Research Advances on the Use of Solid Wastes in Concrete and Asphalt

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ABSTRACT

This proposal describes research designed to expand knowledge pertaining to the use of recycled glass powder (GP) and waste-to-energy bottom ash (WTE BA) in concrete and asphalt. These materials will be evaluated as supplementary cementitious materials (in the case of GP) and as aggregate (WTE BA) in the manufacture of portland cement concrete (PCC) and asphalt. This research builds upon recent work related to the beneficial use of both of these materials, and aims to address new issues identified during the course of this previous research and that are necessary to address to fully assess long term viability of the proposed recycling activity. The research team will start by examining the combined use of GP as a cement replacement and WTE BA as an aggregate replacement. Second, the treatment/conditioning of WTE BA to improve its beneficial use marketability will be explored. Finally, the economic feasibility of using WTE BA and GP instead of natural aggregates and cement in the manufacture of concrete and asphalt will be assessed. The results of this research will provide a resource for future decision-making by facility operators, contractors, engineers and regulators regarding the recycling of WTE ash and post-consumer glass in Florida.

PRINCIPAL INVESTIGATORS

The investigators for the proposed research are Timothy Townsend, a Professor in the Department of Environmental Engineering Sciences, and Chris Ferraro, a Research Assistant Professor in the Department of Civil and Coastal Engineering, both at the University of Florida.

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Dr. Townsend's area of specialization is solid and hazardous waste management and engineering. With 25 years of research experience in different topics of solid waste management, Dr. Townsend's work includes the review of different solid waste materials as supplements to Portland cement in concrete and the environmental effect of WTE ash used as aggregate in concrete. Dr. Ferraro's research focus is the behavior of the physical characteristics and the chemistry of infrastructure materials, the use of alternative pozzolans in cementitious materials, and nondestructive testing of PCC. Both professors have a well-established work relationship with the WTE industry in Florida, the construction industry, and the regulatory community.

MOTIVATION AND PROJECT JUSTIFICATION

Market demand for post-consumer glass is relatively low, causing much of the glass recovered at Florida material recovery facilities to be landfilled. In fact, many communities in the state are now excluding glass from their curbside recycling programs. At the same time, reduction in the use of coal for energy production has caused a shortage of coal fly ash which is commonly used as a supplementary cementitious material (SCM) in the production of Portland cement concrete. Beneficial use of post-consumer glass as a SCM creates a new market for this material, reduces the necessity of mining virgin minerals for the production of cement, and addresses the coal fly ash shortage. Prior research by the University of Florida has shown that GP provides satisfactory performance as a SCM in traditional concrete. However, there are still issues that must be resolved before glass can be recycled as a SCM on a large scale. These issues include development of processes to clean and size-reduce post-consumer glass and examination of the infrastructure necessary for producing this material on a large scale.

Florida has more WTE facilities than any other state in the US, and BA generated by these facilities is currently disposed in landfills. Beneficial use of this material has the potential to reduce landfill airspace consumption and the necessity of mining virgin aggregates for the production of asphalt and Portland cement concrete. The University of Florida and other researchers around the world have shown that WTE BA can provide adequate performance in concrete and asphalt pavements as a partial coarse aggregate substitute. However, metals (i.e. aluminum), ions (i.e. chloride, sulfate), and fine particulates within untreated WTE ash have been shown to be detrimental to concrete and asphalt pavement performance.

BACKGROUND

The use of solid waste materials in the production of concrete has been proposed as a beneficial use application of different waste streams. Potential applications include not only the replacement of the aggregates, but also the replacement of Portland cement in the mix. Considerations when evaluating the suitability of a waste material for beneficial use include potential environmental impact, the quality of the product created, and the economic feasibility of reusing the material (along with any required pretreatment). Among the most effective materials used as supplementary cementitious materials (SCM) are coal fly ash, rice husk ash, sugar cane baggase ash, and recycled glass. UF researchers have recently examined the performance of glass powder (GP) as a SCM (Paris et al. 2015) and the use of waste-to-energy bottom ash (WTE BA) as aggregate replacement in Portland cement concrete (PCC) and asphalt pavement (Ferraro et al. 2016, Roessler et al. 2016). The State of Florida, through the Hinkley Center and the FDOT, have lead the way nationally on these issues, and while these beneficial use options hold great promise, additional technical, environmental and economic issues remain to be addressed. Research is proposed here to address these issues and to complement previous and ongoing work so that facility operators, contractors, engineers and regulators can make more informed decisions regarding the recycling of WTE ash and post-consumer glass in Florida.

The use of WTE ash in concrete is currently the focus of UF research. As part of research for Pasco County, the Solid Waste Authority (SWA) of Palm Beach County, and Hillsborough County, the team has found that aggregate products derived from WTE ash can indeed meet necessary compressive strength requirements at meaningful large aggregate replacement percentages. More recent testing has begun to examine the long term durability associated with WTE ash used as an aggregate. For example, the potential for expansion due to alkali silicate reactivity (ASR) has been tested following ASTM C1260, which is an accelerated testing method. Figure 1 shows the results after 14 days expansion of mortar bars due to ASR with different ash replacements using ash from the two SWA facilities. The testing indicates that high percentages of ash replacement can result in deleterious expansion of the concrete. This is not surprising, given the chemical nature of WTE ash, however this finding does not diminish the viability of WTE ash recycling as an aggregate. It suggests that steps should be implemented to mitigate ASR as part of a concrete mix design It has been reported the use of different solid wastes such as coal fly ash and glass powder for replacing Portland cement in concrete due to their pozzolanic nature; beyond this, coal fly ash has been found to offer a benefit in terms of reducing the potential for ASR expansion.

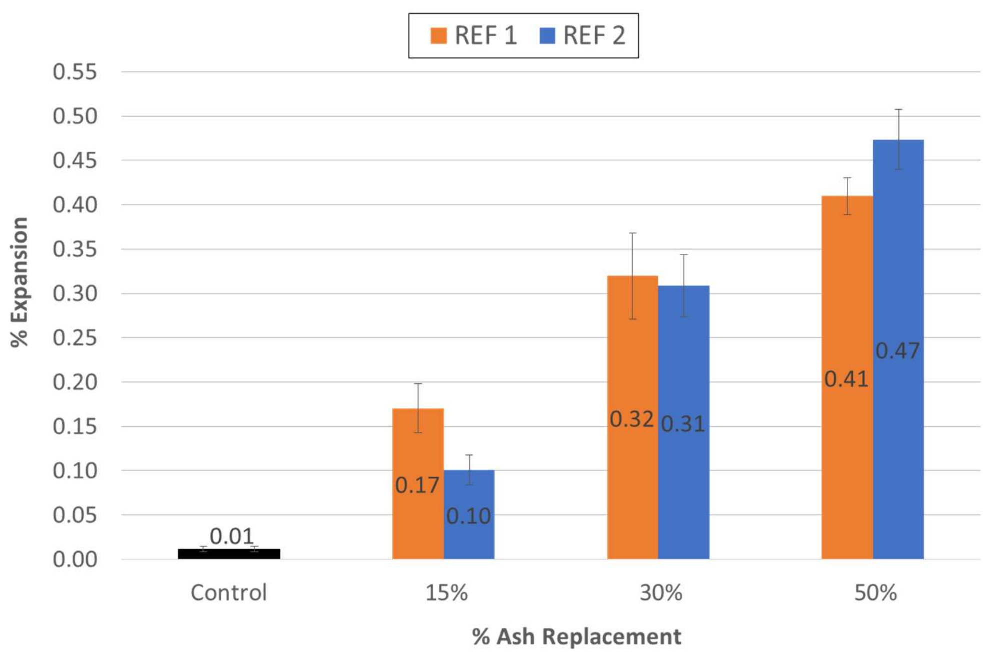

Figure 1. Alkali Silica Reaction expansion after exposure per ASTM C1260. Concrete mixes using 3 levels of bottom ash replacement as coarse aggregate. Bottom ash obtained from two SWA WTE facilities.

Glass powder made from recycled glass processed to reach a particle size of less than 45 µm has been shown to have the potential to behave as a pozzolan in this team's research as well as other Hinkley Center work. There are still many technical issues that must be resolved before glass can be sustainably recycled as a SCM. Perhaps the most challenging aspect of this recycling approach is the development of infrastructure and markets to capture this glass, process it, and route it to appropriate end-users. For example, glass cullet recovered from a municipal recycling system must be cleaned to a sufficient purity and size-reduced to an appropriate dimension. Figure 2 shows the results of a glass composition study conducted by the research team on the recycled glass stream at Alachua County's Material Recovery Facility. The necessary infrastructure (and associated costs) for cleaning and processing the glass requires additional investigation to determine how viable this practice is.

The benefits of combining WTE ash and GP warrant additional investigation; given the relation of the WTE facilities to municipal recycling programs, the combined use of both materials may offer some synergistic opportunities for beneficial use.

Similar to GP, WTE ash also requires processing to make a viable product. To date, the research team's efforts have focused on screening and aging the ash. Another possible treatment step that could be implemented is washing the ash, which has been observed by the PI in Japan (see Figures 3 and 4) and Europe. This step clearly adds additional cost to the process, but it has the potential to create ash products that would have more widespread applications, better performance and pose a lesser risk to the environment.

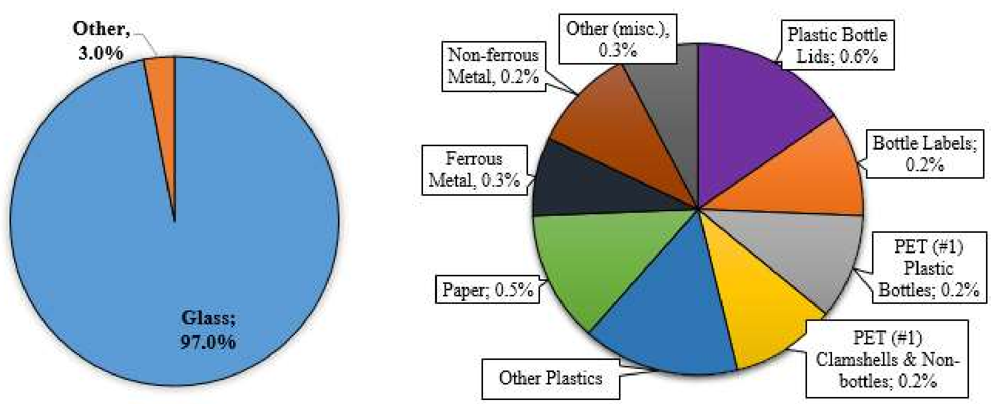

Figure 2. Left - Composition of Recycled Glass stream at the Leveda Brown Materials Recovery Facility in Alachua County. Right – Detail of other materials found in the Recycled Glass stream.

Washing would be beneficial in removing excess chlorides in the ash. As the fine particles in ash are very absorptive, washed ash results in a better product for aggregate in concrete (lower water to cement ratios) and asphalt pavement (lower binder requirements). Furthermore, washing has been shown to lower heavy metal concentrations in the ash such as lead and zinc (Wilewska-Bien et al. 2007).

The costs of WTE ash and GP processing should be evaluated as part of an overall market assessment. Such an evaluation would not only require evaluation of processing costs, but also factor in the market value of the raw materials being replaced, landfill avoidance savings, and transportation. This proposal addresses items 6 and 10 on the 2016-2017 Hinkley Center RFP. This proposal not only targets the use of solid waste materials in concrete and asphalt pavement, but also it evaluates methods for the processing of these materials prior its application and the economic implications.

Figure 3. Bottom ash washing system at Mitsubishi Materials Cement Manufacturing Facility Kurosaki Division, Japan.

Figure 4. Bottom ash washing system at Mitsubishi Materials Cement Manufacturing Facility Kurosaki Division, Japan.

OBJECTIVES

The specific objectives of this research project are as follows:

1. Expand on previous research regarding the use of GP as replacement for Portland cement by examining the combined use of GP and WTE ash in concrete mixes. A specific focus will be on the necessary mitigation for ASR through the use of GP (so both of these components can be beneficially utilized).

2. Conduct research on the benefits of WTE ash washing as a pretreatment step to create products to be used as concrete aggregate and asphalt pavement aggregate.

3. Examine the infrastructure needs and associated costs for the implementation of glass recycling to SCM and WTE ash recycling for aggregate, as well as the combined beneficial use of these materials.

METHODOLOGY AND SCIENTIFIC APPROACH

Task 1. Assessment of GP as supplementary cementitious material in ash-amended concrete.

The research team will evaluate the behavior of GP as a SCM in concrete and mortar bars samples made with WTE bottom ash as aggregate. Comparison against different types of SCM will be performed by creating ash amended specimens with coal fly ash as the SCM. As means of control, specimens created with no WTE BA will be included and will provide information about the behavior of GP alone. In order to address the issues identified by previous research on the beneficial use of GP and WTE BA, testing of the concrete specimens will focus on compressive strength, while testing of the mortar bars will focus on alkali-silica reactivity (following ASTM C1260, Standard Test Method for Potential Alkali Reactivity of Aggregates).

Task 2. Evaluation of WTE ash pre-processing.

In order to improve the quality of the ash to be beneficially used, ash washing will be explored as a treatment option to target several issues for the cement, concrete and asphalt industries such as high aluminum content, elevated concentration of chloride and sulfate ions and the presence of fine particulates (< 0.075 mm). The effects of the washing will be evaluated for three beneficial use applications (i) aggregate in concrete and (ii) aggregate in asphalt pavement. The research team will perform preliminary tests to determine the optimum liquid-to-solid ratio (LS) and contact time for washing the ash to maximize metal, ion, and fine particulate removal. Conductivity will be used as an indication of the effectiveness of washing ions from the ash. To simulate the effect of the pre-processing prior using the ash as kiln feed, Portland cement concrete will be produced in the laboratory using washed ash. Chloride and sulfate content of the ash-amended Portland cement and asphalt concrete will be determined following the methods outlined in ASTM. The compressive strength and potential reactivity due to accelerated ASR testing of the concrete specimens will be determined. Finally, the research team will determine a mix design that will examine the required binder content in the asphalt specimens for both washed and unwashed ash.

Task 3. Analysis of the engineering costs and feasibility of WTE ash and GP recycling.

The research team will conduct a cost feasibility analysis for recycling WTE BA and GP in the manners described above. A cost model will be developed to estimate capital and operation costs associated with processing. Transportation and material market prices (virgin aggregate, coal fly ash, cement) will be included in the examination.

BENEFITS

The solid waste community in Florida will benefit from the knowledge generated regarding the recycling of WTE ash and glass and their use in Portland cement concrete and asphalt. This research will allow the industry and the regulatory community to better assess the recycling of these waste materials in the most cost efficient manner possible. While the work accomplished to date as a result of the Hinkley Center (and other funding) has made great strides, additional research is needed to fully assess the long-term sustainable management of WTE ash and GP.

DELIVERABLES

Deliverables for the proposed work include quarterly progress reports to the Center, metrics, a draft and final technical reports, and any manuscripts or thesis chapters completed by students working on this project as part of their degree requirement. Additionally, a Technical Awareness Group (TAG) will be formed and two meetings will be held: one at the beginning of the project and a second one at the end. All other deliverables required by the Center will be completed. Finally, a project website will be developed and maintained where project information such as the full proposal, TAG member information and quarterly reports will be published.

CANDIDATE TAG MEMBERS

The investigators have found excellent support from TAG members in past Hinkley Center funded projects. For this proposed research project, the following individuals will be invited to be part of the TAG meetings to be held twice for the duration of this project.

Jason Gorie, JMG Engineering

Ramana Kari, Palm Beach County SWA

Tim Ruelke, FDOT

Kim Byer, Hillsborough County

Keith Howard, Lee County

Chris Eckert, City of Tampa

David Gregory, CH2MHill

David Dee, Gardner, Bist, Bowden, Bush, Dee, LaVia & Wright, P.A.

Cory Dilmore, FDEP