Iowa State University
Institute for Transportation

Beneficial Use of Iowa Waste Ashes in Concrete through Carbon Sequestration

tech transfer summary

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RESEARCH PROJECT TITLE
Beneficial Use of Iowa Waste Ashes in Concrete through Carbon Sequestration

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The mission of the Institute for Transportation (InTrans) at Iowa State University is to save lives and improve economic vitality through discovery, research innovation, outreach, and the implementation of bold ideas.

Certain types of waste ashes can increase the decarbonation of cement and concrete, providing a use for the waste ashes and promoting sustainability.

Objectives and/or Goal

This project aimed to investigate the potential for the utilization of carbon-treated waste ashes in concrete by doing the following:

- Optimize carbon treatment conditions
- Investigate the effects of carbon treatment on the properties of waste ashes
- Examine the effects of carbon-treated ashes on the properties of cement-based materials
- Assess the embodied carbon reduction potential of mortar containing carbon-treated ashes

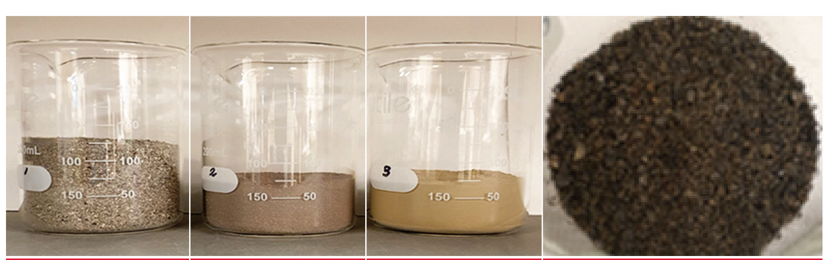
Background and Problem Statement

Annual cement consumption has increased steadily over the last decade. Because each pound of concrete releases 0.93 lb of carbon dioxide, it is important to consider the environmental impact of this increase.

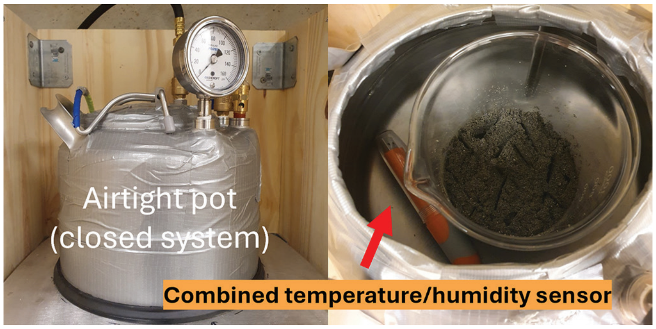
Recycled wastes (e.g., slag and fly ash) are widely used as supplementary cementitious materials (SCMs), which can help reduce the environmental impact of concrete. However, a significant amount of waste ashes cannot be used because they do not meet national and state material specifications. Additionally, safely disposing of these waste ashes poses a problem for power plants. Current disposal options pose risks to the surrounding environment, such as ground and surface water contamination.

Research Description

Physical and chemical analyses were carried out on four different ashes. Two of the ashes were refuse-derived fuel (RDF) ashes from the Ames Municipal Power Plant, which included RDF fly ash (RFA) and RDF bottom ash (RBA). The other two were coal ash (IFA) from the Iowa State University (ISU) Power Plant and a commercial Class C fly ash (CFA).



Ashes collected



Experimental setup for carbon treatment: carbon chamber (left) and sample in the chamber (right)

Carbon treatments of the waste ashes were performed under different CO_2 pressures and moisture contents. The carbon sequestration capacities of the waste ashes were assessed based on the weight loss of the tested samples measured using thermogravimetric analysis (TGA).

The carbon-treated fly ashes were then used as cement replacement in mortar, and the carbon-treated bottom ashes were used as sand replacement in mortar. Each mortar mixture was mixed following ASTM C305, and flow table testing was conducted immediately after mixing according to ASTM C1437. The mortar mixtures were cast in 2 in. cube molds, and compressive strength testing was performed at the ages of 3, 28, and 56 days.

Key Findings

Properties of Waste Ashes

- RFA and IFA displayed mostly irregularly shaped particles. Their fineness values, chemical composition, $SiO_2 + Al_2O_3 + Fe_2O_3$ content, and loss on ignition (LOI) did not satisfy the requirements of ASTM C618.

- RFA also had an alkali $(Na_2O)_{eq}$ content significantly higher than the ASTM C618 requirement. It contained a certain amount of metallic aluminum and zinc, which could hydrate and generate air bubbles, causing severe cement paste expansion.

- IFA had a sulfur (SO_3) content significantly higher than that required by ASTM C618.

- RBA displayed a similar particle shape to RFA and had a lower specific gravity and higher absorption than river sand.

Carbon Sequestration Capacity

- IFA had the highest carbon sequestration capacity (CO_2 intake), followed by RFA and then RBA. Carbon treatment for CFA was not effective.

- Moisture content had the most significant effect on the carbon treatment effectiveness. The optimal moisture content for carbon treatment was 10% to 20% for IFA, 20% to 70% for RFA, and near 20% for RBA.

- The effect of CO_2 pressure on carbon sequestration capacity varies depending upon the moisture condition and type of the waste ashes. The highest carbon sequestration capacity occurred at a pressure of 200 kPa and a moisture condition of 10% for IFA, at a pressure of 200 kPa and a moisture condition of 40% for RFA, and at a pressure of 100 kPa and a moisture condition of 20% for RBA.

- At a high moisture content, reactive fly ashes (IFA and CFA) began to harden during carbon treatment due to hydration and carbonation reactions.

Effects of Carbon-Treated Ashes on the Properties of Cement-Based Materials

- During the carbon treatment, the metallic aluminum was oxidized, and therefore carbon-treated RFA used in cement-based materials showed little to no visible expansion.

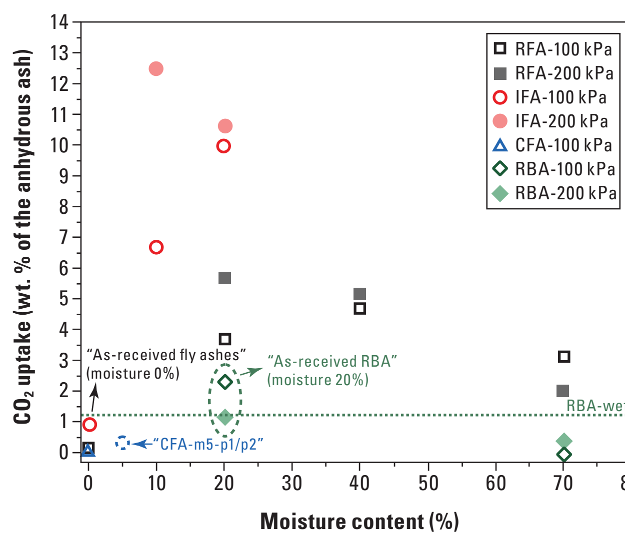
- Carbon treatment of RFA and RBA effectively improved their mortar flowability and strength.

- Carbon-treated CFA suffered from particle agglomeration and pre-hydration, leading to negative effects on both flowability and strength.

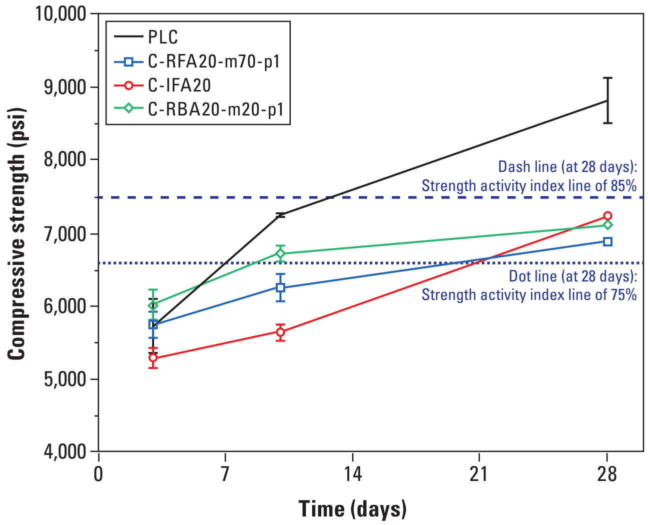
Effects of Carbon Curing for Mortar Containing Carbon-Treated Waste Ashes

- Applying carbon curing for cast mortar samples further reduced the embodied carbon in the mortar, leading to the total reduction of the mortar by 20% to 25%.

- The compressive strength of mortars containing carbon-treated RFA and RBA and subjected to a carbon curing process was comparable to that of portland limestone cement (PLC) at 3 days but was about 80% of the strength of PLC at 28 days.



Effect of ash moisture content on carbon intake



Compressive strength of mortar cubes containing carbon-treated ashes and subjected to carbon curing after casting

Carbon Intensity of Mortar

- Carbon-cured mortar mixes C-RFA-m70-p1 (containing 20% RFA carbon-treated at a moisture content of 70% and 100 kPa pressure), C-IFA20 (containing 20% untreated IFA), and C-RBA-m20-p1 (containing 20% RBA carbon-treated at a moisture content of 20% and 100 kPa pressure) showed strength-normalized embodied carbon intensities (i.e., the embodied carbon per strength and per volume of the tested mortar) approximately 35% and 22% lower than those of non-carbon-cured ordinary portland cement (OPC) and PLC mortar mixes at the ages of 3 and 28 days, respectively.
- In consideration of cement and transportation costs, use of 20% carbon treated waste fly ashes to replace cement in normal strength concrete (3000-5000 psi) can save the concrete material cost over 20%.

Recommendations and Conclusions

- The as-received RFA and IFA do not meet ASTM C618, and therefore these ashes cannot be used as supplementary cementitious materials directly.
- The moisture content of waste ashes, followed by CO_2 injecting pressure, has a significant impact on the effectiveness of carbon treatment.
- From the perspective of concrete strength, carbon treated RFA and RBA can be used as cement replacement and sand replacement in concrete, respectively.
- From the perspective of reducing the embodied carbon in concrete, 20% carbon-treated RFA can be used as cement replacement in mortar and concrete.
- Carbon treatment is not recommended for reactive ashes like IFA and CFA.

Implementation Readiness and Benefits

Certain types of waste ashes can aid in the decarbonation of cement and concrete. This provides a use for the waste ashes and promotes sustainability through carbon sequestration.

Based on the research findings, using carbon-treated waste ashes as a substitute for cement and sand replacement is a viable option. The recommendations resulting from this research offer more specific information and guidance on the most beneficial types of waste ashes to use, though further research should be conducted on the effects of carbon-treated waste ashes on concrete durability.