ENHANCING FLY ASH UTILISATION IN CONCRETE

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JUNE 2017

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by

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Submitted
in fulfilment of the requirements for the degree of Doctor of Philosophy
to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

JUNE 2017

Certificate

This is to certify that the thesis entitled **“Enhancing Fly Ash Utilisation in Concrete”** submitted by **Khuito Murumi** to the Indian Institute of Technology Delhi for the award of degree of **Doctor of Philosophy** in Civil Engineering is a bona fide record of research work carried out by him under my supervision. The thesis work, in my opinion, has reached the requisite standard of fulfilling the requirements for the degree of Doctor of Philosophy.

The results contained in this thesis have not been submitted, in part or full, to any other university or institute for the award of any degree or diploma.

Date: 13/06/2017
Place: New Delhi

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Acknowledgements

Praise and glory be to the Almighty God who is the source of inspiration, knowledge and blessings. I thank you from the depths of my heart for helping me to accomplish my research at the Indian Institute of Technology (IIT) Delhi. You have introduced me to so many beautiful people to enrich my life. Thank you, Lord, for all You've done.

I would like to express my sincere gratitude to my supervisor, Dr Supratic Gupta for his advice, motivation, patience and all kinds of support. His immense knowledge and philosophy have broadened my outlook. I would also like to thank his wife, Mrs Malancha Gupta, for her warm hospitality during my stay at IIT Delhi.

I am very grateful to the members of Student Research Committee (SRC), IIT Delhi– Prof. Arvind K Nema, Prof. S N Maiti and Dr Shashank Bishnoi for their cordial advice and constructive comments. I would like to offer my special thanks to Dr Gurmail S Benipal and the reviewers of this thesis, namely Prof. Sudhirkumar Barai (IIT Kharagpur, West Bengal) and Prof. Jay G Sanjayan (Swinburne University of Technology, Melbourne) for their sincere comments and suggestions.

Dr Anuj Maheshwari, Reliance Industries Limited shared his experience and knowledge on concrete with me. Research colleagues at IIT Delhi, specifically Mr Ashish Kumar Dash, Ms Miss Meera, Mr Kumar Supravin and Mr Oinam Romanbabu Meetei helped me in various ways. Mr Ashish Kumar (MTech. in Structural Engineering) helped in translating the abstract of the thesis from English to Hindi. I would also like to thank the laboratory staff, namely Mr Pradeep Singh Negi, Mr Gautam Barai, Mr Biri Singh and other attendants who assisted me throughout casting of concrete and experimental work.

I wish to acknowledge the support provided by various stakeholders and personnel of several construction companies for technical inputs and cooperation during interviews. Particular thanks to the Thermal Civil Division of Central Electricity Authority, Ministry of Power, Government of India; Building Materials and Technology Promotion Council, Ministry of Housing and Urban Poverty Alleviation, Government of India; and Delhi Pollution Control Committee, Government of NCT of Delhi for sharing information related to fly ash utilisation. Apologies to any of the people I may have inadvertently overlooked.

I am grateful to the Government of Nagaland for granting me study leave. I wish to thank my colleagues and staff of Nagaland Public Works Department who helped me in all possible manners.

Sincere love and gratitude to my family, friends and well-wishers at home and elsewhere for their encouragement, prayers and support.

Khuito Murumi
June 13, 2017

Abstract

The knowledge about the utility of fly ash is well known but optimal utilisation is not yet achieved in India. Most of the construction agencies, especially in governmental works, prefer to use only ordinary Portland cement (OPC) in concrete without fly ash. In order to understand the reasons for this underutilisation of fly ash in concrete, field visits were carried out to interact with different categories of stakeholders; standards and documents related to fly ash utilisation were studied; and experiments were conducted.

Investigation on availability and quality of fly ash shows that it is abundantly available for the most part in India and fly ash is mainly of siliceous type (ASTM Class F). Fly ash percentage of 15-55% covering about 20-60 MPa strength (conventional structural concrete) were considered for experimental work. The detailed experimental study confirms the applicability of efficiency factor method in the mix design and strength prediction of fly ash concrete.

Mix optimisation of concrete with fly ash shows that the utility of fly ash increases with decrease in design strength of concrete. For a fixed grade of concrete, there is a significant improvement of resistance of concrete against water penetration and water absorption upon fly ash usage, especially in lower strength concretes.

Use of fly ash up to its optimum limit in a pumping concrete ensuring the minimum strength requirement of current standards and codes satisfies the minimum cement content criterion for durability. In the present scenario, fly ash-based Portland pozzolana cement (PPC) concrete and OPC concrete provide higher profit to the construction agencies than fly ash concrete due to the cost calculation methodology of the Central Public Works Department (CPWD) in Analysis of Rates for Delhi and Delhi Schedule of Rates.

Although there are green building incentives for utilisation of fly ash-based products based on ratings like that of Green Rating for Integrated Habitat Assessment (GRIHA), current incentives are still insufficient to promote utilisation of fly ash in concrete. The gain in points for incentives should also depend on the fly ash percentage used in concrete.

The major reason behind underutilisation of fly ash in concrete is due to the reduction in contractors' profit upon fly ash usage. Fly ash utilisation can be significantly enhanced if CPWD's rate of concrete is based on the grade of concrete instead of cement content utilised; by sharing transportation cost of fly ash between thermal power stations and construction agencies as notified by the Ministry of Environment, Forest and Climate Change (MoEFCC); and by enhancing fly ash-related green building incentives.

This thesis has shown the reasons for underutilisation of fly ash in concrete and has demonstrated why and how fly ash should be used. It has also presented the implications of provisions in standards and CPWD documents in relation to fly ash utilisation that need attention. The government and all stakeholders should act on the issues pointed out in this thesis for achieving a sustainable construction.

Keywords: *Cement; Concrete; Cost; Efficiency Factor; Fly Ash; Profit; Standards; Strength*

सार

भारत में फ्लाई ऐश की उपयोगिता के बारे में ज्ञान अच्छी तरह ज्ञात है। लेकिन इसका इष्टतम उपयोग अभी तक हासिल नही हुआ है। अधिकांश निर्माण एजेंसियां, खासकर सरकारी कार्यों में, केवल साधारण पोर्टलैंड सीमेंट (ओ पी सी) को फ्लाई ऐश के बिना कंक्रीट में इस्तेमाल करना पसंद करती हैं। कंक्रीट में फ्लाई ऐश की इस अधोसंरचना के कारणों को समझने के लिए विभिन्न श्रेणियों के हितधारकों के साथ बातचीत करने के लिए क्षेत्रीय यात्राओं का आयोजन किया गया। मानकों और दस्तावेजों का अध्ययन किया गया और प्रयोग किए गए।

फ्लाई ऐश की उपलब्धता और गुणवत्ता पर जांच से पता चलता है कि यह भारत में अधिकांश भाग मे अधिकतम मात्रा में और सिलिसिस प्रकार के (ए एस टी एम कक्षा एफ) उपलब्ध है। प्रायोगिक कार्य के लिए लगभग २०-६० एमपीए ताकत (पारंपरिक संरचनात्मक कंक्रीट) को कवर करने वाली १५-५५% फ्लाई ऐश के इस्तेमाल पर विचार किया गया था। विस्तृत प्रयोगात्मक अध्ययन मिक्स डिज़ाइन और फ्लाई ऐश कंक्रीट की पूर्वानुमान शक्ति में दक्षता कारक विधि की प्रयोज्यता की पुष्टि करता है।

कंक्रीट का फ्लाई ऐश के साथ मिश्रण अनुकूलन से पता चलता है कि जब डिजाइन में कंक्रीट की मज़बूती कम होती है तब कंक्रीट में फ्लाई ऐश कि उपयोगिता बढ़ जाती है। कंक्रीट की एक निश्चित श्रेणी के लिये फ्लाई ऐश के उपयोग से कंक्रीट में पानी प्रवेश और पानी अवशोषण का प्रतिरोध बढ़ जाता है, विशेषकर जब कंक्रीट कम मजबूत होती है।

वर्तमान मानकों और संहिताओं की न्यूनतम ताकत की आवश्यकता सुनिश्चित करने के लिए पंपिंग कंक्रीट में अपनी इष्टतम सीमा तक फ्लाई ऐश का उपयोग स्थायित्व के लिए न्यूनतम सीमेंट सामग्री मानदंड को संतुष्ट करता है। वर्तमान परिदृश्य में, फ्लाई ऐश आधारित पोर्टलैंड पॉज़ोलाना सीमेंट (पी पी सी) ठोस और ओपीसी कंक्रीट फ्लाई ऐश कंक्रीट की तुलना में निर्माण एजेंसियों को अधिक लाभ प्रदान करते हैं यह एनालिसिस ऑफ रेट्स फार दिल्ली तथा दिल्ली शेड्यूल ऑफ रेट्स में केंद्रीय लोक निर्माण विभाग (सी पी डब्ल्यू डी) की लागत गणना पद्धति के कारण ऐसा होता है।

यद्यपि एकीकृत आवास मूल्यांकन के लिए ग्रीन रेटिंग जैसी रेटिंग के आधार पर फ्लाई ऐश-आधारित उत्पादों के उपयोग के लिए हरे रंग की इमारत प्रोत्साहन हैं (जी आर आइ एच ए), हालांकि अभी भी मौजूदा प्रोत्साहनों को ठोस में फ्लाई ऐश के उपयोग को बढ़ावा देने के लिए अपर्याप्त हैं। प्रोत्साहन के लिए अंक में लाभ को कंक्रीट में फ्लाई ऐश प्रतिशत पर भी निर्भर होना चाहिए।

कंक्रीट में फ्लाई ऐश के कम उपयोग के पीछे प्रमुख कारण फ्लाई ऐश के उपयोग पर ठेकेदारों के लाभ में कमी एक मुख्य कारण होता है। यदि कंक्रीट की सीपीडब्ल्यूडी की दर सीमेंट की जगह कंक्रीट की श्रेणी पर आधारित होती है तो फ्लाई ऐश का उपयोग काफी बढ़ सकता है; पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय (एम ओ ई एफ सी सी) द्वारा अधिसूचित थर्मल पावर स्टेशनों और निर्माण एजेंसियों के बीच फ्लाई ऐश की परिवहन लागत साझा करके और फ्लाई ऐश से संबंधित हरी इमारत प्रोत्साहनों को बढ़ाकर फ्लाई ऐश का उपयोग बढ़ाया जा सकता है।

इस थीसिस ने कंक्रीट में फ्लाई ऐश के कम निष्पादन के कारणों को दिखाया है और यह दर्शाया है कि क्यों और कैसे फ्लाई ऐश का उपयोग किया जाना चाहिए। फ्लाई ऐश के उपयोग के संबंध में मानकों और सीपीडब्ल्यूडी दस्तावेजों के प्रावधानों के प्रभाव को प्रस्तुत किया गया है जिसमें ध्यान देने की आवश्यकता है। एक स्थायी निर्माण प्राप्त करने के लिए इस शोध में बताए गए मुद्दों पर सरकार और सभी हितधारकों को काम करना चाहिए।

संकेतशब्द: *सीमेंट; कंक्रीट; लागत; दक्षता फैक्टर; फ्लाई ऐश; फायदा; मानक; मजबूती*

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Abbreviations, Symbols and Notations

Abbreviations

ACI	American Concrete Institute
Admix.	Chemical admixture
ARD	Analysis of Rates for Delhi
ASTM Int’l	American Society for Testing and Materials International
BIS	Bureau of Indian Standards
BS	British Standard
BSI	British Standards Institution
BWOCM	By weight of cementitious material
CA	Coarse aggregate
CEA	Central Electricity Authority
CEM	Ordinary Portland cement
Concr.	Concrete
CPOH	Contractor’s Profit and Overhead
CPWD	Central Public Works Department
DSR	Delhi Schedule of Rates
FA	Fly ash
GGBS	Ground granulated blast furnace slag
GRIHA	Green Rating for Integrated Habitat Assessment
IIT	Indian Institute of Technology
INR	Indian Rupee
IRC	Indian Roads Congress
IRS	Indian Railway Standard

IS	Indian Standard
m.s.a.	Maximum size of aggregate
Max.	Maximum
Min.	Minimum
MLS	Modified lignosulfonate
MoEF	Ministry of Environment and Forests
MoEFCC	Ministry of Environment, Forest and Climate Change
MoRTH	Ministry of Road Transport and Highways
NBCC Ltd	National Buildings Construction Corporation Limited
OPC	Ordinary Portland cement
OPT 1	Lower optimised fly ash percentage
OPT 2	Upper optimised fly ash percentage
OPT	Cost optimised fly ash percentage
PCC	Plain cement concrete
PCE	Polycarboxylate ether
PPC	Portland pozzolana cement (fly ash-based)
PSC	Portland slag cement or prestressed concrete
RCC	Reinforced cement concrete
RDSO	Research Designs and Standards Organisation
RMC	Ready-mixed concrete
SCC	Self-compacting concrete
SEM	Scanning electron microscope
Strength	Compressive strength of concrete at a particular age

Symbols and Notations

₹	Indian Rupee
b	Effective binder, that is, $c+kf$ (kg/m^3)
c	Ordinary Portland cement (kg/m^3) unless otherwise stated
C_{28}	Compressive strength of concrete of 150 mm cubes at 28 days (MPa)
C_7	Compressive strength of concrete of 150 mm cubes at 7 days (MPa)
cm	Cementitious material, that is, the sum of cement and fly ash (kg/m^3)
f	Fly ash (kg/m^3)
F	Fly ash percentage (%), that is, $f/(c+f)$
f_{ck}	Characteristic compressive strength of concrete (MPa)
k_{28}	Efficiency factor of fly ash at 28 days
k_7	Efficiency factor of fly ash at 7 days
k-value	Efficiency factor of fly ash
min	Minute (time)
Mt	Million tonne
p	Powder content, that is, the sum of cement and fly ash (kg/m^3)
s	Natural sand or fine aggregate (kg/m^3)
s/a	Sand to total aggregate ratio
S_{28}	Split tensile strength of concrete at 28 days (MPa)
t	Tonne
w	Water (kg/m^3)
w/b	Effective water to binder ratio, that is, $w/(c+kf)$
w/c	Water to cement ratio
w/cm	Water to cementitious material ratio, that is, $w/(c+f)$
w/p	Water to powder ratio, that is, $w/(c+f)$