

**A STUDY ON THE CHARACTERISATION AND USE OF
PONDED FLY ASH AS FINE AGGREGATE IN
CEMENT CONCRETE**

By
RANGANATH R.V.

*Thesis submitted
in fulfilment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY*

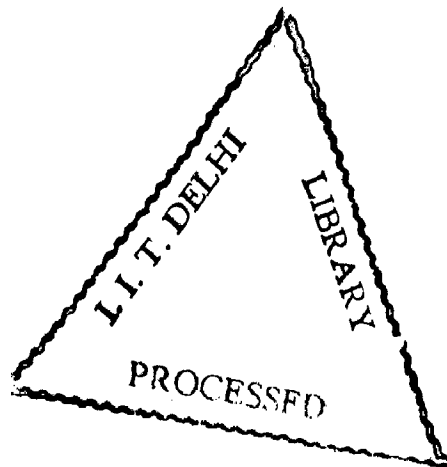


Department of Civil Engineering
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
HAUZ KHAS, NEW DELHI-110016, INDIA
AUGUST, 1995

Dedicated to

My parents

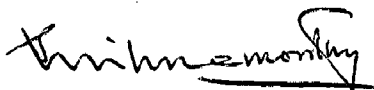
& uncle Dr. P.T. Naidu



CERTIFICATE

This is to certify that thesis entitled "A STUDY ON THE CHARACTERISATION AND USE OF PONDED FLY ASH AS FINE AGGREGATE IN CEMENT CONCRETE" being submitted by **Mr. Ranganath R.V.** to the Indian Institute of Technology, Delhi, India, for the award of the "DOCTOR OF PHILOSOPHY IN CIVIL ENGINEERING," is a record of bonafide research work carried out by him under our guidance and supervision.

To the best of our knowledge the thesis has reached the requisite standard. The material presented in this thesis has not been submitted in part or full to any other university or institution for award of a degree or diploma.



Dr. S. KRISHNAMOORTHY

Professor (Retd.)
Department of Civil Engineering
Indian Institute of Technology
New Delhi-110 016
India

(Supervisor)



Dr. B. BHATTACHARJEE

Asst. Professor
Department of Civil Engineering
Indian Institute of Technology
New Delhi-110 016
India

(Supervisor)

ACKNOWLEDGEMENTS

I am one of those fortunate few, who could get an opportunity to work under Prof. S. Krishnamoorthy and Dr. B. Bhattacharjee. It was Prof. Krishnamoorthy, who introduced me to the field of Concrete Technology, nurtured me with new ideas and helped me to develop interest in this field. His independent thinking, meticulous guidance, incessant encouragement, and watchful supervision were instrumental in carrying out this investigation. He was of great help to me as a guide and philosopher. I will remain immensely grateful and owe him a great deal. I also express my gratitude to Smt. Savithri Krishnamoorthy who has always been kind and affectionate to me.

I am grateful to my guide Dr. B. Bhattacharjee whose constant encouragement, friendly advice, helpful suggestions, comments and criticisms were instrumental in shaping this thesis. I would also like to express my gratitude to him for the wonderful time spent together in discussing various issues.

I am greatly indebted to Dr. R.C. Sharma, Dr. R. Pathak and Smt. Sowmini Ravi for their help rendered in understanding and carrying out the chemical analyses. I am thankful to Dr. N.K. Jain, Dr. V.B. Deshpande and Dr. Benipal for their constant encouragement and suggestions.

I am thankful to the supporting staff of Structures and Building Materials laboratory, and specially, to Chaudhary Badle Ram, who has been very kind and helpful to me during the entire period of investigation.

I thank the authorities of National Council of Cement and Building Materials, Ballabgarh, Haryana, and Central Soil Materials Research Station, New Delhi for enabling me to utilise their instrumental facilities.

I am extremely thankful to the management and principal, Jawaharlal Nehru National College of Engineering, Shimoga, Karnataka, for encouraging me to pursue the M.Tech and then the Ph.D programme by providing study leave.

The final form of the thesis is due exclusively to the untiring efforts of my friends Sushil, Satish, Sharat, Jaideep, Rafeeq, Deepa, and others. I thank them all.

I am thankful to my colleagues and friends, specially to the gang— Satish, Sushil, Jaideep, Nidhi, Nawab, Himanshu, Rajneesh, Achar and Palai for the wonderful time spent together. Without them, I would not have enjoyed my stay in Delhi.

I owe my gratitude to my mother Smt. Sharada and father Mr. R. Venkataswamy who always stood by me and encouraged me in this endeavour. I also express my gratitude to my uncle Dr. S.T. Naidu and aunt Prema for their help and encouragement.

I am thankful to all the members of my family and other friends, with particular reference to my brother Rajendra, and brothers-in-law Bhimanna and late Kumar, in-laws Mrs. and Mr. K.V. Ramana, and friends Swamy, Bharath, Yashawanth, and Mahesh, without whose support and encouragement, I would not have reached this stage.

Last, but not means the least, I wish to express my love and gratitude to my wife Sushma for the continuous support, encouragement and understanding provided during this period, and tolerating with the strenuous schedule.

The wonderful time spent from the past one year with my son Kirthi eased the strenuous work schedule. I gratefully acknowledge his share.

Ranganath R.V.
(R.V. Ranganath)

ABSTRACT

Most of the Thermal Power Plants in India adopt wet methods of disposal and storage of the ash in large ponds and dykes. In the wet method, both the fly ash collected from electrostatic precipitators and the bottom or grate ash are mixed with water and transported to the ponds in a slurry form.

About 1000 million tonnes of ponded ash is available in India at present. Its effective utilisation is important. Its use in cement concrete has not been well investigated.

This study presents the characteristics of ponded ash in terms of their physical properties, chemical composition, mineralogical composition, and morphology to ascertain the variability of these within a single source, and also with those of fly ash. The study also examines workability, compressive strength, pore size distribution, and drying shrinkage of ponded ash admixed concrete.

The results show that the ponded ash differs from dry hopper collected fly ash in that it contains a large proportion of coarser particles ($>75 \mu\text{m}$) which primarily would come from bottom ash. The characteristics of these coarse particles are mainly responsible for the reduced reactivity in comparison to fly ash. However, the variation among the samples collected from a single source is not significant and the fine particles present show considerable pozzolanic activity. In structural concretes, ponded ash can be best used as a part of fine aggregate instead of as a cementitious material.

The loss of workability which may occur on incorporation of ponded ash can be restored to a large extent by adopting suitable reportioning of coarse aggregate and fine aggregate ratio in the total aggregate. Considerable amounts of fly ash can be utilised thus in concrete. The results of long term compressive strength tests indicate additional benefits in using ponded ash as a part replacement of fine aggregate. Porosity, pore size distribution, and drying shrinkage studies of ponded ash concrete show that it is either comparable or superior to reference concrete, particularly in long term durability.

A specification, suitable to adoption at construction sites, is given for ponded ash and also simple methods of reportioning concrete mixes in which ponded ash is being incorporated.

CONTENTS

CERTIFICATE	
ACKNOWLEDGEMENT	i
ABSTRACT	iii
CONTENTS	iv
LIST OF FIGURES	ix
LIST OF PLATES	xi
LIST OF TABLES	xii
CHAPTER 1: INTRODUCTION	1-6
1.1 Fly ash	1
1.2 Fly ash concrete	2
1.3 Need for further research	3
1.4 Past research work with ponded ash	4
1.5 Objectives	5
1.6 Experimental programme	5
1.7 Organisation of the thesis	6
CHAPTER 2 : LITERATURE REVIEW	7-50
2.1 Introduction	7
2.2 Physical characteristics of fly ash	7
2.2.1 Grain size distribution	7
2.2.2 Fineness	8
2.2.3 Specific gravity	10
2.2.4 Summary for physical characteristics	11
2.3 Chemical composition of fly ash	11
2.3.1 Loss on ignition	11
2.3.2 Oxide composition	12
2.3.3 Summary on chemical composition	17
2.4 Mineralogical composition	18
2.4.1 Summary on mineralogical composition	19
2.5 Morphology of fly ashes	19
2.5.1 Summary on morphology of fly ashes	22

2.6	Pozzolanic activity of fly ash	22
2.6.1	Lime-pozzolan reactions	23
2.6.2	Cement-pozzolan interactions	24
2.6.3	Evaluation of pozzolanic activity	27
2.7	Workability	32
2.7.1	Assessment of workability	32
2.7.2	Effect of fly ash on workability of cement mortar and concrete	33
2.7.3	Summary	37
2.8	Effect of fly ash on compressive strength of concrete	38
2.8.1	Summary	44
2.9	Effect of fly ash on the pore structure of mortars and concrete	45
2.9.1	Summary	48
2.10	Effect of fly ash on shrinkage of cement concrete	48
2.11	Other properties	50
CHAPTER 3 : CHARACTERISATION OF PONDED ASH		51-61
3.1	Introduction	51
3.2	Sample procurement	51
3.3	Physical characteristics of the ponded ash	52
3.3.1	Granulometric analysis	52
3.3.2	Specific gravity	53
3.3.3	Fineness	54
3.3.4	Lime reactivity	54
3.4	Chemical analysis	57
3.4.1	Loss on ignition	57
3.4.2	Oxide compositions	57
3.5	Reactive silica	58
3.5.1	General	58
3.5.2	Soluble silica content	58
3.5.3	Alkali soluble silica	59
3.6	X-ray diffraction	59
3.7	Scanning Electron Microscope (SEM) studies	60
3.8	Summary	60

CHAPTER 4 : INFLUENCE OF SIZE FRACTIONS OF PONDED ASH ON ITS POZZOLANIC ACTIVITY	62-70
4.1 Introduction	62
4.2 Physical characteristics	62
4.3 Chemical composition	63
4.4 Mineralogical composition	63
4.5 Morphological studies	64
4.6.1 SEM studies on lime-hydrated ponded ash samples	64
4.6.2 Mercury Intrusion Porosimetry (MIP) studies on lime-hydrated mortar samples	65
4.6 Reactivity evaluation of ponded ash with lime at various ages	66
4.7 Summary	70
 CHAPTER 5 : WORKABILITY OF PONDED ASH CONCRETE	 71-94
5.1 Introduction	71
5.2 Material	71
5.2.1 Cement	71
5.2.2 Fine aggregate	71
5.2.3 Coarse aggregate	71
5.2.4 Ponded ash	71
5.3 Method adopted to arrive at the optimum mixtures	72
5.4 Results and discussion	74
5.4.1 Workability of mixes with $v_p = 0.28$, Cement = 306 kg/m ³ and w/c = 0.60	74
5.4.2 Workability of mixes with $v_p = 0.30$, Cement = 328kg/m ³ and w/c = 0.60	76
5.4.3 Workability of mixes with $v_p = 0.32$, Cement = 350kg/m ³ and w/c = 0.60	76
5.4.4 Workability of mixes with $v_p = 0.36$, Cement = 510 kg/m ³ and w/c = 0.40	79
5.4.5 Discussion on optimal mixes	79
5.4.6 Workability with ponded ash P ₁₁	83
5.5 Analysis of surface indices of ponded ash added combined aggregate	83
5.5.1 Relative surface area	84

5.6	Fine aggregate for optimum workability vis-a-vis fine aggregate for least voids	88
5.6.1	Least voids aggregate mixture	88
5.6.2	Discussion	90
5.7	Procedure for proportioning of aggregates in concrete mixes with ponded ash	92
5.7.1	Procedure	92
5.8	Summary	93

CHAPTER 6 : COMPRESSIVE STRENGTH OF PONDED ASH CONCRETE 95-98

6.1	Introduction	95
6.2	Experimental procedure	95
6.3	Discussion	95
6.3.1	Compressive strength of mixes with $v_p = 0.28$, $w/c = 0.60$, Cement = 306 kg/m ³ , superplasticizer = 0.5%	95
6.3.2	Compressive strength of mixes with $v_p = 0.30$, $w/c = 0.60$, Cement = 328 kg/m ³	96
6.3.3	Compressive strength of mixes with $v_p = 0.32$, $w/c = 0.60$, Cement = 350 kg/m ³	97
6.3.4	Compressive strength of mixes with $v_p = 0.36$, $w/c=0.40$, Cement=510 kg/m ³	97
6.4	Summary	98

CHAPTER 7 : POROSITY, PORE SIZE DISTRIBUTION AND DRYING SHRINKAGE OF PONDED ASH CONCRETE 99-104

7.1	Mercury Intrusion Porosimetry (MIP)	99
7.1.1	Introduction	99
7.1.2	Experimental	99
7.1.3	Results and discussion	100
7.2	Comparison of pore size distribution of ponded ash concrete with fly ash concrete	102
7.3	Drying shrinkage	103
7.3.1	Introduction	103
7.3.2	Experimental	103
7.4	Summary	104

CHAPTER 8 : CONCLUSIONS	105-109
8.1 Characteristics of ponded ash	105
8.2 Influence of size fractions of ponded ash on its pozzolanic activity	106
8.3 Workability of ponded ash concrete	107
8.4 Compressive strength of ponded ash concrete	108
8.5 Porosity, pore size distribution and drying shrinkage	109
CHAPTER 9 : SUMMARY, RECOMMENDATIONS AND NEEDED RESEARCH	110-114
9.1 Summary	110
9.2 Recommended procedure for use of ponded ash	110
9.3 Utilisation and economic potential of ponded ash	112
9.3.1 Economic potential	112
9.3.2 Cost factors	114
9.4 Needed research	114
REFERENCES	115-127
APPENDIX	A.I - 1-7