

# **WATER PERMEABILITY PROPERTIES OF FLY ASH AND MARBLE POWDER CONCRETE**

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**DEPARTMENT OF CIVIL ENGINEERING  
INDIAN INSTITUTE OF TECHNOLOGY DELHI**

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# **WATER PERMEABILITY PROPERTIES OF FLY ASH AND MARBLE POWDER CONCRETE**

by

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Submitted

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

to the



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# Certificate

This is to certify that the thesis entitled “**Water Permeability Properties of Fly Ash and Marble Powder Concrete**” submitted by **Kumar Supravin** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy** in Civil Engineering is a bonafide 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: 05/12/2021

Place: New Delhi

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Indian Institute of Technology Delhi

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*My teaching is not a philosophy. It is the result of direct experience.*

*My teaching is a means of practice, not something to hold onto or worship.*

*My teaching is like a raft used to cross the river.*

*Only a fool would carry the raft around*

*After he had already reached the other shore of liberation.*

--Gautama, the Buddha

ॐ असतो मा सद्गमय ।

तमसो मा ज्योतिर्गमय ।

मृत्योर्मा अमृतं गमय ।

ॐ शान्तिः शान्तिः शान्तिः ॥

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# Abstract

In the construction industry, concrete is the most used construction material. With the large-scale depletion of non-renewable natural resources, material optimization is important for the future sustainability of the construction industry. The amount of cement consumption has decreased due to the use of chemical admixture and fly ash. The knowledge about fly ash as a civil engineering material dates back to more than a century. However, research on marble powder as an engineering material is just 15-20 years old and the understanding regarding its use as an inert filler material is not yet fully understood. The utilization of fly ash as a pozzolana and marble powder as a non-pozzolanic inert filler material opens a lot of possibilities in concrete production of desirable texture and workability. With the use of the efficiency factor for fly ash and proper water correction for marble powder, then the concrete can be confidently designed for the desired strength. Granite powder also presents a similar possibility as that of marble powder.

Both fly ash (mainly Siliceous Type – ASTM Class F) and marble/granite powder are abundantly available in the country. Even though extensive research and the Indian code support fly ash utilization, government projects still have problems in using fly ash. Since the benefits of utilization of fly ash are not understood and often the cost paid to the contractors is based on the amount of cement consumption, hence the contractors end up getting paid less as there is a decrease in cement consumption on account of fly ash utilization. Thus ironically, a superior material is being underpaid affecting the optimum utilization of fly ash. The utilization of marble powder is yet a dream, as it is not incorporated in any code except EFNARC specifications for Self Compacting Concrete.

Limited optimization work on fly ash was carried out in the past with the proposed concept of effective water to cement ratio. Whenever fly ash is used in concrete, it is important to define effective water to cement ratio between water to binder such that binder is not cement plus fly ash but it is rather the cement plus the efficiency factor for fly ash times the amount of fly ash. For a proper design of the mix using marble powder, it is assumed to be inert with no influence on the effective water to cement ratio. Limited work on marble powder was carried out with the proposal that it is important to assume higher water absorption of marble powder. This concept was extended and verified in lower strength ranges also. In this thesis, extensive work has been carried out in normal and high strength ranges using fly ash and marble powder utilizing these concepts.

Fly ash and marble powder mixes were used for effective water-cement ratios in the range of 0.50 to 0.20. 28 days compressive strength up to 96 MPa was achieved without the use of micro-silica. Marble powder has been added taking the total powder content up to 900 kg/m<sup>3</sup>, saving a significant amount of aggregate and improving the cohesiveness of the concrete.

Water permeability is usually measured using DIN: 1048 (Part 5)/ (IS 516 (part2/Sec 1), 2018). While it is reported that usage of fly ash improves (decreases) water permeability of concrete by making it more impervious, the reported data does not provide a clear quantitative estimation of water ingress for comparisons. Because of all of this, it is essential to carry out a study of structural concrete, both in the normal strength and high strength range, towards understanding optimal usage of materials and their effects on the durability parameter of water permeability. Water permeability has also been measured using a new method developed at IIT Delhi. Limited mercury intrusion porosimeter experiments have also been carried out.

This detailed experimental work presents the limit of fly ash utilization without the use of micro silica in high strength range up to 96.2 MPa. It was found that the fly ash utilization limit percentage decreases with the increase in strength. In addition, the utilization limits and

benefits of using marble powder are also demonstrated. Optimum cement savings has been achieved when it is used with 15% fly ash. One could use marble powder up to maximum powder content of 800-900 kg/m<sup>3</sup>, demonstrating the higher possibility of marble powder utilization in lower strength ranges. Plasticizer dosage percentage, which is a percentage of the total weight of powder including cement, fly ash and marble powder, depends more upon effective w/c and less on fly ash % or quantity of marble powder used. Through the use of quantitative methods, it was found that the water permeability improved significantly with the use of fly ash and less significantly but noticeably due to the use of marble powder. The water permeability method developed at IIT Delhi was easy to conduct and reliable. This work provided a clear understanding of the effect of the utilization of fly ash and marble powder on the strength and durability of concrete.

In concluding, it was found that with the proper utilization of fly ash, high strength concrete can be produced even without the use of micro silica. Further, there is an upper limit of fly ash % that can be utilized as a function of effective w/c of the target strength of the concrete. The industrial waste product of marble powder can be utilized optimally to get good cohesive mix with either 0% or 15% fly ash in normal strength and in high strength concrete. The 15% fly ash mix along with marble powder provides the best opportunity as there is the optimum saving of cement along with optimal utilization of the industrial waste of marble powder.

***Keywords: Optimization, Fly ash, Pozzolana, Marble powder, Water correction, Water permeability, Durability, Mercury intrusion porosimeter***

# सारांश

निर्माण उद्योग में, कंक्रीट सबसे अधिक उपयोग की जाने वाली निर्माण सामग्री है। गैर-नवीकरणीय प्राकृतिक संसाधनों की बड़े पैमाने पर कमी के साथ, निर्माण उद्योग की भविष्य की स्थिरता के लिए सामग्री अनुकूलन महत्वपूर्ण है। रासायनिक मिश्रण और फ्लाई ऐश के उपयोग के कारण सीमेंट की उपयोग में कमी आई है। सिविल इंजीनियरिंग सामग्री के रूप में फ्लाई ऐश से सम्बंधित ज्ञान एक सदी से भी अधिक पुराना है। हालांकि, इंजीनियरिंग सामग्री के रूप में मार्बल पाउडर पर शोध सिर्फ 15-20 साल पुराना है और एक अक्रिय भराव सामग्री के रूप में इसके उपयोग के बारे में समझ अभी तक पूरी तरह से नहीं आई है। एक पॉज़ोलाना के रूप में फ्लाई ऐश का उपयोग और गैर-पॉज़ोलैनिक अक्रिय भराव सामग्री के रूप में संगमरमर पाउडर का उपयोग वांछनीय बनावट और व्यावहारिकता के ठोस उत्पादन में बहुत सारी संभावनाएं खोलता है। फ्लाई ऐश के लिए दक्षता कारक के उपयोग और संगमरमर पाउडर के लिए उचित जल सुधार के साथ, कंक्रीट को वांछित ताकत के लिए आत्मविश्वास से डिजाइन किया जा सकता है। ग्रेनाइट पाउडर भी मार्बल पाउडर के समान ही संभावना प्रस्तुत करता है।

देश में फ्लाई ऐश (मुख्य रूप से सिलिसियस टाइप - ASTM Class F) और मार्बल/ग्रेनाइट पाउडर दोनों ही प्रचुर मात्रा में उपलब्ध हैं। हालांकि व्यापक शोध और भारतीय कोड फ्लाई ऐश के उपयोग का समर्थन करते हैं, सरकारी परियोजनाओं में अभी भी फ्लाई ऐश का उपयोग करने में समस्या है। चूंकि फ्लाई ऐश के उपयोग के लाभों को समझा नहीं जाता है और अक्सर ठेकेदारों को भुगतान की जाने वाली लागत सीमेंट की खपत की मात्रा पर आधारित होती है, इसलिए ठेकेदारों को कम भुगतान किया जाता है क्योंकि फ्लाई ऐश के उपयोग के कारण सीमेंट की खपत में कमी होती है। इस प्रकार विडंबना यह है कि फ्लाई ऐश के इष्टतम उपयोग को प्रभावित करने वाली एक बेहतर सामग्री का कम भुगतान किया जा रहा है। मार्बल पाउडर का उपयोग अभी तक एक सपना है, क्योंकि इसे सेल्फ

कॉम्पेक्टिंग कंक्रीट के लिए EFNARC विनिर्देशों को छोड़कर किसी भी कोड में शामिल नहीं किया गया है।

फ्लाई ऐश पर सीमित अनुकूलन कार्य अतीत में प्रभावी जल-सीमेंट अनुपात के लिए प्रस्तावित अवधारणा के साथ किया गया था। जब भी फ्लाई ऐश का उपयोग कंक्रीट में किया जाता है, तो पानी से बाइंडर के बीच प्रभावी पानी से सीमेंट अनुपात को परिभाषित करना महत्वपूर्ण है, जैसे कि बाइंडर सीमेंट प्लस फ्लाई ऐश नहीं है, बल्कि यह सीमेंट प्लस फ्लाई ऐश के लिए दक्षता कारक है जो फ्लाई ऐश की मात्रा है। संगमरमर के पाउडर का उपयोग करके मिश्रण के उचित डिजाइन के लिए, इसे प्रभावी पानी से सीमेंट अनुपात पर कोई प्रभाव नहीं होने के साथ निष्क्रिय माना जाता है। मार्बल पाउडर पर सीमित कार्य इस प्रस्ताव के साथ किया गया था कि मार्बल पाउडर के उच्च जल अवशोषण को मान लेना महत्वपूर्ण है। इस अवधारणा को बढ़ाया गया और कम ताकत वाली श्रेणियों में भी सत्यापित किया गया था। इस थीसिस में इन अवधारणाओं का उपयोग करते हुए फ्लाई ऐश और मार्बल पाउडर का उपयोग करके सामान्य और उच्च शक्ति वाले क्षेत्रों में व्यापक कार्य किया गया है। फ्लाई ऐश और मार्बल पाउडर मिश्रण का उपयोग 0.50 से 0.20 के बीच प्रभावी जल-सीमेंट अनुपात के लिए किया गया था। माइक्रो-सिलिका के उपयोग के बिना 96 MPa तक 28-दिन की संपीड़ित ताकत हासिल की गई थी। कुल पाउडर सामग्री को 900 kg/m<sup>3</sup> तक लेते हुए मार्बल पाउडर को जोड़ा गया है, जिससे एक महत्वपूर्ण मात्रा में कुल की बचत होती है और कंक्रीट की एकजुटता में सुधार होता है।

पानी की पारगम्यता को आमतौर पर DIN: 1048 (Part 5)/ (IS 516 (part2/Sec 1), 2018) का उपयोग करके मापा जाता है। जबकि यह बताया गया है कि फ्लाई ऐश के उपयोग से कंक्रीट की पानी की पारगम्यता में सुधार (कमी) हो जाता है, जिससे यह अधिक अभेद्य हो जाता है, रिपोर्ट किए गए डेटा तुलना के लिए पानी के प्रवेश का स्पष्ट मात्रात्मक अनुमान प्रदान नहीं करते हैं। इस सब के कारण, सामग्री के इष्टतम उपयोग और जल पारगम्यता के स्थायित्व पैरामीटर पर उनके प्रभावों को समझने के लिए, सामान्य ताकत और उच्च शक्ति सीमा दोनों में संरचनात्मक कंक्रीट का अध्ययन करना आवश्यक है।

IIA दिल्ली में विकसित एक नई विधि का उपयोग करके जल पारगम्यता को भी मापा गया है। सीमित पारा घुसपैठ पोरोसिमीटर प्रयोग भी किए गए हैं।

यह विस्तृत प्रायोगिक कार्य 96.2 MPa तक की उच्च शक्ति रेंज में माइक्रो सिलिका के उपयोग के बिना फ्लाई ऐश के उपयोग की सीमा को प्रस्तुत करता है। यह पाया गया कि शक्ति में वृद्धि के साथ फ्लाई ऐश उपयोग सीमा प्रतिशत घट जाती है। इसके अलावा, मार्बल पाउडर के उपयोग की उपयोग सीमा और लाभ भी प्रदर्शित किए जाते हैं। 15% फ्लाई ऐश के साथ उपयोग किए जाने पर इष्टतम सीमेंट बचत प्राप्त हुई है। कोई भी व्यक्ति 800-900 kg/m<sup>3</sup> की अधिकतम पाउडर सामग्री तक मार्बल पाउडर का उपयोग कर सकता है, जो निम्न शक्ति रेंज में मार्बल पाउडर के उपयोग की उच्च संभावना को प्रदर्शित करता है। प्लास्टिसाइज़र खुराक प्रतिशत, जो सीमेंट, फ्लाई ऐश और मार्बल पाउडर सहित पाउडर के कुल वजन का प्रतिशत है, प्रभावी w/c पर अधिक और फ्लाई ऐश% या उपयोग किए गए संगमरमर पाउडर की मात्रा पर कम निर्भर करता है। मात्रात्मक विधियों के उपयोग के माध्यम से, यह पाया गया कि फ्लाई ऐश के उपयोग से पानी की पारगम्यता में उल्लेखनीय रूप से सुधार हुआ और कम महत्वपूर्ण रूप से लेकिन संगमरमर के पाउडर के उपयोग के कारण उल्लेखनीय रूप से सुधार हुआ। IIA दिल्ली में विकसित जल पारगम्यता पद्धति का संचालन करना आसान और विश्वसनीय था। इस काम ने कंक्रीट की मजबूती और स्थायित्व पर फ्लाई ऐश और मार्बल पाउडर के उपयोग के प्रभाव की स्पष्ट समझ प्रदान की। निष्कर्ष में, यह पाया गया कि फ्लाई ऐश के उचित उपयोग से माइक्रो सिलिका के उपयोग के बिना भी उच्च शक्ति कंक्रीट का उत्पादन किया जा सकता है।

इसके अलावा, फ्लाई ऐश% की एक ऊपरी सीमा है जिसका उपयोग कंक्रीट की लक्ष्य शक्ति के प्रभावी w/c के कार्य के रूप में किया जा सकता है। मार्बल पाउडर के औद्योगिक अपशिष्ट उत्पाद को सामान्य शक्ति और उच्च शक्ति कंक्रीट में 0% या 15% फ्लाई ऐश के साथ अच्छा चिपकने वाला मिश्रण प्राप्त करने के लिए इष्टतम रूप से उपयोग किया जा सकता है। मार्बल पाउडर के साथ 15% फ्लाई ऐश

मिक्स सबसे अच्छा अवसर प्रदान करता है क्योंकि मार्बल पाउडर के औद्योगिक कचरे के इष्टतम उपयोग के साथ-साथ सीमेंट की इष्टतम बचत होती है।

**कीवर्ड:** अनुकूलन, फ्लाई ऐश, पॉज़ोलाना, मार्बल पाउडर, जल सुधार, जल पारगम्यता, स्थायित्व, पारा घुसपैठ पोरोसिमीटर

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# Abbreviations, Symbols and Notations

## Abbreviations

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BIS	Bureau of Indian Standards
BSE	Back-scattered electrons
BSEN	British Standard European Norm
BSI	British Standards Institution
CA	Coarse aggregate
CEM	Cement
DIN	Deutsches Institute for Normung (meaning German institute for standardisation)
D <sub>xx</sub>	'xx' percent of sample mass has diameter less than D-value
EFNARC	European Federation of National Associations Representing for Concrete
FA	Fly ash
GGBS	Ground granulated blast furnace slag
HS	High strength
IIT	Indian Institute of Technology
IRC	Indian Roads Congress
IRS	Indian Railway Standard
IS	Indian Standard
LS	Low strength
MMF model	Morgan, Mercer, and Flodin model
MoRTH	Ministry of Road Transport and Highways
MLS	Modified lignosulfonates (a naphthalene-based admixture)
MP	Marble Powder
M.S.A.	Maximum size of aggregate
NCCBM	National Council for Cement and Building Materials
NS	Normal strength
OPC	Ordinary Portland cement
PCC	Plain cement concrete
PCE	Polycarboxylate ether
PPC	Portland pozzolana cement (fly ash-based)

PSC	Pre-stressed concrete
$R^2$	Coefficient of determination
RCC	Reinforced cement concrete
$S_{7 \text{ days}}$	7 days compressive strength of concrete
$S_{28 \text{ days}}$	28 days compressive strength of concrete
SCC	Self-compacting concrete
SEM	Scanning electron microscope
Strength	Compressive strength of concrete at a particular age
SG	Specific Gravity
SSD	Saturated surface dry
WA	Water Absorption

## Symbols and Notations

₹	Indian National Rupee
$Al_2O_3$	Alumina
b	Effective binder, that is, $c+kf$ ( $kg/m^3$ )
c	Ordinary Portland cement ( $kg/m^3$ ) unless otherwise stated
$Ca(OH)_2$	Calcium hydroxide
C7	Compressive strength of concrete of 150 mm cubes at 7 days (MPa)
C28	Compressive strength of concrete of 150 mm cubes at 28 days (MPa)
cm	Cementitious material, that is, the sum of cement and fly ash ( $kg/m^3$ )
f	Fly ash ( $kg/m^3$ )
F	Foam Volume
F%, f%	Fly ash percentage (%), that is, $f/(c+f)$
k-value	Efficiency factor of fly ash
$k_7$	Efficiency factor of fly ash at 7 days
$k_{28}$	Efficiency factor of fly ash at 28 days
$\ln R_m$	Logarithms natural base of $R_m$
min	Minute (time)
NO <sub>x</sub>	Oxide of nitrogen
p	Powder content as the sum of cement and fly ash and Marble powder ( $kg/m^3$ )
$R_{50}$ or $R_m$	Mean pore radius
s	Natural sand or fine aggregate ( $kg/m^3$ )

s/a	Sand to total aggregate ratio
SiO <sub>2</sub>	Silicon dioxide (a constituent of calcium silicate hydrate)
SO <sub>x</sub>	Oxide of sulphur
T25	Time required for 25mm of water penetration from the concrete surface
w	Water (kg/ m <sup>3</sup> )
w/b	Water to binder (c+f) ratio
w/c+kf	Effective water to cement ratio

*Dedicated to*

*My Beloved Parents, Late Smt. Laxmi Devi and Late Ganesh*

*Prasad Manjhi, who all through considered their lives much*

*less valuable than that of mine, and took me to heights*

*against All Odds*