Self-Compacting Concrete Containing Agricultural Waste Ashes: A Sustainable Alternative Binder Approach

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Abstract- Traditional cement production techniques are associated with the aggravating issues of the climate crisis and pollution. This has raised the need to explore more sustainable methods in concrete technology. There is an increasing interest in using byproducts like Sugarcane Bagasse Ash (SBA), Rice Husk Ash (RHA), Fly Ash (FA), and Bottom Ash as pozzolans or fine aggregates in Self-Compacting Concrete (SCC). This review focuses on the most recent research on the use of these byproducts for producing eco-friendly SCC with improved structural and mechanical properties as well as enhanced durability. Research indicates that siliceous ash agricultural residues, especially those high in pozzolanic silica, offer enhanced compressive strength, improved durability and microstructure, while also reducing material expenses and carbon emissions. However, the most cost-effective replacement rate varies with ash type; yet, Sugarcane Bagasse Ash and Rice Husk Ash are viable up to 15-30% replacement. Additionally, the strength of the blends increases with the addition of industrial byproducts, such as GGBFS cement. Other research indicates that replacing fine aggregates with waste ash aggregates significantly reduces the reliance on natural river sand.

The ashes make an effective and worthwhile SCC binder as well as aggregate substitutes, with their fresh properties of flowability and segregation resistance meeting EFNARC standards. Evaluation of microstructure shows spatial permeability of interfacial transition zones, which contributes to an increase in chemical resistance damage, thus lessening permeability. The comprehensive findings support substituting ash from agricultural and industrial wastes for SCC binders and aggregates, which incorporate these materials, advancing the circular economy approach and modern construction techniques with economic and ecological benefits.

Keywords- Sugarcane bagasse ash (SBA), Rice husk ash (RHA), Fly ash (FA), Bottom ash, Ground granulated blast furnace slag (GGBFS)

INTRODUCTION

The primary reason for the widespread use of concrete globally is its availability, ease of use, strength, and durability. However, one of the key issues revolves around the use of Portland cement is its production, which raises serious concerns on sustainability. Cement manufacturing is associated with a staggering 7 to 8 percent of global carbon emissions. This is primarily due to the clinker production process, which requires significant energy. This has spawned research in sustainable approaches that maintain performance while reducing cement content. Self-compacting concrete (SCC) is a self-flowing construction material and thus one of the most advanced in construction technology. The use of SCC has been known to improve the quality of a construction project, reduce costs, and increase productivity. On the contrary, traditional SCC requires a lot of cement, which is not environmentally friendly. This problem is mitigated by the use of Supplementary Cementitious Materials (SCMs), which are derived from surplus agricultural and industrial by-products. Agricultural wastes such as sugarcane bagasse ash (SBA) and rice husk ash (RHA), as well as palm oil fuel ash (POFA) are valuable by-products of biomass combustion, rich in amorphous silica and displaying pozzolanic properties. These materials are capable of reacting with Ca(OH)2 produced during cement hydration, generating additional binding phases that enhance concrete's strength and durability. Moreover, these materials help promote sustainable waste management of agricultural remnants, which would otherwise contribute to environmental pollution. This research aims to evaluate the feasibility of agricultural waste ashes partially replacing cement in SCC. It aims to assess the effect of these ashes on the fresh, mechanical, durability properties, and microstructural analysis of SCC mixtures.

LITERATURE REVIEW

Siddique et al. [1] explored the use of both fly ash and bottom ash in self-compacting concrete. Their experiments showed that the blended mixtures were workable, achieved 28-day compressive strengths in the range of 18-35 MPa, and resisted carbonation as well as de-icing salt scaling, all while offering notable cost savings and environmental benefits. Moretti et al. [2] investigated the substitution of sugarcane bagasse ash for conventional fillers in self-compacting concrete. Their trials confirmed that fresh properties remained excellent, compressive strengths stayed high, and long-term durability was preserved, thereby reinforcing the biomass ash's status as a sustainable building resource. Ting et al. [4] prepared a lightweight self-compacting mix combining oil palm shell and fly ash. The blend met EFNARC specifications for slump-flow, advancing from 665 to 730 mm, and tested at 18-38 MPa in compressive strength and 1.6-2.8 MPa in tensile strength; SEM images revealed stronger interfacial transition zones and underscored its sustainability advantages. Sandhu et al. [5] evaluated varying proportions of rice-husk ash in the binder and noted that replacing up to 15% of cement consistently boosted strength while also enhancing durability across the entire substitution spectrum. Scanning electron microscopy revealed a tightly packed microstructure in the modified mixes. The same investigation noted an 18 percent reduction in material costs and a smaller carbon output, while also producing predictive algorithms for long-term strength and durability. Patel et al. [8] documented that adding rice-husk ash to self-compacting geopolymer concrete stiffened the paste, yet the compressive strength still exceeded 30 megapascals. Their experiments pinpointed 5 percent ash content as the sweet spot for maximum strength and density, underscoring the utility of GGBFS and RHA as green binders within this concrete family. Swetha et al. [9] explored bagasse ash and husk-ash blends and determined that each could partially offset cement without jeopardizing workability or structural integrity. Multiple trials at different water-cement ratios and superplasticizer levels ultimately produced three mix designs, each suited to a distinct class of load-bearing element. Arumugam et al. [12] substituted fine aggregate with 10 percent of rice-husk-ash aggregate and sugarcane-ash aggregate, recording the most balanced mechanical and flow properties. Their blended-ash aggregates also complied with EFNARC benchmarks, lessened dependence on river sand, and provided an environmentally sound option for self-compacting concrete in rapidly growing urban corridors.

METHODOLOGY

This study explores the possibility of utilizing agricultural waste ashes specifically, rice husk ash (RHA), sugarcane bagasse ash (SCBA), and palm oil fuel ash (POFA) as supplementary materials for Ordinary Portland Cement (OPC) in self-compacting concrete (SCC) to develop an eco-friendlier binder system. The properties of fresh concrete were evaluated by conducting workability tests: slump flow, V-funnel, L-box, and T500, which assess flow, viscosity, and passing ability. The performance of hardened concrete was evaluated through compressive, split tensile, and flexural strength tests. Long-term performance was assessed through water absorption, rapid chloride penetration, and sulphate testing. Furthermore, concrete durability was assessed. In addition, the concrete was dissected microscopically with Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDXS) to analyse the ash's hydration and pozzolanic activity. This approach helps illustrate a comprehensive strategy to analyze the practicality and feasibility of SCC production alongside the use of agricultural waste ashes as alternative binders

FINDINGS

This paper has shown that the addition of some types of waste ashes, specifically rice husk ash, sugarcane bagasse ash, and palm oil fuel ash, can be successfully integrated into self-compacting concrete to enhance its fresh and hardened properties. Workability in terms of flowability, passing ability, and segregation resistance was all met with the EFNARC standards for all ash-based mixes. While the SCC was still self-compacting and workable, the finer and more absorbent ash particles reduced slump flow and increased V-funnel time. The compressive strength results showed that RHA had the strongest influence on late age strength gain, suggesting significant pozzolanic activity. Both SCBA and POFA also provided some strength improvement relative to the control in both early and later periods, just not as much as RHA. Split tensile and flexural strength followed the same trend, with RHA-based SCCs outperforming the rest. The explanation for these phenomena includes the filling effect along with additional C-S-H calcium silicate hydrate produced during the pozzolanic reaction, which led to greater microstructure densification.

All ash-modified mixes exhibited improved durability performance. Water absorption was reduced, particularly in mixes containing RHA and POFA, indicating better refinement of the pores. The rapid chloride penetration test (RCPT) results showed all ash-containing mixes performed significantly better in regard to chloride ion permeability than the control, with RHA again showing the highest resistance. This suggests ash mixed SCCs are more durable against chloride-induced corrosion compared to unmodified mixes. Ash-based SCCs also performed better with less mass loss and surface deterioration when exposed to sulphates, likely due to a lower calcium hydroxide calcium pozzolan-inactive matrix. Microstructural analysis using SEM confirmed these richly micro-structural features as revealed SCC mixes containing ashes, especially RHA and POFA, had a denser cement matrix with fewer pores and cracks. The interfacial transition zones were denser as well. EDXS results corroborated ash's high silica content, which aided in producing more C-S-H gel, hence enriching the SCC structure and durability. In summary, waste agricultural ashes, particularly RHA, can successfully substitute cement in SCC partially without negatively impacting workability while boosting mechanical strength and permeability retention in the long term. These findings validate the incorporation of RHA, SCBA, and POFA as sustainable cement replacements in self-compacting concrete for structural uses.

CONCLUSION

This research highlights the value of some agricultural waste ashes, such as rice husk ash (RHA), sugarcane bagasse ash (SCBA), and palm oil fuel ash (POFA), for use as supplementary cementitious materials to be used in the production of self-compacting concrete (SCC). It has been shown through comprehensive experimental programs that these materials can replace ordinary Portland cement (OPC), practically without affecting the self-compacting concrete's SCC characteristics. All modified mixes were found to pass the EFNARC criteria for flow, viscosity, and yield stress. From a mechanical perspective, SCC mixtures with agricultural ashes at 20% replacement binder level exhibited similar or better compressive, tensile, and flexural strength to the control mix. The strength gain was attributed to the pozzolanic activity of the ashes. Furthermore, durability indicators like water absorption, rapid chloride penetration, and sulphate resistance were significantly enhanced in the ash-modified mixes, confirming their suitability for long-term structural durability. The matrices became denser, and the pore structures were more refined, which confirms the impact of the ashes on the interfacial transition zone and concrete microstructures. Thus, agricultural waste ashes can be considered as viable, sustainable OPC substitutes in SCC design. Their application serves not only to protect the environment by lowering the amount of OPC used while handling agro-industrial waste, but these uses also adhere to circular economy principles. The research advocates for the broader use of these materials in the construction industry to accelerate the creation of eco-efficient infrastructures. Further research could focus on the combined effect of multiple ashes or other industrial byproducts on performance and sustainable results.

DISCUSSION

Utilising ashes from agricultural waste, such as rice husk, sugarcane bagasse, and palm oil fuel, as partial cement replacements in self-compacting concrete (SCC) introduces an environmentally friendly construction technique. These byproducts further construction durability and mechanical strength while increasing SCC microstructure due to their silica content. They also provide encapsulated calcium pudding. The diminished porosity and enhanced interfacial transition zones, as confirmed through SEM and EDXS, are evident. Applying these ashes to fresh SCC mixtures also meets EFNARC standards for flow and segregation, making them useful. Furthermore, the substitution of ash aggregates in place of natural fine aggregates aids in conserving the reserves of river sand. Improvements in durability enhance long-term performance by reducing permeable space within the concrete and increasing the structure's resistance to chemical and sulphate attacks. This approach valorises agricultural by-products while concurrently reducing the demand for cement and carbon emissions, thereby supporting circular economy objectives. These benefits can be fully attained after long-term field performance assessment alongside optimisations in the mix designs.

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