

**STRUCTURAL CHARACTERISATION AND
QUALITY ASSESSMENT OF PRIMARY
REINFORCED CONCRETE BUILDING
MATERIALS**

By

Opeyemi Joshua

(CUGP070200)

**A Research Thesis Submitted to the School of
Postgraduate Studies in Partial Fulfilment for the
Award of Ph.D Building Technology (Building
Structures), Covenant University, Ota.**

November, 2015

CERTIFICATION

This is to certify that this thesis was undertaken by OPEYEMI JOSHUA, it has not been published anywhere else and should not be replicated or produced in any form but could be used for literary purpose only. It meets the requirement for the award of Doctor of Philosophy (Ph.D) in Building Structures in the Department of Building Technology, Covenant University, Ota. Nigeria.

Opeyemi Joshua

Date



Dr. Kolapo O. Olusola
(Project Supervisor)

Date

Prof. Olabosipo I. Fagbenle
(Co-supervisor)

Date

Dr. James D. Owolabi
(Head of Department)

Date

Prof. Fred Job
(External Examiner)

Date

DEDICATION

This work is dedicated to the almighty God to whom all the glory associated to this study belongs, the gift of life and all the directions necessary for the completion of this study and to my parents, Late Mr. T. E. Joshua, and mummy, Mrs. E. O. Joshua, whom God have used tremendously to impact discipline and build the fear of God in me.

ACKNOWLEDGMENT

Glory be to God for His grace, wisdom and knowledge given me that has enabled me complete this study.

I appreciate the role of the Chancellor and my mentor, Dr. David O. Oyedepo and the Covenant University management team, notably the Vice-Chancellor, Professor Charles Ayo, the Deputy Vice-Chancellor, Professor Taiwo Abioye (Mummy), the Registrar, Pastor Olamide Olusegun, the Dean and Sub-Dean, School of Post-Graduate Studies, Professor Shallom Chinedu and Professor Samuel Oloyede respectively and the Dean and Sub-Dean, College of Science and Technology, Professor Nickolas Omoregbe and Professor Albert Adeboye respectively.

I acknowledge with profound gratitude, the cooperation and quality guidance of my supervisor and mentor, Dr. Kolapo Olusola, and his wife Mrs Janet Olusola. His immense contributions towards the realization of this research work, his spiritual encouragement as a Pastor, financial encouragements and bearing my health challenges with me during the course of the work. Despite the demands of his higher responsibility during the cause of this study, he still dedicated time to ensure its completion. It is only God that can reward your efforts on me during the cause of this work. Many thanks to my co-supervisor, Professor Olabosipo Fagbenle, for his technical and editorial contributions. He was the quality controller of this thesis.

I sincerely appreciate the contributions of Professor Timothy Mosaku, his weight, encouragements and endless ideas were sources of speed to this study. He ensured that I remain in this discipline despite my initial stance to quit for another discipline.

I sincerely appreciate the Head of Department, Building Technology, Dr. James D. Owolabi for his final push and encouragements towards the timely completion of the work. My appreciations to my colleagues, Dr. James Rotimi, Dr. Ayodeji Ogunde, Dr. Lekan Amusan, Dr. Patience Tunji-Olayeni, Dr. Babatunde Olawuyi, Dr. Samson Adeosun, Mr. Ignatius Omuh, Mr. Ayodeji Afolabi, Mr. Raphael Ojelabi, Mr. Benjamin Babalola, Mr. Kunle Ajao, Mr. Babatunde Ogunbayo, Dr. Emmanuel Olanipekun, Engr. Richard Leramo, Mr. Kunle Ogundipe, Mr. David Jonah, Mr. Joel Adediran, Mr. Lameed Adebayo (Larfarge, Ewekoro), Mr. Adebisi Adedokun, Mrs. Uju Agoha and Miss Idowu for their criticisms, assistance in the Laboratory procedures and other forms of assistance during the course of the work. Appreciations also to my assessors, Dr. Olugbenga Ata, Dr. Akaninyene Umuh, Dr. David Imhonopi, Dr. John Ameh, Dr. Oluseyi Ajayi and Dr. Adedapo Oluwatayo, Dr. Eziyi Ibem, Dr. Olusola Ajibola and to my external examiner, Professor Fred Job. All your contributions in form of criticisms and corrections brought out the quality in this study.

I recognise the moral support from my wife, Mrs. Joyce Joshua and sons Daniel, Iyanuoluwa and Oluwatisegun Joshua. My profound gratitude to my mother, Mrs. Elizabeth Joshua, siblings, Dr. Olusegun Joshua, Mr. Ekundayo Joshua, Mr. Babatope Joshua, Mrs. Olubunmi Agbana and Mrs. Oluwaseyi Richard and my In-laws Bishop and Pastor (Mrs.) Frank and Christie Abuka.

No man can make himself, thank you to all, both mentioned and unmentioned above that contributed to this work and for being part of my story to this day. I pray you all Gods immeasurable rewards in Jesus name. Amen.

TABLE OF CONTENTS

Content	Page
Certification	ii
Dedication	iii
Acknowledgement	iv
Table of Contents	vi
List of Tables	xii
List of Figures	xv
List of Plates	xvii
Abstract	xviii
CHAPTER ONE: INTRODUCTION	1
1.1 Background to the Study	1
1.2 Statement of the Research Problem	6
1.3 Aim and Objectives	8
1.4 Justification of the Study	9
1.5 Scope and Limitation of the Study	9
1.6 The Study Area	9

CHAPTER TWO: LITERATURE REVIEW	11
2.1 Reinforced Concrete as a Building Structural Material	11
2.2 Cement	12
2.2.1 Chemistry of Cement	13
2.2.2 Roles of the Components of Cement	15
2.2.3 Typical Standard Requirements of Cement Components	16
2.3 Some Important Ratios or Moduli of Cement	20
2.3.1. Lime Saturation Factor (LSF)	21
2.3.2 Silica Ratio or Moduli (SR)	21
2.3.3. Alumina Ratio or Moduli (AR)	22
2.4 Factors Influencing Strength Development of Cement.	23
2.4.1 Fineness	23
2.4.2 Loss on Ignition (LOI)	24
2.4.3 Free Lime Content	24
2.4.4 Compound Composition	25
2.4.5 Alkaline And SO ₃ Content	25
2.5 Aggregates	25
2.5.1 Effect of Aggregate Characteristics on Concrete Performance	27
2.5.1.1 Shape and Surface Texture Effects	28
2.5.1.2 Effect of Grading	33
2.5.1.3 Effect of Fine content	35

2.5.1.4	Effect of Absorption	36
2.5.1.5	Effect of Mineralogy and Coatings	36
2.5.1.6	Effect of Strength and Stiffness	37
2.5.1.7	Effect of Maximum Size	39
2.5.1.8	Effect of Relative Density (Specific Gravity)	40
2.5.1.9	Effect of Soundness	40
2.6	Steel Reinforcing Bars (Rebars)	41
2.6.1	Chemical characteristics Requirements	43
2.6.2:	Mechanical Properties	44
2.6.3:	Microstructures in Steel	45
2.7	Microstructural Characterization of Materials	46
2.7.1	X-Ray Diffraction Method	47
2.7.2	Electron Microscopy	47
2.7.2.1	Transmission Electron Microscopes (TEM)	48
2.7.2.2	Scanning Electron Microscopes (SEM)	48
CHAPTER THREE: CONCEPTUAL FRAME WORK		50
3.1	Preamble	50
3.2.	Proposed Conceptual Framework Model to Tackle Building Failures Due to Substandard Materials	53

CHAPTER FOUR: RESEARCH METHODOLOGY	56
4.1 Preamble	56
4.2 Sampling	56
4.3 Laboratory Experiments	57
4.4 Instrumentation	57
4.5 Method of Data Collection and Analysis.	58
CHAPTER FIVE: DATA ANALYSIS AND DISCUSSION OF RESULTS	63
5.1 Preamble	63
5.2 Cement Test Result and Analysis	63
5.2.1 Paste of Standard Consistence and Setting Times	64
5.2.2 Mechanical Properties of the Cement Sampled Brands.	64
5.2.3 Results on the Chemical Analysis of the Various Brands of Cement	65
5.2.4 Microstructural characterization of cement paste.	68
5.3 Aggregates Results and Analysis.	75
5.3.1 Coarse Aggregates	77
5.3.1.1 Gradation, Sieve Analysis	77
5.3.1.2 Angularity of the Coarse Aggregates.	79
5.3.1.3 Aggregate Crushing Value (ACV)	79

5.3.1.4	Aggregate Impact Value (AIV)	80
5.3.1.5	Los Angeles Abrasion Value (LAAV)	80
5.3.1.6	Petrographic Classification of the Coarse Aggregates	81
5.3.2	Fine Aggregates	83
5.3.2.1	Gradation, Sieve Analysis	83
5.3.2.2:	Fineness Modulus of the Fine Aggregates	85
5.3.2.3:	Properties of the Fine Aggregates	85
5.3.2.4:	Chemical Contents and Oxide Compositions of the Fine Aggregates Samples	87
5.4:	Reinforcing Steel Results and Discussions	91
5.4.1:	Geometrical and Physical Properties of the Reinforcing Steel Bars	92
5.4.2:	Mechanical Properties of the Reinforcing Steel Bars	103
5.4.2.1:	Normal Mechanical Properties of the Reinforcing Steel Bars	103
5.4.2.2:	Effects of Reduced Bar Diameter on Mechanical Properties of the Reinforcing Steel Bars	109
5.4.3:	Chemical Compositions of the Reinforcing Steel Bars	114
5.4.4:	Microstructural Characteristics of the Steel Rebar Brands	117
5.5:	Performance Evaluation of the Studied Primary Reinforced Concrete Materials in Concrete	125

5.5.1:	Concrete Cube Strength Evaluation of the Cement, Fine and Coarse Aggregates	125
5.5.2:	Bond Characteristics of the Steel Brands with Normal Strength Concrete	133
5.6:	Contributions to Knowledge	136
CHAPTER SIX: SUMMARY CONCLUSION AND RECOMMENDATION		138
6.1:	Summary and Conclusions	138
6.1.1:	Cement	138
6.1.2:	Aggregates	139
6.1.3:	Steel Reinforcements	142
6.1.4:	Material Performance in Reinforced Concrete	146
6.2:	Recommendation	148
6.2.1:	Cement.	148
6.2.2:	Aggregates	149
6.2.3:	Steel Reinforcement	149
6.2.4:	Material Performance in Reinforced Concrete	150
References		152

List of Tables

Table 2.1: Main Compounds of Portland Cement	14
Table 2.2: Typical Functions of Modern Portland Cement Mineralogical Composites.	15
Table 2.3: Mechanical and Physical Requirements given as Characteristic Values.	16
Table 2.4: Chemical Requirements Given as Characteristic Values	17
Table 2.5: Limit Values for Single Compressive Strength Results	18
Table 2.6: Categories for Maximum Values of Flakiness Index (FI)	32
Table 2.7: Categories for Maximum Values of Shape Index (SI)	33
Table 2.8: General Grading Requirements	35
Table 2.9: Categories for Maximum Values of Fines Content	36
Table 2.10 Categories for Maximum Values of Los Angeles Coefficients	38
Table 2.11 Categories for Maximum Values of Resistance to Impact	38
Table 2.12: Categories for Maximum Values of Resistance to Wear	39
Table 2.13: Categories for Maximum Values of Resistance to Surface Abrasion	39
Table 2.14: Influence of Different Chemical Ingredients in Steel on Properties of Rebars	42
Table 2.15: Percentage Chemical Composition of Ladle Analysis.	43
Table 2.16: Tensile Properties	44

Table 2.17: Cross Sectional Area and Mass Per Length	44
Table 5.1: Paste of Standard Consistence and Setting Times of Cement.	64
Table 5.2: Compressive Strength of Cement Mortar Cubes at Different Curing Ages	65
Table 5.3: Results of Oxide and Cement Compositions from X-Ray Fraction Analysis and Basic Ratios	67
Table 5.4: Sieve Analysis of Coarse Aggregates and Shape Parameter Coefficients	77
Table 5.5: Physical and mechanical properties of the Coarse Aggregate Study SampleTable	78
Table 5.6: Geo-Chemical Analysis of the Coarse Aggregate Samples	82
Table 5.7: Sieve Analysis of Fine Aggregates and Shape Parameter Coefficients	83
Table 5.8: Properties of the Fine Aggregate Samples	85
Table 5.9: Chloride and Sulphate Contents of the Fine Aggregate Samples	87
Table 5.10: Oxide Compositions of the Fine Aggregate Samples	90
Table 5.11: Geometric and Physical Characteristics of the Reinforcing Steel	92
Table 5.12: Mechanical Properties of the Steel Rebars.	104
Table 5.13: Chemical Composition of the Steel Rebars.	116
Table 5.14:28-day Concrete Cube Strengths from Study Materials.	127
Table 5.15: Summary of Actual Mean Strengths of the Compositional Material in Concrete	128

Table 5.16: Significance Level of the Dependent Variables, Cement Fine and Coarse Aggregates.	128
Table 5.17: Bond Strength of the Steel Brands in 17.5 MPa Concrete Cylinder	133

List of Figures

Figure 1.1: Details of Number and Percentage of Collapsed Buildings According to Local Governments in Lagos State within 1978-2007	10
Figure 2.1: Iron-Carbon Phase Diagram Pollack	46
Figure 3.1: Fundamental Approach of Material Research.	51
Figure 3.2: Fundamental Approach of Material Research Developed by USNRC.	51
Figure 3.3: Measurement as an Essential Part of Materials Science and Engineering.	52
Figure 3.4: Conceptual Frame Work Model to Tackling Building Failures Due to Substandard Materials	55
Figure 5.1: Grain Size Distribution for the Coarse Aggregates.	77
Figure 5.2: Grain Size Distribution for the Fine Aggregates.	84
Figure 5.3: Percentage Compliance to the Standard Mass/Length of the Rebars	93
Figure 5.4: Percentage Compliance to the Standard Bar Diameters	94
Figure 5.5: Rib Spacing of the Rebars and compliance Level	97
Figure 5.6: Rib Height of the Rebars and compliance Level	98
Figure 5.7: Rib Inclination Angles of the Rebars and Standards Levels	100
Figure 5.8: Rib Face Angles of the Rebars and Standards Levels.	101
Figure 5.9: Relative Rib Area of the Rebars and Standards Levels	102

Figure 5.10: Mean Yield Tensile Strength (f_{ym}) of the Steel Brands.	106
Figure 5.11: Characteristics Yield Tensile Strength (f_k) of the Steel Brands.	106
Figure 5.12: Characteristics Ultimate/Yield Strength Ratio of the Steel Brands.	107
Figure 5.13: Percentage Elongation of the Steel Brands, (a) Characteristic Value and (b) Mean Value	108
Figure 5.14: Effect of Reduced Bar Diameter on the Yield Strength	110
Figure 5.15: Effect of Reduced Bar Diameter on the Characteristic Strength	111
Figure 5.16: Effect of Reduced Bar Diameter on the Mean Ultimate Strength	112
Figure 5.17: Effects of Reduced Bar Diameter on the Characteristic Ultimate Strength.	113
Figure 5.18: Percentage Strength Decrease Due to the Reduced Bar Diameter	114
Figure 5.19: Estimated Marginal Means of the Compressive Strengths of Cement Brands in MPa.	130
Figure 5.20: Estimated Marginal Means of the Compressive Strengths of Sand from Different Sources in MPa.	131
Figure 5.21: Estimated Marginal Means of the Compressive Strengths of Gravel in MPa.	132
Figure 5.22: Bond Strength of the Steel Brands in 17.5 MPa Concrete Cylinder	135
Figure 5.23: Bond Strength Relationship with the Relative Rib Area.	136

List of Plates

Plate 5.1: Microstructure of Sample from Cement Brand C1	69
Plate 5.2: Microstructure of Sample from Cement Brand C2	70
Plate 5.3: Microstructure of Sample from Cement Brand C3.	72
Plate 5.4: Microstructure of Sample from Cement Brand C4.	74
Plate 5.5: Microstructure of Sample from Cement Brand C5	75
Plate 5.6: Samples from the Fine Aggregates in this Study.	76
Plate 5.7: Microstructure of Steel from Brand ST-1 to ST-9	121

Abstract

This research assessed the structural characteristics and quality of reinforced concrete primary materials which are cements, aggregates (fine and coarse) and reinforcing steel used in concrete works in Lagos State with a view to determining the extent to which they conform with the requirements of relevant standards. This is achieved by using relevant laboratory procedures to determine their physical, mechanical, chemical and microstructural properties and compare them with the relevant standards. Concrete cube crushing and pullout bond strength tests were performed in standard manner to measure the performance of the studied materials in reinforced concrete. The results of the various tests were analysed using relevant statistical tools such as Analysis of variance, mean standard deviation and relevant characteristic formulae as recommended in the appropriate standards. The highest 28-day cement mortar strength developed by the tested cement brands was 45.06 MPa (Brand C3). Two of the tested cement brands had 28-day compressive strengths below 28 MPa and hence did not meet the strength requirements, 32.5 MPa or 42.5 MPa, as specified in standards and they were the brands whose strength details (strength class and type) were not displayed on the bags unlike the other brands that complied. The cement microstructures complements the findings in the chemical and mechanical analyses. The fine aggregates met most of the standard requirements but the river-dredged fine aggregates performed better than its burrow-pit counterparts with both containing higher chloride content of about 0.3% as against the specified maximum of 0.2% with the river-dredged sand recording higher values (0.304% average) than the burrow-pit sand (0.152% average). All the coarse aggregates possesses satisfactory mechanical properties with samples G3 and G4 slightly more satisfactory. The physical and chemical properties of the steel brands were marginally satisfactory though None of the tested steel samples measured up to the actual diameter. The reduced bar

diameter reduced the strength further by as high as 23%. The performance of these primary materials in normal strength concrete was marginally satisfactory as they produced concrete of around 20 MPa but concretes made with cements brands with unbranded strength properties performed a little below standard (0.205 MPa mean deviation lower from the standard value) and others produced 2.893 MPa, mean deviation higher from the standard value; higher 28-day concrete compressive strengths were obtained with the river-dredged fine aggregate when compared with values recorded using the burrow-pit sand as fine aggregates in the tested concrete samples. The difference in the coarse aggregate performance was also marginal with the coarsest performing least in normal concrete. It was observed that interaction of fine aggregates and coarse aggregates had significant effects ($\alpha < 0.05$) on the compressive strengths of the resulting concrete. The 12mm diameter steel rebars possess better bonding properties than its 16mm counterpart and steels with higher relative rib area possess better bond strength with concrete. The best concrete performance was obtained with a combination of tested cement brand C3, fine aggregate sample S3 and coarse aggregate sample G3, with the recorded mean strength of 26.51 MPa, 32.5% above targeted mean value of 20 MPa. The study further revealed that the concrete's primary materials available in Lagos State are adequate to produce a good normal concrete but the steel reinforcements possess deficient mechanical properties that could compromise its role in reinforced concrete structures. It is recommended that only branded cements with defined type and strength label be utilized in concrete production, fine aggregates be sieved and washed before application in concrete for optimum performance and Nigerian Standard Organizations should further monitor the steel industry for greater compliance with standards.