

THE PERFORMANCE OF COAL BOTTOM ASH AND BIOMASS FLY ASH IN CONCRETE

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DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI

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THE PERFORMANCE OF COAL BOTTOM ASH AND BIOMASS FLY ASH IN CONCRETE

by

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DEPARTMENT OF CIVIL ENGINEERING

Submitted

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

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Dedicated to

*My Beloved Parents,
Wife, Daughter and Son*

Certificate

This is to certify that the thesis entitled “**The Performance of Coal Bottom Ash And Biomass Fly Ash in Concrete**” submitted by **Arun NR** 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.

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Abstract

Concrete is one of the most widely used construction materials and cement is the main ingredient in it and provides strength to the concrete. However, cement production significantly contributes to carbon emissions and the depletion of non-renewable resources. Hence it is very essential to minimize the usage of cement for sustainable construction practices.

In concrete mix design, the plasticizer is utilized to enhance the properties of concrete. In normal and low-strength concrete we can use either low-cost pozzolanic materials like fly ash, or non-reactive powders such as marble and granite powder. The utilization of pozzolanic material, fly ash improves the strength, durability, and workability of concrete. Utilization of inert material like marble powder, granite powder, and stone dust in concrete does not provide strength but enhances the workability and durability significantly, both utilisations are solutions to get powder-rich concrete.

Thus, it is clear that fly ash is a crucial construction material that plays a key role in improving the strength, workability, and durability of concrete and reducing cement consumption. At present, the availability of fly ash remains abundant, but the major concern is the future availability of fly ash because it is being generated from burning natural resources like coal. The global energy production drastically transitioning from conventional natural resource-based energy to sustainable renewable energy sources like wind, solar power, etc., would decrease the dependence on coal-based thermal power plants, thereby decreasing the production of fly ash. Hence, it is important to find an alternate source as a substitute of fly ash or use the present supply of fly ash more effectively.

This research explores alternative pozzolanic materials, specifically bottom ash and biomass fly ash, to reduce cement consumption and enhance the sustainability of concrete production.

Bottom ash was obtained from NTPC Faridabad and biomass fly ash from JSW Delhi. The bottom ash was ground for 30 minutes to 3 hours and tested for suitability as a construction material. In addition, Biomass fly ash has also been studied for suitability as a construction material. Various tests were conducted to assess their chemical and physical characteristics, reactivity, and overall performance in concrete mixes. The efficiency factor method was employed to evaluate the contributions of both ashes to concrete strength and workability.

The research involved a thorough investigation of particle size distribution both wet and dry sieving, Blaine fineness, and scanning electron microscopy (SEM) imaging. Second, the reactivity of both ashes was assessed using established codes. A comparative study of these codes, along with their flaws is presented. Most codes except EN450 used water content based on workability requirements which is not correct. Lime reactivity test was there only in Indian code. In the detailed study the standard lime reactivity test, and mortar-based Strength Activity Index was employed assuming 20% fly ash and fixed water powder ratio was adopted. All these studies pointed out that 45 min ground bottom ash has similar properties to that of normal fly ash and further grinding increased the effectiveness of the bottom ash. This experimental series provided the efficiency factor for 20% fly ash cases.

Experiment set 1, with effective w/c of 0.5, 0.45, and 0.4 with all ashes percentages of 0%, 25%, 35% and 45% was carried out. This provided the efficiency factor for the different fly ashes at different fly ash percentages. Experiment set 2 was repeated with three different levels of ashes for wide range of effective w/c and the results confirmed the efficiency factor determined in Experiment Set 1.

Durability studies, including Water permeability (DIN 1048 Part 5), Modified water permeability, and rapid chloride penetration tests (RCPT), were conducted to evaluate the performance of concrete mixes incorporating bottom ash and biomass fly ash.

Despite the beneficial effects of biomass fly ash on workability, it does not exhibit any pozzolanic activity. It was realized that further research is required on biomass fly ash to enhance the reactivity of biomass fly ash.

In conclusion, key findings indicate that grinding bottom ash for 45 minutes exhibits its pozzolanic reactivity similar to fly ash, with prolonged grinding further enhancing durability through improved permeability and strength. The findings also suggest that ground bottom ash, especially when ground for three hours, exhibits a high-efficiency factor and can effectively be used in high-strength concrete mix. The research also highlights significant modifications to current lime reactivity evaluation methods, highlighting the potential of these alternative materials to enhance the sustainability of concrete production.

Keywords: Efficiency Factor; Bottom ash; Fly ash, Lime reactivity, Strength activity index, Grinding

सारांश

कंक्रीट निर्माण सामग्री में से एक सबसे अधिक उपयोग होने वाली सामग्री है, और इसमें मुख्य सामग्री सीमेंट होती है, जो कंक्रीट को मजबूती प्रदान करती है। हालांकि, सीमेंट उत्पादन कार्बन उत्सर्जन और गैर-नवीकरणीय संसाधनों के उपयोग में महत्वपूर्ण योगदान करता है। इस कारण, सतत निर्माण प्रथाओं के लिए सीमेंट के उपयोग को कम करना बहुत आवश्यक है।

कंक्रीट मिक्स डिज़ाइन में, कंक्रीट के गुणों को बढ़ाने के लिए प्लास्टिसाइज़र का उपयोग किया जाता है। सामान्य और कम-शक्ति वाले कंक्रीट में हम फ्लाई ऐश जैसी कम लागत वाली पॉज़ोलानिक सामग्री या संगमरमर और ग्रेनाइट पाउडर जैसे गैर-प्रतिक्रियाशील पाउडर का उपयोग कर सकते हैं। पॉज़ोलानिक सामग्री, फ्लाई ऐश का उपयोग कंक्रीट की ताकत, स्थायित्व और कार्यशीलता में सुधार करता है। कंक्रीट में संगमरमर पाउडर, ग्रेनाइट पाउडर और पत्थर के चूर्ण जैसी निष्क्रिय सामग्री का उपयोग ताकत प्रदान नहीं करता है, लेकिन कार्यशीलता और स्थायित्व में काफी सुधार करता है, ये दोनों उपयोग कंक्रीट को पाउडर युक्त बनाने के समाधान हैं।

इस प्रकार, यह स्पष्ट है कि फ्लाई ऐश एक महत्वपूर्ण निर्माण सामग्री है जो कंक्रीट की ताकत, कार्यशीलता और स्थायित्व को सुधारने और सीमेंट की खपत को कम करने में महत्वपूर्ण भूमिका निभाती है। वर्तमान में फ्लाई ऐश की उपलब्धता प्रचुर मात्रा में है, लेकिन प्रमुख चिंता यह है कि भविष्य में फ्लाई ऐश की उपलब्धता कम हो सकती है, क्योंकि यह प्राकृतिक संसाधनों जैसे कोयला को जलाने से उत्पन्न होती है। वैश्विक ऊर्जा उत्पादन पारंपरिक प्राकृतिक संसाधन-आधारित ऊर्जा से स्थायी नवीकरणीय ऊर्जा स्रोतों जैसे पवन, सौर शक्ति, आदि में तेजी से संक्रमण कर रहा है, जिससे कोयला आधारित तापीय ऊर्जा संयंत्रों पर निर्भरता कम हो रही है, और इसके परिणामस्वरूप फ्लाई ऐश का उत्पादन कम होगा। इस प्रकार, फ्लाई ऐश के वैकल्पिक स्रोत को ढूंढना या वर्तमान फ्लाई ऐश आपूर्ति का अधिक प्रभावी ढंग से उपयोग करना महत्वपूर्ण है।

यह शोध कंक्रीट उत्पादन में सीमेंट की खपत को कम करने और स्थिरता बढ़ाने के लिए वैकल्पिक पोज़ोलानिक सामग्री, विशेष रूप से बॉटम ऐश और बायोमास फ्लाई ऐश की जांच करता है।

बॉटम ऐश को एनटीपीसी फरीदाबाद से प्राप्त किया गया और बायोमास फ्लाई ऐश को जेएसडब्ल्यू दिल्ली से प्राप्त किया गया। बॉटम ऐश को 30 मिनट से लेकर 3 घंटे तक पीसा गया और इसे निर्माण सामग्री के रूप में उपयुक्तता के लिए परीक्षण किया गया। इसके अतिरिक्त, बायोमास फ्लाई ऐश की भी निर्माण सामग्री के रूप में उपयुक्तता के लिए जांच की गई। उनके रासायनिक और भौतिक गुण, प्रतिक्रियाशीलता, और कंक्रीट मिश्रण में समग्र प्रदर्शन का आकलन करने के लिए विभिन्न परीक्षण किए गए। दोनों ऐश के कंक्रीट की ताकत और कार्यशीलता में योगदान का मूल्यांकन करने के लिए दक्षता तत्व विधि (Efficiency factor method) का उपयोग किया गया।

शोध में गीले और सूखे छलनी, ब्लेन फाइननेस और स्कैनिंग इलेक्ट्रॉन माइक्रोस्कोपी (एसईएम) इमेजिंग दोनों में कण आकार वितरण की गहन जांच शामिल थी। दूसरा, दोनों राख की प्रतिक्रियाशीलता का आकलन स्थापित कोडों का उपयोग करके किया गया था। इन कोडों का तुलनात्मक अध्ययन, उनकी खामियों के साथ प्रस्तुत किया गया है। EN450 को छोड़कर अधिकांश कोड कार्यशीलता आवश्यकताओं के आधार पर पानी की मात्रा का उपयोग करते हैं जो सही नहीं है। चूना प्रतिक्रियाशीलता परीक्षण केवल भारतीय कोड में था। विस्तृत अध्ययन में मानक चूना प्रतिक्रियाशीलता परीक्षण और मोर्टार-आधारित शक्ति गतिविधि सूचकांक का उपयोग किया गया था, जिसमें 20% फ्लाई ऐश और निश्चित जल पाउडर अनुपात को अपनाया गया था। इन सभी अध्ययनों से पता चला है कि 45 मिनट तक पीसने पर बॉटम ऐश के गुण सामान्य फ्लाई ऐश के समान ही होते हैं और आगे पीसने से बॉटम ऐश की प्रभावशीलता बढ़ जाती है। इस प्रायोगिक श्रृंखला ने 20% फ्लाई ऐश मामलों के लिए दक्षता कारक प्रदान किया।

प्रयोग सेट 1, 0.5, 0.45 और 0.4 के प्रभावी w/c के साथ सभी राख प्रतिशत 0%, 25%, 35% और 45% के साथ किया गया था। इसने अलग-अलग फ्लाई ऐश प्रतिशत पर अलग-अलग फ्लाई ऐश के लिए दक्षता कारक प्रदान किया। प्रयोग सेट 2 को राख के तीन अलग-अलग स्तरों के साथ प्रभावी w/c की विस्तृत श्रृंखला के लिए दोहराया गया और परिणामों ने प्रयोग सेट 1 में निर्धारित दक्षता कारक की पुष्टि की।

बॉटम ऐश और बायोमास फ्लाई ऐश को शामिल करने वाले कंक्रीट मिक्स के प्रदर्शन का मूल्यांकन करने के लिए जल पारगम्यता (DIN 1048 भाग 5), संशोधित जल पारगम्यता और रैपिड क्लोराइड प्रवेश परीक्षण (RCPT) सहित स्थायित्व अध्ययन किए गए।

बायोमास फ्लाई ऐश के कार्यक्षमता पर लाभकारी प्रभावों के बावजूद, यह किसी भी पॉज़ोलानिक गतिविधि को प्रदर्शित नहीं करता है। यह महसूस किया गया कि बायोमास फ्लाई ऐश की प्रतिक्रियाशीलता को बढ़ाने के लिए बायोमास फ्लाई ऐश पर आगे अनुसंधान की आवश्यकता है।

निष्कर्ष में, मुख्य निष्कर्ष बताते हैं कि 45 मिनट के लिए नीचे की राख को पीसने से फ्लाई ऐश के समान इसकी पॉज़ोलानिक प्रतिक्रियाशीलता प्रदर्शित होती है, लंबे समय तक पीसने से बेहतर पारगम्यता और ताकत के माध्यम से स्थायित्व में वृद्धि होती है। निष्कर्ष यह भी सुझाव देते हैं कि ग्राउंड बॉटम ऐश, विशेष रूप से जब तीन घंटे के लिए पीसा जाता है, एक उच्च दक्षता कारक प्रदर्शित करता है और प्रभावी रूप से उच्च शक्ति वाले कंक्रीट मिश्रण में उपयोग किया जा सकता है। शोध में वर्तमान चूने की प्रतिक्रियाशीलता मूल्यांकन विधियों में महत्वपूर्ण संशोधनों पर भी प्रकाश डाला गया है, जो कंक्रीट उत्पादन की स्थिरता को बढ़ाने के लिए इन वैकल्पिक सामग्रियों की क्षमता पर प्रकाश डालता है।

कीवर्ड्स: दक्षता तत्व, बॉटम ऐश, फ्लाई ऐश, चूने की प्रतिक्रियाशीलता, स्ट्रेंथ एक्टिविटी इंडेक्स, पीसाई

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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
CEM	Cement
DIN	Deutsches Institute for Normung (meaning German institute for standardisation)
Dxx	‘xx’ percent of sample mass has diameter less than D-value
FA	Fly ash
GGBS	Ground granulated blast furnace slag
HS	High strength
IIT	Indian Institute of Technology
IS	Indian Standard
LS	Low strength
NS	Normal strength
OPC	Ordinary Portland cement
PCE	Polycarboxylate ether
PPC	Portland pozzolana cement (fly ash-based)
S _{7 days}	7 days compressive strength of concrete
S _{28 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

Al ₂ O 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%,f%	Fly ash percentage (%), that is, $f/(c+f)$
k-value	Efficiency factor of fly ash
min	Minute (time)
s/a	Sand to total aggregate ratio
T25	Time required for 25mm of water penetration from the concrete surface
w	Water (kg/ m^3)
w/b	Water to binder (c+f) ratio
w/c+kf	Effective water to cement ratio