ABSTRACT

De la Varga, Igor. Ph.D., Purdue University, August 2013. Increased Fly Ash Volume and Internal Curing in Concrete Structures and Pavements. Major Professor: W. Jason Weiss.

Fly ash, a by-product generated by the combustion of coal, has been broadly used in concrete applications over the last half century. Fly ash is typically used as either an addition or as a cement replacement. It is the replacement of cement with fly ash however that enables the fly ash to have sustainability benefits as it can efficiently reduce the clinker factor, and CO_2 production in concrete. Fly ash use in the US accounted for a 12% average replacement of cement in 2008, but it is frequently used in higher dosages for certain applications (e.g., mass concrete). In addition to its benefit in reducing the clinker content and embodied CO_2 per yard of concrete, fly ash is an industrial by-product that is able to be re-used thus preventing the need for it to be land-filled. The use of fly ash can also increase the long-term strength and durability of concrete. This is the reason why many producers and transportation agencies are investigating the use of higher volumes of fly ash.

In this work concrete mixture designs have been developed with cement replacement levels of more than 40 % by volume. However, many hurdles exist to implementing this type of mixtures in practice, including: 1) potential incompatibilities among fly ash,

admixtures, and cement; 2) strict limits on the maximum fly ash permitted and the time of the year that it can be used; 3) delays in set time and strength development that slow construction operations; and 4) concerns about providing enough and proper curing. This thesis examined potential solutions for items 2 through 4.

This thesis develops a strategy for using high volumes of fly ash to replace cement in concrete (higher volumes than conventionally used). The work seeks to minimize potential issues associated with early strength development that occur when fly ash replaces part of the cement fraction by using a lower water-to-cementitious materials ratio (*w/cm*). While a lower *w/cm* would be beneficial in terms of improved mechanical and transport properties, it has been shown that these mixtures may be more susceptible to early-age shrinkage cracking and poor curing due to the slower reaction of the fly ash. This thesis evaluates the use of internal curing using pre-wetted lightweight aggregates to reduce autogenous shrinkage and cracking potential while enabling more of the fly ash to react by providing water curing for longer time periods.

An extensive study that evaluates mechanical, shrinkage, hydration, and transport properties of low *w/cm* internally cured HVFA mortar mixtures is presented in this thesis. The HVFA mixtures performance is compared to that of the mortar fraction of a typical bridge deck concrete mixture design used in the state of Indiana (with *w/c*=0.42). The main findings include similar early-age strength development and increased long-term strength in the low *w/cm* internally cured HVFA mixtures. These mixtures also have a reduced potential for autogenous and thermal shrinkage cracking. It is also shown in this thesis that while the transport properties of low *w/cm* High Volume Fly Ash mixtures (with or without internal curing) are considerably reduced compared to a control *w/c*=0.42 mixture, internal curing provides similar transport properties in concrete with similar cementitious content. Two additional chapters are included in the thesis where the interpretation of electrical properties and fly ash reactivity of HVFA mixtures is discussed. The first of these two chapters explains the differences in the measured electrical conductivity between 100 % ordinary portland cement and high volume fly ash systems. The proper interpretation of these results becomes crucial when using electrical properties as long-term performance predictors. In regards to the study on fly ash reactivity, the results obtained show both physical (i.e., provision of additional nucleation sites and increased cement particles spacing) and chemical (i.e., pozzolanic activity) contributions of the fly ash during the first days of hydration and a more dominant chemical effect at later ages.

The results obtained in this thesis show that low *w/cm* internally cured HVFA mixtures provide additional benefits that should permit a larger use of fly ash and internal curing in concrete applications.