A STUDY ON THE EFFECT OF NANO-SILICA ON THE STRENGTH AND SORPTION CHARACTERISTICS OF CEMENT-SILICA FUME SYSTEMS

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OCTOBER 2016

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by

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Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

OCTOBER 2016

DEDICATED

TO

MY FAMILY

CERTIFICATE

This is to certify that the thesis entitled, **"A STUDY ON THE EFFECT OF NANO-SILICA ON THE STRENGTH AND SORPTION CHARACTERISTICS OF CEMENT-SILICA FUME SYSTEMS"**, being submitted by **Mr. V.Sairam** for the award of the degree of **Doctor of Philosophy** to the Department of Civil Engineering, Indian Institute of Technology Delhi, New Delhi, is a record of bonafide research work carried out by him under my guidance and supervision.

Mr. V.Sairam has fulfilled the requirements for the submission of this thesis, which to my knowledge has reached the requisite standard. The results contained in this thesis have not been submitted in part or in full to any other university or institute for the award of any degree or diploma.

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ACKNOWLEDGMENTS

It gives me immense pleasure in expressing my regards and deep sense of gratitude to **Dr. B. Bhattacharjee**, Professor, Department of Civil Engineering, Indian Institute of Technology Delhi, India, for introducing the wonders and frustrations of scientific research. He has been teaching all about self-discipline in laboratory work and in written scientific communication. I thank him for his invaluable guidance and constant encouragement throughout the period of doctoral programme.

I take this opportunity to extend my sincere thanks to my research scholar colleagues and friends Dr. B.Kondrai Vendhan, Dr. Jitu Kujur, Dr. Kamal Kant Jain, Mr. Kaustav Sarkar and Miss Amarpreet Kaur for their cooperation during my study at IIT Delhi. I express my sincere thanks to M.Tech students N.Aparna, Nachiappan AL and Shanshank Sonal for their help in preparing the thesis.

I would like to acknowledge my sincere thanks to companies BASF, FOSROC, CICO, ASIAN Laboratories, SIKA, SEW for providing the superplasticizers at free of cost. I also thank EKA Chemicals, Sweden, Beechem company, Kanpur, BASF company for providing me nanosilica samples at free of cost and Elkem company for providing me silica fume at free of cost. I also wish to thank Mr. Goutam Barai, Mr. Nitin Chaurasia, Mr. Lal Singh, and Mr. Biri Singh and other staff members of Materials Research Laboratory and Structures Laboratory for their cooperation during the experimental work. I express my sincere thanks to Mr. Nabeel Ahmed Khan Ph.D. scholar to relieve from my last minute tension.

I take this opportunity to extend my sincere gratitude to **Dr.G.V.Ramana**, Professor, Department of Civil Engineering, IIT Delhi for motivated and supported me throughout my life at IIT Delhi.

Last but not least, I am greatly indebted to my beloved mother Mrs.V.Ratnamma, father V.P.Sreenivasulu Chetty, brother V.Balaji and father-in-law B.Venkateswarulu for their support in all possible ways and have made me what I am today. I am grateful to my wife Mrs. V.Sarada for her patience, understanding and interest in my research work without which it would not have been possible to complete the thesis and to my little prince, my daughter V.Vishnu Priya for supporting me in her own way.

V.SAIRAM

ABSTRACT

Concrete is the single most widely used material in the world – and it has a carbon footprint to match. The production of concrete contributes 5% of annual anthropogenic global CO_2 production mainly because of such vast quantities being used. Researches all over the world are currently aiming at reducing the amount of cement content in concrete which is the prime contributor to carbon emissions. Development of new concrete additives could produce a stronger, more workable material while reducing the amount of cement required and the resulting CO_2 emissions. Whilst the addition of substitute materials like fly ash, metakaolin, rice husk ash etc. has helped in achieving the above stated objectives, there still exists a lot of scope for other additives especially pertaining to nanotechnology. Nanomaterials like nano-silica, nano-alumina and nano-titania are known to improve properties of cementitious systems but there is a lack of systematic research in this field on the different possibilities that they may offer. With this view, thus in this research work an attempt is made to investigate the effect of nanosilica on cement-silica fume system at low and high w/b ratios.

In the first phase of experimental work on cement-silica fume paste, mortar and concrete, four mixes with water to binder ratio of 0.25, 0.35, 0.45 and 0.55 were used. Six curing ages of 3, 7, 28, 56, 90 and 180 days with six replacements of silica fume levels at 0%, 5%, 10%, 15%, 20% and 25% are adopted. For measuring the compressive strength the size of the specimens in the case of paste and mortar 5 cm cubes were used, and in the case of concrete it was 10 cm cubes.

In the second phase of experimental work on cement-silica fume-nanosilica paste, mortar and concrete, four levels of silica fume replacements i.e, 0%, 5%, 10% and 15% were used. Nanosilica was used at 2% of the total cementitious materials and same w/b ratios as that of cement-silica fume system are adopted. For measuring the compressive strength, the specimen size same as that of cement-silica fume system were adopted.

For the third phase of experimental work on cement-silica fume concrete, the curing ages and silica fume replacements and the water-binder ratios were same as that used for compressive strength test. In this phase of work, sorptivity test was performed on cast specimens.

For the fourth phase of experimental work on cement-silica fume-nano silica concrete, the curing ages and silica fume replacements were same as that used for compressive strength measurements. In this phase of work also, sorptivity test was performed on cast specimens.

Water permeable porosity test was performed for the cement-silica fume concrete specimens at 90 days and 180 days curing ages. For cement-silica fume-nanosilica concrete, the same test is conducted for specimens at 3, 7, 28, 56, 90 and 180 days curing ages.

Through the water permeable porosity and sorptivity data, the pore radius is calculated for the cement-silica fume concrete and cement-silica fume-nano silica concretes.

From the results of cement-silica fume system, it was observed that silica fume incorporating at 15% of total cementitious materials provided the maximum compressive strength in all w/b ratios at all curing ages.

For the cement-silica fume-nanosilica system, it was observed that in most of the cases the nanosilica samples with no silica fume provides the best results and it was observed that maximum % of silica fume that can be used is 5% along with nanosilica.

From the results of sorptivity test on cement-silica fume concrete, it was observed that silica fume concrete provides lower sorptivity values at w/b ratio of 0.35, 0.45 and 0.55.

From the results of sorptivity test on cement-silica fume- nanosilica concrete, it was observed that at lower w/b ratios, concrete with 0% silica fume and 0% nanosilica provided the best results. While in higher w/b ratios, nanosilica with 0% silica fume provided the lowest sorptivity values.

From the results of water absorption test on cement silica fume concrete and cement-silica fume-nanosilica concrete, it was observed that the addition of silica fume do not change the porosity significantly. The water permeable porosity increases with increase in water to binder ratio in both silica fume and nanosilica concretes. Mean permeable pore radius do not exhibit systematic variation with W/B ratio or SF content in all cases encountered.

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ABBREVIATIONS AND SYMBOLS

AS	Amorphous silica
ASR	Alkali-silica reaction
bwoc	Based on the weight of cement
CH	Calcium hydroxide
CNS	Colloidal nanosilica
CSF	condensed silica fume
C-S-H	Calcium Silicate Hydrate
ESEM	Environmental Scanning Electron Microscopy
FA	Fly ash
GGBFS	Ground Granulated Blast Furnace slag
HCP	Hardened cement paste
HPC	High performance concrete
HPSCC	High performance self-compacting concrete
HRM	High-reactive Metakaolin
HRWRA	High Range Water Reducing Admixture
HVFA	High Volume Fly Ash
ISSA	Incinerated sewage sludge ash
LD C-S-H	Low Density Calcium Silicate Hydrate
MK	Metakaolin
NMK	Nano metakaolin
NS	Nanosilica
NSS	Nano-silica solution
OPC	Ordinary Portland cement
PC	Portland cement

PWC	Portland White Cement
RHA	Rice husk ash
SCC	Self-Compacting Concrete
SCE	Saturated calomel electrode
SF	Silica fume
SP	Superplasticizer
STEM	Scanning Transmission Electron Microscopy
UHPC	Ultra-high performance concrete
UHPC	Ultra-high strength and performance concrete
w/b	water to binder ratio
w/c	water to cement ratio
w/cm	water to cementitious ratio
dQ/dt	volumetric flow rate
r	Radius of pore
Δp	Pressure drop
μ	Dynamic viscosity
l	Distance penetration
dh/dt	velocity of liquid
σ	Surface tension
Ө	Contact angle
Ø	Porosity
m	mass of water
ρ	Density
S	Sorpivity
i	Absorption