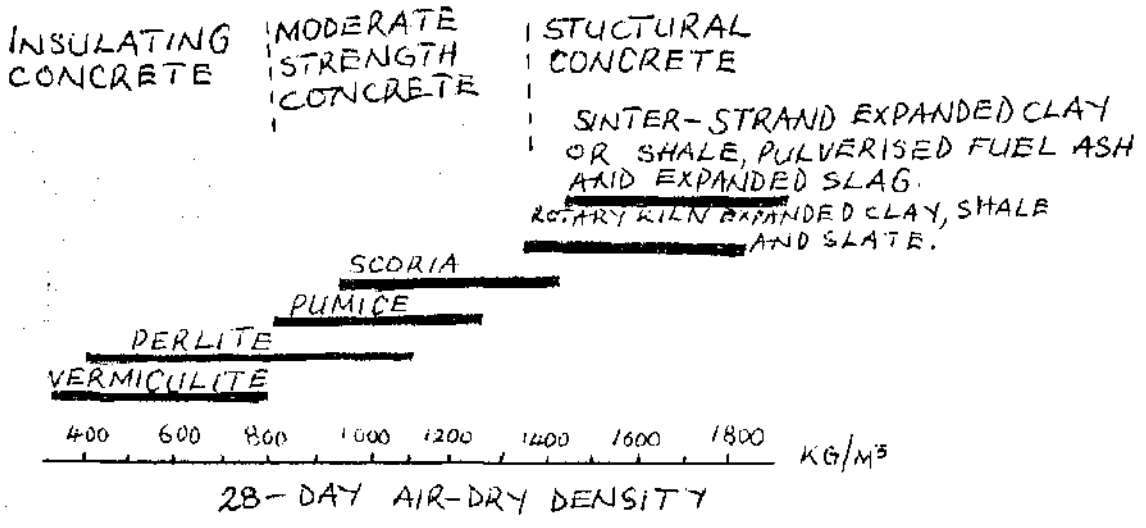


Fig. 2.1. Typical ranges of densities of concrete made with various lightweight aggregates.

Source: Properties of Concrete (Neville, 1977).

Neville (1977) has agreed that there is no simple correlation between the strength of the aggregate as such and the strength of the concrete made with the given aggregate. Requirements for lightweight aggregates as prescribed by A.S.T.M. standards C330-69, C331-69, C332-66 and by B.S. 3797:1964 are reproduced in tables 2.1; 2.2, 2.3 and 2.4 respectively.

Table 2.1 A.S.T.M. C330-69 Grading Requirement for Lightweight Aggregates for Structural Concrete.

A.S.T.M. Sieve Size	Percentage by Weight Passing A.S.T.M. Sieves							
	Nominal Size of Graded Coarse Aggregate							
	25mm–13mm	25mm–5mm	19mm–5mm	13mm–5mm	10mm–2mm	Fine Aggregate.	13mm	10mm
25.40mm	95–100	95–100	100	–	–	–	–	–
19.05mm	–	–	90–100	100	–	–	100	–
12.70mm	0–10	25–60	–	90–100	100	–	95–100	100
9.52mm	–	–	20–60	40–80	80–100	100	–	90–100
4.76mm	–	0–10	0–10	0–20	5–40	85–100	50–80	65–90
2.38mm	–	–	–	0–10	0–20	–	–	35–65
1.19mm	–	–	–	–	–	40–80	–	–
297um	–	–	–	–	–	10–35	5–20	10–25
149um	–	–	–	–	–	5–25	2–15	5–15

Source: Properties of Concrete (Neville, 1977).

Table 2.2. BS3797:1964 Grading Limits of Coarse Lightweight Aggregate

B.S. Sieve Size	Percentage by Weight Passing B.S. Sieves					
	Nominal Size of Graded Aggregate			Norminal Size of Single-Size Aggregate		
	19mm–5mm	13mm 5mm	10mm–3mm	19mm	13mm	10mm
38.10mm	100	–	–	100	–	–
19.05mm	95–100	100	–	85–100	100	–
12.70	–	90–100	100	–	85–100	100
9.52mm	25–55	40–85	80–100	0–20	0–30	85–100
4.76mm	0–10	0–10	5–40	0–5	0–10	0–20
2.40mm	–	–	0–15	–	–	0–5

Source: Properties of Concrete (Neville, 1977).

Table 2.3. B.S. 3797: 1964 Grading Zones of Fine Lightweight Aggregate

	Percentage by Weight Passing B.S. Sieves	
	Grading Zone L1	Grading Zone L2
9.52mm	100	100
4.76mm	90–100	90–100
2.40mm	55–95	60–100
1.20mm	35–70	40–80
600um	20–50	30–60
300um	10–30	25–40
150um	5–19	20–35

Note: Certain departures from a zone are permitted.

Source: Properties of Concrete (Neville, 1977).

KASHIM IBRAHIM LIBRARY
AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA.

2.3.0. Chemistry of Lightweight Concrete

Chemical reactions control the setting of cement, the development of strength and the subsequent durability of concrete.

Portland cement is made from limestone and clay. These raw materials are proportioned and heated at a temperature of 1,400°C in the kiln to form clinker. This clinker is composed of aluminates and silicates. The clinker is finely ground to produce cement.

The two main reactions that take place in concrete are hydrolysis and hydration. The product of these reactions is free hydroxide of lime which is aalkaline and is responsible for the protection of steel against corrosion. It is also the component that is vulnerable to attack by acid, sugar and very pure water (Short and Kinniburgh, (1963). Acid dissolves calcium hydroxide, sugar prevents its formation and pure water leaches it from the concrete mass.

Soluble sulphate destroys concrete by attacking tricalcium silicate, a component mineral in cement. Sulphate resisting cements are made by reducing the amount of tricalcium silicate.

2.3.1. The Process of Hydration in Lightweight Concrete

Concrete consists of cement-water paste and mineral particles. As hydration progresses, the surface of the cement particles becomes coated with gel. This gel grows outward and meets with gel from other particles hence increasing the strength of the concrete.

According to Toxell et. al. (1956), "... for a given dilution of paste the finer the particles, the closer together they are initally and-because of this great r area of surface exposed to the water of hydration - the more rapid the formation of gel. Often a so-called

high-early-strength cement is merely one which is ground finer than the normal cement from a given supply of clinker".

The water needed for hydration is roughly equal to half the water used. The excess is needed for workability. Curing essentially entails retaining water that is already present - (Toxell el. al, 1956).

The basic reactions of cement with water as reported by Short and Kinniburgh (1963) can be shown thus:

$3\ CaO.S_iO_2 + H_2O$	$X\ CaO.y.\ S_iO_2\ aq + Ca(OH)_2$	
Anhydrous	Hydrated	Calcium
Tricalcium	Calcium	Hydroxide
Silicate	Silicate	(Slaked Lime)

In the formation of aerated concrete from portland cement aluminium powder is added to the mix. This aluminium powder reacts with the calcium hydroxide (slaked lime) to produce hydrogen which forms bubbles and is trapped in the concrete mass.

$2\ Al + 3\ Ca\ (OH)_2 + 6\ HO_2$			$3\ CaO.Al_2O_3.6H_2O + 3H_2$	
Aluminium Powder	Calcium Hydroxide	Water	Tricalcium Aluminate Hydrate	Hydrogen

2.3.2. Pozzolanas in Lightweight Concrete

Pozzolanas are a class of siliceous materials that do not posses cementing properties on their own. But when in finely divided form, pozzolanas, when added to concrete, combine with lime in the presence of water at ordinary temperature to form stable insoluble compounds that posses cementitious properties. Short and Kinniburgh (1963) found that most lightweight aggregates posses some pozzolanic properties which enhance the strenght of the resultant concrete.

2.3.3. Carbonation in Lightweight Concrete

All products of portland cement, when exposed to the carbon dioxide of the atmosphere, decompose to form calcium carbonate, hydrated silica, alumina and ferric oxide. However, in dense concretes, the penetration of air is so small that the rate of carbonation is negligible. Lightweight concretes, on the other hand, are particularly vulnerable to carbonation due to their porosity. The carbon dioxide decomposes the calcium silicate hydrates thereby causing considerable shrinkage.

2.3.4. Additives in Lightweight Concrete

Additives may be added to concrete to achieve some desired effects. These additives may be divided into "retarders" and "accelerators" reducing and increasing the rate of hardening of the concrete respectively.

An example of retarder is sugar, while calcium chloride acts as an accelerator. It is normally added at the rate of 2 per cent by weight of cement. If the amount of calcium chloride is below 1 percent by weight of cement it retards rather than accelarate the

setting of the concrete. If the percentage is higher than 3 per cent it causes "flash set". If, however, the concrete is not well compacted, calcium chloride has the effect of corroding the steel reinforcement.

The workability of lightweight aggregate concrete is usually very poor. Additives can, however, be used to increase the workability. Such additives include raw pulverized fuel ash, diatomaceous earth, salts of sulphonated aliphatic compounds and soluble derivatives of natural resins. These are used at the rate of 0.01 per cent by weight of cement. These workability enhancing agents are sometimes referred to as "plasticisers".

2.4. Curing of Lightweight Concrete

The hardening of fresh concrete is as a result of the hydrolysis and hydration reactions between the mineral components of cement and water. These chemical reactions are accelerated by certain conditions of moisture and temperature. The maintenance of hardening concrete under these conditions is termed "curing".

Experiments carried out by Lea and others, and reported by Short and Kinniburgh (1963), have shown that the rate at which concrete developes strength is greatly affected by a rise in temperature, especially at the early ages. However, the strength gain in later ages is reduced so that the ultimate strength developed may be less than that developed by curing at ordinary temperature.

It has been observed from experience that better strength development is achieved if the fresh concrete is maintained at ordinary temperature for a few hours, usually three hours, before subjecting it to high temperature curing. This is due to the fact that hydrolysis, which is the principal reaction at the initial stage is retarded by high temperature. Subsequently, hydration reaction which is a accelerated by heat, picks up and predominates.

There are generally three methods of curing:

(i) Air-curing,

(ii) Low-pressure steam-curing, and

(iii) High-pressure steam-curing.

2.4.1. Air Curing

In this method of curing the concrete products are stacked in the open yard. Depending on the weather conditions they may be repeatedly watered if the situation is dry. Tarpaulin, hessian or polythene sheeting may be used to maintain the moisture condition at ordinary temperature and pressure. This condition is maintained for 28 days. The products are thereafter left to dry out before being used. This is necessary so as to allow drying shrinkage to take place before the concrete products are used. This way excessive cracking is prevented.

2.4.2. Low-Pressure Steam-Curing

Short and Kinniburgh (1963) describe low-pressure steam-curing as curing in steam at atmospheric pressure with the temperature being in the range of 60-80^{o}C. This process can be continuous or intermittent. In the continuous process the concrete products are conveyed through a tunnel on bogies.

Saturated steam is then passed through the tunnel.

The rate of travel of the bogies through the tunnel is controlled in order to ensure that the concrete products receive adequate exposure to the steam.

The second method, the intermittent method, consists of kilns into which the concrete products are stacked. Steam is then introduced. Generally low-pressure steam-curing has no remarkable effect upon drying shrinkage.

2.4.3. High-Pressure Steam-Curing

In this method of curing the concrete products are stacked in autoclaves. A pressure of between 0.689 N/mm^2 and 1.1 N/mm^2 is then applied. The autoclaves are cylinders 1.8 to 3.6m in diameter and from 15 to 30m in length. These clyinders have doors that may be of the quarter-turn or breach-lock pattern.

When the concrete products have been placed the doors of the autoclave are closed and the steam pressure is gradually brought up, usually over a period of 3-6 hours, to the maximum. The maximum pressure is maintained for periods ranging from 4 to 18 hours depending on the type of concrete products and the qualities desired.

High-pressure steam-curing has some desirable advantages. It initiates reactions which will not occur in ordinary conditions.

According to Short and Kinniburgh (1963), in high pressure steam-curing, quartz sand will react with the lime formed by setting of the cement to form a cementing material which contributes to the strength development of the product. This process, by hastening the curing process, increases the turn over by liberating the moulds and pellets quickly for another batch of products to be autoclaved. This process also produces superior products. High-pressure steam-curing also reduces the drying shrinkage by about half what it will otherwise be under normal moist air-curing.

Short and Kinniburgh (1963) gave reasons for this phenomenon. The matrix of cement in the concrete behaves like a gel. It swells on absorbing water and shrinks on drying. This swelling and drying is responsible for the perceived shrinkage of concrete. However, in dense concrete, the rigidity of the aggregate restricts these movements hence giving the concrete a low drying shrinkage.

In lightweight concrete no restraints is provided to check this swelling and shrinkage because the aggregate is less rigid. This leads to high drying shrinkage. High-pressure steam-curing checks this high drying shrinkage by transforming the cement matrix from a gel-like structure to one of more crystalline nature and hence greater dimensional stability.

High-pressure steam-curing has the effect of greatly improving the resistance of concrete to attack by sulphate bearing waters.

2.5. *Drying Shrinkage and Cracking*

Concrete products, on drying, undergo shrinkage known as"initial drying shrinkage". On subsequent wetting and drying these products expand and contract respectively. This is known as "reversible moisture movement". Initial drying shrinkage is by far greater than the reversible moisture movement in ordinary dense concrete. But research has shown that with lightweight concrete the moisture movement is as high as the initial drying shrinkage. Generally, autoclaved concrete products show low drying shrinkage while air-cured ones show high drying shrinkage.

Shrinkage causes the build up of tensile stress in the concrete member. If these stresses exceed the tensile strength of the member cracking results. Some of these stresses are, however, relieved by the creep and the elastic extensibility of the concrete.

The British Standard for concrete blocks B.S. 2028:1953, gives the following limits for movements of lightweight blocks:

Initial drying shrinkage ... Class B 0.06 per cent

Class C 0.08 per cent

Reversible moisture movement ... Class B 0.05 per cent.

According to the Building Research Station Digest No. 6, "the avoidance of cracking in masonry construction of concrete or sand-lime bricks", the following measures can be taken to reduce serious cracking due to shrinkage.

(i) Storage: Blocks should be stored in a dry site and must remain dry until used. They should be stacked in such a way that air circulates freely through the stack.

(ii) Wetting: Very dry bricks have to be wetted before bedding. This is to prevent the brick from absorbing water from the jointing mortar. However, the wetting should be sparingly done.

(iii) Mortar: The mortar should be of weak type. Strong martar exhibits high shrinkage. The following proportions are recommended for motars:

1:2:8–9 cement: hydrated lime: sand.

1:1:5–6 cement: hydrated lime: sand.

1:8: cement: sand.

(iv) Reinforcement: Steel reinforcement may be used in bed-joints of blockwork close to window and door openings. The steel reinforcement prevents the cracks from becoming pronounced.

(v) Design: The building may be designed in such a way as to provide contraction joints at suitable intervals.

2.6.0. Creep of Lightweight Concrete

The range of creep in lightweight concrete is the same as the range of creep in normal-weight concrete. Creep is dependent upon magnitude of stress, strength of concrete, age at loading, time after loading, method of curing and moisture condition of the concrete.

2.7 Functional Properties of Lightweight Concrete

2.7.1. Thermal Insulation

Temperature difference between the inside and the outside of a wall causes heat flow from the warmer to the colder side. The magnitude of this temperature difference is termed as Temperature Gradient.

The wall offers resistance to this heat flow but does not completely stop the flow. Thermal Insulation is therefore the Coefficient of resistance to heat transfer.

Heat insulation is inversely proportional to the density of the material. Lightweight concretes, with their high porosities exhibit high values of thermal insulation. To achieve good thermal insulation it is advisable to use weaker and lighter aggregates or lean mixes with heavier lightweight aggregate.

There are three methods through which heat is transferred.

(i) Conduction: By this method heat travels through a solid material or from one material to another in intimate contact with it. Because of the porosity of lightweight concretes they contain air in their pores. Air being a poor conductor of heat enhances the heat insulation properties of lightweight concretes.

(ii) Convection: Gases, when heated become lighter and move upwards while cooler and heavier gas moves down. This sets up a current refered to as convection currents. This process of transfer of heat from one place to another is called convection.

(iii) Radiation: This is a process whereby heat is emitted from the surface of a material and transmitted through space as energy.

Radiant energy is in form of wave motion the wavelength depending on the temperature of the radiating surface. Heat loss through a wall is partly through radiation and partly through convection. Moisture content of a material has a marked effect on the thermal conductivity of that material. The higher the moisture content the higher the conductivity. As a result of this rain penetration and condensation through the wall should be avoided if the insulating value is not to be lowered.

2.7.2. Thermal Expansion/Conductivity

Lightweight aggregate concrete has generally lower thermal expansion than ordinary concrete. Because of this property, lightweight concrete exhibits reduced tendency to warp or bukle when the two faces of a concrete member are subjected to different temperatures. Lightweight aggregagate concrete has a low thermal conductivity. In case of fire this property reduces the temperature rise of the embedded steel. Neville (1973) has tabulated values of coefficient of thermal expansion for various lightweight aggregate concretes and are reproduced in Table 2.5.

Table 2.5 Coefficient of Thermal Expansion of Concretes Made With Lightweight Aggregates

Type of Aggregate Used	Linear Coefficient of Thermal Exansion (Determined Over a Range of $-22^{\circ}C$ to $52^{\circ}C$). 10^{-6} Per $^{\circ}C$
Pumice	9.4 to 10.8
Perlite	7.6 to 11.0
Vermiculite	8.3 to 14.2
Cinders	About 3.8
Expanded shale	6.5 to 8.1
Expanded slag	7.0 to 11.2

Source: Properties of Concrete (Neville, 1977).

2.7.3 Fire Resistance/Protection

As reported by Neville (1973), the fire resistance of lightweight aggregate concrete is greater than that of ordinary concrete. (Typical values are shown in Table 2.6). This phenomenon is so because lightweight aggregate concrete has a lesser tendency to spall. Ordinary dense concrete losses a greater proportion of its original strength with rise in temperature (See Table 2.4).

Short and Kinniburgh (1963) reported that the ability of a structural element to resist fire is not so much a property of the material it is made of as it is a function of the assembly of materials stored inside it. Though the combustibility of a material may be important the severity of fire depends not so much on the fabric of the structure as from its contents. Though a material may not be good in fire protection its resistance can be improved by suitable protection. An example is by rendering with gypsum plaster. Gypsum plaster is a non-combustible material. It's resistance to fire is attributed to the large quantity of chemically bonded water which it contains and which must be removed before failure takes place. The temperature reached, the duration of the fire and the nature of the unit and its intrinsic resistance to thermal damage determine the effect of fire on a structural element of a building.

Table 2.6. Estimated Fire Resistance of Hollow Masonry Walls

Type of Aggregate Used	Minimum equivalent thickness for ratings of:			
	4h mm	3h mm	2h mm	1h mm
Expanded slag or pumice	119	102	81	53
Expanded clay or shale	145	122	96	66
Limestone, cinders or unexpanded slag	150	127	102	69
Calcereous gravel	157	135	107	71
Siliceous gravel	170	145	114	76

Source: Properties of Concrete (Neville, 1977).

The British Standard 476 prescribes test for the fire-resistance of buildings. The structural element is placed in a furnace which reproduces conditions similar to an actual fire and the period of time, reckoned in hour, which the unit can remain exposed to the fire of standard severity without functional failure is used as an index of fire resistance.

2.7.4. Durability of Lightweight Concrete

The ability of a material to withstand the effects of its environment is called its durability. In buildings these effects may be chemical attack, physical stress or mechanical assault.

Chemical attack is usually caused by sulphate attack in aggressive ground water, polluted air and spillage of reactive liquids. Because of its porosity, lightweight concrete is more vulnerable to these attacks. As a result of this, lightweight concrete is not recommended for use under damp-course. Attack by air pollution is rare. It only occurs under severe conditions of air pollution.

Physical stresses are developed in lightweight concrete as a result of frost action, shrinkage and temperature stresses. These actions adversely affect its durability. Lightweight concrete is therefore not suitable for use below ground level in frost prone areas. Shrinkage and temperature stresses are not as disruptive as frost action.

Their effect is minimised by the provision of temperature reinforcement and expansion joints. Mechanical damage may result from abrasion or impact which might arise from excessive loading of flexural members. Corrosion of reinforcement steel causes spalling of lightweight concrete which adversely affects its durability.

2.7.5. Water Absorption of Lightweight Concrete

Because of their porous nature lightweight concretes have a higher water absorption than ordinary dense concrete. However, this is no hinderance to their application in wet climates because they are seldom used without adequate protection by the use of suitable protective rendering. The thickness of the member may also be increased to enhance the water exclusion ability of lightweight concrete elements.

2.7.6. Accustic Properties

The sound reduction factor (dB) is defined as the ratio of the energy of the sound at its source to that at any other location. It is expressed in decibels (dB). Density of a material is the major determinant of the materials sound insulation properties. On this score lightweight concrete elements are at a disadvantage. Costly remedial measures are necessary.

However, lightweight concrete has good sound absorption. The absorption coefficient of sound is about twice that for ordinary concrete.

2.7.7. Rain Penetration of Lightweight Concrete.

A very important function of walls is to exclude rain-water. In cavity construction the problem of rain-water penetration is eliminated. But when lightweight concrete walls are constructed in single skin this problem is very serious.

Rain penetration largely occurs through carpillary cracks in the joints. The more impervious the concrete is the more is rain penetration through these cracks. Lightweight concrete, inspite of its porosity, renders good resistance to rain penetration when built in sufficient thickness and adequately protected by porous rendering.

Standard tests have been devised to assess the resistance of walls to rain-penetration. This test involves the spraying of water on to the face of the wall, either continuously or intermittently, at a predetermined rate. Artificially simulated wind pressure may or may not be applied. After a specified period of time, if moisture does not show on the other face of the wall then its resistence to rain penetration is satisfactory.

2.8. Aerated Concrete.

Aerated concrete is a lightweight concrete obtained by introducing gas bubbles into the cement matrix. This procedure produces a material with a cellular structure. Hence the name cellular or aerated concrete. There are two basic methods of producing aerated concrete:

2.8.1. Gas Concrete

This is achieved by the introduction of finely divided aluminium powder, powdered zinc or aluminium alloy into fresh morter. The active powder reacts with hydrozide of calcium liberating hydrogen. This hydrogen forms a large number of bubbles which expand the morter but do not escape. To achieve this, the speed of gas evolution, the consistence of mortar and its setting time must be carefully matched.

In certain instances hydrogen peroxide is used instead. This liberates oxygen instead of hydrogen. In either case the amount of powder added is of the order of 0.2 per cent by weight of cement, as reported by Neville (1973).

2.8.2.. Foamed Concrete

This involves the addition of a foaming agent into the matrix. This introduces and retains air bubbles when mixing at high speed. The foaming agents commonly used are usually made from hydrolysed protein or resin soap. In some instances, a stable pre-formed foam is added into the mortar during mixing at ordinary speed.

Aerated concrete can be structural or non-structural. Non-structural aerated concrete is mostly used for insulation purposes. It does not require coarse aggregate. The density ranges between 200 and 300 kg/m^3.

Structural aerated concrete has a density range of between 500 and 1,100 kg/m^3. The strength and thermal conductivity of aerated concrete, like all other lightweight concretes, varies in proportion to density. For example, with a density of 500 kg/m^3, the strength will be in the region of 3 to 4 N/mm^2 and the thermal conductivity 0.1 $Jm/m^2 S^oc$. And for a density of 1,400 kg/m^3 the strength range is between 12 and 14 N/mm^2 and the thermal conductivity 0.4 Jm/m^2S^oc. The conductivity of aerated concrete is about 10 times lower than that of ordinary concrete. The modulus of elasticity for aerated concrete ranges between 1.7 to 3.5 GN/m^2. Their creep is the same with ordinary concrete (Neville, 1977).

Compared with lightweight aggregate concrete of the same strength, aerated concrete has higher tharmal movement, high shrinkage and moisture movement. However, high-pressure steam-curing increases the comperessive strength and reduces the thermal movement, shrinkage and moisture movement. This relationship is shown in Fig. 2.2.

2.8.3. Uses of Aerated Concrete

Because of its low thermal conductivity aerated concrete has a wide application for partitions, for heat insulation and fire proofing. In fire resistance it performs better than ordinary concrete. Structural aerated concrete is used for floor construction instead of hollow tile floor. It is also used in the form of high-pressure steam-cured blocks and precast members. It is reasonably durable, can be sawn and it can hold nails. Its rate of water absorption is high. However, the rate of water penetration is low due to the large pores which do not allow the ingress of water by carpillary action. Hence when properly rendered, it exhibits good frost resistance and can be used in wall construction.

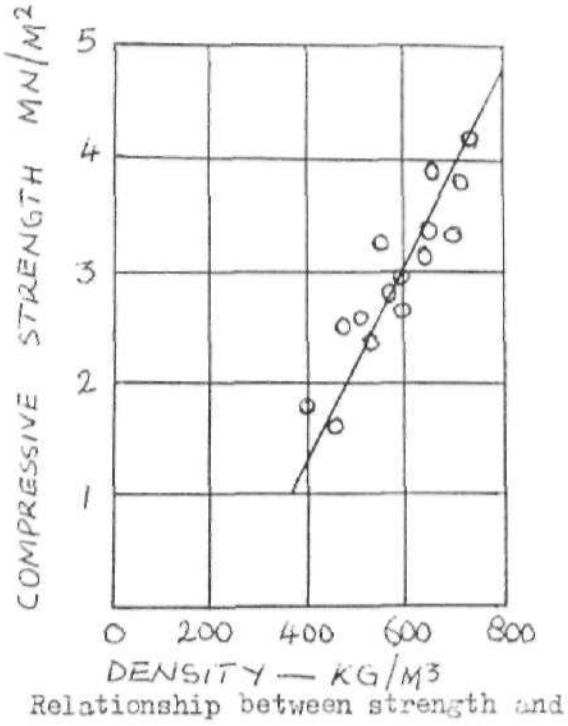


Fig. 2.2. Relationship between strength and density of high-pressure steam-cured aerated concrete.

Source: Properties of Concrete (Neville, 1977).

When used with reinforcement special protection against corrosion is needed. This is done by dipping the reinforcement in bituminous solutions or epoxy resins. However, care must be taken as some anti-corrosion agents affect the bond strength adversely.

2.9.0. "No-Fines" Concrete

No-fines concrete is produced by the elimination of the fine aggregate in a mix. Coarse aggregate alone is mixed with cement paste to produce no-fines concrete. No-fines concrete has large pores which do not allow movement of water by carpillary action.

No-fines concrete has lower strength than ordinary concrete. However, its strength is adequate enough to construct buildings up to 20 storeys high, as was built in Dusseldord, Germany (Short and Kinnibur h, 1963, Neville, 1977).

2.9.1. Density of No-Fines Concrete

The density of no-fines concrete depends on the grading of the aggregate. This is so because a well graded aggregate packs more compactly together than single-size aggregate. The usual range of aggregate sizes is 9.5mm to 19mm. When a well graded aggregate is used the density is 10 per cent higher than when a single-size is used (Neville, 1977).

The density of no-fines concrete made with normal aggregate ranges between 1,600 kg/m^3 to 2,000 kg/m^3. However, when lightweight aggregate is used the density could be as low as 640 kg/m^3. The data for 9.5mm to 19mm no-fines aggregate as reported by Neville (1977) is shown in Table 2.7.

Table 2.7. Typical Data for 9.5-19mm No-Fines Concrete

Aggregate/ Cement Ratio by Volume	Water/Cement Ratio by Weight	Density Kg/m^3	28-Day Compressive Strength N/mm^2
6	0.38	2,020	14
7	0.40	1,970	12
8	0.41	1,940	10
10	0.45	1,870	7

Source: Properties of Concrete (Neville, 1977).

2.9.2. Compaction, Placing and Elastic Modulus of No-Fines Concrete

No-fines concrete does not segregate and can be dropped from great heights. Because of the absence of sand there is less surface area to be coated by cement paste. This means that less cement is required in no-fines concrete - about 70 to 130 kg/m^3 of concrete (Neville, 1977). This feature of no-fines concrete makes it cheaper than other lightweight aggregate concretes.

Rodding is not recommended for no-fines concrete as this causes high local density. The strength of no-fines concrete ranges between 1.4 to 14 N/mm^2 (Neville, 1977). The water/cement ratio should be carefully determined for each given aggregate. If it is too high the cement paste drains away from the aggregate particles. When it is low the cement paste will not be adequately adhesive and there will be no proper compaction. The usual proportion for no-fines concrete is from 1:6 to 1:10 - Short and Kinniburgh (1963). However, lean mixes of ratio 1:20 (cement/aggregate) and a cement content of 70 kg/m^3 are possible (Neville, 1977).

Typical values of elasticity for concretes made of different strengths are shown in Table 2.8.

Table 2.8: Relation Between Modulus of Elasticity and Strength

Compressive Strength N/mm^2	Modulus of Elasticity GN/m^2
4.8	10.3
3.4	9.0
2.4	6.9

Source: Properties of Concrete (Neville, 1977).

KASHIM IBRAHIM LIBRARY
IHMAIU, BELLO UNIVERSITY
ARIA, NIGERIA.

2.9.3. Shrinkage of NO-Fines Concrete

The cement paste forms a thin coating over the aggregate particles. On drying, the cement contracts. But this contraction is restrained by the large aggregate particles. This gives no-fines concrete its characteristics low drying shrinkage. However, the rate of shrinkage is high due to the exposure of the cement paste to the air. For example half the total shrinkage takes place in only ten days while it is completed in about one month - Neville (1977).

2.9.4. Thermal Expansion of No-Fines Concrete

The coefficient of thermal expansion of no-fines concrete depends on the type of aggregate used. The thermal movement is about 0.6 to 0.8 that of normal concrete. The coefficient of thermal conductivity is between 0.69 and 0.94 Jm/m^2S^oC when ordinary aggregate is used and about 0.22 Jm/m^2S^oC when lightweight aggregate is used - Neville (1977)

2.9.5. Frost Resistance of No-Fines Concrete

No-fines concrete is resistant to frost action, due to the absence of carpillaries. However, the large pores must not be filled with wateras this leads to total disintegration of the concrete on freezing.

2.9.6. Water Absorption of No-Fines Concrete

The water absorption of lightweight aggregate no-fines concrete is as high as 25 per cent by volume - Neville (1977). For this reason it is not suitable for use in foundations and in areas where it will be in contact with water. External walls have to be rendered on both sides. However, this reduces the sound absorption properties because air permeability is reduced. Therefore in cases where acoustic properties are of paramount importance, one face is normally left unrendered.

2.9.7. Reinforement of No-Fines Concrete

When reinforcement is to be used with no-fines concrete it has to be coated with cement paste so as to improve the bond strength. This is done by "guniting" - Neville (1977).

2.10.0. Saw Dust Concrete

Saw dust concrete is made by proportioning equal volumes of portland cement, sand and pine sawdust. Water is added to give a slump of 25mm to 50mm - Neville (1977).

2.10.1. Uses of Saw-Dust Concrete

Saw dust concrete is used as nailing concrete. This is a material into which nails can be driven and held firmly. It is used in some lightweight concrete and roof constructions that have poor nailing properties.

2.10.2. Properties of Saw-Dust Concrete

Saw dust concrete has a large moisture movement and should not be exposed to moisture conditions. Chemical treatment is sometimes applied to obviate adverse effects on setting and hydration, to prevent the rotting of the sawdust and to reduce moisture movement. Saw dust has a density range of between 650 kg/m^3 and 1,600 kg/m^3.

2.10.3. Other Organic Aggregate Lightweight Concretes

Neville (1977) reported that other wood wastes such as splinters, shavings, rice husks and wheat have been used to produce non-load bearing concrete with a density range of 800 kg/m^3. Synthetic organic materials, like polystyrene, have also been used to produce lightweight concrete of good insulating properties.

2.11.0. Cork Lightweight Concrete

Aziz and his colleagues at the University of Singapore developed the cork lightweight concrete in 1978. There is abundance of cork granules in Singapore largely used as packing material for imported fruits. So they decided to use it for concrete.

2.11.1. Physical Properties of Cork

The physical properties as determined by Aziz et. al. (1978) for cork are shown in Table 2.9.

Table 2.9. Physical Properties of Cork Granules

Specific Gravity	0.172 to 0.175
Finess Modulus	4. 10 to 4. 30
Moisture Content %	0. 25 to 0. 30
Absorption %	230 to 240
Density Kg/m^3	68.50 to 70.50
Voids %	55 to 60
Grain Size mm	0.30 to 2.35

Source: International Journal of Lightweight Concrete (1979).

2.11.2 Uptimum Water/Cememt Ratio for Cock Lightweight Concrete

Trial mixes were made of ratios 1:1, 1:2 and 1:3 cement: cork granules. It was discovered that the uptimum water/cement ratio was 0.35 for mixes 1:1 and 1:2 and 0.30 for mix Fig. 2.3 shows a comparison of water/cement ratio and compressive strength (Aziz et. al. 1978).

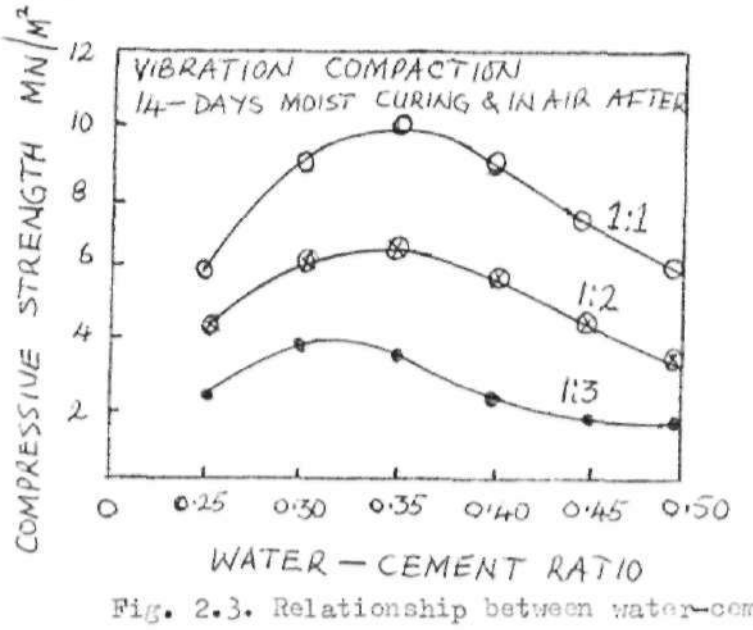


Fig. 2.3. Relationship between water-cement ratio and compressive strength.

Source: International Journal of Lightweight Concrete (1979).

2.11.3. Compaction of Cork-Lightweight Concrete

Methods of compaction were also investigated. Vibration was found to be the most suitable method of compaction. Fig. 2.4 shows the relationship between compaction methods and compressive strength.

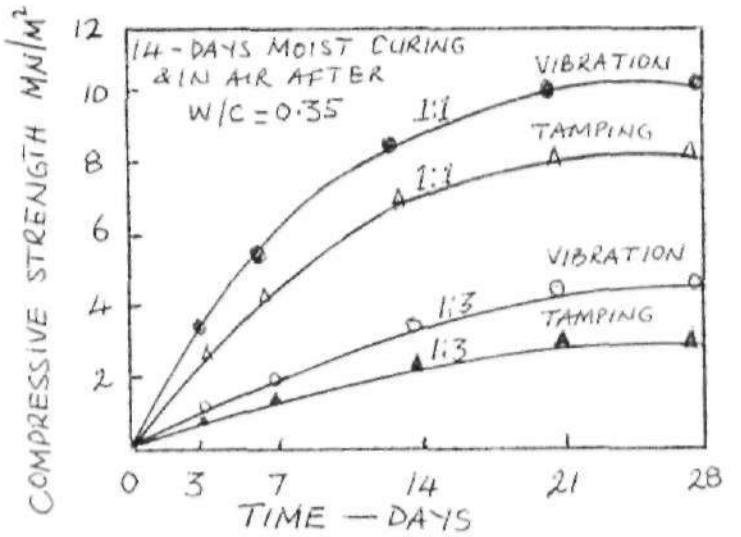


Fig. 2.4. Influence of compaction methods on compressive strength.

Source: International Journal of Lightweight Concrete (1979).

2.11.4 Methods of Curing

All cubes were cured in water for varuous periods of time Aziz et. al. (1978) discovered that continuous moist curing reduce the strength after 14 days. They also discovered a steady increase in strength for cubes having 14-days.moist curing and dry air-curing afterwards. This was explained as being caused by the rapid initial hydration and setting of cement during the 14-day moist curing.

Afterwards, when the cubes are kept in air, the moisture present is sufficient to cause further setting of cement and hence continuous gain in strength. Continous moist curing, on the other hand, causes the specimens to be supersaturated after 14-days in water. This lowers the strength.

2.11.5. Compressive Strength of Cork Lightweight Concrete

The compressive strength of both cubes and cylinders were also compared. The ratio of cube to cylinder strength was found to be in the range of 0.80 to 0.86.

2.11.6. Bond Strength of Cork Lightweight Concrete

At a fixed water/cement ratio of 0.35 the bond stresses were found to be 0.4 N/mm^2, 0.25 N/mm^2 and 0.1 N/mm^2 for mixes 1:1 1:2, 1:3 respectively. The relationship between water/cement ratio and bond strength, as determined by Aziz et. al. (1978) is reproduced in Fig. 2.5.

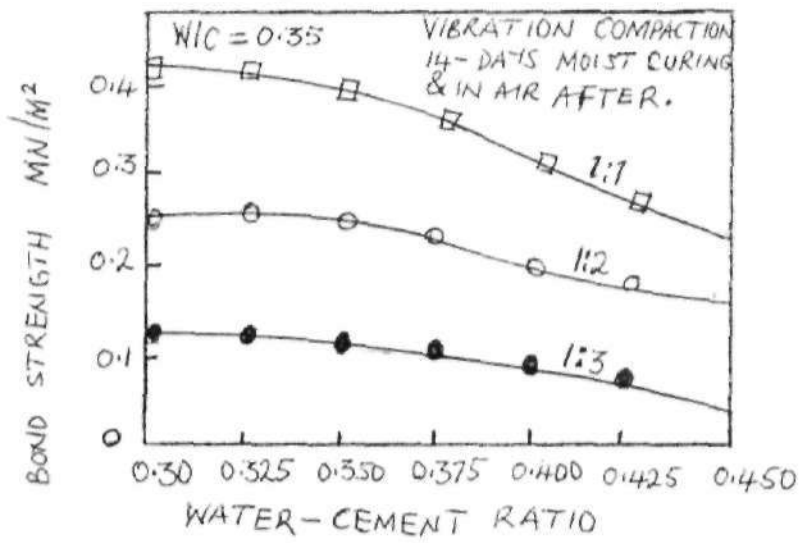


Fig: 2.5: Influence of water/cement ratio on bond Strength for various mixes.

Source: International Journal of Lightweight Concrete (1979).

Fig. 2.5. Influence of water-cement ratio on bond strength for various mixes.

Source: International Journal of Lightweight Concrete (1979).

2.11.7. Properties of Cork Lightweight Concrete

The tensile strengths were found to be 2 N/mm^2, 1 N/mm^2 and 0.65 N/mm^2 for mixes 1:1, 1:2 and 1:3 respectively. On the whole cork lightweight concrete was found to exhbit better nailing, shrinkage and thermal properties than lightweight concretes made from organic aggregates. The properties of cork lightweight concrete are determined and represented in Table 2.10.

Table 2.10. Properties of Cork Lightweight Concrete

Properties	Mix Proportion		
	1:1	1:2	1:3
Dry density kg/m^3	870-890	590-640	475-495
Compressive strength N/mm^2	11.00-12.00	6.50-6.80	4.20-4.50
Tensile strength N/mm^2	1.85-2.00	0.95-1.00	0.600-0.700
Modulus of Elasticity N/mm^2	4,000-4,500	-	-
Dry Shrinkage%	0.025-0.035	-	-
Termal Conductivity W/m deg C	0.19-0.23	0.14-0.16	0.10-0.12

Source: International Journal of Lightweight Concrete (1979).

2.11.8. Uses of Cork Lightweight Concrete

Aziz et. al. (1978) concluded by suggesting possible areas where cork lightweight concrete can be used. These include:

(i) Concrete fill over buried pipe structures.

(ii) Fill material behind retaining walls.

(iii) Improvement of embankment stability.

(iv) Improvement of safety of waterfront structures.

(v) Fill material at bridge approach.

(vi) Fill over galvanised steel and concrete decks.

2.12.0 Testing of Hardened Concrete

Properties of hardened concrete depend on time and ambient temperature. There are various tests that could be performed to assess the properties of hardened concrete. Ordinarily, the tests are classified into destructive tests and non-destructive tests. The destructive tests include compressive test, flexure test, split tensile test and penetration resistance test. The compressive test is the most common and the most important. This is because nearly all properties of concrete are related to its compressive strength in a qualitative sense.

2.12.1. Factors Affecting Tests on Hardened Concrete

There are several factors affecting the results of tests on hardened Concrete. Some of these factors are:

(i) End conditions

(ii) Moisture condition

(iii) Influence of rate of load application

(iv) Characteristics of concrete

(v) Age and other factors.

2.12.1.1 End Condition

The smoothness of the ends of test specimens has a great influence on their strength. When the rough surface of a specimen is brought into contact with the platens of the crushing machine, stress concentrations ensue. These lower the apparent strength of the concrete.

According to Neville (1977), lack of planeness of 0.25mm lowers the strength by one-third. Convex end surfaces cause a greater reduction in strength than concave ones. This is because the former lead to higher stress concentrations.

A.S.T.M. standard C617-71 requires the end surfaces of a cylinder to be plane within 0.05mm as determined by a straight edge and a feeler gauge.

The contact surface should be free from grains of sand and other debris from previous tests. The presence of these grains of sand leads to premature failure and even violent splitting in some extreme cases.

The side-effects of the uneven end surface of the specimen can be overcome by three alternative means: Packing, Capping and Grinding.

A bedding material is used as packing between the platens and the specimen's surfaces. However, packing lowers the apparent mean strength due to the lateral strains induced in the specimen by the poisson's ratio effect of the packing material.

It also affects the scatter of strength results because it eliminates the effects of defects in the planeness of cylinders - main cause of the scatter.

Capping involves the application of a material in a thin layer over the cylinder's surfaces. When a suitable material is used, capping does not affect the strength and the scatter of the strength results. However, the capping material should have strength and elastic properties similar to those of the concrete being tested. A common capping material is neat cement applied in thin layers.

Grinding involves polishing the bearing surface of the specimen until it is plane and square. It produces satisfactory results but because of its cost it is rarely used (Neville, 1977).

2.12.1.2. Moisture Condition

Moisture influences the strength of test specimens. The modulus of rupture, for example of a dry specimen is lower than that of a saturated specimen. When the specimen absorbs water it makes the cement gel to dilate. This decreases the forces of cohesion of the solid particles. On drying, the wedge action of water decreases and the strength increases. This variation in strength due to drying is a reversible phenomenon.

The British standard B.S. 1881:1970 prescribes that cubes and flexure specimens should be tested immediately on removal from water. This is borne out of the fact that it is easier to maintain the moist condition than it is to maintain the dry condition.

2.12.1.3 Influence of Rate of Load Application

The rate of application of load greatly affects the apparent strength of the concrete. The lower the rate of application of stress the lower the recorded strength. This is caused by the increase in strain with time due to creep. Applying the load over a period of 30 to 40 minutes causes failure at 84 to 88 percent of the ultimate strength obtained when the load is applied at the rate of $12N/mm^2/min$. Increasing the rate of application of load from $0.04N/mm^2/min$ to $4 \times 10^6 N/mm^2 min$ doubles the apparent strength of concrete - Neville (1977).

The magnitude of the observed strains and the curvature of the stress-strain relationship in a modulus of elasticity test is partly determined by the rate of application of stress. When the rate of application of stress is rapid (in less than 0.01 second), the strains recorded are greatly reduced. The curvature of the stress - strain curves becomes extremely small. Increase in the loading time increases the strain.

There is no clear demarcation between elastic and inelastic deformation. However, it is generally assumed that deformations that occur when loading are considered elastic. Subsequent increases in strain are regarded as creep (Neville, 1977).

The standard rates of applying load have been prescribed by B.S. 1881:1970 as $1.6N/mm^2/min$. The A.S.T.M. standard C78-64(1972) prescribes a speed of $1.03N/mm^2/min$.

Slater and Glanville have shown that the curvature of the stress – strain diagram becomes sharper the slower the rate of loading. The computed modulus is also low. A loading of over 10 to 20 min period produces a secant modulus of about 15 percent lower than for a five second loading period (Troxell et al, 1956). However, changing the loading time from 2 minutes to 20 minutes has no significant effect upon the modulus at allowable stress.

2.12.1.4. Effects of Characteristics of Concrete

The characteristic features of concrete greatly affect its compressive strength, tensile strength and modulus of elasticity, among others. The higher the modulus of elasticity of the aggregate with which the concrete is made the higher the modulus of elasticity of the concrete. Modulus also increases with fineness modulus. This is due to the decrease in water – cement ratio with increase in coarseness of grading.

2.12.1.5. Age and other Factors

The modulus of elasticity increases with age. The richer the mix the greater the increase in modulus with age.

Higher values of water – cement ratio tend to reduce the value of the modulus. The properties of the testing machine also influence the features of the stress – strain curve.

2.12.2.0. Compressive Test

The compressive strength of concrete is its most important property. Compressive tests can be carried out in cubes, cylinders and prisms.

2.12.2.1 Cube Test

The cube mould is made up of cast - iron of dimensions 150mm x 150m m x 150mm. The mould and its base are rigidly clamped together so as to reduce leakages during casting. The sides of the cubeare thinly oiled before casting so as to prevent the development of bond between the concrete and the mould.

According to the standard practice prescribed by B.S. 1881:1970, the cube is filled in three layers. Each layer is compacted by 35 strokes of a 25mm square steel punner. The ramming is done efficiently to ensure full compaction.

The cube is then cleaned of excess concrete by passing an iron rod in a sawing motion over the top of the cube. The surface is then finished by means of a trowel. The cube is then stored for 24 hours undisturbed at a temperature of 18C^{o} to 22^{o}c and a relative humidity of not less than 90 percent. After 24 hours the mould is striped and the cubes are stored in water for further curing at 19 to 21^{o}c. This is the specification of the British standard B.S. 1881:1970.

At the age of test thecubes are crushed with the cast faces in contact with the platens of the testing machine. The B.S. 1881:1970 prescribes that the load on the cube should be applied at the rate of 15N/mm^{2}/min. The rate of increase in strain is progressively increased as failure is approached. This is due to the non-linearity of the stress/strain relationship for concrete at high stresses. The strength at failure is reported to the nearest 0.5N/mm^{2} (Neville, 1977).

2.12.2.2. Ratio of 7 - Day to 28 - Day Strength

The 28 - day strength of concrete made with ordinary portland cement is roughly 1.5 times the 7 - day strength. However, the British code of practice CP114 (1969) accepts a 7-day strength equal to but not less than two - thirds of the required 28 - day strength.

The ratio of 28 - day to 7 - day strength for ordinary concrete lies within the range of 1.3 to 1.7. In hot climate this ratio is lower than in cooler climate. This is also the case with lightweight aggregate concretes. In either case the difference is due to the fact that in hot climate the early strength gain is high (Newman, 1971). Lightweight aggregate concrete also develops high early strength (Neville, 1977).

In Germany the relation between the 28 - day and 7-day strength is taken between

$$\beta 28 = 1.4\beta 7 + 1.0$$
$$\text{and}\ \beta 28 = 1.7\beta 7 + 5.9$$

Where $\beta 28$ and $\beta 7$ are the 28-day and 7-day strength in N/mm^2 respectively.

2.12.3.0. Modulus of Elasticity Test

Modulus of elasticity is defined as the change of stress with respect to elastic strain (deformation) and may be computed from the equation:

$$\text{Modulus of Elasticity} = \frac{\text{unit stress}}{\text{unit strain}}$$

It is the measure of the stiffness or resistance of the material to deformation. Modulus of elasticity is used in the analysis of reinforced concrete structures to determine stresses, moments, and deflections in both simple and complicated structures.

2.12.3.1. Methods of Determining Moduli of Elasticity

The modulus of elasticity is determined using the standard cylinder and extensometers or strain gauges.

The standard cylinder has a diameter of 150mm and a height of 300mm. It is made of steel or cast iron. The cylinder is cast in three layers and each layer is rammed 25 times using a 16mm diameter round-nosed rod.

Strains encountered within the elastic range of stress in engineering materials are in the region of 1 part in 1000 (Ryder, 1969). Extensometers are used to measure these small linear movements. The extensometer is clamped round the cylinder and placed under the testing machine.

There are three methods of determining the modulus of elasticity (Troxell et al, 1956).

i) Initial tangent modulus: this is represented by the slope of a tangent to the stress - strain curve, drawn through the origin.

ii) The tangent modulus: this is represented by the slope of a line drawn tangent to the stress-strain curve at any point A on the curve.

(iii) The secant modulus: this is represented by the slope of a line drawn from the origin to any point B on the curve.

Figure 2.6 shows stress-strain diagrams for concrete and the various methods of determining moduli of elasticity.

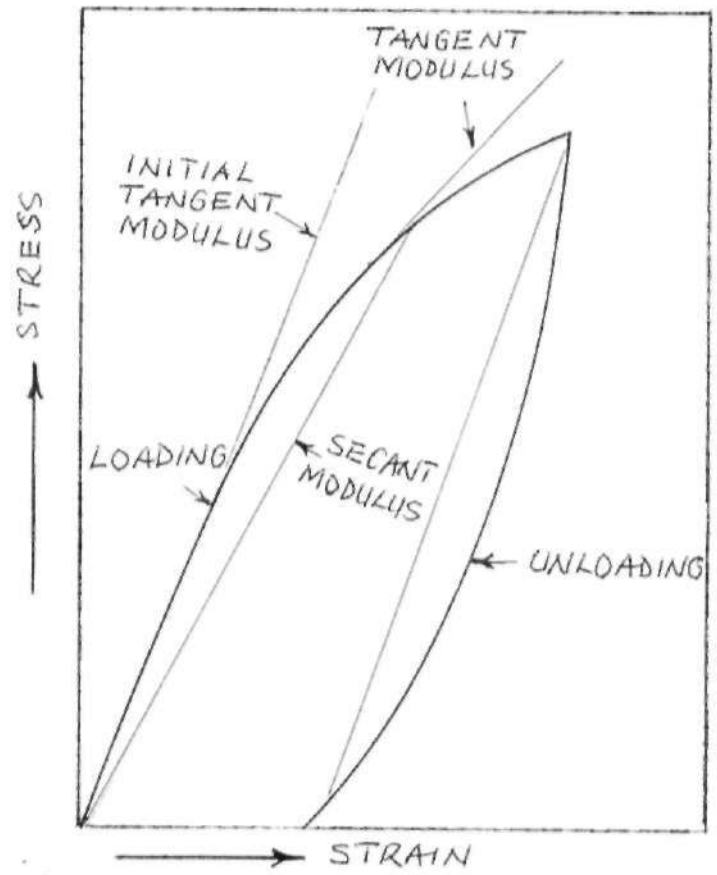


Fig. 2.6 Typical Stress-Strain Curve for concrete and various Moduli of elasticity.

Source: Properties of Concrete (Neville, 1977).

The initial tangent modulus is used only for low stresses. The tangent modulus cannot be determined with accuracy. The secant modulus is the most practical and the most widely used. It represents the actual deformation at the selected point (Troxell et al, 1956).

There is, however no standard method of determining the scent modulus (Neville, 1977). It is generally measured at stresses representing 15, 25, 33, or 50 percent of the ultimate strength of the concrete specimen. The secant (static) modulus decreases with increase in stress. Therefore the stress at which the modulus is determined must always be stated.

2.12.3.2. Relation of Modulus of Elasticity to Strength

The increase in strength causes an increase in the modulus of elasticity of concrete though not in a clearly defined manner. The ACI code for reinforced concrete design states that the modulus shall be taken as 1,000 times the compressive strength at 28 days (Troxell et al, 1956). The modulus approximately increases with the square root of its strength.

The British code of practice for structural use of concrete CP 110; 1972 relates tangent modulus of elasticity in GN/m^2 to the cube strength in MN/m^2 by the following relationship:

$$Ec = 4.5\sqrt{U} \quad \ldots (1)$$

When the density is between 1,400 to 2,300kg/m^3 the British expression for modulus of elasticity is:

$$Ec = 0.85\, p^2\sqrt{U} \times 10^{-6} \quad \ldots (2)$$

For lightweight concrete, the comité European du Beton recommends:

$$Ec = \frac{1}{1.8} \times 10^{-4} \, p^{1.5} \sqrt{fc} \qquad \ldots(3)$$

Where:

Ec = tangent modulus of elasticity, GN/m^2

U = cube strength, MN/m^2

P = density, kg/m^3

fc = cylinder strength MN/m^2

Table 2.8 shows the moduli of elasticity of concretes of different strengths.

2.12.4.0. Tensile Test

There are many methods of determining the tensile strength of concrete. Some of these methods include modulus of rupture test, direct tensile test and split tensile test.

Split tensile test is very simple to perform. It also gives more uniform results than the other tests.

2.12.4.1. The Split Tensile Test

This test was suggested by a Brazillian named Fernando Carneiro.
That is why it is sometimes called the Brazillian test.

The test is carried out on the standard cylinder (See article 2.12.3.1.). The concrete cylinder is placed between the platens of the testing machine. Its axis should be horizontal between the platens. A narrow strip of packing material is placed between the cylinder and the platens (See figure 2.7).

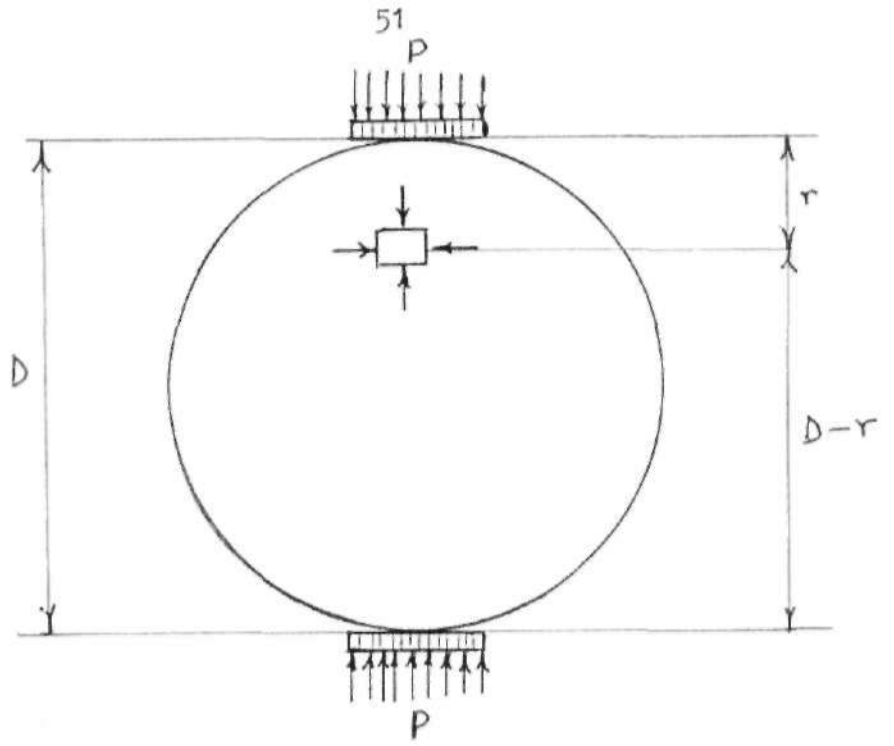


Fig 2.7: Split tensile Test.

Source: Properties of concrete, (Neville (1977).

The A.S.T.M. standard C496-71 prescribes the size of the strip to be 25mm. The load is gradually increased until failure takes place by splitting along the vertical diameter.

An element on the vertical diameter of the cylinder experiences a horizontal tensile stress of:

$\frac{2P}{LD}$ where P = compressive load on the clylinder
L = length of cylinder
D = diameter of cylinder.

2.12.4.2.: Relation between Compressive Strength and Tensile Strength

The tensile strength of concrete is very small compared to its compressive strength. The increase in tensile strength of concrete slow down after one month. Inadequate curing affects the tensile strength more than the compressive strength of concrete.

The ratio of tensile to compressive strength of air-cured concrete is lower than that of concrete cured in water and tested wet. Entrained air lowers the compressive strength more than the tensile strength of concrete. Incomplete compaction has the same effect as entrained air.

The relationship between tensile strength and compressive strength for normal concrete is the same for lightweight concrete. This value for lightweight concrete ranges between 0.16 to 0.07.

However, "in view of the numerous factors influencing the ratio of the strengths it is not surprising that no simple relation is generally applicable" - Neville (1977).

2.13.0. Palm Kernel

2.13.1. Historical Background

It is pertinent to take a look at the subject matter of this study. The genetic name of the palm commonly grown in Nigeria is ELAEIS and its specific name is GUINEENSIS.

Oil palms are grown in the rain forest zones of Nigeria. The major producing states are Ogun, Bendel, Imo, Anambra, Rivers, Cross River and Ondo. Other minor producing states are Lagos, Oyo, Benue, Gongola, Kwara and Niger States (Orewa, not dated).

The ratio of tensile to compressive strength of air-cured concrete is lower than that of concrete cured in water and tested wet. Entrained air lowers the compressive strength more than the tensile strength of concrete. Incomplete compaction has the same effect as entrained air.

The relationship between tensile strength and compressive strength for normal concrete is the same for lightweight concrete. This value for lightweight concrete ranges between 0.16 to 0.07.

However, "in view of the numerous factors influencing the ratio of the strengths it is not surprising that no simple relation is generally applicable" - Neville (1977).

2.13.0. Palm Kernel

2.13.1. Historical Background

It is pertinent to take a look at the subject matter of this study. The genetic name of the palm commonly grown in Nigeria is ELAEIS and its specific name is GUINEENSIS.

Oil palms are grown in the rain forest zones of Nigeria. The major producing states are Ogun, Bendel, Imo, Anambra, Rivers, Cross River and Ondo. Other minor producing states are Lagos, Oyo, Benue, Gongola, Kwara and Niger States (Orewa, not dated).

The oil palm tree grows to a height of over 10.m. Short stem verieties are, however, available. The oil palm tree is a monocotyledonous plant. It has a fibrous root system.

The fruits are borne on short stalked roundish dense bunches about 46cm across. A bunch weights up to 27 kg. There may be up to 1500 fruits in a bunch. The fruits are a deep violet turning orangered when ripe. The fleshy outer layer (the mesocarp), bears the oil. Beneath it is the shell which encloses the kernel (Corner, 1966).

Oil palm trees were first thought to have been brought to Africa from South America. But studies have shown palm pollen in geologically ancient mud in the Niger Delta. This confirms that oil palm is indigenous to Africa (Corner, 1966).

Nigeria used to be the largest producer and exporter of oil palm with the average of 162,000 tonnes per annum or 21% of the total world production. However, by 1985, Malaysis had overtaken Nigeria as the major producer of oil palm (NIFOR, Highlights of Activities and Achievements, 1985).

Due to the fact that the rate of production of palm oil has failed to keep pace with the rate of population growth it is predicted that there will be a shortfall of over 400,000 tonnes of palm oil for domestic use by the year 2000 (Nifor, 1985.

2.13.2. Recent Research and Development

Oil palm exists in nature predominantly as the DURA fruit form. This constitutes over 95% of the wild population. There is however the improved variety, the elite hybrid TENERA, developed by researchers at the Nigerian Institute for Oil Palm Research, Nifor, Benin.

The DURA fruit has a thick shell, large kernel and a thin mesocarp, the oil bearing part. On the other hand the TENERA has a thick mesocarp, thin shell and small kernel. The components of these two varieties have been analysed and a comparison made. Table 2.11 shows the oil yield components of Nifor elite TENERA compared with the improved and unimproved DURA (Nifor, 1985).

Table 2.11. Oil Yield Component of Nifor Elite Tenera Compared With The Imroved and Unimproved Dura

Oil Yield Component	Nifor Elite Tenera	Improved Dura	Unimproved Dura in the Wild
Mean FFB Fresh Fruit	15-18 Tonnes/ ha/year	15-18 tonnes/ years.	3 Tonnes/ha/ ha/year.
% Fruit/Bunch	60-70	65-75	50-75
% Mesocarp/Fruit	80-85	30-60	20-50
% Shell/Fruit	5-15	30-50	30-65
% Kernel/Fruit	5-13	7-20	7-20
Oil yield in Tonnes/ ha/year	4-5-tonnes	2.2 tonnes	0.5.tonnes

Source: NIFOR, Highlights of Activities and Achievements (1985).

2.13.3. Production potential

The oil palm production potential of Nigeria is very high indeed. According to Orewa (1986) the total exploitation potential is 6,460,818 tonnes of the fresh fruit bunch (ffb) per annum. Out of this amount DURA accounts for 4,800,000 tonnes of the ffb per annum. The remaining 1,660,818 tonnes of ffb is contributed by the TENERA.

By 1986 the wild groove DURA veriety covers an area of approximately 2.4 million hectares. The improved TENERA variety covers a hecterage of 170,000 ha (Orewa, 1986)

2.13.4. Availability of Palm Kernel Shell

From the production potential and the information given in table 2.11 an approximate idea of the quantity of palm kernel shell available in Nigeria can be obtained.

DURA:

Total potential = 4,800,000 tonnes of ffb per annum.

% fruit/bunch = 65–75 (average 70%).

∴ Totaly yield of fruit = 0.7 x 4,800,000
= 3,360,000 tonnes of fruit per annum.

% shell/fruit = 30–50 (average 40%).

∴ Amount of shell = 0.4 x 3,360,000
= 1,344,000 tonnes of shell per annum.

TENERA:

Total potential = 1,660,818 tonnes of ffb per annum.

% fruit/bunch = 60–70 (average 65%)

∴ Total yield of fruit = 0.65 x 1,660,818
= 1,079,532 tonnes of fruit per annum.

KASHIM IBRAHIM LIBRARY
AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA.

% Shell/fruit = 5-15 (average 10%)

Amount of shell = 0.1 x 1,079,532

= 107,953.2 tonnes of shell per annum.

The total output of shell from the two varieties of oil palm per annum is 1,344,000 + 107,953.2 = 1,451,953.2 tonnes of shell per annum.

2.14.0. Other Uses of Palm Kernel

According to the Information Bulletin No. 5 (1985) of the Nigerian Institute for Oil Palm Research, oil palm products can be categorised into two broad groups: the primary products and the secondary products.

(i) Primary products include:

(a) Palm oil

(b) Palm kernels

(c) Palm wine

(ii) Secondary products include:

(a) Shell

(b) Fibre

(c) Leaves

(d) Trunk

2.14.1. Palm Oil

Palm oil is a very important source of food. It is the main cooking oil in Nigeria. It contains carotene, the component that gives it its characteristic red colour. This carotene contains vitamin A.

Palm oil is also used for the manufacture of margerine, shortenings used in making bread, cakes, cream and sweets. Manufacturers of livestock feed use it as an additive.

Palm oil also has other non-edible uses. For example it is used extensively in the manufacture of soap. It is also used in the tin plating industry. Due to the readiness with which it is absorbed by the skin, the cosmetics industry uses it extensively in the manufacture of creams, ointments and lotions. Before the advent of petroleum palm oil was used as diesel and lubricating fuels during the industrial revolution. It is still used as a component in the making of lubricating oils, greases, plasticizers, candles and polish - Nifor (1985).

2.14.2. Palm Kernel Oil

The kernel inside the nut is crushed and palm kernel oil is extracted from it. This oil is used in cooking, confectionary, bakery. It is also used to make ice cream and mayonnaise.

Other non-edible uses of palm kernel oil are in the manufacture of soap, pomades, detergents and glycerine. The palm kernel cake, which is the residue after the extraction of oil, is used as livestock feed (Nifor, 1985).

2.14.3. Palm Wine

Palm wine is tapped from the inflorescence and the trunk of the palm tree. It is very nutritious and contains sugars, vitamins, proteins and minerals.

Palm wine is now bottled in commercial quantities in distillaries and is being exported in large quantities to neighbouring African countries, Europe and America. Palm wine could also be distilled to produce ethanol (Nifor, 1985).

2.14.4. Shell and Fibres

The fibres and shells are mostly used as fuel for firing boilers to generate steam in oil mills. "The shells are also used as aggregates for flooring". (Nifor, 1985).

2.14.5. Leaves

The leaves of palm oil trees have application in many ways. They are used as thatch for roofing houses. The rachises are used for fencing and reinforcing mud buildings. The midribs of the leaflets are used as brooms. The cabbage from young tender leaves found at the apex of the stem is used as vegetable in making many delicacies.

2.14.6. Trunk and Bunch Refuse

The trunk is mostly used as timber in building construction. Bunch refuse, the material left after the fruits have been removed from the fresh fruit bunch (ffb), is used in making traditional soap. It is also used as a fertilizer. It is a good source of potassium (Nifor, 1985).

The palm kernel shell used in this research work was obtained from Ughelli, in the delta area of Bendel State. The crushed shell was obtained from a native oil and soap manufacturer. It was transported in sacks to Zaria by bus.

The palm kernel nuts were obtained in two batches. The first batch was obtained from Sokoto and transport to Zaria. The second batch was obtained locally in Zaria.

The Palm kernel shell was bought at six Naira (₦6.00) per 45 kg. The palm kernel nut was bought at the rate of twelve Naira (₦12.00) per 50 kg.

Altogether a total of 350.7 kg of palm kernel shell and 243.8 kg of palm kernel nut were bought for this research work.

CHAPTER THREE

3.0.0. Physical Properties of Palm Kernel Aggregate.

Aggregate was initially seen as a material that only increases the volume of concrete and thus effects some savings in cost. But it is now known that aggregate influences the strength, durability and structural behaviour of concrete. It also constitutes three-quarters of the volume of concrete. These influences of aggregate on concrete are attributed to its physical, thermal and even chemical properties. Hence, the importance of the determination of the physical properties of palm kernel aggregate cannot be more underscored.

3.1.0. Specific Gravity of Palm Kernel Aggregate

Specific gravity is defined as the ratio of the weight of the material to the weight of an equal volume of water. The specific gravity of a material depends on the amount of voids, porosity and the specific gravities of the minerals of which it is composed.

For concrete purposes, calculation of specific gravity is based on the saturated surface - dry condition of the aggregate.

3.1.1. Procedure of Determining the Specific Gravity

The specific gravity is determined using a pycnometer or cylinder. The weight of the cylinder is determined first.

The cylinder is filled with water and weighed. The water is poured into a container and the cylinder is filled with the material and then weighed. The cylinder, with the material, is then topped up with water and weighed.

If the weight of empty cylinder = D

Weight of saturated surface - dry sample = C

Weight of cylinder full of water = B

Weight of cylinder with sample topped up with water = A

∴ The weight of water occupying the same volume as the sample is given by:

$$B - (A-C)$$

Whence the specific gravity = $\frac{C}{B-A+C}$

3.1.2. Specific Gravity of Palm Kernel Shell

D = 420 gm

C = 1685 - 420 = 1265 gm

B = 2720 - 420 = 2300 gm

A = 2985 - 420 = 2565 gm

∴ The specific gravity of palm kernel shell = $\frac{1265}{2300-2565+1265}$

= 1.265

3.1.3. Specific Gravity of Palm Kernel Nut

D = 420 gm

C = 1907 - 420 = 1487 gm

B = 2720 - 420 = 2300 gm

A = 2915 - 420 = 2495 gm

∴ The specific gravity of palm kernel nut = $\frac{1487}{2300 - 2495 + 1487}$

= 1.15

Table 3.1 shows the specific gravities of palm kernel shell and nut.

Table 3.1 Specific Gravities of Palm Kernel

	Palm Kernel Shell	Palm Kernel Nut
Weight of Empty Cylinder (D)	420 gm	420 gm
Weight of Cylinder + Sample (C)	1685 gm	1907 gm
Weight of Cylinder + Water (B)	2720 gm	2720 gm
Weight of Cylinder + Sample + Water (A)	2985 gm	2915 gm
Specific Gravity	1.265	1.15

From the results shown in Table 3.1 it is found that the specific gravity of palm kernel shell is greater than that of the nut. This can be explained as a result of the high voids ratio and porosity of the palm kernel shell compared with the nut (see articles 3.1.0, 3.3.0 and Table 3.4).

The specific gravities of palm kernel are relatively low compared with the range of values for different rock groups. Most natural aggregates have a specific gravity of between 2.6 and 2.7- Neville (1977).

The specific gravities of different aggregates are given in Table 3.2 for comparison with the values in Table 3.1.

The specific gravity of aggregates is used for the calculation of quantities of material in mix design. It is however not a measure of the quality of the aggregate.

The specific gravity of palm kernel shell is between 46 to 48 per cent that of natural aggregate. That of palm kernel nut is between 42 to 44 percent the specific gravity of natural aggregate.

Table 3.2. Apparent Specific Gravities of Different Rock Groups

Rock Group	Average Specific Gravity	Range of Specific Gravities
Basalt	2.80	2.6 - 3.0
Flint	2.54	2.4 - 2.6
Granite	2.69	2.6 - 3.0
Gritstone	2.99	2.6 - 2.9
Hornfels	2.82	2.7 - 3.0
Limestone	2.66	2.5 - 2.8
Porphyry	2.73	2.6 - 2.9
Quartzite	2.62	2.6 - 2.7

Source: Crown Copyright.

3.2.0. Bulk Density of Palm Kernel Aggregate

The bulk density of a material is the weight of the material that would fill a container of unit volume. The degree to which the aggregate is densely packed determines the bulk density. It also depends on the size distribution and shape of particles. This can be demonstrated by packing large single size aggregate in a container. The bulk density can be increased by packing smaller size particles to fill in the voids between the larger particles.

The bulk density of a material is used in converting quantities by weight to quantities by volume. The higher the bulk density of an aggregate the fewer the voids to be filled by sand and cement.

Bulk density is largely influenced by the nature of compaction employed. B.S. 812:1967 specifies two degrees of compaction; loose or uncompacted and compacted.

For the loose bulk density the material is carefully placed into a container to overflowing. It is then levelled by passing a steel rod over the container. On the other hand, in the compacted bulk density the material is placed in three layers. Each layer is rodded 25 times with a 16mm diameter round-nosed rod.

The net weight of the material divided by its volume gives the bulk density. Table 3.3 gives the bulk densities of palm kernel.

Table 3.3. Bulk Densitite of Palm Kernel

	Dimensions of Container	Uncompacted Weight Kg	Uncompacted Bulk Density Kg/m^3	Compacted Weight Kg	Compacted Bulk Density Kg/m^3
Palm Kernel Shell	0.15 x 0.15 x 0.15 m	2.135	632.59	2.610	773.33
Palm Kernel Nut	0.15 x 0.15 x 0.15 m	2.220	657.77	2.669	7:8.74

From Table 3.3 it can be seen that the bulk density of palm kernel nut is greater than that of the palm kernel shell.

"The shape of the particles greatly affects the closeness of packing that can be achieved" - Neville (1977). Since the shape of the nut is spherical, the particles tend to pack densely together. This explains the disparity between the two bulk densities.

The bulk density of natural aggregate is generally taken to be 1600 kg/m^3. This indicates that the bulk density of palm kernel shell is 48 per cent that of natural aggregate, while that ot palm kernel nut is 49 percent.

The uncompactel bulk density was used in this research work. This is because, in practical application, the material will not be compacted before used in mixes.

3.3.0. Voids Ratio of Palm Kernel Aggregate

An aggregate that is well graded with a minimum volume of voids will require only a moderate amount of cement. It will also produce a concrete with somewhat small drying shrinkage and thermal movement.

It is therefore necessary to determine the voids ratio of an aggregate.

The voids ratio is defined as the ratio of volume of voids to volume of solids. It is determined from the following relationship:

$$\text{Voids ratio} = 1 - \frac{\text{bulk density}}{\text{Specific gravity x Unit weight water}}$$

$$\therefore \text{Voids ratio of palm kernel shell} = 1 - \frac{632.59}{2.65 \times 1000}$$

$$= \underline{0.76}$$

$$\text{Voids ratio of palm kernel nut} = 1 - \frac{657.79}{1.15 \times 1000}$$

$$= \underline{0.428}$$

From the results obtained it is shown that palm kernel nut has a lower voids ratio than palm kernel shell. As explained in article. 3.2.0. palm kernel nut tends to pack closely together due to its spherical shape and its particle distribution thereby exhibiting a lower voids ratio. This means that palm kernel nut requires less sand and cement in concrete mix.

3.4.0. Porosity of Palm Kernel Aggregate

According to Neville (1977) the porosity, permeability and absorption of an aggregate influence such properties of the aggregate as the bond between it and the cement paste, the resistance of concrete to freezing and thawing, chemical stability and resistance to abrasion.

The porosity of an aggregate effectively contributes to the overall porosity of the concrete. The aggregate is said to be saturated surface - dry when all the pores are full with water.

From the results obtained in the bulk density test the percentage porosity can be determined from the following expression:

$$\text{Percentage porosity} = \left(1 - \frac{B}{S}\right) \times 100$$

Where B = Uncompacted bulk density.

S = Compacted bulk density.

Table 3.4: shows the percentage porosities of palm kernel.

Table 3.4. Percentage Porosities of Palm Kernel Aggregate

Sample	% Porosity $\left(1 - \frac{B}{S}\right) \times 100$
Palm Kernel Shell	18.2
Palm Kernel Nut	16.6

When compared with the porosities of some common rocks (see Table 3.5) palm kernel exhibits a rather high percentage porosity. This property of palm kernel will make it vulnerable to frost action.

When used as an aggregate it is advisable to wet it prior to being used in concrete making.

Table 3.5. Porosity of Some Common Rocks

Rock Group	Porosity, Percent
Gritstone	0.0 – 48.0
Quartzite	1.9 – 15.1
Limestone	0.0 – 37.6
Granite	0.4 – 3.8

Source: Properties of Concrete (Neville, (Neville, 1977).

3.5.0. Absorption of Palm Kernel Aggregate

The water absorption of an aggregate is very important in determining the water/cement ratio for a given mix. The workability of the concrete mix is greatly affected by the absorption of the aggregate.

To obtain the water absorption of an aggregate it is first necessary to dry the sample in an oven at a temperature of 100°c for 24 hours. The sample is then soaked in water for24 hours. It is then surface – dried and weighed.

The ratio of the increase in weight to the weight of dry sample expressed as a percentage gives the absorption of the sample. Absorption represents the water contained in an aggregate in a saturated surface – dry condition.

In this research work two tests were carried out. In this first test the absorption was determined without heating the samples. The results are shown table 3.6.

Table 3.6. Absorption of Palm Kernel Aggregate before Heating

Samples	Weight of container gm	Weight of Dry sample (A) gm	Weight of Soaked sample (B) gm	Increase in weight (b–A) gm	Percentage absorption %
Palm Kernel shell	420	1265	1292	27	2.134
Palm Kernel Nut	420	1487	1550	63	4.237

In the second test the samples were heated and soaked in water as described above. The results are shown in table 3.7.

Table 3.7: Absorption of Palm Kernel Aggregate after Heating

Sample	Weight of container gm	Weight of Dry sample (A) gm	Weight of soaked sample (B) gm	Increase in weight (B – A) gm	Percentage absorption
Palm Kernel shell	410	1185	1366	181	15.3%
Palm Kernel nut	410	1385	1505	120	8.6%

From the results obtained it is found that palm kernel aggregate absorbed more water after heating than it did before heating. After being heated at 100°c for 24 hours the moisture contained in its pores was driven off. That is why when it was subsequently soaked in water it showed a high percentage absorption. The low value obtained before heating was because of the moisture already present in the samples.

Generally the palm kernel shell has a higher percentage absorption than the nut. This is as a result of the large surface area of the palm kernel as compared with palm kernel nut. It's high porocity is also a contributory factor.

The absorption of palm kernel aggregate is higher than for mineral aggregates. The range of values for different aggregates is 0.20 to 4.53 percent (crown copyright).

This high absorption will make palm kernel concrete dry due to the absorption of water by the aggregate. Aggregates with absorption higher than 10% should be soaked in water before use. (See article 4.3.1.). Alternatively, adjustment in the water content of the concrete mix is made.

The results obtained in the second test (See table 3.7 above) were used in the design of mixes in this research work. Adjustment was made to the weight of water used so as to take care of the aggregate's absorption.

However, in practical appllication, it is recommended that use be made of results obtained in the first test in which the aggregate was not heated. This test reflects the natural condition of the aggregate which is more likely to be encountered in the site.

3.6.0. Moisture Content of Palm Kernel Aggregate

Aggregate exposed to rain absorbs water in its pores. Further wetting causes it to be surrounded by a film of moisture. This surface or free moisture is very important in the design of concrete mixes. The free moisture tends to off - set the workability by altering the water/cement ratio and hence the water content. It is therefore necessary to determine the moisture content of an aggregate and adequate allowance made in calculating batch quantities.

The moisture content of an aggregate is determined using the pycnometer or cylinder.

If the weight of the cylinder full of water = B

the weight of cylinder with moist sample = C

the weight of cylinder with sample topped =

up with water = A

Therefore, the moisture content of the aggregate is given by the following expression:

$$\text{Moisture content} = \frac{C}{A-B}\frac{(P-1)}{P} - 1 \times 100$$

Where P = specific gravity of the aggregate.

Two separate moisture content tests were carried out on the aggregate. In the first test the sample was not heated in the oven. The results are tabulated in table 3.8.

Table 3.8: Moisture Content of Palm Kernel Aggregate before Heating

Sample	Specific gravity	Weight of Cylinder full of water (B) gm	Weight of cylinder moist sample (C) gm	Weight of cylinder moist sample + water (A) gm	Equivalent weight of water (- B) gm	Percentage moisture content %
Palm Kernel shell	1.26	2720	1410	3070	350	-16
Palm Kernel nut	1.15	2720	1470	2920	200	14.1

In the second test the oven-dried samples uused in the absorption test were used. They were soaked in water and were used in the saturated surface - dry condition. The results obtained are shown in table 3.9.

Table 3.9: Moisture Content of Palm Kernel Aggregate after Heating

Sample	Specific Gravity	Weight of cylinder full of water (B) gm	Weight of cylineer moist sample water (C) gm	Weight of cylinder moist sample water (A) gm	Equivalent weight of water (A -) gm	Percent-age moisture content
Palm Kernel shell	1.26	2280	1305	2580	302	-10.85
Palm Kernel nut	1.15	2280	1440	2480	200	-6.08

The values of moisture content for the palm kernel aggregate are all negative. According to Tsoxel elal (1956) this is to be expected when the aggregate is too dry and has a relatively high degree of absorption (as shown in the absorption tests above).

This means that the aggregate will absorp high amount of water from the concrete and additional water has to be added to compensate for this absorption. The negative percentage moisture content represents the amount of water that will be absorbed by the aggregate.

This amount of water was allowed over the calculated quantity in all mix calculations in this study.

3.7.0. Sieve Analysis of Palm Kernel Aggregate

Sieve analysis simply means the separation of an aggregate into fractions. Each fractions comprises particles between specific limits. These limits are the openings of standard sieve sizes.

Sieve analysis is carried out using standard sieve sizes. The openings of these sieves are prescribed by the British standard B.S. 410: 1969 and the American standard A.S.T.M: E11 - 70

The sieves are mounted in frames one atop the other in order of size. The largest sieve is at the top while the smallest is at the bottom. The aggregate should be air-dried in order to prevent the clogging of the openings.

3.7.1. The Sieving Process

The aggregate to be sieved is then weighed. The British standard B.S. 812: 1967 gives the minimum weight of sample for sieve analysis based on the maximum size present in substantial quantities.

The sample is placed in the top sieve and shaken either manually or mechanically. The material retained in a given sieve represents the fraction of aggregate coarser than the retaining sieve but finer than the sieve above.

Tables 3.7 and 3.8 show the results of sieve analysis for palm kernel shell and nut respectively.

All sizes above 5mm are coarse aggregate. Sizes smaller than 5mm are fine aggregate. These results are shown on plates 3.1 and 3.2 for the palm kernel shell and nut respectively.

Table 3.10) Sieve Analysis of Palm Kernel Shell. Total weight sieved = 50kg

B.S Sieve mm	Weight Retained (kg)	Percentage retained	Cumulative Percentage Passing	Cumulative Percentage Retained
20	0.225	0.45	99.55	0.45
10	26.0	52.0	47.55	52.45
5	16.8	33.6	13.95	85.05
2.36	2.9	5.8	8.15	91.85
1.18	0.4	0.8	7.35	92.65
600um	0.9	1.8	5.55	94.45
300um	1.1	2.2	3.35	96.65
150um	0.9	1.8	1.55	98.45
Pan	0.5	1.0	0.55	99.45
Total	49.725			

Table 3.11: Seive Analysis of Palm Kernel Nut. Total Weight Sieved=50kg

B.S. Sieve mm	Weight Retained (kg)	Percentage Retained	Cumulative Percentage Passing	Cumulative Percentage Retained
20	18.3	36.6	63.4	36.6
10	29.6	59.2	4.2	95.8
2.36	0.3	0.6	3.6	96.4
1.18	0.62	1.24	2.16	97.84
600um	0.105	0.21	1.95	98.05
300um	0.13	0.26	1.69	98.31
150um	0.165	0.33	1.36	98.64
Pan	0.05	0.1	1.26	98.74
Total				

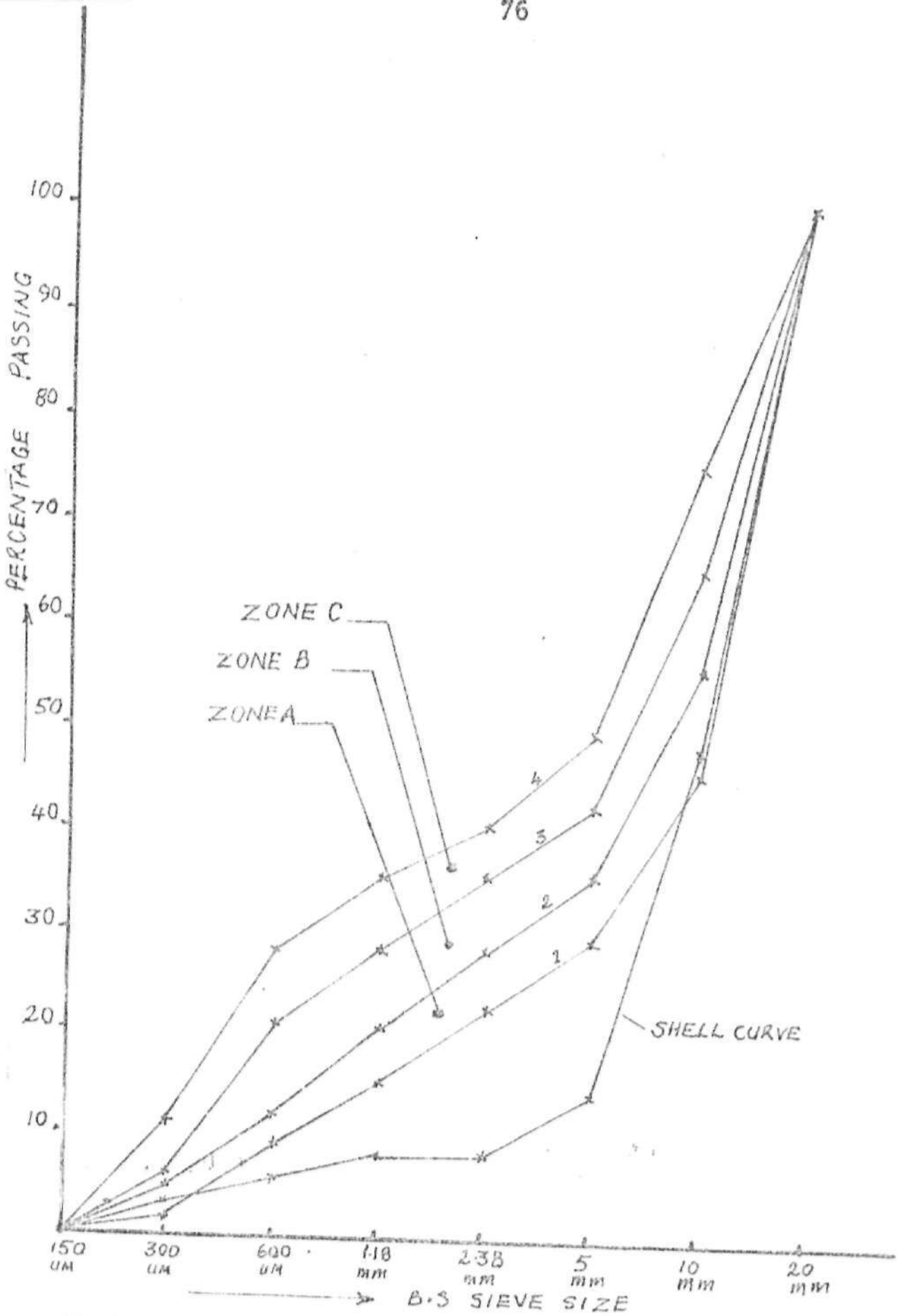


FIG 3·1 GRADING CURVE FOR PALM KERNEL SHELL

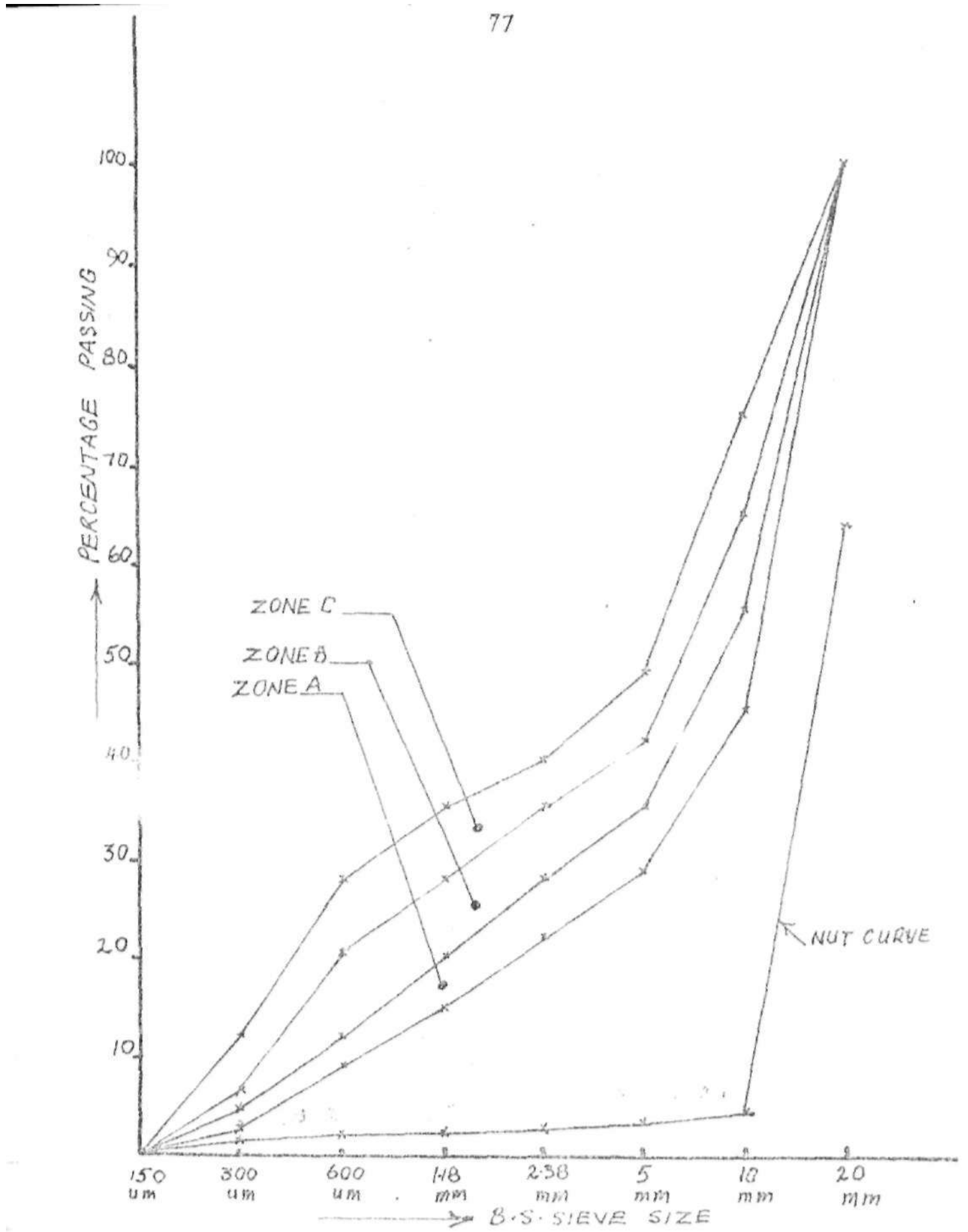


FIG 3·2 GRADING CURVE FOR PALM KERNEL NUT

3.7.2. Grading Curves for Palm Kerner Aggregate

Grading curves are a graphical means of representing the result of sieve analysis. The cumulative percentage passing is plotted on the ordinates and the sieve sizes on the abscissa.

Aggregates do not rigidly conform to particular grading curves. The aggregates found in a locality will have to be used, anyway, so it is not possible to specify a particular grading curve in a given job. However, grading curves fall within certain zones referred to as grading zones.

Reference grading zones commonly used are those of the Road Research Note No. 4 on the Design of Concrete Mixes and the one prepared by McIntosh and Erntroy of the Cement and Concrete Association.

The curves of the Road Research Note No. 4 have been super imposed on the grading curves of the palm kernel shell and nut and are reproduce in figures 3.1. and 3.2. respectively.

Though the Road Research Note curves are meant for only natural aggregates a comparison could be made with the curves of the palm kernel aggregate.

In the Road Research Note No. 4, curve No. 1 represents the coarsest grading. This is suitable for mixes with low water/cement ratio and/or rich mixes. Curve No. 4 represents a fine grading which makes cohesive mixes that are not very workable. Curves Nos 2 and 3 are the intermediate of the two extremes.

It is observed that the palm kernel gradings fall completely out of the Road Research grading zones. As explained above the gradings are not for lightweight aggregate. But from the location of the palm kernel grading curves it can be seen that the latter are coarser than natural aggregates.

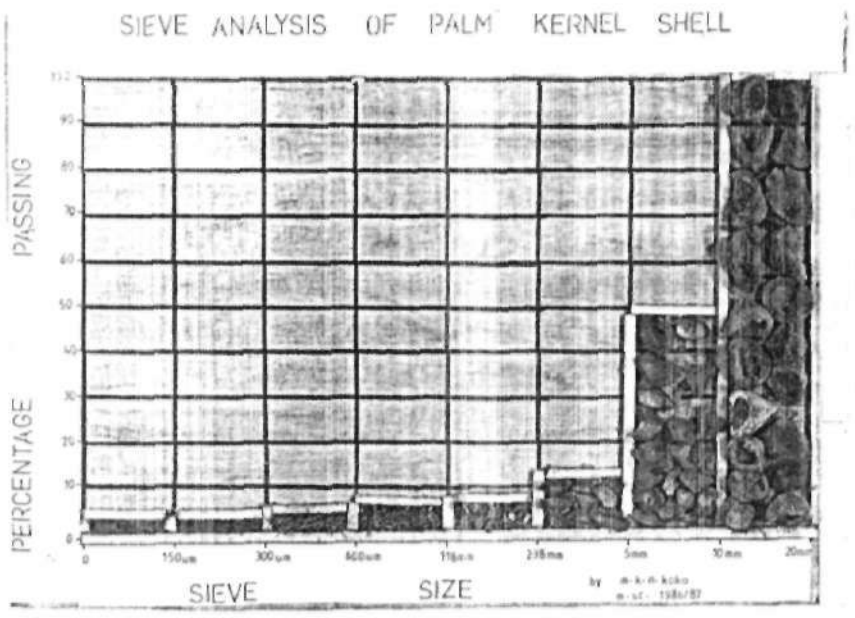


Plate .I: Particle Sizes of Palm Kernel Shell.

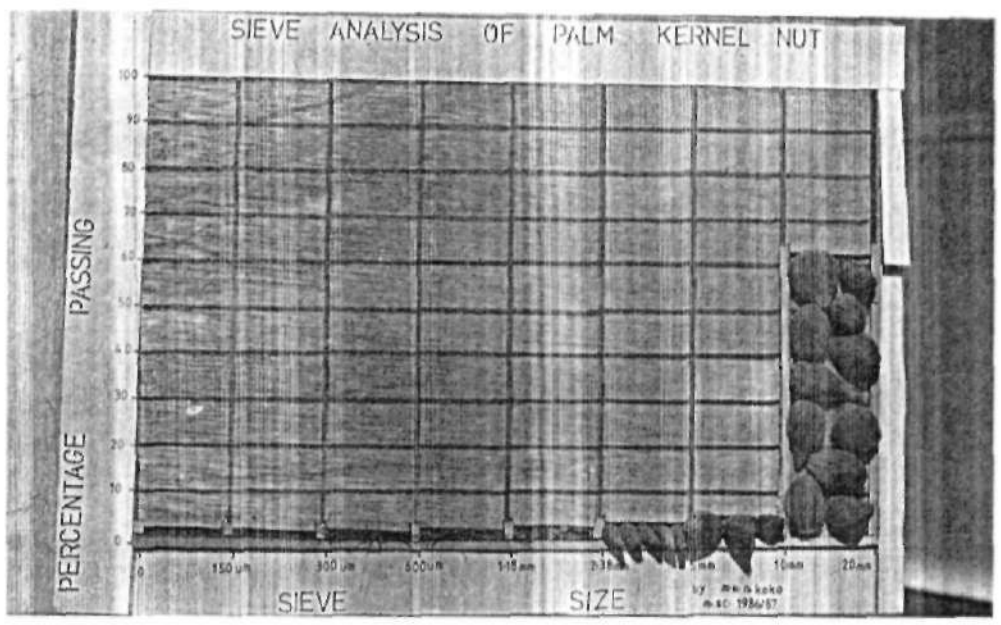


Plate .II: Particle Sizes of Palm Kernel Nut.

It is also observed that the curves suddenly steep up as they approach sieve Nos 10 and 20. All these indicate that some size fractions (i.e. 10mm and 20mm sieve - size) predominate to the virtual exclusion of other size fractions.

This results in gap grading which is defined as a grading in which one or more intermediate size fractions are omitted. The horizontal part of the curves over sieve sizes 150um to 5mm represent the gap grading. The sieve sizes 150um to 5mm are the range of sizes that are omitted from the aggregate.

Test by Shacklock have indicated that the highest workability is obtained with a lower sand content in the case of gap - graded aggregate than when continuously graded aggregate is used, for a given aggregate/cement ratio and water/cement ratio.

This will make palm kernel aggregate produce a workable mix. However, there is the danger of segregation.

The general requirements for lightweight aggregate have been covered by A.S.T.M. standard C330 - 69, C331 - 69, C332 - 66 and B.S. 3797:1964. (Chapter two). It can be seen that palm kernel aggregates conform to these requirements (See Chapter two Tables 2.1. and 2.2).

3.7.3. Grading Requirement

An important factor affecting the grading of an aggregate is the surface area. It determines the amount of water necessary to wet all the solids, the relative volume occupied by the aggregate, the workability of the mix and the teniency to seggregation.

A good grading should produce a workable concrete that can be compacted to maximum density using a reasonable amount of work. A good grading should give not only a reasonable workability but also minimum segregation. The voids in the combined aggregate should be sufficiently small to prevent the cement paste from passing through and thereby segregating out. For sufficient workability the grading must contain an adequate amount of materials smaller than 300 um sieve. It is, however, important to note that a richer mix requires a lower content of fine sand than lean mix.

It has been found out that the greater the amount of aggregate that can be packed in a mix the greater its strength - (Road Research Note No. 4). However, this should not be done at the expense of the required cement content.

3.7.4. Fineness Modulus of Palm Kernel

Fineness modulus is defined as the sum of the cumulative percentage retained on the sieves of the standard sizes, 150um 300um up to the largest sieve size persent. The fineness modulus is sometimes viewed as the weighted average size of a sieve on which a material is retained - counting the sieves from the finest.

The calucated fineness modulus of palm kernel is shown below :

Fineness modulus for palm kernel shell = 7.12

Fineness modulus for palm kernel nut = 8.16

From the results obtained it can be seen that the average sizes for the palm kernel shell and nut are the seventh and eighth sieves respectively.

The higher the value of fineness modulus the coarser the aggregate. This indicatesthat the palm kernel is a coarse aggregate. Fineness modulus is not a tool for describing the grading of an aggregate. But it can be used as a guide to check slight variations in the aggregate from a particular source on a day-to-day basis. It also gives an indication of the probable behaviour of concrete mix made with aggregate of a particular grading.

From the results obtained in this chapter it can be seen that the physical properties of palm kernel aggregate conform to all known properties of lightweight aggregate. This effectively makes it a lightweight aggregate.

CHAPTER FOUR

4.00. MIX DESIGN

4.1.0. Introduction

The design of a concrete mix is defined as the selection of the most suitable materials and the most economical proportions of cement, water and the various sizes of aggregate to produce a concrete having the desired physical properties - Short and Kinniburgh (1963).

Economy of concrete mixes depends primarily on cost of materials rather than cost of labour and other related factors. Therefore, in proportioning, attention is directed primarily on the cost of materials.

4.2.0. Objectives of Mix Design

According to the requirements of B.S. 1882:1954 "Coarse and Fine Aggregates From Natural Sources for Concrete", the two main properties for which concrete is designed are workability and crushing strength at 28 days. A good mix should therefore aim at achieving a good degree of workability and high strength at 28 days.

For many years concrete mixes have been designed as nominal volumetric proportions such as 1:2:4 cement/sand/coarse aggregate. But the modern method of design now is to specify the cement content in kilograms per cubic metre of fresh concrete (Building Research Establishment Digest No. 244, 1980)

The cement content should neither be inadequate nor in excess. Inadequate cement produces a weak concrete. An excess of cement increases cost, drying shrinkage, greater susceptibility to water percolation and attack by aggressive waters - Toxell et.al. (1956).

4.3.0. Factors To Be Considered In Mix Design

The design of lightweight concrete is different from normal structural concrete. Each aggregate (i.e. lightweight) has to be separately considered - Short and Kinniburgh (1963).

The various factors to be considered in the proportioning of concrete mix are:

(i) Water-Cement ratio.
(ii) Cement content.
(iii) Grading of aggregate.
(iv) Workability.
(v) Curing condition.
(vi) Design strength.

4.3.1. Water-Cement Ratio

Lightweight aggregate has a high percentage of absorption - up to 20 per cent. It is difficult to determine how much of the total water is absorbed by the aggregate and how much goes into the paste. The net water/cement ratio is therefore dependent on the rate of absorption and moisture content of the aggregate.

According to Short and Kinniburgh (1963), "the design curves correlating the cube strength and water-cement ratio of dense gravel concrete do not apply to lightweight aggregate concrete. Due perhaps to their porosity and inferior workability, the latter generally need a higher water content for the same strength".

If the absorption of the aggregate exceeds 10 per cent, it should be soaked before use. If the moisture content of the aggregate is high, the water content of the mix should be adjusted. However, the ACI method of mix design can be used for aggregates in any condition of moisture.

The palm kernel shell and nut have absorptions of 15.3% and 8.6% respectively. During the mix design additional water was added to compensate for this high absorption.

4.3.2. Cement Content

The strength of concrete is directly related to the cement content. The cement content used in this study was calculated using the absolute volume method of design in accordance with CP114. In the ACI design method the cement content was read from Table 4.1. In either case the maximum cement content was used so as to avoid cracking due to temperature movement and shrinkage.

Table 4.1. Approximate Relationship Between Strength of Lightweight Aggregate Concrete and Cement Content

Compressive Strength of Standard Cylinders N/mm^2	Cement Content Kg/m^2
14	230 to 390
21	280 to 450
28	330 to 510
34	390 to 560

Source: Journal of the American Concrete Institute (January, 1968)

4.3.3. Grading of Aggregate

Grading of the aggregate is one of the most important factors in the selection of mix proportions.

"A well graded aggregate with minimum volume of voids will require only a moderate amount of cement and is likely to produce concrete with a comparatively small drying shrinkage and thermal movement" - Neville (1977).

The coarse aggregate used in this research work (palm kernel shell) has a high percentage of the 10mm size fraction. About 80% of the aggregate was made up of this fraction, which will make it produce a harsh mix. To prevent the formation of a harsh mix a high percentage of quartz sand was used. (See article 3.7.2, figures 3.1. and 3.2).

Quartz river sand when used to replace part of the lightweight aggregate in a mix increases the compressive strength and the bond strength of the resulting concrete. Sand in lightweight concrete also improves the durability, enhances protection against corrosion of steel, improves workability, reduces cement content and drying shrinkage. Indeed, research at the British Research Station shows that for various types of lightweight concretes and various mixes, the cement requirements were reduced by as much as 13 to 25 per cent by weight, if half the lightweight fines by volume was replaced by river sand.

The sand used in this research work conforms to British Standard B.S. 882:1965. The sand content was higher than the aggregate content for reasons expounded above.

4.3.4. Workability

For improved workability a high proportion of fine aggregate is required. According to Short and Kinniburgh (1963), the total aggregate proportion should consist of 50 per cent fines and 50 per cent coarse aggregate.

In this research work the proportioning of fine/coarse aggregate was done in such a way as to give a workable mix. The percentage was not strictly fixed at 50 per cent. The percentage of sand was between 60 and 75.

4.3.5. Curing Condition

The strength of concrete increases with age under favourable conditions of curing, both of temperature and humidity.
The B.S. 1881: Part 3 specification for the standard conditions of curing were adhered to in this research work.

4.3.6. Design Strength

Design strength refers to the desired strength of concrete that is specified at the start of mix proportioning.
The British code of Practice for the Structural Use of Concrete CP110:1972 specifies minimum strength of concrete for various uses. These values are given below:

Table 4.2: CP110:1972: Minimum Strengths of Concrete for various uses

Types of concrete for various uses	Minimum Strength N/mm^2
Plain Concrete	7
Reinforced Concrete with lightweight aggregate	15
Reinforced Concrete with normal aggregate	20
Post-tensioned Concrete	30
Pre-tensioned Concrete	40

Source: Properties of Concrete, Neville (1977).

Compressive strength is an important indicator of the various properties of concrete. The mean compressive strength at 28 days determines the water/cement ratio of the mix.

Strength is normally specified in terms of the characteristic strength of the concrete which is defined as the strength exceeded by 95 per cent of test specimens. Variations could arise in the strength of concrete due to inadequate mixing, insufficient compaction, irregular curing and variations in the methods of testing. Variations in the moisture content of aggregate could seriously affecte the strength of concrete. Compensation has to be made in the amount of water added (See article 4.3.1.)

4.4.0. Mixing of Palm Kernel Lightweight Concrete

Lightweight concrete requires more mixing than normal-weight concrete. The aggregate is first charged into the mixer. About three-quarters of the required water is added and then mixed for several revolutions. Cement and more water are then added and the mixing continued for about 60 more revolutions - Waddel (1962).

When this procedure was not adhered to on the first mix the aggregate floated to the top. The mixer had to be stopped and the mixing partly done manually before it was continued with the mixer. Thereafter no more problem was encountered.

4.5.0. Mix Design Procedure

During the preliminary trial mix design the specific gravity (volumetric) method of batching was employed. Four trial mixes were designed.

(i) Palm Kernel shell "no-fines" using ratio 1:8 cement:shell.

(ii) Palm Kernel nut "no-fines" using ratio 1:8 cement: nut.

(iii) Palm kernel shell concrete using ratio1:2:4 cement: sand:shell.

(iv) Palm kernel nut concrete using ratio 1:2:4 cement:sand: nut.

A water/cement ratio of 0.45 was used for the first two mixes. For the third and fourth mixes water/cement ratios of 0.78 and 0.75 were used respectively.

The selection of these water/cement ratios was based on the range of water/cement ratios for "no-fines" and lightweight aggregate concrete as suggested by Short and Kinniburgh (1963).

After the preliminary mixes, three other mixes were designed, produced and tested for compressive strength at 7 and 28 days, modulus of elasticity and split tensile test.

The mixes used are:

(i) 1:1½:3 and a water/cement ratio of 0.85.

(ii) 1:2:4 with a water/cement ratio of 0.53.

(iii) This mix was designed in accordance with ACI 211.1-70 standard of the American Concrete Institute.

No provision was made for wastage in the calculations. This was due to the scarcity of the material which made wastage intolerable.

4.5.1. Palm Kernel Shell "No-Fines"

Ratio 1:8, w/c = 0.45

Density of shell = 632.5 kg/m^3

Specific gravity of shell = 1.26

Density of cement = 1440 kg/m^3

Specific gravity of cement = 3.15

ABSOLUTE VOLUME

Shell = $\frac{8 \times 632.5}{1.26}$ = 4016 l.

Cement = $\frac{1 \times 1440}{3.15}$ = 457 L

Water = $\frac{1440 \times 0.45}{1}$ = 648 L

Total Absolute Volume = 5.121 m^3

Volume of 1 cube = 0.003375 m^3

Volume of 6 cubes = 0.02025 m^3

QUANTITY OF MATERIALS FOR 6 CUBES

Shell = $\frac{8 \times 632.5 \times 2.025 \times 10^{-2}}{5.121}$ = 20 kg

Cement = $\frac{1 \times 1440 \times 2.025 \times 10^{-2}}{5.121}$ = 2.7 kg

Water = $\frac{1440 \times 0.45 \times 2.025 \times 10^{-2}}{5.121}$ = 2.6 kg

ADJUSTMENT FOR ABSORPTION

Weight of shell needed = 20 kg

Percentage absorption of shell = 15.3%

∴ Amount of water absorbed by shell = 0.153 x 20

= 3.06 Kg.

Amount of water calculated = 2.6 Kg

Net amount of water needed = 2.6 + 3.06

= 5.66 Kg

4.5.2. Palm Kernel Nut "No-Fines"

Ratio 1:8; W/c = 0.45

Density of nut = 657.77 Kg/m^3

ABSOLUTE VOLUME:

Uncrushed nut = $\frac{8 \times 657.77}{1.15}$ = 4576 l

Cement = $\frac{1 \times 1440}{3.15}$ = 457 l

Water = $\frac{1440 \times 0.45}{1}$ = 648 l

Total absolute volume = 5681 l

= 5.681 m^3

QUANTITY OF MATERIALS FOR 6 CUBES

Uncrushed nut = $\frac{8 \times 657.77 \times 2.025 \times 10^{-2}}{5.681}$ = 18.7 Kg

Cement = $\frac{1 \times 1440 \times 2.025 \times 10^{-2}}{5.681}$ = 5 .1 Kg

Water = $\frac{1440 \times 2.025 \times 10^{-2}}{5.681}$ = 2.5 Kg

Amount of water absorbed by nut = 0.086 x 18.7

= 1.608 Kg.

∴ Net amount of water needed = 2.5+1.6 = 4.1 kg

4.5.3 Palm Kernel Shell Concrete

Ratio 1:2:4: W/c = 0.78

Density of sand = 1570 Kg/m^3

Specific gravity of sand = 2.60

The densities and specific gravities of other materials remain the sand.

ABSOLUTE VOLUME:

Crushed shell = $\frac{4 \times 632.6}{1.26}$ = 2008 l

Sand = $\frac{1570 \times 2}{2.6}$ = 457 l

Cement = $\frac{1440 \times 1}{3.15}$ = 457 l

Water = $\frac{1440 \times 0.78}{1}$ = 1123 l

Total Absolute Volume = 4796 l

= 4.796 m^3

QUANTITY OF MATERIAL FOR 6 CUBES

Crushed shell = $\frac{4 \times 632.6 \times 2.025 \times 10^{-2}}{4.796}$ =10.7 Kg

Sand = $\frac{2 \times 1570 \times 2.025 \times 10^{-2}}{4.796}$ = 13.2 Kg

Cement = $\frac{1 \times 1440 \times 2.025 \times 10^{-2}}{4.796}$ = 6.0 Kg

Water = $\frac{1440 \times 0.78 \times 2.025 \times 10^{-2}}{4.796}$ = 4.7 Kg

4.5.4 Palm Kernel Nut Concrete

Ratio 1:2:4: W/c = 0.75

ABSOLUTE VOLUME:

Uncrushed nut = $\frac{4 \times 657.77}{1.15}$ = 2288 l

Sand = $\frac{1 \times 1570}{2.6}$ = 1207.6 l

Cement = $\frac{1 \times 1440}{3.15}$ = 457.1 l

Water = $\frac{1440 \times 0.75}{1}$ = 1080 l

Total absolute volume = = 5033 l

= 5.033 m^3

QUANTITY OF MATERIALS FOR 6 CUBES:

Uncrushed nut = $\frac{4 \times 657.77 \times 2.035 \times 10^{-2}}{5.033}$ = 10.6 Kg

Sand = $\frac{2 \times 1570 \times 2.025 \times 10^{-2}}{5.033}$ = 12.6 Kg

Water = $\frac{1440 \times 0.75 \times 2.025 \times 10^{-2}}{5.033}$ = 4.3 Kg

Amount of water absorbed by nut = 0.086 x 10.6
= 4.3 ÷ 0.912
= 5.121 Kg

4.5.5 Palm Kernel Shell Concrete 1:1½:3

W/c = 0.53

ABSOLUTE VOLUME:

Cement = $\frac{1 \times 1440}{3.15}$ = 457.143 l

Sand = $\frac{2 \times 1570}{2.6}$ = 905.769 l

Shell = $\frac{4 \times 632.6}{1.26}$ = 1506.191 l

Water = $\frac{1 \times 1440 \times 0.53}{1}$ = 1224 l

Total Absolute Volume = 4.093 m^3

QUANTITY OF MATERIALS FOR 30 CUBES:

Cement = $\frac{1 \times 1440 \times 3.375 \times 10^{-3} \times 30}{4.093}$ = 35.622 Kg

Sand = $\frac{1.5 \times 1570 \times 3.375 \times 10^{-3} \times 30}{4.093}$ = 58.256 Kg

Shell = $\frac{3 \times 632.6 \times 3.375 \times 10^{-3} \times 30}{4.093}$ = 46.946 Kg

Water = $\frac{1 \times 1440 \times 0.85 \times 3.375 \times 10^{-3} \times 30}{4.093}$ = 30.278 Kg

QUANTITY OF MATERIALS FOR 6 CYLINDERS:

Volume of 1 cylinder = 5.301×10^{-3} m^3.

Cement = $\frac{1 \times 1440 \times 5.301 \times 10^{-3} \times 6}{4.093}$ = 11.18 Kg

Sand = $\frac{1.5 \times 1570 \times 5.301 \times 10^{-3} \times 6}{4.093}$ = 18.3 Kg

Shell = $\frac{3 \times 632.6 \times 5.301 \times 10^{-3} \times 6}{4.093}$ = 14.747 Kg

Water = $\frac{1 \times 1440 \times 0.85\ 5.301 \times 10^{-3} \times 6}{4.093}$ = 9.5 Kg

Amount of water absorbed by shell = 0.153 x 18.3 = 2.799 Kg.

∴ Net amount of water needed = 9.5 x 2.799 = 12.299 Kg.

4.5.6 Palm Kernel Shell Concrete 1:2:4.

ABSOLUTE VOLUME:

Cement = $\frac{1 \times 1440}{3.15}$ = 457.143 l

Sand = $\frac{2 \times 1570}{2.6}$ = 1207.692 l

Shell = $\frac{4 \times 632.6}{1.26}$ = 2008.254 l

Water = $\frac{1 \times 1440 \times 0.53}{1}$ = 763.2 l

Total Absolute Volume = 4.436 m^3

QUANTITY OF MATERIALS FOR 30 CUBES:

Cement = $\frac{1 \times 1440 \times 3.375 \times 10^{-3} \times 30}{4.436}$ = 32.867 Kg

Sand = $\frac{2 \times 1570 \times 3.375 \times 10^{-3} \times 30}{4.436}$ = 71.669 Kg

Shell = $\frac{4 \times 632.6 \times 3.375 \times 10^{-3} \times 30}{4.436}$ = 57.755 Kg

Water = $\frac{1 \times 1440 \times 0.53 \times 3.375 \times 10^{-3} \times 30}{4.436}$ = 17.419 Kg

QUANTITY OF MATERIALS FOR 6 CYLINDERS

Cement = $\frac{1 \times 1440 \times 5.301 \times 10^{-3} \times 6}{4.436}$ = 10.325 Kg

Sand = $\frac{2 \times 1570 \times 5.301 \times 10^{-3} \times 6}{4.436}$ = 22.514 Kg

Shell = $\frac{4 \times 632.6 \times 5.301 \times 10^{-3} \times 6}{4.436}$ = 18.143 Kg

Water = $\frac{1 \times 1440 \times 0.53 \times 5.301 \times 10^{-3} \times 6}{4.436}$ = 5.472 Kg

Amount of water absorbed by shell = 0.153 x 18.143 = 2.776 Kg

∴ Net amount of water needed = 5.472 + 2.776 = 8.248 Kg

4.5.7. Palm Kernel Shell Concrete Designed to ACI Standards

From Table 4.1 cement content is taken as 500 Kg/m^3 corresponding to a strength of 28 N/mm^2 and slump of 50 mm.

Maximum size of aggregate = 10mm
Water content is taken as = 205 Kg/m^3
and entrapped air content = 3%
The water/cement ratio is taken as = 0.59
W/c = o.59 where c = 500
$\therefore$ W/500 = 0.59
$\therefore$ Water content, w = 500 x 0.59 = 295 Kg/m^3.

The bulk volume of coarse aggregate per unit volume of concrete is 0.48.

$\therefore$ Weight of palm kernel shall per m^3 of concrete = 0.48 x 632.6 = 303.6 Kg/m^3

Absolute volume of mix ingredients per m^3 of concrete:

$$\text{Cement} = \frac{500}{3.15 \times 1000} \; 0.159 \; m^3 \quad (1000 = \text{density of water})$$

$$\text{Water} = \frac{295}{1000} = 0.295 \; m^3$$

$$\text{Palm kernel shell} = \frac{303.6}{1.26 \times 1000} \; 66 = 0.241 \; m^3$$

Entrapped air = 0.03

Total Absolute Volume = 0.725m^3
$\therefore$ Volume of fine aggregate = 1-0.725
$\therefore$ Weight of sand = 0.275 x 1570 = 431.75 Kg.

Quantity of materials per m^3:

Cement	=	500 kg
Sand	=	432 kg
Palm kernel shell	=	303.6 kg
Water	=	295 kg
Density of the concrete	=	1530.6 Kg/m^3
Volume of 30 cubes	=	0.10125 m^3
Volume of 6 cylinders	=	0.03181 m^3
		0.13306 m^3

QUANTITY OF MATERIALS FOR 30 CUBES AND 6 CYLINDERS:

Cement	=	500 x 0.13306	= 66.53 kg
Sand	=	432 x 0.13306	= 57.48 kg
Palm kernel shell	=	303.6 x0.13306	= 40.39 kg
Water	=	295 x 0.13306	= 39.25 kg

No adjustment for water was made in this mix design because, with this method, the aggregate can be used in any condition of moisture (See Article 4.3.1).

This gave a mix ratio of 1.6:1.4:1 Cement:Sand:Shell.

CHAPTER FIVE

5.0.0.: Properties of Fresh Palm Kernel Concrete

5.1.0. Introduction

The properties of fresh concrete are very vital because they affect the ultimate strength development. The degree of compaction, for example, seriously affects the strength of concrete. The degree of compaction of concrete is measured from its workability, slump test and compaction factor.

In this research work, tests on fresh palm kernel concrete were only carried out on the four preliminary mixes. Subsequent mixes were not tested for workability, slump test and compacting factor.

5.2.0 Workability of Palm Kernel Concrete

Glanville, Collins and Matthews define workability as the amount of useful internal work necessary to produce full compaction.

When concrete is being compacted by ramming or vibration, part of the energy is used to overcome internal friction between the particles and the surface friction between the concrete mass and the walls of the mould. This is the useful internal work done. However, part of the energy goes in shaking the mould and part of the concrete that has already been compacted. This forms the wasted work done.

Workability, as a measure of the degree of compaction of concrete, plays an important role in the ultimate strength of concrete. Therefore, the consistence of the concrete must be such as to allow it to be transported, placed and finished sufficiently easily without segregation

However, in choosing a particular workability for a given mix consideration should be given to the means of compaction available. If the compaction is to be done manually a higher workability should be aimed at. This means, in effect, increasing the water content of the mix. Other factors that influence workability are the water/cement ratio, aggregate/cement ratio, maximum size, grading, shape and texture of the aggregate.

It is worth noting that the aim of achieving good workability is to minimise the amount of voids in the concrete on placement. 2 percent of voids can lower the strength of concrete by about 10 percent. 5percent of voids reduces the strength by as much as 30 percent(Neville 1977).

Care was therefore taken in this study to arrive at a mix that was workable and compacted by hand without the use of mechanical vibrators. However, in the case of palm kernel nut concrete some difficulty was encountered during compaction. The nut exhibited some degree of buoyancy. As it was being tamped it kept popping up.

313625

5.3.0 Slupm Test on Palm Kernel Concrete

Workability is not directly measured by the slump test. The slump test provides a useful way of detecting variations in the uniformity of a mix of given nominal proportions.

The apparatus is made up of a cone 300mm high. The cone is held down against its base with the smaller opening at the top. It is then filled in four layers. Each layer is tamped 25 times with a standard 16mm diameter stell rod rounded at the end. The level is struck off with a trowel. The spilt concrete around the base of the cone is cleared off. The cone is then lifted slowly. The slump is then measured to the nearest milimetre.

For Lightweight concrete a slump of 50mm to 75mm is considered high. A slump above 75mm is very high and the mix may segregate.

The palm kernel nut "no-fines" produced a slump of 135mm. This indicated a high workability which would make the mix suitable for sections with congested reinforcement. However, no vibration is required as this may leal to segregation.

The palm kernel shell "no-fines" gave a collapse slump. Three further tests produced the same result. This was as a result of lack of cohesion within the mix which was due to the absence of fine. aggregate.

The palm kernel nut concrete gave a slump of 25mm . This indicated a very low workability. In the event of its use in construction power vibration may, however, not be needed.

The palm kernel shell concrete slumped to 15mm. This is still a very low degree of workability. However, this is not to suggest that these concretes will always yield a low workability. Certainly more trial mixes should be carried out to achieve the desired workability.

5.4.0. Compacting Factor for Palm Kernel Concrete

The compacting factor test gives the nearest indication of the degree of workability of a concrete mix. The degree of compaction, i.e. compacting factor, is the ratio of the density actually achieved in the test to the density of the same concrete when fully compacted (i.e. without voids).

The apparatus consists of two cone-shaped hoppers one above the other. The upper one is slightly larger. The hoppers, whose surfaces are polished to reduce friction, have hinged trap doors at the bottom. At the base of the apparatus is the cylinder into which the concrete drops from the two upper hoppers.

The upper hopper is gently filled with concrete. This is done so as to prevent premature compaction. The bottom door of the upper hopper is then released so that the concrete falls into the lower hopper to overflowing. The bottom door of the second hopper is now released so that the concrete falls into the cylinder below. Excess concrete is then wiped off the cylinder and its weight is taken. The compacting factor is given by

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

5.4.1 Compacting Factor for Palm Kernel Shell "No-Fines"

W/c =0.45

Volume of cylinder =5450cm^3

Weight of partially compacted concrete = 3.45kg.

Table 5.1: Compacting Factor for Palm Kernel Shell "No-fines"

	Weight kg	Proportion by weight	Specific Gravity	Proportion by Weight / Specific Gravity
Weight of Cement	5.7	1.0	3.15	0.32
Weight of Shell	2.0	3.509	1.26	2.785
Weight of Water	2.6	0.459	1.00	0.456
Total	4.965			3.561

Weight of concrete to fill cylinder without voids =

$$\frac{4.965 \times 5450}{3.561} = 7.597\text{kg}$$

Compacting factor = $\frac{3.45\text{kg}}{7.597\text{kg}}$

= 0.454

5.4.2. Compacting Factor for Palm Kernel nut "no-fines"

W/c = 0.45

Volume of cylinder = 545cm^3

Weight of partially compacted concrete = 3.8kg

Table 5.2: Compacting Factor for Palm Nut "no-fines"

	Weight kg	Proportion by weight	Specific Gravity	Proportion by Weitht / Specific Gravity
Weight of Cement	5.1	1.0	3.15	0.317
Weight of Nut	18.7	18.7	1.15	3.188
Weight of Water	2.3	2.3	1.0	0.451
Total				3.956

Weight of concrete to fill cylinder without voids =

$$\therefore \quad \frac{5.117 \times 5450}{3.956} = 7.049\text{kg}$$

$$\therefore \quad \text{Compacting factor} = \frac{3.8}{7.049} = \underline{0.539}$$

5.4.3. Compacting Factor for Palm Kernel Shell Concrete

W/c = 0.78

Volume of cylinder = 5450cm^3

Weight of partially compacted concrete = 5.9kg

Table 5.3: Compacting Factor for Palm Kernel Shell Concrete

	Weight kg	Proportion by Weight	Specific Gravity	Proportion by weight / Specific Gravity
Weight of Cement	6.0	1.0	3.15	0.317
Weight of Sand	13.2	2.2	2.6	0.846
Weight of Shell	10.7	1.783	1.26	1.415
Weight of Water	4.7	0.783	1.00	0.785
Total		5.766		3.363

Weight of concrete to fill cylinder without voids

$$= \frac{5.766 \times 5450}{3.363} = 9.344kg$$

$$\therefore \text{Compacting factor} = \frac{5.9}{9.344} = 0.631$$

5.4.4.: Compacting Factor for Palm Kernel nut Concrete

W/c = 0.75

Volume of cylinder = $5450cm^3$

Weight of partially compacted concrete = 7.4kg

Table 5.4.: Compacting Factor for Palm Kernel Nut Concrete

	Weight kg	Proportion by Weight	Specific Gravity	Proportion by Weight / Specific Gravity
Weight of Cement	5.8	1.0	3.15	0.317
Weight of Sand	12.6	2.172	2.6	0.835
Weight of Nut	10.6	1.828	1.15	1.589
Weight of Water	4.3	0.741	1.0	0.741
Total		5.741		3.482

Weight of concrete to fill cylinder without voids

$$= \frac{5.741 \times 5450}{3.482} = 8.985kg$$

$$\therefore \text{ Compacting factor } = \frac{7.4}{8.985} = \underline{0.824}$$

5.4.5.: *Compacting Factor Range*

The range of compacting factor for lightweight concrete is smaller than for dense concrete. According to Short and Kinniburgh (1963), the range of compacting factor for structural lightweight concrete is 0.80 to 0.85.

The "no-fines" concretes have relatively low compacting factors.

This is as a result of the fact that no fines concrete does not flow and it does not segregate. It can easily be dropped into place (See article 2.9.2.). Therefore the difference between the degree of compaction actually achieved in the test and the full compaction is small. That is why the two no-fines concrete produced low compacting factors.

The compacting factor for palm kernel shell concrete falls below the range of compacting factor for structural lightweight concrete. This was as a result of the stiftness of the mix as can be seen from its low slump (See article 5.3.0.).

The compacting factor for the palm kernel nut concrete falls squarely within the range for structural highweight concretes. Its slump of 25mm (See article 5.3.0.) is also reasonable. This concrete possesses good workability. It does not segregate. It is not too stiff and can be placed easily with minimum effort. It does not require vibration. In fact vibration or tamping causes the nut to float to the top (See article 5.2.0.).

CHAPTER SIX

6. Properties of Hardened Palm Kernel Lightweight Concrete

The results of the investigation carried out on the properties of hardened palm kernel lightweight concrete are presented and discussed in this chapter.

The tests carried out were:

(i) Compressive strength test
(ii) Modulus of elasticity test
(iii) Split tensile test

6.1.0. Compressive Strength of Hardened Palm Kernel Lightweight Concrete

The compressive test was carried out on cubes cured for 7 days and 28 days respectively. All tests were carried out in accordance with the British standard of practice B.S. 1881:1970 (See article 2.12.2.1.) Plate III shows a cube being crused.

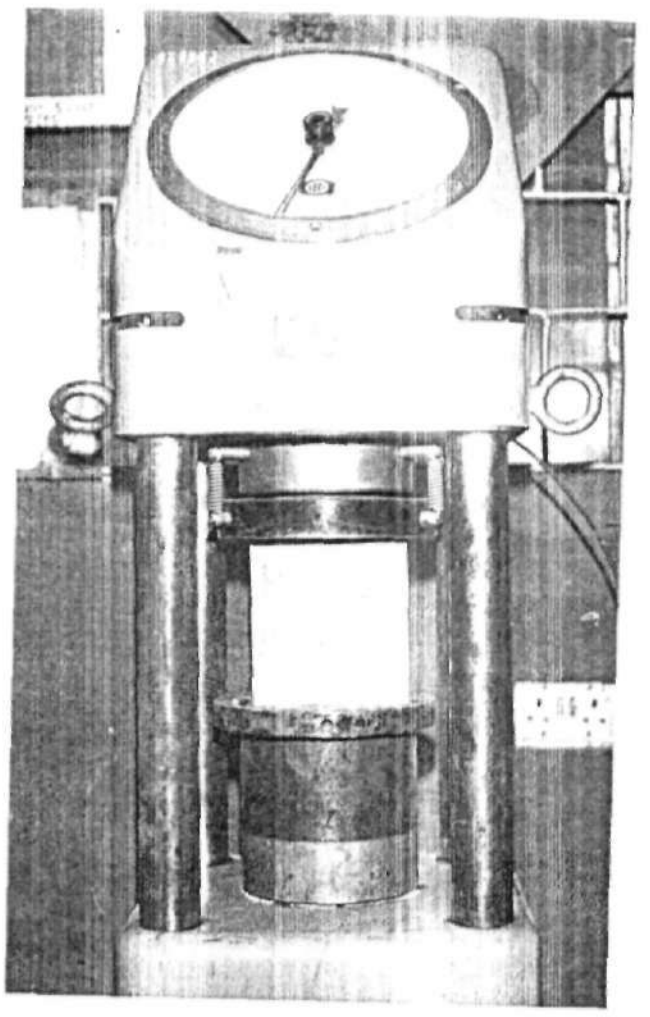


Plate III: Compressive Strength Test on Palm Kernel Lightweight Concrete.

6.1.1. Preliminary mix Design Strength

The design calculations of the preliminary mixes have been treated in Chapter four. The cubes were crushed at 7 and 28 days respectively. The 7-day and 28-day strength results are presented in appendices A and B respectively. Table 6.1. below shows the summary of the results.

Table 6.1.: Summary of Preliminary Mix Design Data

	1 : 8 Cement: Shell	1 : 2 : 4 Cememt : Sand Shell	1 : 2 : 4 Cement: Sand : Nut
7 - day strength N/mm^2	0.711	6.222	3.380
28 - day strength N/mm^2	0.770	6.518	3.440
Ratio of 28-day to 7-day strength	1.08	1.05	1.02
Density	829.63	1674.1	1676.5

Since only 6 cubes of each mix proportion were testel no statistical analysis was undertaken. The palm kernel nut "no-fines", whose data does not appear in table 6.1. disintegrated on demoulding. This was due to the lack of formation of bond between the cement paste and the nut because of its smoothness and the absence of fine aggregate in the mix.

The ratio of 28-day to 7-day strength for the palm kernel shell "no-fines" is 1.08. Its average strength is 0.074 N/mm^2. This is not strong enough for structural uses. It can however be used as fill material around sewage pipes, over concrete decks and behind retaining structures. It compares favourably with cork lightweight concrete (See article 2.11.8).

Palm Kernel shell concrete on the other hand exhibited remarkable strength. The strength of $7N/mm^2$ developed by this concrete will make it suitable for use as material for load - bearing walls. The normal range of strength for load - bearing materials is $7N/mm^2$ to $21N/mm^2$ (Sroka, undated).

The strength developed by the palm kernel nut concrete is $3.4N/mm^2$. It will be suitable for non-load bearing purposes. However, it may pose a problem when used in wet conditions. After crushing it was found that some of the nuts had started to rot - a process that may lead to their actual germination. For this reason palm kernel nut concrete may have little use beyond the research laboratory.

6.1.2. Compressive Strength of Mix 1: 1½ : 3.

The results of the 7 - day and 28 - day strengths and the statistical analysis are presented in appendix c. The results obtained are summarised *on page 114*.

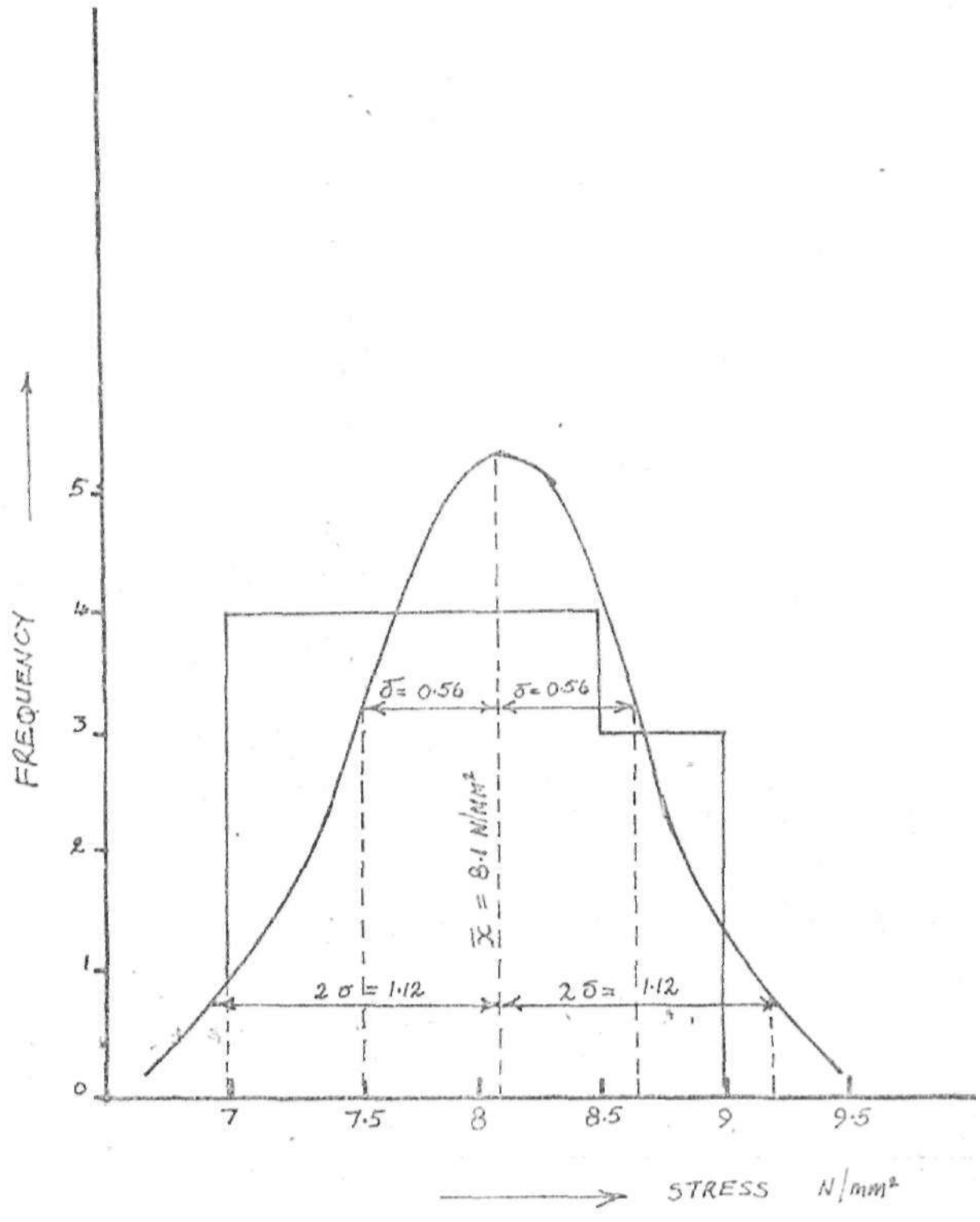


FIG 6.1 NORMAL DIST. CURVE. MIX 1:1·5:3
7-DAY STRENGTH

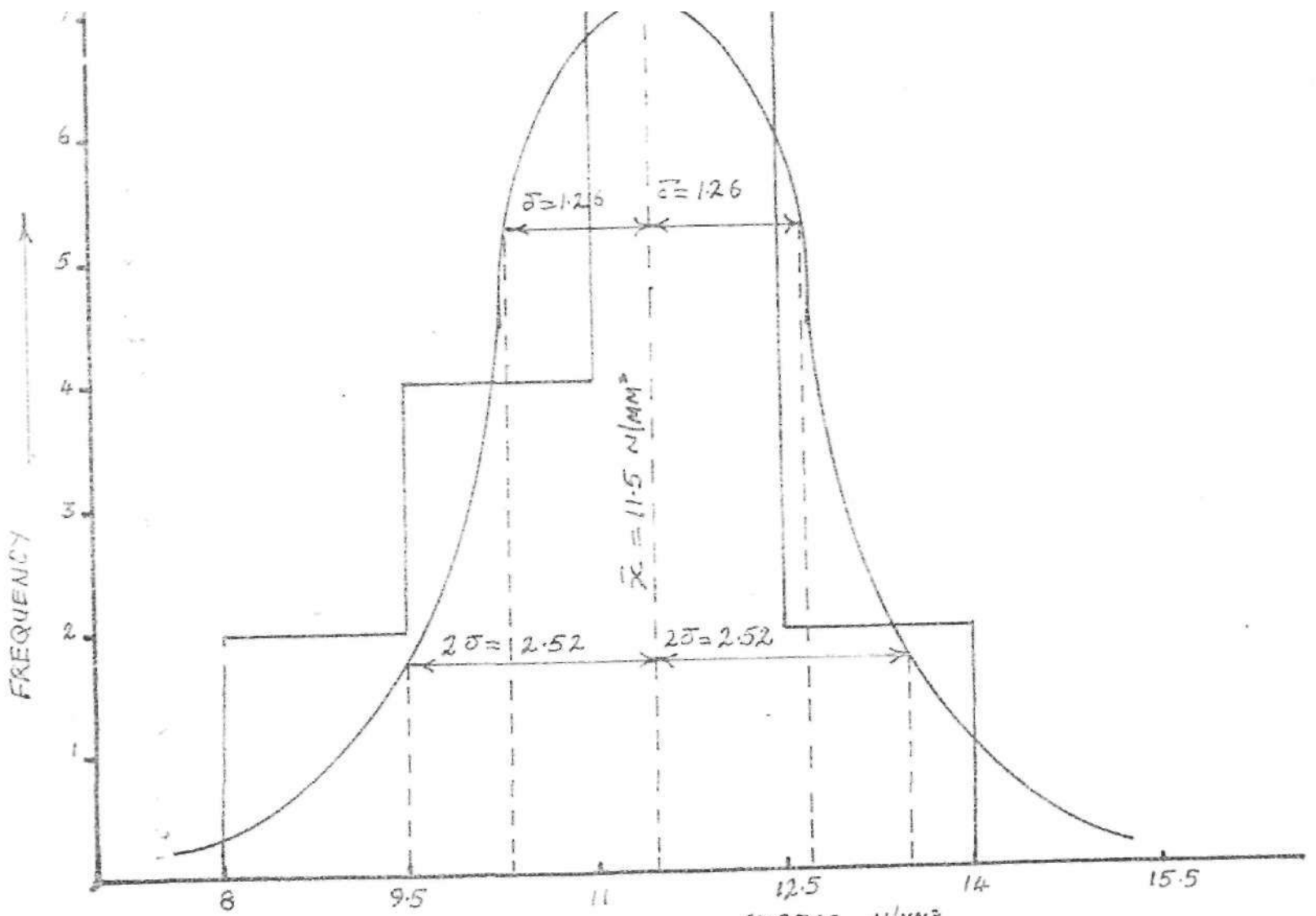


FIG 6.2 NORMAL DIST. CURVE - MIX 1:1.5:3 28-DAY STRENGTH

Table 6.2: Summary of Results for Mix 1 : 1½ : 3.

	7-day Strength	28-day Strength
Mean Strength N/mm^2	8.1	11.5
Standard Deviation N/mm^2	0.56	1.26
Coefficient of Variation %	6.9	10.9
Average Density kg/m^3	1691	1718.5

The normal curves for the mix at 7 and 28 days strengths are shwn in figures 6.1. and 6.2 respectively.

6.1.3. Compressive Strength of Mix 1: 2: 4

The results obtained for the 7-day and 28-day strengths and the statistical analysis are presented in appendix D. The results obtained are summarised below:

Table 6.3: Summary of Results for Mix 1 : 2 : 4

	7-day Strength	28-day Strength
Mean Strength N/mm^2	4.3	6.9
Standard Deviation N/mm^2	0.47	0.71
Coefficient of Variation %	3.1	10.2
Average Density kg/m^3	1633.6	1620

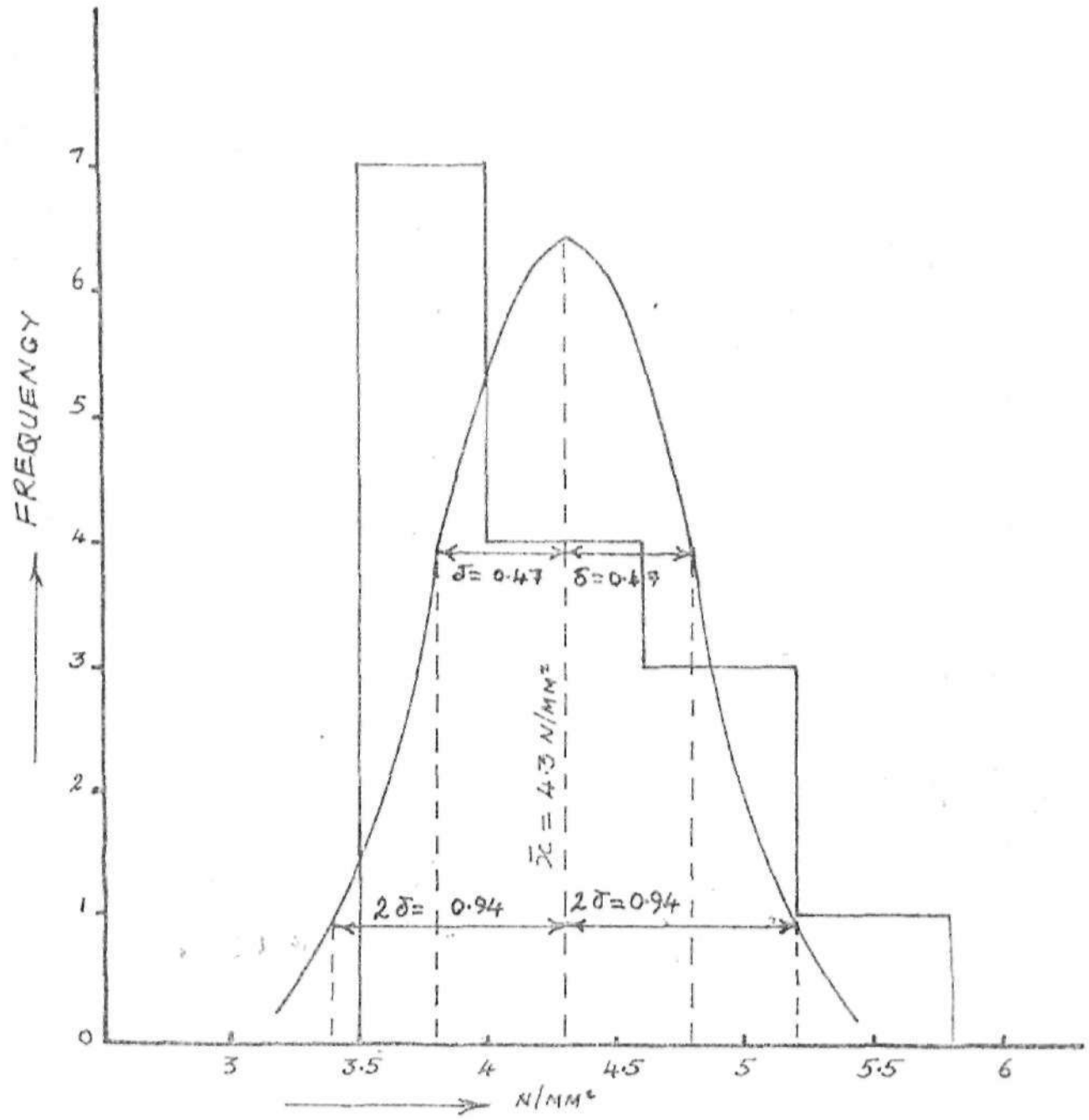


FIG 6·3 NORMAL DIST. CURVE MIX 1:2:4
7-DAY STRENGTH

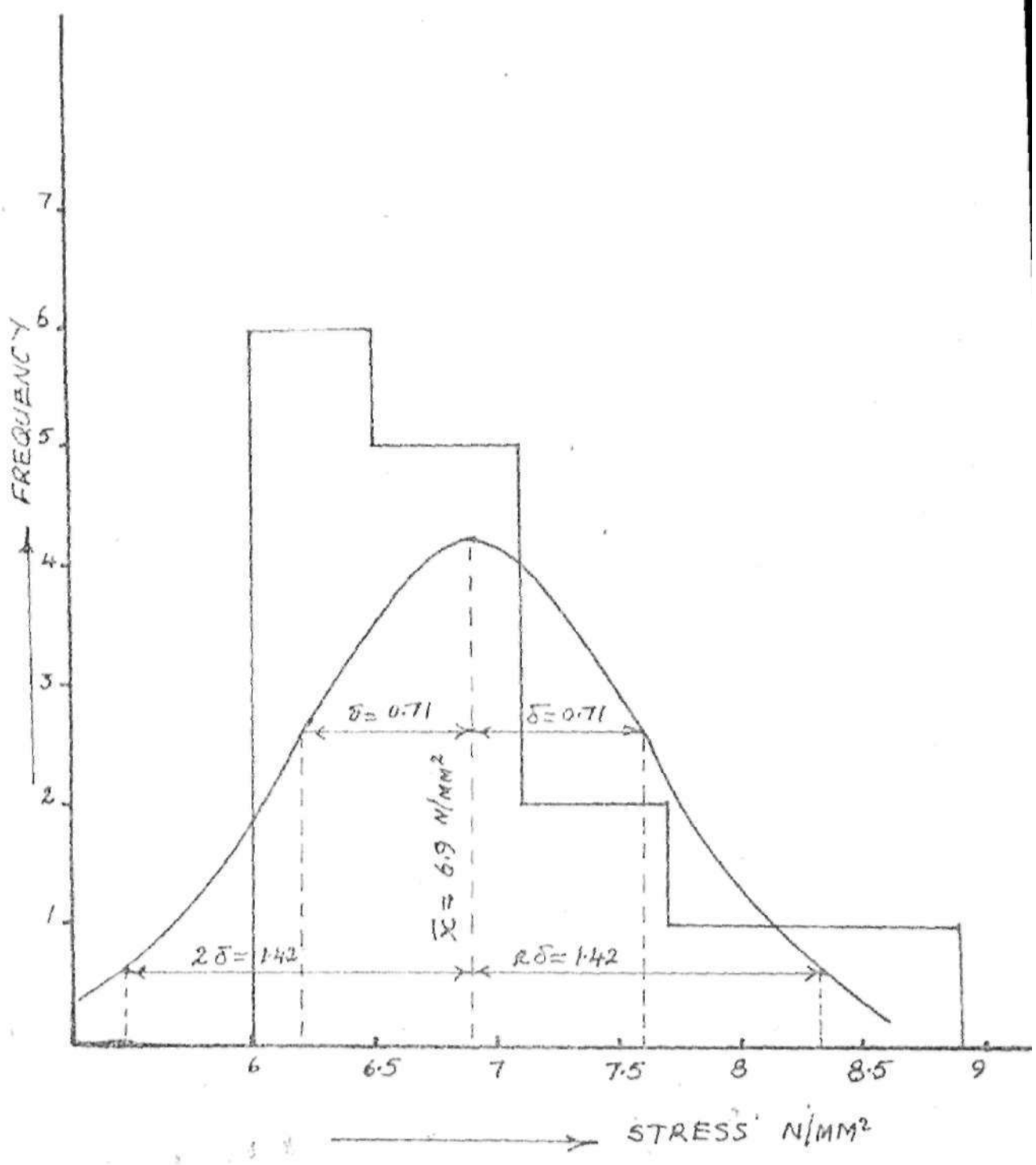


FIG 6.4 NORMAL DIST. CURVE MIX 1:2:4
28-DAY STRENGTH

The normal curves for 7-day and 28-day strengths are shown in figures 6.3. and 6.4 respectively.

6.1.4. Compressive Strength of ACI Mix

The results obtained for the 7-day and 28-day strengths and the statistical analysis are presented in appendix E. The results are summarised below:

Table 6.4: Summary of Results for ACI Mix

	7-day Strength	28-day Strength
Mean Strength N/mm^2	15.8	20.5
Standard Deviation N/mm^2	0.34	0.79
Coefficient of Variation %	2.1	3.8
Average Density kg/m^3	1833	1863

The normal curves for the 7-day and 28-day strengths are shown in figures 6.5 and 6.6 respectively.

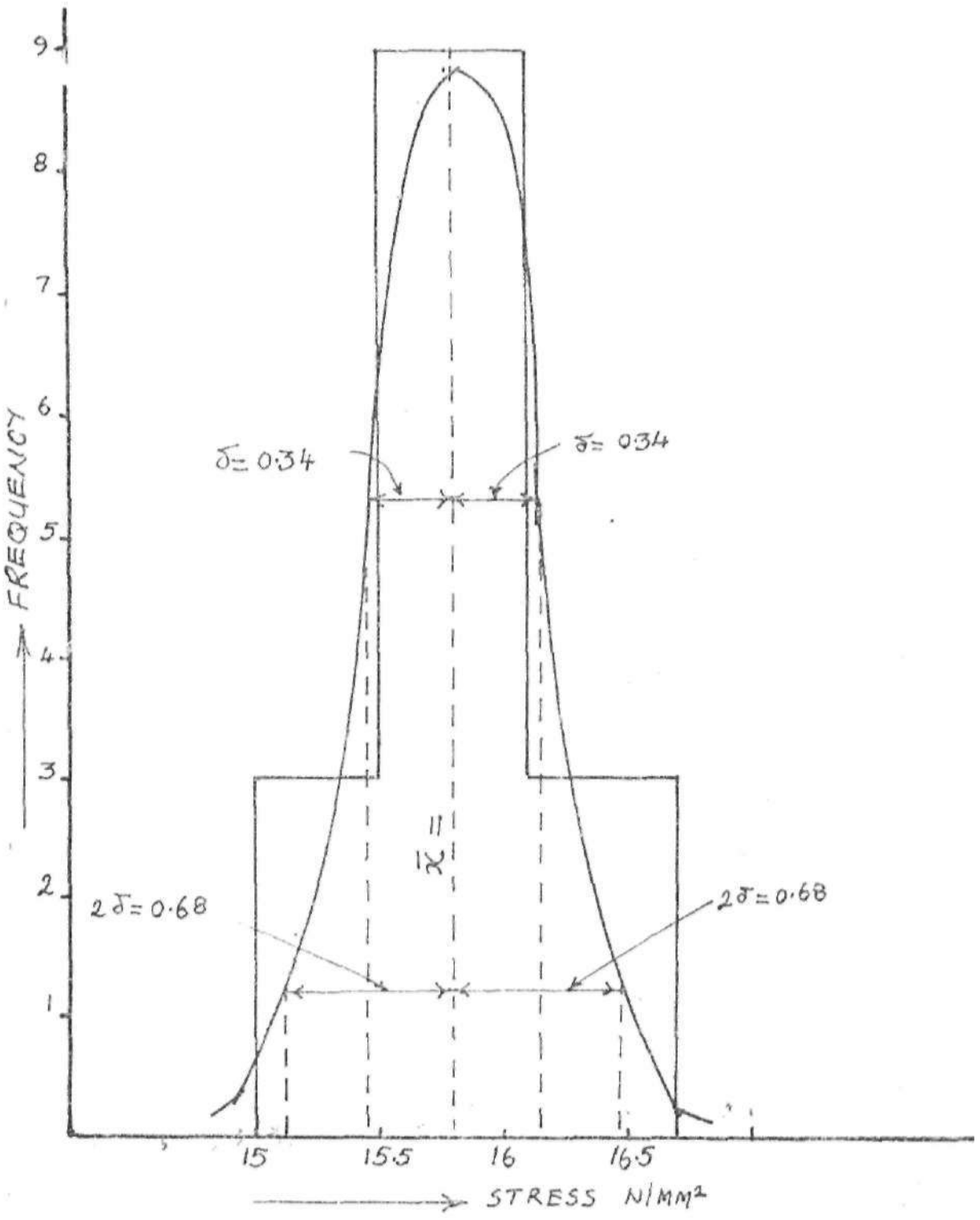


FIG 6·5 NORMAL DIST. CURVE. ACI MIX
7-DAY STRENGTH

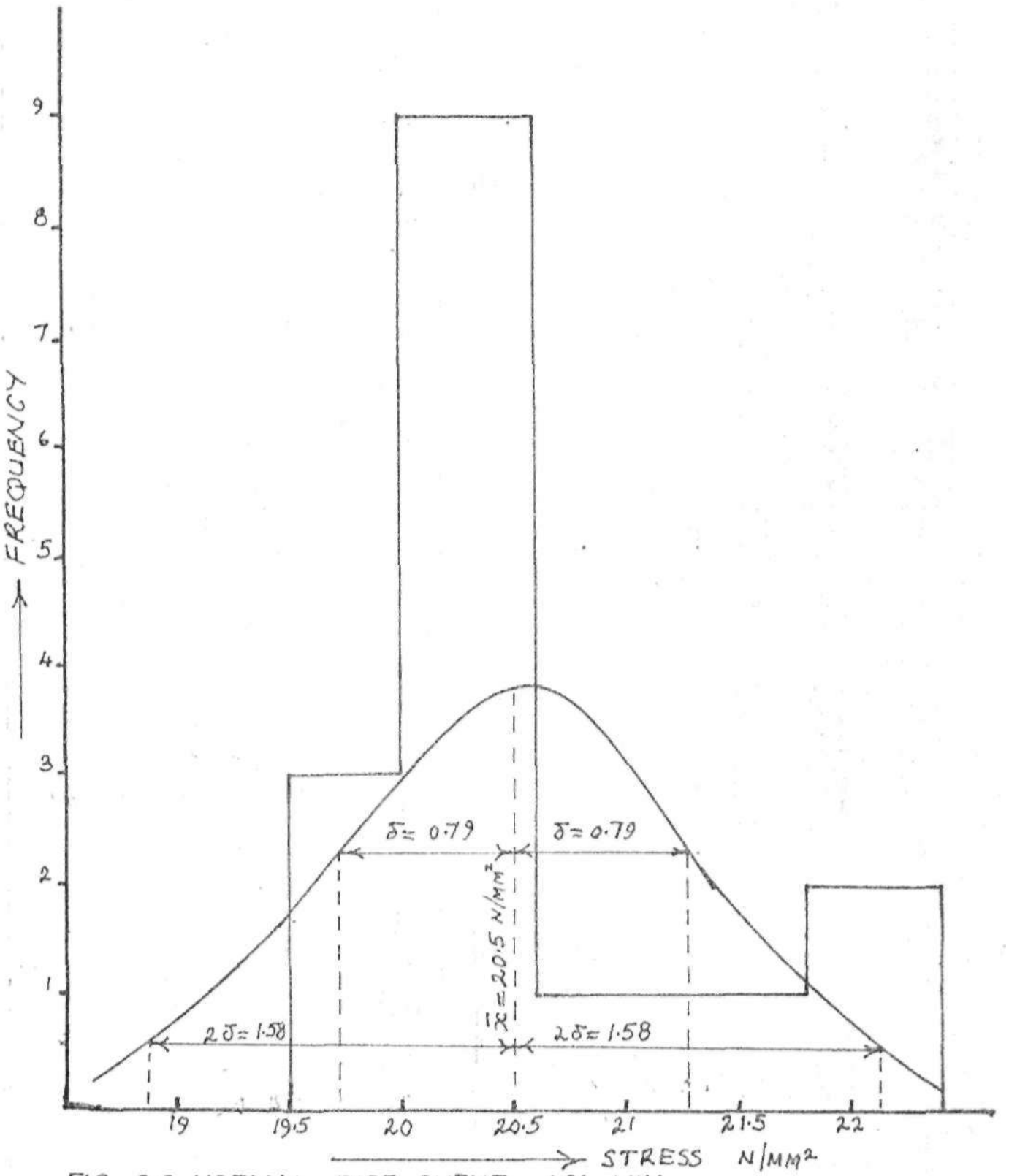


FIG 6·6 NORMAL DIST. CURVE. ACI MIX
28-DAY STRENGTH

6.1.5: Summary and Analysis of Compressive Test Results

Table 6.5.: Summary of Test Results

Design mix	1 : 1½ : 3		1 : 2 : 4		ACI mix	
	7-day	28-day	7-day	28-day	7-day	28 day
Mean Compressive strength N/mm^2	8,1	11.5	4.3	6.9	15.8	20.5
Standard Deviation N/mm^2	0.56	1.26	0.47	0.71	0.34	0.79
Coefficient of Variation %	6.9	10.9	3.1	10.2	2. 1	3.8
Ratio of 28-day to 7-day strength	1.4		1.6		1.3	

From figures 6.1 and 6.2, the standard deviations obtained were small. The coefficients of variation were also small. These indicate better control. The normal distribution curves do not deviate much from the mean of the histogram.

The 28-day strength is 1.4 times the 7-day strength. This indicates normal strength development and good curing methods (See article 2.12.2.2.).

The standard deviations and the coefficients of variation for mix 1:2:4 all indicate good quality control. However, the normal distribution curves (figures 6.3 and 6.4) skew slightly from the maximum strength obtained in the test. That is, the curves do not fit perfectly into the histograms. Since these cubes were cast from the same mix and cured under -

the same condition, the only reason that could be given for this skewness is differential compaction. Some of the cubes (i.e. those outside the curve to the left) were more uniformly compacted than the rest.

The 28-day strength is 1.6 times the 7-day strength. The standard of quality control was therefore good. So also was the curing condition. (See article 2.12.2.2.).

The ACI mix produced the smallest values of standard deviation and coefficient of variation. The high cement content could be responsible for this. Another fact is that it was the last mix to be designed and cast. Therefore, by this time, adequate experience must have been acquired with regards to proportioning, mixing, curing and other general quality control procedures.

The normal curve for the 7-day strength showed a perfect fit with the histogram. This is a measure of the good quality control exercised. The cubes were highly consistent There was little or no segregation and the degree of compaction was adequate and uniform.

The 28-day strength curve showed the histogram shooting well over the normal curve. Since the cubes were made from the same mix with the 7-day cubes, it follows that the disparity could likely be due to the rate of strength development caused by accelerated chemical reaction.

The 28-day strength is 1.3 times the 7-day strength (See article 2.12.2.2.).

From the analysis so far made it can be seen that palm kernel lightweight concrete has developed enough strength to satisfy the British code of practice for the Structural Use of Concrete CP110:1972 (See article 4.3.6.).

The concrete of mix 1:1½:3 developed strength required of load-bearing materials for wall construction. The 1:2:4: mix developed lower strength but, it may be useful as plain concrete for mass concreting and strip foundation for light buildings.

The ACI mix developed the hightest strength. It could be used for reinforced concrete structures.

6.2.0. Modulus of Elasticity

The modulus of elasticity of the three mixes was determined using three cylinders of each.

The secant modulus of elasticity was calculated at 35 per cent of the ultimate cylinder strength of the specimens. (See article 2.12.3.1.). Four readings were taken at four different loadings in each cylinder.

To obtain the curve the stresses were plotted on the ordinates and the strain on the abscissae.

6.2.1. Modulus of Elasticity of Mix 1:1½:3

The results obtained are presented in appendix F. The stress-strain curve is shown in figure 6.7. From the curve the modulus of elasticity was calculated:

35% of cylinder strength = $2.8 N/mm^2$

$\therefore$ $M_oE_o = \frac{2.8}{4400 \times 10^{-4}} = 6.4 KN/mm^2$

Using the Comite European du Beton's expression, the modulus is:

$E_c = \frac{1}{1.8} \times 10^{-4} \times 1719^{1.5} = 8.0$ (See article 2.12.3.2.).

$$E = \frac{2.8}{4400 \times 10^{-4}} = 6.4 \text{ KN/MM}^2$$

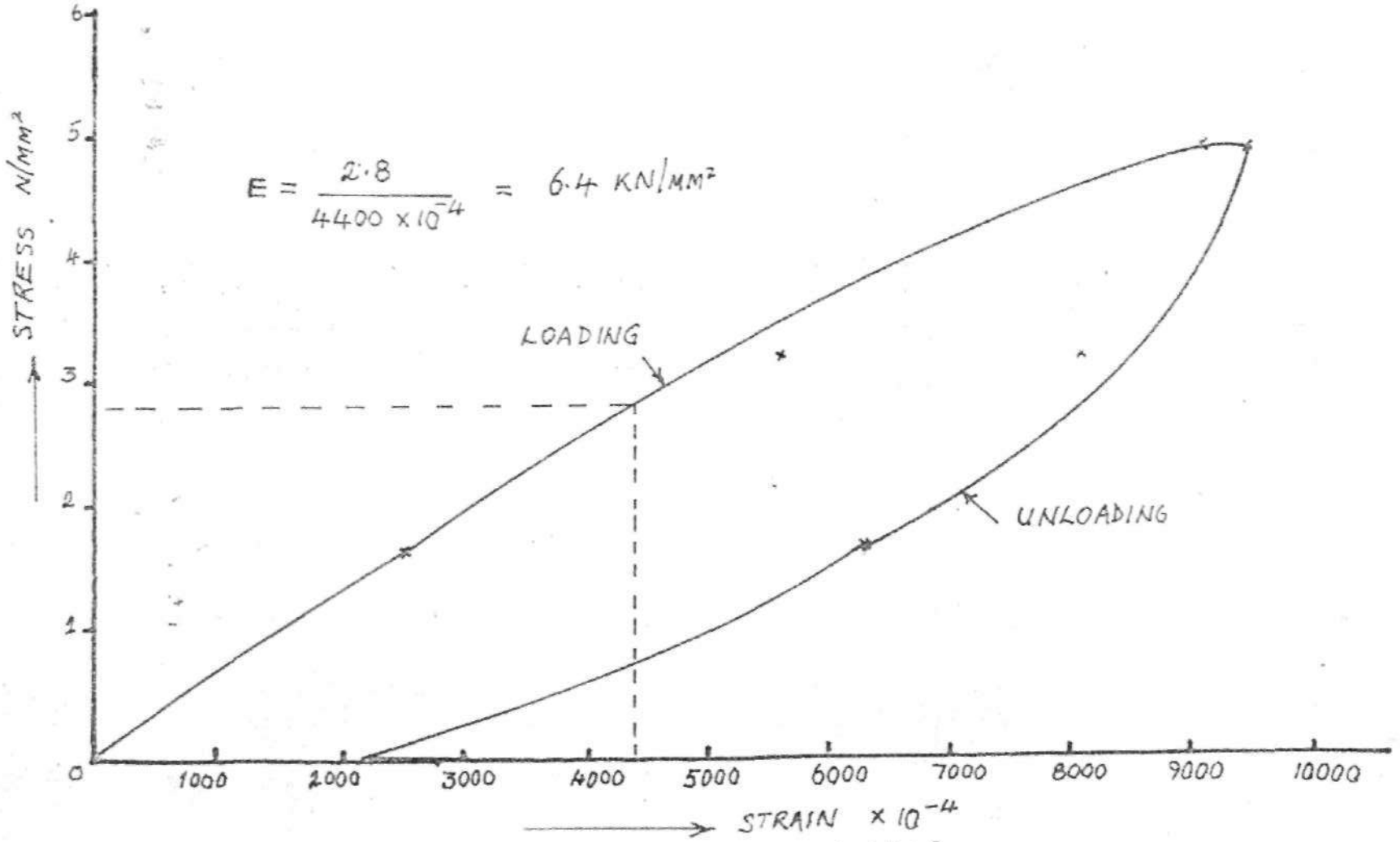


FIG 6.7 MODULUS OF ELASTICITY: MIX 1:1.5:3

$$E = \frac{2.0}{4450 \times 10^{-4}} = 4.5 \ KN/MM^2$$

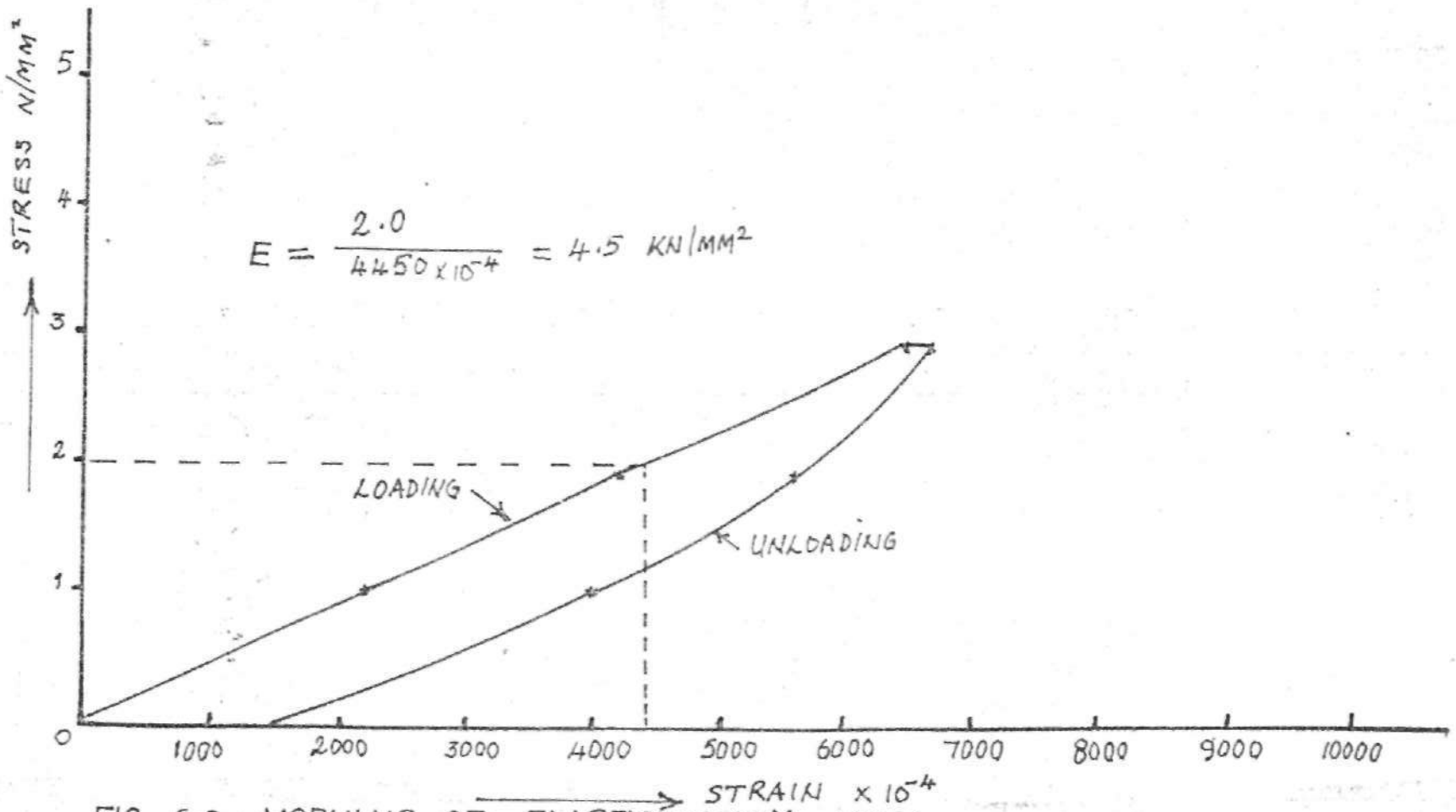


FIG 6·8 MODULUS OF ELASTICITY: MIX 1:2:4

$= 11.19 KN/mm^2$

6.2.2 Modulus of Elasticity of Mix 1 : 2 : 4:

The results obtained are presented in appendix G. The stress-strain curve is shown in figure 6.8. From the curve obtained the modulus is determined thus:

35% of cylinder strength $= 2.0 N/mm^2$

$\therefore$ M.E. $= \frac{2.0}{4450 \times 10^{-4}} = \underline{4.5 KN/mm^2}$

Using the C.E.E. formula the modulus is:

$Ec = \frac{1}{1.8} \times 10^{-4} \times 1620^{1.5}$ 5.7

$= \underline{8.6 KN/mm^2}$

6.2.3. Modulus of Elasticity of ACI Mix

The results obtained are presented in appendix H. The stress-strain curve is shown in figure 6.9. From the curve, the modulus of elasticity is:

35% of cylinder strength $= 3.7 N/mm^2$

$\therefore$ M.E. $= \frac{3.7}{2900 \times 10^{-4}} = 13 KN/mm^2$

from ECB formula:

$EC = \frac{1}{1.8} \times 10^{-4} \times 1863^{1.5}$ 10.5

$= 14.5 KN/mm^2$

$$E = \frac{3.7}{2900 \times 10^{-4}} = 13 \text{ KN/MM}^2$$

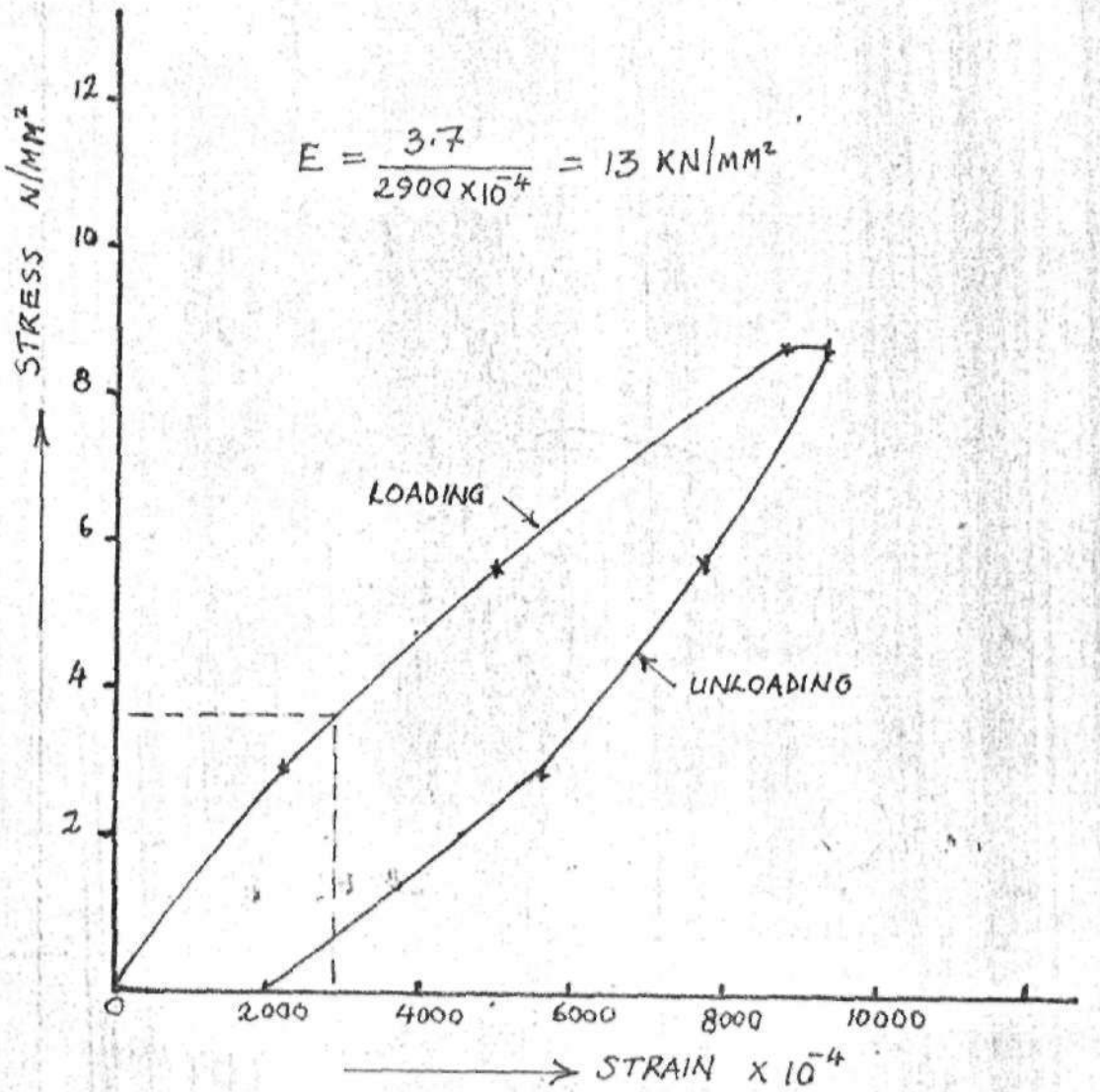


FIG 6·9 MODULUS OF ELASTICITY: ACI MIX

Plate IV shows a cylinder undergoing modulus of elasticity test.

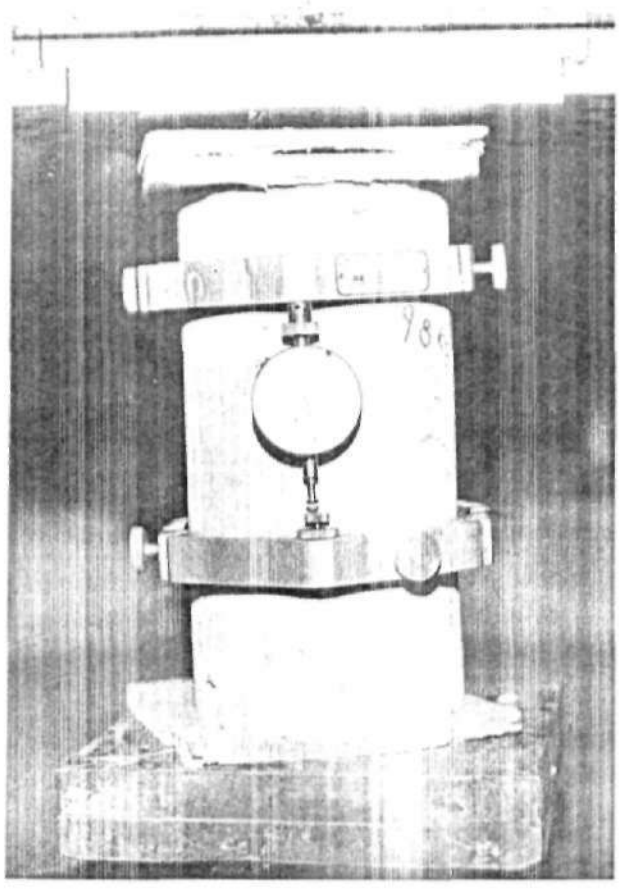


Plate IV: Modulus of Elasticity Test on Palm Kernel Lightweight concrete Cylinder.

6.2.4: Summary of Modulus of Elasticity Test Results

Below is the summary of results of modulus of Elasticity test.

Table 6.6: Summary of Modulus of Elasticity Test Results

Mix	Compressive Strngth N/mm^2	Modulus of Elasticity KN/mm^2
1 : $1\frac{1}{2}$: 3	11.5	6.4
1 : 2 : 4	6.9	4.5
ACI Mix	20.5	13.0

From the results obtained it can be seen that the modulus of elasticity increases with increase in compressive strength. Compared with table 2.8. it is found that the ratio of modulus of elasticity to compressive strength of ordinary concrete is higher than that of palm kernel lightweight concrete.

6.3.0. Split Tensile Test

The split tensile test was carried out on standard cylinders cured in water for 28 days. They were tested dry. (Refer to article 2.12.4.0. for details of experimental procedure). From article 2.12.4.1. the formula for tensile stress is given as:

$$\frac{2P}{LD}$$

Where:

P = Compressive strength on cylinder

L = Length of cylinder = 300mm

D = Diameter of cylinder = 150mm.

Plate V shows the tensile splitting test. Plate VI shows the split cylinders. It can be seen from Plate VI that the palm kernel shell aggregate did not break. Only the cement matrix did. This is an indication of the strength of palm kernel shell aggregate.

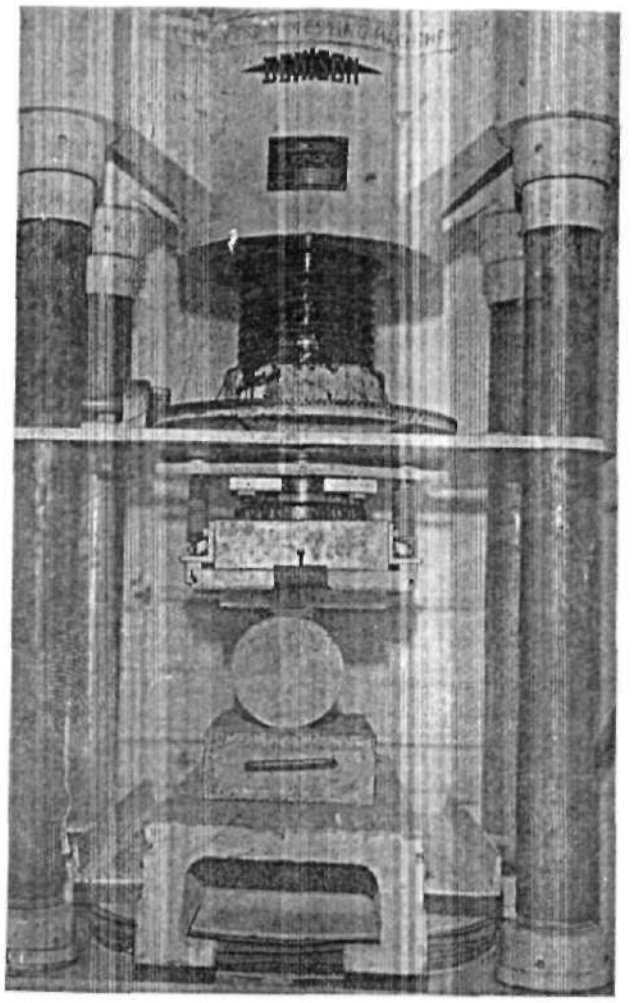


Plate V: Split Tensile Test on Palm Kernel Shell lightweight Concrete.

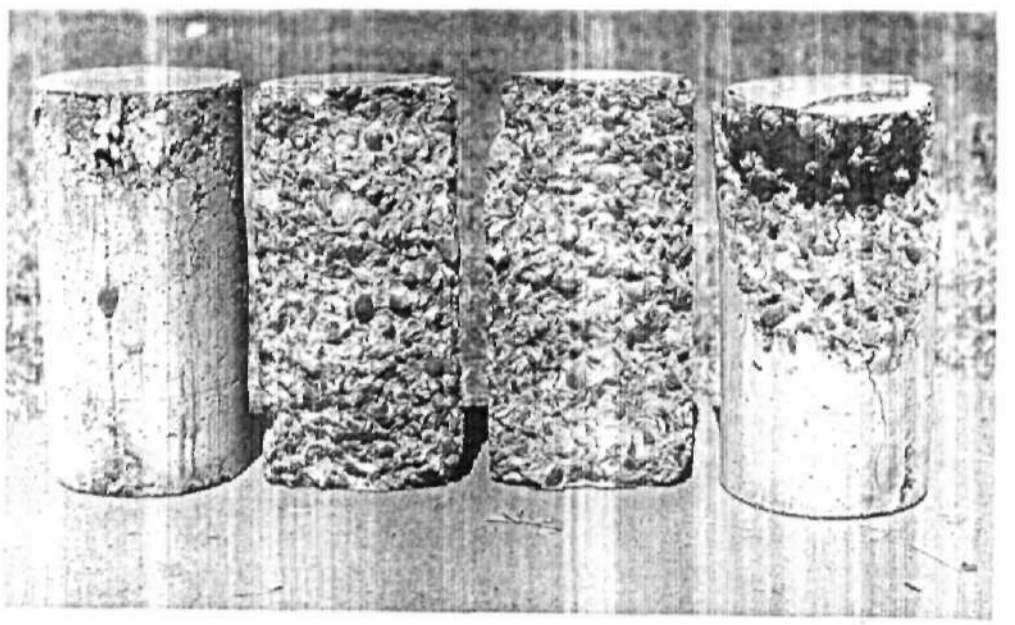


Plate VI: Crushed Palm Kernel Shell lightweight concrete cylinders. Note the aggregate is not broken.

The results of the split tensile tests are presented in table 6.7. The ratios of tensile strength to compressive strength for palm kernel shell lightweight concrete are presented in table 6.8.

Table 6.7.: Results of split tensile tests

MIX	1 : 1½ : 3		1 : 2 : 4		ACI Mix	
Specimen No.	Load KN	Tensile stress N/mm^2	Load KN	Tensile Stress N/mm^2	Load KN	Tensile Stress N/mm^2
1	90	0.64	63	0.45	120	0.85
2	96	0.68	72	0.51	120	0.85
3	72	0.51	63	0.45	110	0.78
Average	86	0.61	66	0.47	116.7	0.83

Table 6.8 Ratio of Tensile Strength to Compressive Strength

MIX	Compressive Strength N/mm^2	Tensile Strength N/mm^2	Ratio of tensile strength to compressive strength
1 : 1½ : 3	11.5	0.61	0.053
1 : 2 : 4	6.9	0.47	0.068
ACI MIX	20.5	0.83	0.040

It can be seen that the tensile strength of palm kernel lightweight concrete is between 4 to 7 percent its compressive strength. The percentage for ordinary concrete is between 8 to 12 per cent (Neville, 1977).

7.0. CONCLUSIONS AND RECOMMENDATIONS

Having carried out the tests and investigations on palm kernel as presented in the various sections the following conclusions are made based on the results obtained:

1. That palm kernel posses all the properties of lightweight aggregate:

   a) Its specific gravity ranges between 1.15 and 1.26. The corresponding values for dense aggregate are between 2.5 to 3.0.

   b) It has an average bulk density of 640kg/m^3, the densities of expanded clay, shale, perlite and slate, which are known lightweight aggregates, are between 30 and 900kg/m^3. The density of universal aggregate is generally taken as 1600kg/m^3.

   c) Lightweight aggregates are known for their high porosities. The porosity of palm kernel is between 16.6 and 18.2 per cent. The porosity of dense aggregates is between 0.0. and 3.8 per cent.

   d) Due to its porosity it has a high percentage of water absorption. The absorption is between 8.6 and 15.3 per cent. The water absorption of some artificial lightweight aggregates is from 12 to 34 percent.

   e) Its moisture content is very small due to its high porosity and percentage absorption.

   f) Its grading characteristics satisfy both the British and the American requirements for lightweight aggregate.

   g) Palm kernel is a very strong aggregate. This can be seen from the cylinder crushing and splitting tests. The cement matrix broke but the palm kernel aggregate did not break (See Plate VI).

It can therefore be safely concluded that palm kernel is a lightweight aggregate.

2. That it is possible to use palm kernel to produce lightweight concrete. The properties of the fresh concrete are excellent. It is very workable, consistent and easily placed. However, the palm kernel nut proved not to be a suitable material due to its tendency to rot in wet environment.
3. That hardened palm kernel lightweight concrete developed enough strength that will make it suitable for a wide range of uses. The various mixes tested produce a strength range of $0.3N/mm^2$ to $20.5N/mm^2$. This range of strength covers such uses as nailing concrete mass concreting and structural concrete.
4. That there is abundant supply of palm kernel shells for use in making lightweight concrete. There is an annual production of 1,451,953.0 tonnes of shell in the country. The use of this material in making concrete will help in removing over 1 million tonnes of waste from the environment annually.

7.1. RECOMMENDATIONS FOR FUTURE WORK

Due to obvious inadequacies and constraints certain tests could not be carried out in this research work. It is, however, recommended that the following tests be carried out on palm kernel lightweight concrete:

a) Flexure test: To determine the behaviour of palm kernel shell lightweight concrete under bending.

b) Bond stress test: To determine the strength of bond palm kernel shell lightweight concrete forms with steel reinforcement

c) Fire protection test: To determine the reistance of palm kernel shell lightweight concrete to fire.

d) To build an experimental house using palm kernel shell lightweight concrete.

REFERENCES

1. Aziz, M.A.; Murphy, C.K. and Ramaswamy, S.D. (1978). On Lightweight Concrete using Cork Granules. The International Journal of Lightweight Concrete Vol. 1 No. 1. (1979) pp. 29 - 32.

2. Anonymous (1985): Highlights of Activities and achievements Pp 1-35. Nigerian Institute for Oil Palm Research.

3. Anonymous (1985): Oil Palm Products and their uses. Information Bulletin No. 5.Nigerian Institute for Oil Palm Research.

4. Anonymous (1985): Report of the Special Committee on New Building Policy

5. Concrete Mixes: Specification, Design and Quality Control. Building Research Establishment Digest Nos. 237 and 244 (1980)

6. Corner, D.J.H. (1966): The Natural History of Palms. Weidenfeld Nicolson, London.

7. Elvery, R.H. (1963): Concrete Practice. C.R. Books Ltd, London.

8. Harrison, W.H. (1971): Concrete and Soluble Salts in Arid Climates. Overseas Building Notes No. 139.

9. Glanville, W.H. Collius, A.R. and matthews, D.D. (1947): The Grading of Aggregates and Workability of Concrete Road Research Tech. Paper No. 5. (London. H.M.S.O.)

10. Komolafe, O.S. (1987): Chemical Admixture in Concrete (A Study of the Potentialities of Oil Palm Derivatives). Paper presented at the 19th annual conference on materials, Testing, Control and Research Kaduna, Nigeria.

11. McIntosh, J.D. and Erntroy, H.C. (1955): The workability of concrete mixes with 3/8 in aggregates. Cement Concrete Association Res. Rep. No. 2.

12. Neville, A.M. (1977): Properties of Concrete 2nd Ed. Pitman Publishing Ltd, London. Pp 103 - 621.

13. Newman, A.J. Problems of concreting in Arid Climates. Overseas Building Notes No. 139

14. Muhu-Koko, M.K. (1987): Investigation on Palm Kernel as an aggregate. Seminar paper presented to the Department of Building, M.Sc., Seminar Series, A.B.U. Zaria, Nigeria,

15. Obatomi, F. (1986): ECOWAS Sub-Regional I.Y.S.H. Seminar, Lagos, Nigeria.

16. Road Research, Design of Concrete Mixes. D.S.I.R. Road Note No.4 (London, H.M.S.O., 1950).

17. Ryder, G.H. (1969): Strength of Materials Macmillan Publishers (Ltd, London, Pp 302 - 320.

18. Short, A. and Kinniburgh, W. (1962: Lightweight Concrete. John Wiley and Sons Inc. London Pp 1 - 160

19. Udom, D.S. and Orewa, S.I. (1986): Economic of palm Oil production and the Nigerian Palm Oil Market. A paper presented at the International Conference on Oil Palm Nov 9 - 15th, Port Harcourt, Nigeria.

20. Waddel, J.J. (1962): Practical Quality Control for Concrete McGraw - Hill Book Co. Inc. N.Y. Pp 22 - 324

21. White, G.R. (1977): Concrete Technology. Van Nostrand Reinhold Co.; London Pp 23 - 115.

APPENDIX A

PRELIMINARY DESIGN MIXES: CUBE STRENGTH FOR 7 DAY

Type of Mix	Identification mark	Date of casting	Water/cement ratio	Curing Condition	Size of cube mm^3	Weight of cube kg	Density of cube kg/m^3	Test date	Maximum size of aggregate	P/load (KN)	Cube strength N/mm^2
Palm Kernel shell no-fines	1	10/2/87	0.45	Water-Cured 7 day	150mm x 150mm x 150mm x	2.9	859.259	17/2/87	20mm	20	0.889
"	2	"	0.45			2.7	800.00	"	"	16	0.711
"	3	"	0.45			2.7	800.00	"	"	12	0.533
Palm Kernel shell concrete	4	11/2/87	0.78			6.0	1777.770	18/12/87	"	160	7.111
"	5	"	0.78			5.6	1659.26	"	"	140	6.222
"	6	"	0.78			5.6	1659.26	"	"	140	5.333
Palm Kernel nut concrete	7	"	0.75			5.6	1659.26	"	"	76	3.377
"	8	"	0.75			5.6	1703.7	"	"	80	3.555
"	9	"	0.75			5.5	1629.63	"	"	72	3.200

APPENDIX B

PRELIMINARY DESIGN MIXES: CUBE STRENGTH FOR 28 DAYS

Type	Ident-ication mark	Date of casting	Water/ cement ratio	Curing Condi-tion	Size of cube mm^3	Weight of cube kg	Density of cube kg/m^3	Test date	Maximum size of agg-regete	P/load (KN)	Cube Strength N/mm^2
Palm Kernel shell no-fines	10	10/2/87	0.45	Water-cube for 28-days	150mm x 150mm x 150mm	2.9	.859.26	10/3/87	20mm	16	0.711
"	11	"	0.45	"	"	2.8	829.63	"	"	20	0.889
"	12	"	0.45	"	"	2.8	829.63	"	"	16	0.711
Palm Kernel shell con-crete	13	11/2/87	0.78	"	"	5.5	1629.63	11/3/87	"	140	6.222
"	14	"	0.78	"	"	5.6	1659.26	"	"	160	7.111
"	15	"	0.78	"	"	5.6	1659.26	"	"	120	6.222
Palm Kernel nut concrete	16	"	0.75	"	"	5.7	1688.89	"	"	76	3.377
"	17	"	0.75	"	"	5.8	1718.52	"	"	84	3.733
"	18	"	0.75	"	"	5.6	1659.26	"	"	72	3.200

APPENDIX C

Water/Cement Ratio = 0.85

Mix Proportion = 1:1½:3 Max Aggregate size = 10mm

Curing Condition = Water Size of Cube = 150mm x 150mm x 150mm

Specimen No.	Density kg/m^3	7-day strength N/mm^2	Specimen No.	Density kg/m^3	28-day strength N/mm^2
1	1659.3	7.4	1	1718.5	11.0
2	1659.3	8.0	2	1689.0	12.0
3	1748.1	8.4	3	1718.5	11.4
4	1659.3	8.0	4	1818.5	12.3
5	1689.0	8.0	5	1748.1	11.0
6	1748.1	9.0	6	1718.5	11.6
7	1689.0	8.0	7	1748.1	9.0
8	1659.3	7.3	8	1818.5	10.6
9	1659.3	8.2	9	1689.0	11.0
10	1718.5	8.2	10	1748.1	13.3
11	1718.5	9.0	11	1718.5	9.0
12	1689.0	9.0	12	1718.5	12.4
13	1689.0	8.3	13	1689.0	13.3
14	1718.5	7.3	14	1718.5	12.4
15	1659.3	7.5	15	1718.5	12.4
Mean	1691	8.1		1718.5	11.5
Standard Deviation N/mm^2		0.56		1718.5	11.5
Coefficient of of variation %		6.9			10.9

APPENDIX C (CONT.)

Normal Curve Equations for Mix 1:1½:3

28-DAY

STRENGTH y = ordinates

$\bar{x}$ = Mean strength = 11.5 N/mm^2

n = No. of specimen = 15

= Standard deviation = 1.26 N/mm^2

c = Cell size = 1.5 N/mm^2

at $\bar{x}$ = 11.5 N/mm^2

$y = 0.3989 \frac{nc}{}$ = 7.1

at $\bar{x} \pm$ = + 12.76 N/mm^2

$y = 0.242 \frac{nc}{}$ = 4.3

at $\bar{x} \pm 2$ = ± 14.02 N/mm^2

$y = 0.053 \frac{nc}{}$ = 1.0

Cell (1.5 N/mm^2)	Frequency
8 – 9.5	2
9.6 – 11	4
11.1 – 12.6	7
12.7 – 14.2	2

APPENDIX C CONT'D

7 - DAY

STRENGTH

$\bar{x}$ = 8.1 M/mm^2

n = 15

= 0.56 N/mm^2

c = 0.5 N/mm^2

at $\bar{x}$ = 8.1 N/mm^2

y = 5.3

at $\bar{x} - +$ = 8.66 N/mm^2

y = 3.2

at $\bar{x} + 2$ = 9.22 N/mm^2

y = 0.72

Cell (0.5)	Frequency
7.0 - 7.5	4
7.6 - 8.0	4
8.1 - 8.6	4
8.7 - 9.2	3

The normal distribution curves for the 7 - day and the 2 - day strengths are plotted on figures 6.1 and 6.2 respectively.

APPENDIX D

Water cement Ratio = 0.53
Mix proportion = 1:2:
curing condition = In Water

Max. size of Aggregate = 10mm
Size of Cube = 150mm x 150 mm x 150mm

Specimen No	Density Kg/m^3	x 7 - day strength N/mm^2	Specimen No	Density Kg/m^3	x 28 -day Strength N/mm^2
1	1629.6	3.7	1	1629.6	6.4
2	1659.3	4.4	2	1600.0	6.8
3	1600.0	3.7	3	1659.3	8.0
4	1689.0	5.0	4	1600.0	6.2
5	1689.0	4.8	5	1659 .3	8.5
6	1659.3	4.7	6	1540.7	6.2
7	1600.0	4.3	7	1570.3	6.2
8	1659.3	4.6	8	1570.3	6.0
9	1629.6	4.0	9	1659.3	7.1
10	1629.6	4.0	10	1629.6	7.1
11	1600.0	4.0	11	1629.6	6.4
12	1600.0	3.8	12	1600.0	6.8
13	1600.0	4.0	13	1629.6	6.6
14	1659.3	5.3	14	1689.0	7.5
15	1600.0	4.4	15	1629.6	7.6
Mean	1633.6	4.3		1620	6.9
Standard Deviation		0.47			0.71
Coefficient of variation %		3.1			10.2

APPENDIX D CONT.

N
Normal Curve Equations for Mix 1:2:4

28 - DAY STRENGTH

$\bar{x}$ = 6.9 N/mm^2

n = 15

= 0.71 N/mm^2

c = 0.5 N/mm^2

at $\bar{x}$ = 6.9 N/mm^2

y = 0.3989 $\frac{nc}{}$ = 4.2

at $\bar{x}$ $\pm$ = $\pm$ 7.61 N/mm^2

y = 0.242 $\frac{nc}{}$ = 2.6

at $\bar{x}$ $\pm$ 2 = $\pm$ 8.32 N/mm^2

y = 0.054 $\frac{nc}{}$ = 0.6

Cell(0.5)	Frequency
6- 6.5	6
6.6 - 7.1	5
7.2 - 7.2	2
7.8 - 8.3	1
8.4 - 8.9	1

APPENDIX D CONT'D

7 - DAY STRENGTH

$\bar{x}$ = 4.3 N/mm^2

n = 15

= 0.47 N/mm^2

= 0.5 N/mm^2

at $\bar{x}$ = 4.3 N/mm^2

y = 6.4

at $\bar{x} \pm$ = 4.77 N/mm^2

y = 3.9

at $\bar{x} \pm 2$ = 5.24 N/mm^2

y = 0.9

Cell (0.5)	Frequency
3.5 - 4	7
4.1 - 4.6	44
4.7 - 5.2	3
5.3 - 5.8	1

The normal distribution curves for the 7 - day and 2
stren ths are shown on figures 6.3 and 6.4 respecti

APPENDIX E CONT.

Normal Curve Equations for ACI Mix

28 - DAY
STRENGTH

$\bar{x}$ = 20.5 N/mm^2

n = 15

= 0.79 N/mm^2

c = 0.5 N/mm^2

at $\bar{x}$ = 20.5 N/mm^2

y = 0.3989 $\frac{cn}{}$ = 3.8

at $\bar{x} \pm$ = = $\pm$ 21.29 N/mm^2

y = 0.242 $\frac{nc}{}$ = 2.3

at $\bar{x} \pm 2$ = $\pm$ 22.1

y = 0.0 54 $\frac{nc}{}$ = 0.5

Cell (0.5)	Frequency
19.5 - 20	3
20.1 - 20.6	9
20.7 - 21.3	
21.3 - 21.8	1
21.9 - 22.4	2

APPENDIX E CONT'D

7 - DAY STRENGTH

$\bar{x}$ = 15.8 N/mm^2

n = 15

= 0.34 N/mm^2

c = 0.5 N/mm^2

at $\bar{x}$ = 15.8 N/mm^2

y = 8.8

at - = 16.14 N/mm^2

y = 5.3

at $\bar{x} \pm 2$ = 16.48 N/mm^2

y = 1.2

Cell (0.5)	Frequency
15.0 - 15.5	3
15.6 - 16.1	9
16.2 - 16.7	3

The normal distribution curves for 7 - day and 28 - day strengths for the ACI mix are shown on figures 6.5 and 6.6 respectively.

APPENDIX F

MODULUS OF ELASTICITY MIX 1 : 1½ : 3

		DIAL READING x 10^{-4}								
		FIRST CYLINDER		SECOND CYLINDER		THIRD CYLINDER		AVERAGE		
S.No.	Stress N/mm²	Loading	Un-Loading	Loading	Un-Loading	Loading	Un-Loading	Loading	Un-Loading	Average cylinder strength N/mm²
1	0	00	2360	0	1720	0	3040	0	2373	
2	1.6	2240	6560	2440	5040	2880	7400	2520	6333	8.0
3	3.2	5600	8040	5160	6920	6120	9320	5627	8093	
4	4.9	9040	9440	8160	8320	10200	10680	9133	9480	

APPENDIX G

MODULUS OF ELASTICITY MIX 1 : 2 : 4

		DIAL READING x 10^{-4}								
		FIRST CYLINDER		SECOND CYLINDER		THIRD CYLINDER		AVERAGE		
S.No.	Stress N/mm^2	Loading	Un-Loading	Loading	Un-Loading	Loading	Un-Loading	Loading	Un-Loading	AVERAGE cylinder strength N/mm^2
1	0	0	1680	0	1520	0	1200	0	1467	5.7
2	0.96	2520	4160	2160	4240	1920	3720	2200	4040	
3	1.92	4160	5600	4440	5920	3960	5360	4187	5627	
4	2.94	6400	6600	9620	7120	6320	6400	6547	6707	

KASHIM ... AHM... ZARIA, NIGERIA.

APPENDIX H

MODULUS OF ELASTICITY ACI MIX

		DIAL READING x 10^{-4}						AVERAGE	
		FIRST CYLINDER		SECOND CYLINDER		THIRD CYLINDER			
S.No.	Stress N/mm^2	Loading	Un-Loading	Loading	Un-Loading	Loading	Un-Loading	Loding	Un-Loading
1	0	0	2440	0	1960	0	1240	0	1880
2	2.9	2400	5960	2120	5880	2160	4840	2227	5560
3	5.8	5320	8000	4880	8000	4680	7040	4960	7680
4	8.7	9280	9600	8680	9480	8360	8760	8773	9280

Average Cylinder Strength = 10.5 N/mm^2