

**A STUDY OF SELF COMPACTING CEMENTITIOUS
SYSTEMS USING
WHEAT STRAW (TOORI) ASH AND CALCINED BENTONITE**

**A STUDY OF SELF COMPACTING CEMENTITIOUS SYSTEM
USING
TOORI ASH AND CALCINED BENTONITE**

By

Rao Arsalan Khushnood

(2009-NUST-MS Ph.D-Str-07)

A Thesis submitted in partial fulfillment of
the requirement for the award of degree of

Master of Science

in

Civil Engineering

National Institute of Transportation
School of Civil Engineering and Environment
National University of Sciences and Technology

Islamabad, Pakistan

(2011)

This is to certify that
thesis entitled

**A STUDY OF SELF COMPACTING CEMENTITIOUS SYSTEM
USING WHEAT STRAW ASH AND BENTONITE**

Submitted by
Rao Arsalan Khushnood

Has been accepted towards the partial fulfillment
of
the requirements
for
Master of Science in Civil Engineering

(Prof. Dr. Syed Ali Rizwan, PhD)
Head of Structural Engineering Department
NUST Institute of Civil Engineering
School of Civil Engineering and Environment

National University of Sciences and Technology
Islamabad, Pakistan

ACKNOWLEDGEMENTS

I bow my head praising Allah Almighty and offer salat-o-salam to His beloved Prophet Hazrat Muhammad (peace be upon him), for all the blessings He showered upon me by providing an opportunity to seek and learn the “Ilm-e-Naffay”.

I express my gratitude and sincere thanks to Prof. Dr.-Ing. Syed Ali Rizwan for graciously providing me his kind encouragement, untiring guidance and able supervision throughout the research work reported in the thesis. I extend my gratitude to Dr Mujahid (HOD Materials) at SCME for helping me to obtain scanning electron microscopic images and in carrying out tests on laser particle size analyzer. I am also thankful to staff of centralized research laboratory Peshawar for providing me XRD results of my samples.

I am also thankful to my supervisory committee members, Brigadier (Retired) Dr. Muhammad Khaliq-ur-Rashid Kayani, Dr. Nasir Amin and Engineer Shazim Ali Memon for their co-operation in timely completion of this work.

I must not forget the supporting role of laboratory staff at SCEE (NUST) & SCME (NUST) Islamabad who provided technical assistance and cooperation during the execution of the research work. My special thanks to laboratory staff at MCE (NUST) Risalpur who helped me out in burning a large quantity of wheat straw in a small size electric furnace.

I appreciate the support provided to me by my parents as this research work would not have been completed without their prayers and whole hearted encouragement.

ABSTRACT

Self Compacting Cementitious Systems (SCCS) is the modern technology of this decade. Secondary Raw Materials (SRM's) form the basic ingredients along with chemical admixtures in SCCS/HPC. Extensive successful research work has been carried out throughout the world on use of secondary raw materials in self compacting cementitious systems and now this practice is quite popular. However, in Pakistan, research is being carried out in phases on pozzolanic materials like Wheat Straw (Toori) Ash, Rice Husk Ash, Ground Granulated Blast Furnace Slag, Glass Powder, Metakaolin, and Bentonite. Accordingly, their usage in the self compacting cementitious systems will take place when the results on local SRM's would be known to practitioners. This study was made to evaluate the feasibility of using Bentonite (BN), a naturally occurring pozzolan and Wheat Straw (Toori) Ash, an artificial pozzolanic material, in single component self compacting paste system with ultimate aim to produce three components self compacting concrete with desired properties. The parameters studied include secondary raw material's particle characterization, flow behavior, strength development, resistance to water absorption and acid attack, x-ray diffraction (XRD) study and microstructural analysis by scanning electron microscopy (SEM) and Mercury Intrusion Porsimetry (MIP).

The results showed that particle characterization of secondary raw materials affects the water demand and super plasticizer demand of self compacting paste system. While the shape, size and surface texture of secondary raw materials along with their chemical and physical properties all have vital effects on the flow behavior, strength and durability. The rate of strength gain of self compacting cementitious system is also an important aspect besides the strength level at a specified age as it varies with the type of secondary raw material being used. Furthermore, the addition of secondary raw materials in replacement mode reduces the permeability of the hardened paste and thus enhances its resistance against sulfate attack. The results show that both secondary raw materials investigated, can be successfully used in self compacting cementitious systems as each contributes positively towards enhancement of certain properties of SCP and the use of SRM's blends can further optimize the response of self compacting concrete system.

TABLE OF CONTENTS

Acknowledgements	iv
Abstract	v
Table of Contents	vi
List of Notations	x
List of Tables	xii
List of Figures	xiv
Chapter 1 Introduction	
1.1 General	1
1.2 Self Compacting Cementitious Systems	2
1.3 Secondary Raw Materials	3
1.3.1 Pozzolans	3
1.3.1.1 Natural Pozzolan	4
1.3.1.2 Artificial Pozzolan	4
1.3.2 Mechanism of Pozzolanic Reaction	4
1.3.3 Bentonite	5
1.3.3.1 Deposits of Bentonite in KPK	5
1.3.4 Wheat Straw Ash	6
1.4 Research Objectives	6
Chapter 2 Literature Review	
2.1 General	8
2.2 Self Compacting Cementitious Systems	8
2.2.1 Brief Development History	8
2.2.2 Literature on SCC	9
2.3 Secondary Raw Materials	11
2.3.1 Bentonite	12
2.3.2 Wheat Straw Ash	14

Chapter 3 Preparation of Secondary Raw Materials

3.1	Bentonite Clay	16
3.2	Wheat Straw Ash	17
3.2.1	Incineration Regime Employed for production of Wheat Straw Ash	17

Chapter 4 Experimental Program

4.1	General	20
4.2	Materials	20
4.3	Mixing Regime and Mix Proportions of SCP Formulations	23
4.4	Water Demand, Super Plasticizer Demand and Setting Times	24
4.5	Flow of Self Compacting Paste Systems	24
4.6	Strength	25
4.7	Calorimetry	26
4.8	Scanning Electron Microscopy (SEM)	27
4.9	Energy Dispersive X-Ray analysis (EDAX)	27
4.10	X – Ray Diffraction (XRD)	28
4.11	Water Absorption Test	28
4.12	Resistance to Acid Attack	29
4.13	Mercury Intrusion Porosimetry	30
4.14	Shrinkage	30
4.15	Specimens Designation	31

Chapter 5 Results

5.1	Tests on Secondary raw materials	32
5.1.1	Particle Characterization by Scanning Electron Microscopy	32
5.1.2	X-Ray Diffraction	34
5.2	Tests on Self Compacting Paste system	36
5.2.1	Water Demand, Super Plasticizer Demand, Setting Times and Mix Proportions	36
5.2.2	Flow of Self Compacting Paste Systems	37
5.2.3	Strength of SCP formulations	37

5.2.4	Water Absorption Test	39
5.2.5	Resistance to Acid Attack	40
5.2.6	Calorimetry	41
5.2.7	Study of Microstructure by Scanning Electron Microscopy	42
5.2.8	Mercury Intrusion Porosimetry	45
5.2.9	Early Shrinkage	47
5.2.10	X-Ray Diffraction	48
Chapter 6 Discussion		
6.1	ASTM Requirements for Pozzolanic Secondary Raw Material	49
6.2	Particles Characterization, Water and Super Plasticizer Demand and Setting Times	51
6.3	Flow of Self Compacting Paste Systems	52
6.4	Strength of Self Compacting Paste Systems	53
6.5	Water Absorption	55
6.6	Resistance to Acid Attack	55
6.7	Microstructure of Self Compacting Paste Systems	56
6.8	Calorimetric study of Self Compacting Paste Systems	57
6.9	Dimensional Stability of Self Compacting Paste Systems	59
Chapter7 Conclusions and Recommendations		
7.1	Conclusions	60
7.2	Recommendation	61
	References	62
	Annexure A	67
	Annexure B	70
	Annexure C	71
	Annexure D	73
	Annexure E	77
	Annexure F	79
	Annexure G	82
	Annexure H	83

LIST OF NOTATIONS

AASHTO	American Association of State Highway and Transportation Officials
Afm	Aluminate Ferrite monosulfate or Alumina, Ferric oxide, mono-sulfate or $Al_2O_3 - Fe_2O_3 - mono$
Aft	Aluminate Ferrite Trisulfate or Alumina, Ferric oxide, tri-sulfate or $Al_2O_3 - Fe_2O_3 - tri$
ASTM	American Society for Testing and Materials
WSA	Wheat Straw Ash
BN	Bentonite
C_2S	Di – Calcium Silicate
C_3A	Tri – Calcium Aluminate
C_3S	Tri – Calcium Silicate
C_4AF	Tetra – Calcium Alumino Ferrite
CH	Calcium Hydroxide
CSH	Calcium Silicate Hydrate
EDAX	Energy Dispersive X – ray Analysis
FHWA	Federal Highway Administration
HPC	High Performance Concrete
ITZ	Interfacial Transition Zone
KPK	Khyber Pukhtoon Khwa
MIP	Mercury Intrusion Porosimetry
NVC	Normal Vibrated Concrete
OPC	Ordinary Portland Cement
PCE	Polycarboxylate ether
SCC	Self Compacting Concrete
SCCS	Self Compacting Cementitious Systems
SCM	Self Compacting Mortar
SCP	Self Compacting Paste
SP	Super Plasticizer
SRM	Secondary Raw Material
TA	Toori Ash

VMA	Viscosity Modifying Agent
w/c ratio	Water Cement Ratio
w/p ratio	Water Powder Ratio
XRD	X – Ray Diffraction

LIST OF TABLES

Table No	Title	Page No
Table 4.2.1	Chemical Composition of Fauji Cement	21
Table 4.2.2	Physical Properties of “As Obtained” and “Calcined” Bentonite	21
Table 4.2.3	Chemical Composition of “As Obtained” and “Calcined” Bentonite	22
Table 4.2.4	Physical Properties of Toori Ash	22
Table 4.2.5	Chemical Composition of Toori Ash under Various Incineration Regimes	23
Table 6.1	Comparison of Chemical and Physical Properties of “As Obtained” and “Calcined” Bentonite with selected ASTM C 618–1 Requirements to Classify a Powder as Pozzolan	49
Table 6.2	Comparison of Chemical and Physical Properties of Toori Ash Under Various Incineration Regimes with selected ASTM C 618–1 Requirements to Classify a Powder as Pozzolan	50
Table 1 of Annexure A	Bogue’s Limit Calculations	66
Table 2 of Annexure A	Mix Proportions of SCP Formulations	67
Table 3 of Annexure A	Water Demand, Super Plasticizer Demand and Setting Times of SCP Formulations	68
Table 1 of Annexure B	Flexure Strength of SCP Formulations	69
Table 2 of Annexure B	Compressive Strength of SCP Formulations	69
Table 1 of Annexure C	Percentage Absorption of SCP Formulations	70
Table 2 of Annexure C	Strength After Exposure to 5% HCl Solution of SCP Formulations for 28 Days	70

Table 3 of Annexure C	Percentage Strength Loss on Exposure to 5% HCl Solution of SCP Formulations	70
Table 4 of Annexure C	Strength After Exposure to 5% H ₂ SO ₄ Solution of SCP Formulations for 28 Days	70
Table 5 of Annexure C	Percentage Strength Loss on Exposure to 5% H ₂ SO ₄ Solution of SCP Formulations	71
Table 6 of Annexure C	Percentage Weight Loss on Exposure to 5% HCl Solution of SCP Formulations	71
Table 7 of Annexure C	Percentage Weight Loss on Exposure to 5% H ₂ SO ₄ Solution of SCP Formulations	71

LIST OF FIGURES

Fig No	Title	Page No
Fig 3.1	Deposits of Bentonite at Jehangira	16
Fig 3.2	Bentonite Collected in Raw Form	16
Fig 3.3	Bentonite Clay after Giving 4500 revolutions in Los Angeles machine	16
Fig 3.4	Bentonite passing sieve # 200 and Calcined at 150°C	16
Fig 3.5	(a) Initial Uncontrolled Burning of Toori Ash (b) Controlled Burning in Electric Furnace (c) Graph Showing Burning of Toori ash as per First Incineration Regime	18
Fig 3.6	Graph Showing Burning of Toori Ash as per Second Incineration Regime	19
Fig 4.1	Hobart Mixer	23
Fig 4.2 (a)	SCP is being Poured in Hagerman's Mini Slump Cone	25
Fig 4.2 (b)	V-Funnel Time for SC Mortars and SCP Systems	25
Fig 4.3 (a)	Casting of Prisms	26
Fig 4.3 (b)	Flexure Testing of SCP Specimens	26
Fig 4.3 (c)	Compressive Testing of SCP Specimens	26
Fig 4.5	SEM at Centralized Research Laboratory Peshawar	27
Fig 4.6	XRD Analysis at Centralized Research Laboratory Peshawar	27
Fig 4.7 (a)	Specimens Immersed in 5% H ₂ SO ₄ Solution	29
Fig 4.7 (b)	Specimens Immersed in 5% HCl Solution	29
Fig 4.8	German Modified Shrinkage Channel Apparatus	30
Fig 5.1	SEM Characterization of "As Obtained" Bentonite Particles	32
Fig 5.2	SEM Characterization of "Calcined" Bentonite Particles	32
Fig 5.3	SEM Characterization of Toori Ash Particles Produced by First Incineration Regime	33

Fig 5.4	SEM Characterization of Toori Ash Particles Produced by Second Incineration Regime	33
Fig 5.5	SEM characterization of Toori Ash Particles Produced by Third Incineration Regime	34
Fig 5.6	XRD Analysis of “As Obtained” and “Calcined” Bentonite	35
Fig 5.7	XRD Analysis of Toori Ash produced by Various Incineration Regimes	35
Fig 5.8 (a)	Water Demand of SCP Formulations	36
Fig 5.8 (b)	Super Plasticizer Demand of SCP Formulations	36
Fig 5.8 (c)	Initial & Final Setting Time of SCP Formulations	36
Fig 5.9	Variation of T ₂₅ time of SCP Formulation	37
Fig 5.10	Variation of V Funnel time of SCP Formulations	37
Fig 5.11	Flexural Strength of SCP Formulations with Various Secondary Raw Materials	38
Fig 5.12	Compressive Strength of SCP with Various Secondary Raw Materials	38
Fig 5.13	Strength Activity Index in Flexure of SCP with Various Secondary Raw Materials	39
Fig 5.14	Strength Activity Index in Compression of SCP with Various Secondary Raw Materials	39
Fig 5.15	Water absorption of SCP systems Using Various Secondary Raw Materials	39
Fig 5.16	Percentage Weight Loss of SCP Systems Using Various SRM’s on Exposure to 5% H ₂ SO ₄ Solution.	40
Fig 5.17	Percentage Weight Loss of SCP Systems Using Various SRM’s on Exposure to 5% HCl Solution.	40
Fig 5.18	Strength after Exposure to 5% H ₂ SO ₄ Solution for 28 Days	41
Fig 5.19	Strength after Exposure to 5% HCl Solution for 28 Days	41
Fig 5.20	Percentage Strength Loss of SCP Systems Using	41

	Various SRM's on Exposure to 5% H ₂ SO ₄ Solution.	
Fig 5.21	Percentage Strength Loss of SCP Systems Using Various SRM's on Exposure to 5% HCl Solution.	41
Fig 5.22	Heat Flow Representation by Calorimetry of Various SCP Systems	42
Fig 5.23 (a to f)	Scanning Electron Microscope Presentation of Products of Hydration along with EDAX	43-45
Fig 5.24	Various Properties of Hydrated Samples Measured by MIP (Niazi)	46
Fig 5.25	MIP Study of Various SCP Systems	47
Fig 5.26	Volume Stability of Various SCP Systems	47
Fig 1 of Annexure D	EDAX of Pure Self Compacting Paste Sample at an Age of 1 Day	72
Fig 2 of Annexure D	EDAX of Pure Self Compacting Paste Sample at an Age of 7 Days	72
Fig 3 of Annexure D	EDAX of Self Compacting Paste Sample Containing 10% Toori Ash in Replacement Mode at an Age of 1 Day.	73
Fig 4 of Annexure D	EDAX of Self Compacting Paste Sample Containing 10% Toori Ash in Replacement Mode at the Age of 7 Days.	73
Fig 5 of Annexure D	EDAX of Self Compacting Paste Sample Containing 10% "Calcined" Bentonite in Replacement Mode at an Age of 1 Day	74
Fig 6 of Annexure D	EDAX of Self Compacting Paste Sample Containing 10% "Calcined" Bentonite in Replacement Mode at the Age of 7 Days	74
Fig 7 of Annexure D	EDAX of Self Compacting Paste Sample Containing 10% "As Obtained" Bentonite in Replacement Mode at an Age of 1 Day	75
Fig 8 of Annexure D	EDAX of Self Compacting Paste Sample Containing 10% "As Obtained" Bentonite in Replacement Mode at	75

	the Age of 7 Days	
Fig 1 of Annexure E	Particle Size Analysis of Faugi Cement Particles	76
Fig 2 of Annexure E	Particle Size Analysis of Toori Ash Particles	76
Fig 3 of Annexure E	Particle Size Analysis of “Calcined” Bentonite Particles	77
Fig 1 of Annexure F	XRF Analysis of Faugi Cement Particles	78
Fig 2 of Annexure F	XRF Analysis of Toori Ash Produced as per First Incineration Regime	78
Fig 3 of Annexure F	XRF Analysis of Toori Ash Produced as per Second Incineration Regime	79
Fig 4 of Annexure F	XRF Analysis of Toori Ash Produced as per Third Incineration Regime	79
Fig 5 of Annexure F	XRF Analysis of “Calcined” Bentonite Particles	80
Fig 1 of Annexure G	Pore Size Distribution (nm) of SCP Formulations by MIP	81
Fig 1 of Annexure H	XRD Analysis of Faugi Cement Particles	82
Fig 2 of Annexure H	XRD Analysis of Pure Self Compacting Paste Sample at an age of 1 Day	83
Fig 3 of Annexure H	XRD Analysis of Pure Self Compacting Paste Sample at an age of 7 Days.	84
Fig 4 of Annexure H	XRD Analysis of SCP Sample Containing 10% Toori Ash in Replacement Mode at an age of 1 Day	85
Fig 5 of Annexure H	XRD Analysis of SCP Sample Containing 10% Toori Ash in Replacement Mode at the age of 7 Days	86
Fig 6 of AnnexureH	XRD Analysis of SCP Sample Containing 10% “Calcined” Bentonite in Replacement Mode at an age of 1 Day	87

Fig 7 of Annexure F	XRD Analysis of SCP Sample Containing 10% “Calcined” Bentonite in Replacement Mode at the age of 7 Days	88
Fig 8 of AnnexureH	XRD Analysis of SCP Sample Containing 10% “As Obtained” Bentonite in Replacement Mode at an age of 1 Day	89
Fig 9 of Annexure F	XRD Analysis of SCP Sample Containing 10% “As Obtained” Bentonite in Replacement Mode at the age of 7 Days	90

