PROJECT SUMMARY

The United States produces approximately 120 million tons of fly ash and other coal combustion products (CCPs) each year. While about 40% of CCPs are used, the rest are generally disposed. Although the benefits of fly ash in concrete (such as reductions in cost and environmental impact and improvements in concrete flow ability and long-term strength) have been well recognized, only 20% or less fly ash is commonly used for portland cement replacement in pavement concrete. Some concerns about slow hydration of fly ash and its inconsistent interactions with other concrete materials (such as supplementary cementitious materials and chemical admixtures) still impede significant use of fly ash. There is an urgent need for properly characterizing and tailoring fly ash concrete materials so as to spur the utilization of a larger volume of fly ash in concrete construction.

Due to its small, smooth, and spherical shape, fly ash can greatly improve fluidity of fresh concrete. It is therefore increasingly used in self-consolidating concrete (SCC). With no need for vibration, SCC delivers easy, fast, and high quality construction. Recently, the SCC concept has been applied to slip form construction by the principle investigators (PIs) of this proposal. Through engineering material mix proportions and properties, semi-fluid SCC (SF SCC) has been developed and successfully applied to field pavements. Research also shows that well-dispersed nano-materials (such as nano-silica and nano-clay) can effectively improve the early age strength and thixtropic behavior of cement-based materials, thereby compensating the deficiency of fly ash concrete at early age.

The goal of the proposed study is to develop a new generation fly ash concrete – a nano-material modified fly ash concrete with high fly ash content – for SCC and pavement application. This goal will be achieved through material modification, multi-scale characterization, and improved processing.

Existing research has approved the concept used in the proposed study for the material modification: when a nano-material is properly incorporated into fly ash concrete, the deficiencies of the nano-material and fly ash will be compensated by the advantages of each material, and the advantages of the both materials will act synergistically. A key component and novel aspect of the proposed work is the study of the interactions between fly ash and nano-materials. Such interactions and their effects on concrete performance will be examined through three stages of material characterizations: (1) raw material characterization at nano/microscale, where the chemistry, particle properties (size distribution, shape and morphology), and reactivity of the raw materials will be investigated; (2) plastic mixture characterization at micro/mesoscale, where rheology and calorimetry of freshly mixed concrete materials will be researched; and (3) hardened material characterization at nano/micro/macroscale, where microstructure, hydration products, mechanical properties, and durability of the concrete materials will be evaluated. The study of concrete processing will be focused on the combined effect of fly ash and nano-particles on concrete rheology, consolidating ability, and shape-holding ability, especially on the flocculation strength enhanced by nano-clay in fly ash concrete. Optimal mix proportions, consisting of a large volume of fly ash and nano-materials, will be developed for SCC and SF SCC based on the characterization results. Nano-indentation will be used for identifying nano-phases influenced by different fly ash compositions as well as for characterizing the paste-aggregate interface. The mixtures that meet defined performance criteria will finally be verified for their applicability for slip form construction using a minipaver, which simulates field slip form construction. The environmental impacts (such as global warming potential, weight resource use, and energy use) of the new generation fly ash concrete will also be assessed.

An important deliverable of the proposed study is a set of SCC and SF SCC mix proportions that contain a large volume of fly ash. These mixes will meet the criteria for satisfactory/excellent performance for pavement construction. The results obtained from the designed experiments will provide insight into the roles of fly ash and its interactions with portland cement and nano-materials in concrete. These results will also help establish guidelines for mix proportioning SCC and SF SCC for concrete pavements.

An interdisciplinary team, consisting of members from Iowa State University (ISU) and Northwestern University (NU), has formed. The team members have successfully developed SF SCC for slip form paving and have done extensive work on cementitious material characterization, hydration, concrete mixture proportioning, rheology, nano-technology, and durability. They are looking forward to accomplishing the proposed transformative research.