Evaluation of Bagasse Ash as Cement and Sand Replacement for the Production of Engineered Cementitious Composites (ECC)

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Investigates the feasibility of using sugarcane bagasse ash as cement and sand replacement in ECC to reduce its cost and increase its practicality and greenness

This study investigated the use of sugarcane bagasse ash (SCBA) in producing cost-effective and green ECC materials. Two classes of ECC mixtures were evaluated in this study: (1) mixtures with Louisiana raw SCBA (RBA) as a partial and complete replacement of sand (i.e., class S mixtures); and (2) mixtures with Louisiana post-processed SCBA (PBA) as a partial replacement of cement (i.e., class C mixtures). Sand replacement levels with RBA evaluated were 25, 50, 75, and 100% (by volume), while cement replacement levels with PBA studied were 40, 50, and 60% (by mass). Tests conducted included compressive strength test, uniaxial tensile test, surface resistivity, and shrinkage.

Background

Engineered Cementitious Composites (ECC), also known as bendable concrete, are a novel class of High Performance Fiber Reinforced Cementitious Composites (HPFRCCs) that are designed and optimized based on micromechanics principles to exhibit a high tensile ductility (1 to 8% strain capacity in tension) through a robust pseudo strain hardening (PSH) behavior at low fiber content (usually 2% volume fraction). However, ECC utilizes manufactured microsilica sand and high cement content, which increases the cost, environmental impact, and decreases the practicality.

In Louisiana, the sugar production industry is of immense relevance. According to the American Sugarcane League, in 2018, more than 16.9 million tons of sugarcane was harvested yielding 1.8 million tons of sugar and nearly 3.5 million tons of a fibrous by-product sugarcane bagasse fiber (SBF). Typically, SBF is burned by the sugar mills to generate energy. After burning of SBF, the produced ash by-product is known as sugarcane bagasse ash (SCBA) and is considered an agricultural waste with no economic value. In addition, bagasse ash constitutes a potential environmental hazard, leading to containment and disposal costs to the industry. Based on the literature, when properly processed (by drying, sieving, burning, and grinding) SCBA can exhibit significant pozzolanic activity due to its chemical composition and small particle size. In turn, this makes post-processed bagasse ash an excellent candidate for an affordable supplementary cementitious material (SCM). While SCBA can serve as an SCM material when adequately processed, raw bagasse ash (i.e., SCBA obtained directly from the mill) exhibits high carbon content and low pozzolanic activity. While raw SCBA cannot be utilized as an SCM, upon minor processing (by drying and sieving) this lower quality ash presents excellent potential as a highly fine aggregate material to replace the expensive microsilica sand used in ECC production.

Figure 1. SBF and raw SCBA Landfills: (a) SBF, and (b) SCBA.

Project Summary

This project evaluated the feasibility of utilizing bagasse ash with different quality levels as cement and fine aggregate replacement for the manufacture of ECC to reduce its cost, make it more practical, and increase its greenness. Two classes of ECC mixtures were evaluated in this study: (1) mixtures with Louisiana raw SCBA (RBA) as a partial and complete replacement of sand (i.e., class S mixtures); and (2) mixtures with Louisiana post-processed SCBA (PBA) as a partial replacement of cement (i.e., class C mixtures). Sand replacement levels with RBA evaluated were 25, 50, 75, and 100% (by volume), while cement replacement levels with PBA studied were 40, 50, and 60% (by mass). Tests conducted included compressive strength test, uniaxial tensile test, surface resistivity, and shrinkage.

Status Update

SCBA Characterization: Both RBA and PBA were thoroughly characterized. It was revealed that RBA is mainly composed. However, RBA presented high carbon content, large particle size (i.e., 256 μm average particle size) relative to cement, and a low strength activity index (SAI); thus, failing to meet ASTM C618 requirements to be classified as a pozzolan. On the other hand, PBA exhibited low carbon content, small particle size (i.e., 28 μm average particles), satisfactory SAI, and a high pozzolanic component to be classified as a class N pozzolan per ASTM C618.

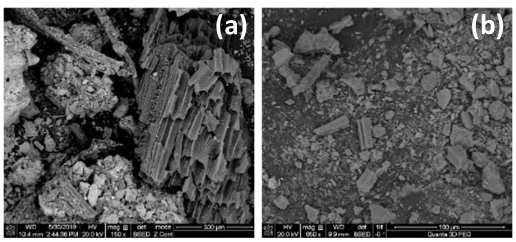

Figure 2. Microstructure of: (a) RBA (b) PBA

ECC Mechanical Properties: The use of RBA as sand replacement caused minor reductions in the compressive strength of ECC (up to 11%), yet it produced dramatic improvements in the tensile ductility (up to 311%). Moreover, the tensile strength of all RBA admixed ECC also improved (up to 22.3%). The use of RBA produced a decrease in the surface resistiviy of ECC. However, all RBA admixed ECC materials fell in the categories of low and medium chloride ion penetrability (CIP). Moreover, small increments in shrinkage were observed in RBA admixed ECC materials compared to control.

The use of PBA as cement replacement produced significant reductions in compressive strength (up to 39.1%) and tensile strength (up to 28.1%). Nevertheless, it increased the tensile ductility of the composites (up to 85%). It is important to mention however, that PBA admixed ECC materials did not exhibit robust PSH behavior. As such, it was concluded that PBA underperforms in contrast to other SCMs such as fly ash conventionally used in the manufacture of ECC. Furthermore, the surface resistivity and shrinkage of PBA admixed ECC increased with the increment in cement replacement with PBA.

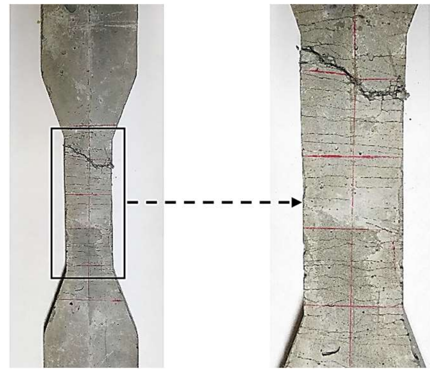

Figure 3. Robust PSH behavior exhibited by ECC using 100% of RBA as a sand replacement

Impacts

SCBA is currently considered waste, without any economic value. The possible implementation of SCBA in ECC formulation opens the possibility to reduce the cost and increase the practicality of ECC materials by partially or completely replacing the expensive and not widely available microsilica sand, as well as to partially replacing cement. Use of local waste materials like SCBA can deliver cost-effective ECC materials readily available for application in local infrastructure. The exceptional ductility exhibited by SCBA admixed ECC can provide a more durable and reliable alternative material for the repair of current infrastructure and construction of new projects. Additionally, the use of SCBA in ECC can help valorize an underutilized waste product and help to solve the environmental landfill problems associated with its disposal.

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