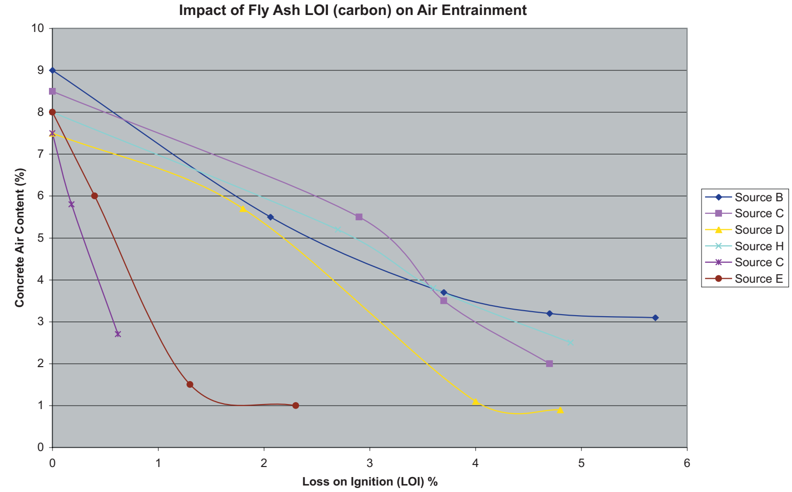
The Impact of **Fly Ash on Air-Entrained Concrete**

Influence of fly ash LOI value on air entrainment of concrete.



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The use of fly ash to produce more durable concrete is a well-established practice. The judicious use of fly ash results in reduced heat of hydration, increased later age concrete strengths, and reduced permeability. The use of appropriate dosages of fly ash enhances durability by providing mitigation of alkali-silica reactions, resistance to sulfate attack, and reduced ingress of potentially deleterious materials such as chloride and water. The widespread use of fly ash in high performance concrete (HPC) was confirmed in a survey of state highway agencies conducted by the FHWA. The survey indicated that 70 percent of the respondents incorporated fly ash in HPC mixtures exposed to aggressive environments.

Perhaps one of the most significant issues that must be considered when utilizing fly ash in concrete is the potential impact this material can have on air entrainment. Special chemical air-entraining admixtures (AEAs), which are based on surfactant chemistry, are used to entrain the correct air-void system in plastic concrete. These chemicals are very effective and only small dosages are generally required; however, the system represents a rather delicate balance of many factors. The Manual on Control of Air Content in Concrete [(1)] lists over 40 parameters that can influence concrete air entrainment. Fly ash is one item on the list, but depending on the nature of the ash, it can have a major influence on air entrainment.

The reason fly ash has such a critical role regarding air entrainment is not due to the ash itself but is related to a potential contaminant that exists in much of the ash produced today. As a by-product of coal combustion, fly ash often contains a small proportion of unburned, residual carbon. This carbon is typically measured by performing a loss on ignition (LOI) test. The carbon component of fly ash can act as an adsorbent of organic material (just as activated carbon is often used to purify water). Fly ash carbon has a strong tendency to interact with the surfactants used as air-entraining admixtures. As the LOI value of fly ash increases, the dosage of air-entrainment chemical required to produce a given air content will generally increase as well. Furthermore, fluctuations in fly ash LOI (carbon) result in fluctuations in concrete air content. This situation requires carefully quality control by the concrete producer and frequent adjustments to admixture dosages.

Because of the negative influence of fly ash carbon on air entrainment, AASHTO M 295 – Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete stipulates a maximum LOI value of 6 percent for fly ash to be used in concrete without further qualification. Many specifying agencies and fly ash suppliers will impose more restrictive LOI limits in an attempt to improve quality.

The past decade has marked changes in the utility industry that have further complicated the use of fly ash for air-entrained concrete. Environmental regulations designed to reduce the quantity of acid rain promoting air pollutants that utilities generate have been broadly implemented. As a result, many utilities are retrofitting plant equipment to operate under new combustion regimes. Unfortunately, the combustion conditions that lead to reduced air emissions can result in increased fly ash carbon contents. For instance, the retrofitting of a utility's combustion units to reduce NOx emissions will often cause the LOI of a given fly ash produced by the facility to more than double.

To further complicate this issue, the modified combustion systems not only impact the amount of carbon available in the ash, but the activity of the carbon as well. The adsorption capacity of fly ash carbon for air-entraining admixtures is a function of carbon mass and other carbon characteristics such as carbon surface area, carbon pore size distribution, and carbon surface chemistry. Modification of any of these parameters can impact the adsorption capacity of the fly ash carbon.

In practical terms, this means that certain changes made by a utility to combustion conditions can result in minimal impact on carbon mass or LOI but will still significantly modify the influence that a fly ash has on air entrainment. This occurs because changes in the carbon's surface area or surface chemistry lead to a change in the carbon's adsorption capacity. Data presented in the figure depicts the influence of LOI (carbon content) on air entrainment for a number of fly ashes collected from different utility sources. It is readily apparent that fly ash from Sources C and E will be the most problematic for air entrainment even though these ashes possess the lowest LOI value of any tested.

The impact that various pollution control technologies will have on fly ash quality varies based on the specific modifications made at a plant, the fuels being fired, the combustion regime already in existence, and the compliance requirements mandated for a particular source. In many situations, the impact may be minimal, but in other cases the quality of the ash will be changed drastically. As future air quality emission standards become more restrictive, it is probable that more fly ash sources will be impacted by these types of combustion modifications.

In order to better manage fly ash quality with respect to air entrainment, many

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suppliers no longer rely strictly on LOI value as a measure of quality. Performance-based testing such as the foam index test (referenced in ACI 232.2) and mortar air testing (AASHTO T 137) are often used to determine product acceptance. Measuring the surface area of fly ashes, using methods such as BET absorption, can generate useful data for those ashes in which the surface area of the carbon has been increased through modified burning processes, but this testing regime is not feasible as a quality control test in most cases. The most direct means for determining a fly ash's potential to impact air entrainment is to perform laboratory or field trial mixtures in concrete with the job specific materials.

Additional advances in the fly ash industry include the development of new beneficiation technologies designed to minimize the impact that fly carbon has on concrete performance. Carbon burn out is one such technology that is in commercial operation. In this system, the carbon-contaminated fly ash is processed through a fluidized bed combustion unit to remove the residual carbon content to an acceptably low level. The processed, reduced-carbon fly ash will have little impact on air entrainment. Another method of reducing carbon in fly ash is the use of electrostatic separators that selectively remove the carbon from the fly ash and subsequently use this removed carbon as a fuel for the combustion process.

Another commercially available technology is based on fly ash carbon treatment (FACT). In this technology, a proprietary chemical formulation is applied to the ash that acts as a sacrificial agent. The sacrificial agent has no influence on concrete air entrainment other than its strong tendency to interact with fly ash carbon and thus reduce its adsorption capacity for AEAs. By "sacrificing" to the carbon, the FACT chemicals effectively reduce fluctuations in air entrainment that would normally be associated with changes in carbon mass or activity.

Research is being conducted by a number of universities, agencies and suppliers to better understand the interactions between fly ash carbon and chemical surfactants. Results from these studies will be used to allow for better utilization of fly ash to produce durable concrete for all environments.

Reference

Whiting, D. A. and Nagi, M. A., "Manual on Control of Air Content in Concrete," Bulletin EB116, Portland Cement Association, Skokie, IL, 1998, 48 pp.

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