Introduction

When incorporated in concrete mixtures, fly ashes are known to influence both their fresh and hardened properties. An accurate and quick technique to predict the extent of this influence, and one which takes into account the physical and chemical characteristics of fly ash, would be highly beneficial in terms of field applications. The current study was an attempt to quantify the effects of fly ashes on the properties of pastes as a function of the mean particle size of the fly ash particles, their fineness, and their chemical composition. In addition, since both the type and the amount of glass present in the fly ash significantly affect its reactivity, this property was also included in the investigation.

Findings

Twenty different fly ashes (ASTM Class C and Class F) obtained from power plants in and around Indiana were characterized during Phase 1 of the study. The information collected included physical characteristics, chemical composition, and the amount and type of glass present. Phase 2 of the study consisted of the evaluation of various properties of binary paste systems (prepared by replacing 20% by weight of cement with one type of fly ash). The evaluated properties included the set time, heat of hydration, strength activity index, non-evaporable water content, and amount of calcium hydroxide formed at different ages.

The results obtained from these two phases of the study were used to build statistical models for prediction of previously evaluated properties for any hypothetical fly ash with similar characteristics. The models included only the most significant variables—that is, those which were found to most strongly affect any specific property. The variables to be included in the model were selected based on the adjusted $R^2$ values.

As a result of the modeling process, it was found that the sets of statistically significant variables affecting the properties consisted of both physical and chemical characteristics of the fly ash, and that the combination of these variables was unique for each property evaluated.

Phase 3 of the study consisted of evaluating the same set of properties but using ternary paste systems (cement and two different fly ashes). The goal for this study was to ascertain the applicability of the weighted sum of the models chosen for the binary paste systems to predict the properties of ternary binder systems. In addition, an analysis to determine which of the chosen variables had the maximum effect on the properties was performed. It was found that the properties of the ternary binder systems were not additive in nature, except for strength activity index at 28 days. Lastly, the percent of influence of each of the chosen independent variables that affected the mentioned properties, was calculated, along with the unexplained variation (error percentage). The error percentages varied for each of the properties, with set time having the maximum error (almost 50%).

The statistical studies resulted in a conclusion that both the physical and the chemical characteristics of fly ash affect the properties of the pastes containing ashes at all the ages. The sets of variables affecting various binder properties were unique for each of the properties evaluated. However, the variable which was found to have the most significant effect on almost all properties was the specific surface area of the fly ash grains.

The Indiana Department of Transportation personnel as well as the contractors using state-approved fly ashes in their mixtures can use the models developed in this study for preliminary performance prediction purposes. In addition, a complete database of all pertinent characteristics of fly ashes from INDOT’s approved sources has been prepared and is available (as a supplement to this report titled Fly Ash Handbook (FAH) and available for download at https://doi.org/10.5703/1288284315213) for quality control and modeling purposes.

Implementation

Based on the data on fly ash characteristics collected in this study and the results of the laboratory experiments performed, the following implementation suggestions are offered:
The results from the paste study and fly ash database compiled in the *Fly Ash Handbook* (FAH) developed over the course of this research can be used as a source of baseline information when performing a comparative assessment of potential influences of changes in the quality of the fly ash on the properties of concrete.

Since the report contains a detailed evaluation of how fly ash characteristics influence properties of both binary and ternary paste systems, the data contained in the FAH can be consulted and used along with the statistical models for prediction of previously evaluated properties for any hypothetical fly ash with similar characteristics.

Requirements related to the need for conducting trial batches in cases involving change of the fly ash source set forth in section 500 of INDOT’s specification should consider allowing a contractor to continue the production if the source of a new pozzolans can be verified (using data supplied in the FAH) as being similar to the old source in terms of physical and chemical characteristics.

Consider initiation of a field trial project to assess the benefits of using ternary mixtures (i.e., portland cement and two fly ashes) and to verify if a blend of good and lesser quality fly ash may produce concrete of a quality comparable to concrete utilizing only high-quality fly ash. If successful, such approach may offer a very effective way of dealing with the seasonal shortages of high-quality fly ash and reduce the cost of construction while improving the quality of concrete.

The benefits of this research include the following:

- Generation of a comprehensive set of information about essential physical and technical characteristics of 20 fly ashes (13 Class C and 7 Class F) available for use in concretes supplied to INDOT.
- Identification of a group of fly ashes with comparable common characteristics, thus providing INDOT engineers with a decision-making tool for potential substitution of sources.
- Development of an easy-to-navigate electronic FAH (a supplemental file to this report, available for download at https://doi.org/10.5703/1288284315213) as a tool for engineers to quickly check the physical and chemical characteristics of fly ashes investigated in this project. The FAH offers the benchmark data which can be used for relative assessment of fly ashes from alternative sources with respect to their suitability for use on INDOT projects.
- Development of a statistical model for prediction of both fresh and hardened properties of binary (cement plus one fly ash) and ternary (cement plus two fly ashes) cementitious systems based on the characteristics of fly ashes included in the FAH.

**Recommended Citation for Report**


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