



Cairo University

PROPERTIES OF CEMENTITIOUS COMPOSITES INCORPORATING DIFFERENT NANO MATERIALS

By

Mohamed Samir Ali Khalfalla

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY

in
STRUCTURAL ENGINEERING

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2016**

PROPERTIES OF CEMENTITIOUS COMPOSITES INCORPORATING DIFFERENT NANO MATERIALS

By

Mohamed Samir Ali Khalfalla

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY

in

STRUCTURAL ENGINEERING

Under the Supervision of

Prof. Dr. Usama A. Hodhod

Prof. Dr. Hamed M. HadHoud

.....

.....

Professor of Strength Materials
Structural Engineering Department
Faculty of Engineering, Cairo University

Professor of Reinforced Concrete Design
Structural Engineering Department
Faculty of Engineering, Cairo University

Prof. Dr. Ihab A. Adam

Prof. Dr. Mohamed A. Ahmed

.....

.....

Professor of Properties and Testing Materials
Construction Research Institute
National Water Research Center

Professor of Experimental Physics
Physics Department
Faculty of Science, Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2016

PROPERTIES OF CEMENTITIOUS COMPOSITES INCORPORATING DIFFERENT NANO MATERIALS

By

Mohamed Samir Ali Khalfalla

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY

in

STRUCTURAL ENGINEERING

Approved by the
Examining Committee

Prof. Dr. Usama A. Hodhod, Thesis Main Advisor

Prof. Dr. Hamed M. HadHoud, Member

Prof. Dr. Ihab A. Adam, Member

Prof. Dr. Ahmed M. Ragab, Internal Examiner

Prof. Dr. Mounir M. Kamal, External Examiner
Professor Emeritus at Faculty of Engineering - Minufiya University

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2016**

Engineer's Name: Mohamed Samir Ali Khalafalla
Date of Birth: 13/04/1984
Nationality: Egyptian
E-mail: Mhamedsmr@gmail.com
Phone: +201002471456
Address: Meleeg, Shpin El-Kom, Minufiya
Registration Date: 01/10/2012
Awarding Date: / /2016
Degree: Doctor of Philosophy
Department: Structural Engineering



Supervisors:

Prof. Usama A. Hodhod
Prof. Hamed M. Hadhoud
Prof. Ihab A Adam (Construction Research Institute-
NWRC)
Prof. Mohamed A. Ahmed (Passed away)

Examiners:

Prof. Mounir M. Kamal (External examiner)
Faculty of Engineering- Minufiya University
Prof. Ahmed M. Ragab (Internal examiner)
Prof. Usama A. Hodhod (Thesis main advisor)
Prof. Hamed M. Hadhoud (Member)
Prof. Ihab A. Adam (Member)
Construction Research Institute-NWRC

Title of Thesis:

**PROPERTIES OF CEMENTITIOUS COMPOSITES INCORPORATING
DIFFERENT NANO MATERIALS**

Key Words:

Cementitious Composite; Nano Silica; Nano Titanium; Carbon Nano Tube; Abaqus

Summary:

The Investigation of cementations composites incorporating nano materials such as, Nano Silica (NS), Nano Titanium (NT), and Carbon Nano Tube (CNT) on the different cement paste/mortar/concrete characteristics is the main purpose of this thesis. The cement paste incorporating NS, takes an important role in generating C-S-H. A 6% replacement achieves the best proportion where increasing both compression and flexure strengths by 42% and 50% respectively, while hydration process increases up to 16% as well. A 1% CNT cement replacement in mortar achieves mechanical characteristics improvement by about 27% in compression and 6% in flexure, while porosity is improved by 30%. A 0.04% CNT cement replacement in concrete achieves 42% improvement in compression under normal condition, and 36% in indirect tensile strength under normal and fire conditions respectively. Furthermore, numerical analysis using (ABAQUS) is conducted to study the strengthening effect of cracked concrete beam using epoxy resin incorporating CNT.

ACKNOWLEDGMENT

The author wishes to express his sincere appreciation to his major advisor, **Prof. Dr. Usama A. Hodhod** Professor of Strength and Testing Materials, Faculty of Engineering, Cairo University for his academic support through the entire study period and his advices to finish this work as it should be.

I am grateful to **Prof. Dr. Hamed M. Hadhoud** Professor of Reinforced Concrete, Faculty of Engineering-Cairo University for his valuable advice and encouragement throughout research period.

Special thanks and greatest gratitude to **Prof. Dr. Ihab A. Adam** Professor of Strength and Testing Materials, Construction Research Institute, National Water Research Center for his technical support, providing valuable literature material, providing the required needs to finish this work as it should be.

Special thanks also go to the administration of the **Construction Research Institute**, National Water Research Center, for the encouragement and the financial support they bestowed me.

DEDICATION

To my parent, my wife, my son, and my daughter

TABLE OF CONTENTS

ACKNOWLEDGMENT	IV
DEDICATION	VI
TABLE OF CONTENTS	VII
LIST OF TABLES.....	XIII
LIST OF FIGURES.....	XIV
ABSTRACT	XIX
INTRODUCTION	1
1.1 BACKGROUND	1
1.2 AIM, SCOPE, AND METHOD OF THE RESEARCH.....	1
1.2.1 Aim.....	1
1.2.2 Scope	2
1.2.3 Method of the Research	2
1.3 CONTENTS	3
LITERATURE REVIEW	4
2.1 INTRODUCTION	4
2.2 DEFINITIONS	4
2.3 CEMENTITIOUS COMPOSITES	5
2.3.1 Introduction	5
2.3.2 Classification of Cementitious Composites	5
A. Cement Paste	5
B. Mortar . . .	5
C. Concrete.....	6
2.3.3 Cementitious Composites Requirements	6
A. Enhancement of Portland Cement Hydration.....	6
B. Enhancement of Durability through Reducing Porosity	7
C. Enhancement of Mechanical Properties of Concrete	8
2.4 NANO-MATERIALS	8
2.5 HISTORICAL DEVELOPMENT OF NANO-MATERIALS	9
2.6 ADVANTAGE OF NANO-MATERIALS	11
2.7 APPLICATION OF NANO-MATERIALS IN DIFFERENT FIELDS.....	11
2.7.1 Nanomaterials for Concrete	11
2.7.2 Nanomaterials for Steel.....	11
2.7.3 Nanomaterials for Wood	12
2.7.4 Nanomaterials for Glass	12
2.7.5 Nanomaterials for Coatings and Paintings	12
2.7.6 Nanomaterials for Fire Protection.....	12
2.7.7 Nanomaterials for Structural Monitoring.....	12
2.8 TYPES OF NANO-MATERIALS	12
2.8.1 Carbon Nano-Tubes (CNT).....	12
2.8.2 Nano Silica (NS)	15
2.8.3 Nano Titanium (NT)	15
2.9 SYNTHESIS OF DIFFERENT NANO-MATERIALS	15
2.9.1 Synthesis of Carbon Nano Tubes	16
A. Arc Discharge Technique	16
B. Chemical of Vapor Deposition Method (CVD)	17
C. Laser Technique	18
2.9.2 Synthesis of Nano Silica	18

A. Technique of Sol Gel.....	19
B. Technique of Pyrogenic.....	19
C. Technique of Olivine.....	19
2.9.3 Synthesis of Nano-Titanium	20
A. Sol Gel Method	20
B. Hydrothermal Technique.....	21
C. Liquid-Phase Method	21
2.10 FACTORS AFFECTING UTILIZATION OF NANO MATERIALS IN BUILDING	22
2.10.1 Price.....	22
2.10.2 Technical Performance.....	22
2.10.3 Sector Awareness	22
2.11 PHILOSOPHY OF NANO-MATERIAL USED WITHIN CEMENTITIOUS COMPOSITES	23
2.12 MECHANISM OF NANO-MATERIALS WITH CEMENTITIOUS COMPOSITES	24
2.13 METHODS OF TESTING CEMENTITIOUS COMPOSITE INCORPORATING NANO-MATERIALS	25
2.13.1 Scanning Electronic Microscopy (SEM)	25
2.13.2 Transmission Electron Microscopy (TEM)	26
2.13.3 Atomic Force Microscopy (AFM)	26
2.13.4 Differential Scanning Calorimetry (DSC)	27
2.13.5 Mercury Intrusion Porosimetry (MIP)	28
2.13.6 X-Ray Diffraction (XRD)	29
2.14 FACTORS AFFECTING CEMENTITIOUS COMPOSITES INCORPORATING NANO-MATERIALS	30
2.15 APPLICATIONS OF DIFFERENT NANO-PARTICLES IN BUILDING AND CONSTRUCTION	31
2.15.1 Cementitious Composites Modified by CNT.....	31
A. Compressive Strength.....	31
B. Indirect Tensile Strength	31
C. Hardness Measurements.....	32
2.15.2 Cementitious Composites Modified by NS.....	32
A. Hydration Process.....	32
B. Workability and Setting Time	33
C. Compressive and Bond Strength	34
EXPERIMENTAL WORK	36
3.1 INTRODUCTION	36
3.2 MATERIALS	40
3.2.1 Water	40
3.2.2 Cement	40
3.2.3 Nano Materials	40
A. Nano Silica (NS)	40
B. Nano Titanium (NT).....	40
C. Carbon Nano Tubes (CNT)	41
3.2.4 Fine Aggregates	42
3.2.5 Coarse Aggregates	43
3.2.6 Superplasticizer	43
3.3 MIX PROPORTIONING	44
3.4 TEST SPECIMINS	44

3.5 MIXING PROCEDURE.....	45
3.5.1 Cement paste	46
A. Mixing... ..	46
B. Casting.....	46
C. Curing... ..	47
3.5.2 Mortar.....	48
A. Mixing... ..	48
B. Casting... ..	48
C. Curing... ..	48
3.5.3 Concrete	48
A. Mixing... ..	48
B. Casting... ..	49
C. Curing... ..	50
3.6 MEASURING PROPERTIES OF FRESH CEMENTITIOUS	
COMPOSITES	51
3.6.1 Flow Table Test.....	51
3.6.2 Slump Tests	52
3.7 MEASURING MECHANICAL PROPERTIES OF HARDENED	
CEMENTITIOUS COMPOSITES	53
3.7.1 Compressive Strength Tests	53
3.7.2 Flexural Strength Tests	53
3.7.3 Indirect Tensile Strength Tests.....	54
3.8 TEST PROCEDURE AND MEASUREMENTS OF PHYSICAL	
PROPERTIES OF HARDENED SPECIMENS	54
3.8.1 X- Ray Diffraction Tests	54
3.8.2 Differential Scanning Calorimetry Tests	55
A. DSC Description.....	55
B. Specimen Preparation.....	55
3.8.3 Porosity And Pore Size Distribution	56
A. Mercury Porosimetry Description	56
B. Specimen Preparation.....	56
3.8.4 Water Absorption Tests.....	57
3.8.5 Scanning Electron Microscopy Test	58
A. SEM Description	58
B. Specimen Preparation.....	58
INVESTIGATION OF CEMENT PASTE INCORPORATING NANO SILICA ..	59
4.1 INTRODUCTION	59
4.2 THE FRESH PROPERTIES OF CEMENT PASTE.....	59
4.3 THE MECHANICAL PROPERTIES OF CEMENT PASTE	60
4.3.1 Compressive Strength	60
4.3.2 Flexural Strength.....	63
4.3.3 Static Modulus of Elasticity and Ductility	66
4.4 PHYSICAL PROPERTIES OF CEMENT PASTE	67
4.4.1 X- Ray Diffraction Test Result	67
a. Cement.....	67
b. Nano Silica	68
4.4.2 Water Absorption of Cement Paste.....	68
4.4.3 Differential Scanning Calorimetric (DSC) Test Result Analysis.	69
a. Cement hydrate after 3 days	69
b. Cement hydrate after 7 day	70

c. Cement hydrate after 28 day	71
4.4.4 Scanning Electron Microscopy Test Analysis.	71
a. Cement hydrate after 3 days	72
b. Cement hydrate after 7 days	74
c. Cement hydrate after 28 days	76
INVESTIGATION OF CEMENT MORTAR INCORPORATING NANO	
TITANIUM	81
5.1 INTRODUCTION	81
5.2 THE FRESH PROPERTIES OF CEMENT MORTAR.....	81
5.3 THE MECHANICAL PROPERTIES OF CEMENT MORTAR.....	82
5.3.1 The Compressive Strength	82
a. At 7 Day of Curing.....	82
b. At 28 Day of Curing.....	83
5.3.2 The Flexure Strength.....	84
a. At 7 Day of Curing.....	85
b. At 28 Day of Curing.....	86
5.3.3 Static Modulus of Elasticity and Ductility	87
5.4 THE PHYSICAL PROPERTIES OF CEMENT MORTAR.....	87
5.4.1 X- Ray Diffraction Test Result	88
a. Cement.....	88
b. Nano titanium	88
5.4.2 Water Absorption of Cement mortar.....	88
5.4.3 Mercury Intrusion Porosimetry (MIP) Test Result Analysis.	89
a. Measurement Theory.....	90
b. Effect of NT percentage on Pore Structure at 7 day of curing.....	90
c. Effect of NT percentage on Pore Structure at 28 day of curing.....	92
5.4.4 Scanning Electron Microscopy Test Analysis.	95
a. SEM of Powder	95
b. After 7 day of curing	95
i. 0.0wt% percentage.....	95
ii. 0.5wt% percentage.....	96
iii. 1.0wt% percentage.....	96
iv. 2.0wt% percentage.....	97
c. Cement hydrate after 28 day	97
i. 0.0wt% percentage.....	97
ii. 0.50 wt% percentage.....	99
iii. 1.0 wt% percentage.....	99
iv. 2.0 wt% percentage.....	100
INVESTIGATION OF CONCRETE INCORPORATING CARBON NANO	
TUBE	101
6.1 INTRODUCTION	101
6.2 FRESH PROPERTIES OF CONCRETE	101
6.3 THE MECHANICAL PROPERTIES OF CONCRETE	102
A. Normal Case (Without Fire)	102
6.3.1 The Compressive Strength	102
a. At 7 Day of Curing.....	102
b. At 28 Day of Curing.....	103
6.3.2 Indirect Tensile Strength	105
a. At 7 Day of Curing.....	105
b. At 28 Day of Curing.....	106

6.3.3 Static Modulus of Elasticity and Ductility	107
B. Effect of Exposure to High Temperature	107
6.3.4 The Compressive Strength	107
a. At 7 Day of Curing.....	108
b. At 28 Day of Curing.....	109
6.3.5 The Indirect Tensile Strength.....	110
a. At 7 Day of Curing.....	110
b. At 28 Day of Curing.....	111
6.3.6 Static Modulus of Elasticity and Ductility	112
6.4 THE PHYSICAL PROPERTIES OF CONCRETE	113
6.4.1 X- Ray Diffraction Test Result	113
a. Cement.....	113
b. Carbon nano tube.....	113
6.4.2 Water Absorption of Concrete	114
6.4.3 Scanning Electron Microscopy Test Analysis.	114
a. SEM of Powder	115
b. After 7 day of curing	115
i. Plain concrete.....	115
ii. 0.02wt% percentage.....	116
iii. 0.03wt% percentage.....	116
iv. 0.04wt% percentage.....	117
v. 0.05wt% percentage.....	117
c. Cement hydrate after 28 day	118
i. Plain Concrete.....	118
ii. 0.02 wt% percentage.....	119
iii. 0.03 wt% percentage.....	119
iv. 0.04 wt% percentage.....	120
v. 0.05 wt% percentage.....	121
7.1 SCOPE OF CHAPTER	122
7.2 ABAQUS FINITE ELEMENT MODEL	122
7.3 ELEMENT TYPES	122
7.3.1 Reinforced Concrete.....	122
7.3.2 Reinforcing Steel.....	122
7.3.3 Steel plate	123
7.3.4 ECNT Laminates:.....	123
7.4 MATERIAL PROPERTIES	123
7.4.1 Concrete:	123
7.4.2 Steel Reinforcement and Steel Plates:.....	124
7.4.3 Epoxy with carbon nano tube (ECNT) properties:	125
7.4.4 Cohesive element	125
7.5 DETAILS OF BEAMS.....	126
7.6 LOADING AND BOUNDARY CONDITIONS	128
7.7 PARAMETER STUDY	129
7.8 VERIFICATION OF MODELS	129
7.9 RESULT AND DISCUSSIONS.....	129
7.9.1 Contour result.....	130
b. Strengthening beam	132
7.9.5 Group A (load-deflection).....	136
7.9.6 Group B (load-deflection)	138
7.9.7 Group C (load-deflection)	140

CONCLUSION AND FURTHER STUDY.....	143
8.1 CONCLUSIONS	143
8.2 FURTHER STUDY	144
REFERENCES	145

LIST OF TABLES

Table 2.1: Area and Scales	23
Table 3.1: Chemical Composition of Cement	40
Table 3.2: Physical Properties of Silica Nanoparticles.....	40
Table 3.3: Physical Properties of Titanium nanoparticles.....	41
Table 3.4: Physical Properties of MWCNT.....	41
Table 3.5: Physical Properties of Fine Aggregates.....	42
Table 3.6: Physical Properties of Coarse Aggregates.....	43
Table 3.7: Physical and Chemical Properties of the Superplasticizer	43
Table 3.8: Cement Paste Composition	47
Table 3.9: Mortar Composition	48
Table 3.10: Concrete Composition.....	50
Table 4.1: Elastic Modulus and Ductility of Best Percent of Cement Paste content NS.	66
Table 4.3: Proportions of the elements in the specimens	77
Table 4.4: Proportions of the elements in the specimens	78
Table 4.5: Proportions of the elements in the specimens	79
Table 5.1: Elastic Modulus and Ductility of the Best Percent of Mortar content NT...87	
Table 5.2: Summary of porosity data of mortar After 7 day of curing.....	90
Table 5.3: Summary of porosity data of mortar After 28 day of curing.....	93
Table 5.4: Proportions of the elements in the specimens	98
Table 5.5: Proportions of the elements in the specimens	100
Table 6.1: Elastic Modulus and Ductility of Best Percent of Concrete content CNT. 107	
Table 6.2: Elastic Modulus and Ductility of Best Percent of Concrete content CNT. 112	
Table 6.3: Proportions of the elements in the specimens	119
Table 6.4: Proportions of the elements in the specimens	121
Table 7.1: specified unit used.....	122
Table 7.1: Summary of material properties for concrete.....	124
Table 7.2: Summary of concrete properties at Damage	124
Table 7.3: Summary of material properties for steel	125
Table 7.4: Summary of ECNT properties.....	125
Table 7.5: Summary of epoxy sheet properties at Damage.....	126

LIST OF FIGURES

Figure 2.1: Small and intermediate size cement grains	7
Figure 2.2: Surface Topography Images and Profile of the Gravel Specimen	8
Figure 2.3: Various Features Contributing to the Diversity of Engineered Nanoparticles	9
Figure 2.4: Microstructure of Haliotis, Abalone Shell	10
Figure 2.5: CNT: Left schematics Diagram & Right Microstructure	10
Figure 2.6: Aerogel.....	11
Figure 2.7: Types of Carbon Nano Tubes	13
Figure 2.8: Shape of Fullerene	13
Figure 2.9: Cylindrical Shape Carbon Nano Tubes.....	14
Figure 2.10: SWCNT and MWCNT	14
Figure 2.11: Description of ““Bottom-up” and ‘Top-down’ Techniques	16
Figure 2.12: Method of Electric-Arc Discharge	16
Figure 2.13: (a) CNT Moving and Creation in Cover (b) Arc-Discharge Procedure.....	17
Figure 2.14: Schematic Diagram of CVD Apparatus.....	18
Figure 2.15: Laser Ablation Technique.....	18
Figure 2.16: Sol Gel Technique.....	19
Figure 2.17: Olivine Technique.....	20
Figure 2.18: Nano-TiO ₂ Powder Production by Sol-Gel Method	21
Figure 2.19: "Liquid-Phase Method", Microwave (MW) Plasma System	22
Figure 2.20: Presence of Nano-Products at Workplace, 2009-Survey	23
Figure 2.21: SEM Micrographs of CNT	24
Figure 2.22: Design Approach for Nano-Binder	25
Figure 2.23: Nano-SiO ₂ Particles under TEM.....	25
Figure 2.24: Scanning Electron Microscope (SEM)	26
Figure 2.25: Transmission Electronic Microscopy (TEM)	26
Figure 2.26: Atomic Force Microscope (AFM)	27
Figure 2.27: Schematic Diagram of AFM Principles	27
Figure 2.28: Differential Scanning Calorimetry "DSC" "Schimadzu-50"	28
Figure 2.29: Hand Press for DSC Specimens.....	28
Figure 2.30: Mercury Intrusion Porosimetry Apparatus	29
Figure 2.31: Schematic of Mercury Intrusion Porosimetry Principles.....	29
Figure 2.32: X-Ray Diffraction Apparatus.....	30
Figure 2.33: Particle Size of Different Concrete Materials.....	31
Figure 2.34: Variation of Compressive Strength of CNTCC with CNT Ratio	31
Figure 2.35: Variation of Indirect Tensile Strength of CNTCC with CNT Ratio.....	32
Figure 2.36: Variation of Hardness of CNTCC with different CNT ratios.....	32
Figure 2.37: Effects of NS on Cement Hydration	33
Figure 2.38: The Effect of NS on the Workability of Concrete	34
Figure 2.39: Variation of Setting Times of Mortar with NS	34
Figure 2.40: Interaction Between NS and Ca(OH) ₂ Determined by XRD.....	35
Figure 2.41: Compressive Strength of Pastes without Superplasticizers	35
Figure 3.1: Study Program for Cement Paste	37
Figure 3.2: Study Program for Mortar.....	38
Figure 3.3: Study Program for Concrete	39
Figure 3.4: SiO ₂ Nanoparticles.....	40
Figure 3.5: TiO ₂ Nanoparticles.....	41

Figure 3.6: CNT Nanoparticles	42
Figure 3.7: Grading Curve for Fine Aggregates.....	42
Figure 3.8: Grading Curve for Coarse Aggregates.....	43
Figure 3.9: Cement Paste Specimens Incorporating NS	44
Figure 3.10: Mortar Specimens Incorporating NT	45
Figure 3.11: Concrete Specimens Incorporating CNT	45
Figure 3.12: Mortar Mixer.....	46
Figure 3.13: Casting in Moulds	47
Figure 3.14: Control Unit in Treatment Chamber	47
Figure 3.15: Ultrasonic Equipment for CNT Dispersion	49
Figure 3.16: Casting in Wood Moulds with Internal Vibration	50
Figure 3.17: Water Curing Steel Tub	51
Figure 3.18: Flow Table Test Apparatus.....	52
Figure 3.19: Slump Test Apparatus.....	52
Figure 3.20: Universal Testing Machine (UTM)	53
Figure 3.21: Flexural Strength Test Apparatus	53
Figure 3.22: Indirect Tensile Strength Test Apparatus	54
Figure 3.23: X-Ray Diffraction Apparatus.....	55
Figure 3.24: Differential Scanning Calorimeter	55
Figure 3.25: Pore-Sizer 932.....	57
Figure 3.26: Weighting Process	57
Figure 3.27: Scanning Electron Microscope	58
Figure 4.1: The Relationship between NS Percentage in Paste and Table Diameter.....	59
Figure 4.2: Stress-Strain Curve of Individual Paste Specimen Incorporating NS at 3 Days	60
Figure 4.3: Average Compressive Strength of Paste Specimens at 3 Days.	61
Figure 4.4: Stress-Strain Curve of Individual Paste Specimen Incorporating NS at 7 Days.	61
Figure 4.5: Average Compressive Strength of Paste Specimens at 7 Days.	62
Figure 4.6: Stress-Strain Curve of Individual Specimen Incorporating NS at 28 Days...62	62
Figure 4.7: Average Compressive Strength of Paste Specimens at 28 Days.	63
Figure 4.8: Stress- Strain Curve of Individual Paste Specimen Incorporating NS Exposed to Flexural Stress at 3 Days	63
Figure 4.9: Average Flexural Strength of Paste specimens Incorporating NS at 3 Days.64	64
Figure 4.10: Stress-Strain Curve of Individual Paste Specimen Incorporating NS Exposed to Flexural Stress at 7 Days	64
Figure 4.11: Average Flexural Strength of Paste Specimens Incorporating NS at 7 Days	65
Figure 4.12: Stress-Strain Curve of Individual Paste Specimen Incorporating NS Exposed to Flexural Stress at 28 days	65
Figure 4.13: Average Flexural Strength of Paste Specimens Incorporating NS at 28 Days	66
Figure 4.14: XRD of cement Powder	67
Figure 4.15: XRD of Nano-Silica (ANS).....	68
Figure 4.16: Relationship between Nano Silica Percent and Water Absorption.....69	69
Figure 4.17: Temperature-Heat Flow Figure for Comparison between Cement Paste Incorporating Different Percentages of Nano Silica at 3 days.	69
Figure 4.18: Temperature-Heat Flow Figure for Comparison between Cement Paste Incorporating Different Percentages of Nano Silica at 7 days.	70