SUSTAINABLE SELF-COMPACTING CONCRETE INCORPORATING WHEAT STRAW ASH AND FLY ASH AS CEMENT REPLACEMENTS

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Abstract- The rapid growth of the construction industry has led to an increasing demand for cement, a material whose production consumes large amounts of energy, depletes natural resources, and emits significant quantities of carbon dioxide into the atmosphere. This emission of greenhouse gases contributes to environmental degradation and climate change. At the same time, agricultural and industrial wastes such as fly ash and wheat straw ash are often discarded improperly, posing serious environmental hazards due to the release of toxic gases. This study investigates the potential of using these organic waste materials as partial replacements for cement in the development of ecofriendly self-compacting concrete. The goal is to reduce cement consumption while promoting sustainable construction practices. In this experimental work, self-compacting concrete was prepared with varying replacement levels of cement at 5%, 10%, 15%, 17% and 20% using fly ash and wheat straw ash. A polycarboxylate based superplasticizer was used to improve the workability of the mix without affecting its strength. The performance of each mix was evaluated through tests on workability and compressive strength. The results demonstrated that selected combinations of organic waste materials not only enhanced the fresh properties of self-compacting concrete but also maintained adequate strength compared to conventional concrete. This research supports the use of agricultural and industrial byproducts as sustainable alternatives in concrete production, offering both environmental and economic benefits while contributing to the advancement of green construction practices.

Keywords- Ecofriendly Concrete, Cement Replacement, Sustainable Construction, Self-Compacting Concrete

1 Introduction

Self-Compacting Concrete (SCC) is a special concrete which has revolutionized concrete placement, eliminating the need for vibrators as it flows under its own weight, a characteristic that ensures excellent workability and compaction without segregation or bleeding [1-3]. Initially developed in Japan in the 1980s, SCC is now utilized globally, particularly in countries like Denmark, where it accounts for 20-30% of the total concrete production in the ready-mix and precast concrete industries [4]. SCC is known for its early strength, reduced water-cement ratio, and enhanced durability, particularly when superplasticizers are incorporated. These additives help decrease the water-cement ratio, further enhancing the concrete's mechanical properties [5]. The inclusion of materials such as silica fume, fly ash (FA), wheat straw ash (WSA), and sugar cane bagasse ash has significantly contributed to improving the properties of SCC [6, 7]. Wheat straw, when appropriately pre-treated, can notably enhance the energy absorption characteristics of concrete [8]. Additionally, using materials like FA and WSA in SCC helps lower the carbon footprint, as the replacement of cement with these materials reduces CO_2 emissions, making the concrete more sustainable [9].

The substitution of cement with wheat straw ash (WSA) has been studied for its impact on the mechanical properties and workability of SCC. Research indicates that up to a 10% replacement of cement with WSA improves the hardened properties of SCC, with compressive strength increasing due to the filler capacity and chemical reactions with calcium hydroxide [10]. WSA is considered a sustainable alternative to cement due to its pozzolanic nature, which improves concrete's durability and compressive strength [11]. Similarly, other studies suggest that the use of WSA in SCC improves its overall performance and contributes to the sustainability of concrete [12]. Wheat straw, often burned openly, causes pollution; controlled burning produces ash with cementing properties for concrete use [14]. Given the abundant production of wheat straw in agricultural countries like Pakistan, the use of WSA in concrete offers an eco-friendly solution, addressing both waste management and environmental sustainability challenges [13]. This study examines the combined use of wheat straw ash (WSA) and fly ash (FA) as partial cement replacements in self-compacting concrete (SCC), focusing on their impact on fresh and hardened properties. In Pakistan, where wheat straw is abundantly produced and often burned openly, utilizing WSA in concrete offers a sustainable solution to waste management while promoting greener construction practices tailored to local needs.

2 Research Methodology

This research focused on evaluating the fresh and hardened properties of self-compacting concrete (SCC) using sustainable cement replacements. The methodology involved selection of appropriate materials, execution of standardized laboratory tests, and development of optimized mix designs in line with SCC performance criteria.

2.1 Materials

The materials were selected based on their local availability, cost-effectiveness and compatibility with SCC production. Ordinary Portland Cement (OPC) conforming to ASTM C150 was used, sourced from DG Khan Cement. Harrow sand and Sargodha crush were used as fine and coarse aggregates respectively, both complying with ASTM C33. The fine aggregate passed through a No. 4 sieve and exhibited proper grading, while the 25 mm angular coarse aggregate offered strength and interlock. Aggregates were oven-dried at 105°C for 24 hours prior to testing.

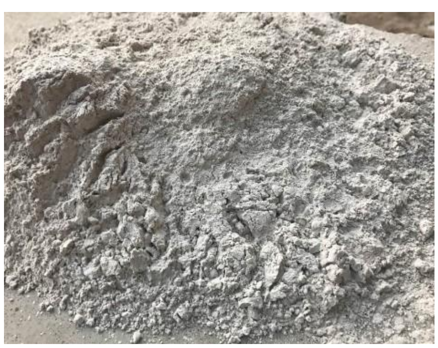
a)  b) 

Figure 1: Laboratory Samples of Ashes, a) Fly Ash (FA), and b) Wheat Straw Ash (WSA) for current study

Class F Fly Ash (ASTM C618) and Wheat Straw Ash (WSA) were used as partial cement replacements. Both were sieved through a No. 200 mesh. Although WSA lacks a formal ASTM classification, its pozzolanic nature was confirmed through preliminary assessments. Samples of both ashes used in this study are shown in Figure 1. A polycarboxylate ether-based superplasticizer (ASTM C494 Type F) was added to enhance SCC flowability. Water and setting times were determined using the Vicat apparatus.

2.2 Laboratory Testing

In this study, a series of laboratory tests were conducted to assess the physical properties of raw materials and the performance of concrete mixes. Aggregates were tested for particle size distribution, cleanliness, and water absorption. The fineness modulus of sand was 2.502, falling within the ASTM C136 recommended range of 2–4. Cement consistency (ASTM C187-16) and setting time (ASTM C191-13) were within standard limits, with a consistency of 5.5 mm, an initial setting time of 57 minutes, and a final setting time of 9 hours 51 minutes. Fine aggregates showed a specific gravity of 2.805 (SSD) and 0.6% water absorption, both meeting ASTM C128-15. Coarse aggregate tests (ASTM C127-15) gave a crushing value of 15.57% and bulk density of 1566.81 kg/m³. Fly ash (ASTM C136/C136M-16) had a fineness of 95.16% and a specific gravity of 2.33 (ASTM D854), while wheat straw ash showed 95.8% fineness and a specific gravity of 1.852. The summarized results of cementitious materials are shown in Table 1, while the physical properties of coarse and fine aggregates are presented in Table 2. In addition to material characterization, tests on fresh concrete (such as workability and flow) and hardened samples (compressive strength) were conducted to assess overall mix performance. All procedures followed ASTM standards to ensure data accuracy and reliability for mix design.

Table 1 Characteristics of Cement, Fly Ash and Wheat Straw Ash

Material	**Property**	**Results**
Cement	Fineness	95%
	Consistency	5.5mm
	Specific Gravity	3.15
	Initial Setting Time	57mins
	Final Setting Time	591mins
	Soundness	1.72%
	Compressive Strength	42 MPa
Fly Ash	Colour	Tan Grey
	Fineness	95.16%
	Specific Gravity	2.33
Wheat Straw Ash	Colour	Dark Grey
	Fineness	95.8%
	Specific Gravity	1.852

Table 2 Properties of Coarse and Fine Aggregate

Material	**Tested Parameters**	**Results**
Coarse Aggregate	Impact Value	1.626%
	Crushing Value	15.57%
	Specific Gravity	2.789 (SSD)
	Water Absorption	1%
	LA Abrasion Value	18.21%
	Bulk Density	1566.81 Kg/m^3
Fine Aggregate	Fineness Modulus	2.805 (SSD)
	Specific Gravity	2.65
	Water Absorption	0.6%
	Loose Bulk Density	1.304 g/cm^3
	Compacted Bulk Density	1.471 g/cm^3

2.3 Concrete Mix Design

The concrete mix was designed as per Grade M30 specifications, targeting a compressive strength of 31.6 MPa using the formula $f'c = f + 1.65s$, where a standard deviation of 4 MPa was adopted. Based on strength and slump requirements, a water–cement (W/C) ratio of 0.44 was determined through interpolation. For the required workability range of 30–50 mm slump, the water content was fixed at 165 kg/m³. Accordingly, the cement content was calculated as 375 kg/m³. The coarse aggregate quantity was established using a volume fraction of 0.65 (based on the fineness modulus of sand, 2.49), resulting in 1018.42 kg/m³ of 20 mm Sargodha crush with a specific gravity of 2.798 and bulk density of 1566.81 kg/m³. The remaining mass, accounting for 721.48 kg/m³, was allocated to fine aggregate (harrow sand) to maintain the target concrete density of 2280 kg/m³. The resulting mix ratio for this M30 concrete is 1:1.9:2.71 (cement: sand: coarse aggregate), forming the base control mix for comparative evaluation against SCC variants with partial cement replacements.

2.4 Specimen Preparation and Curing

A total of 144 cylindrical specimens (4 in. × 8 in.) were cast, including 135 with varying levels of fly ash, wheat straw ash, and their combination, and 9 control samples. Concrete was mixed according to design proportions and placed in molds in three layers with proper compaction. Specimens were demolded after 24 hours and cured in water at 23 ± 2°C. Testing was conducted at 3, 14, and 28 days to evaluate strength development.

3 Results

3.1 Workability Assessment of Fresh Concrete

The workability of Self-Compacting Concrete (SCC) was evaluated with varying cement replacements using fly ash (FA), wheat straw ash (WSA), and their combination. The control mix had low workability (12.7 mm). FA increased workability, reaching a maximum of 190.5 mm at 20% replacement. WSA achieved its highest workability (183.11 mm) at 10% replacement, but declined thereafter. Combining FA and WSA showed optimum workability at 10% replacement (176.33 mm). Overall, controlled ash proportions improved SCC flow characteristics. The variation in workability is shown in the combined graph (Figure 2).

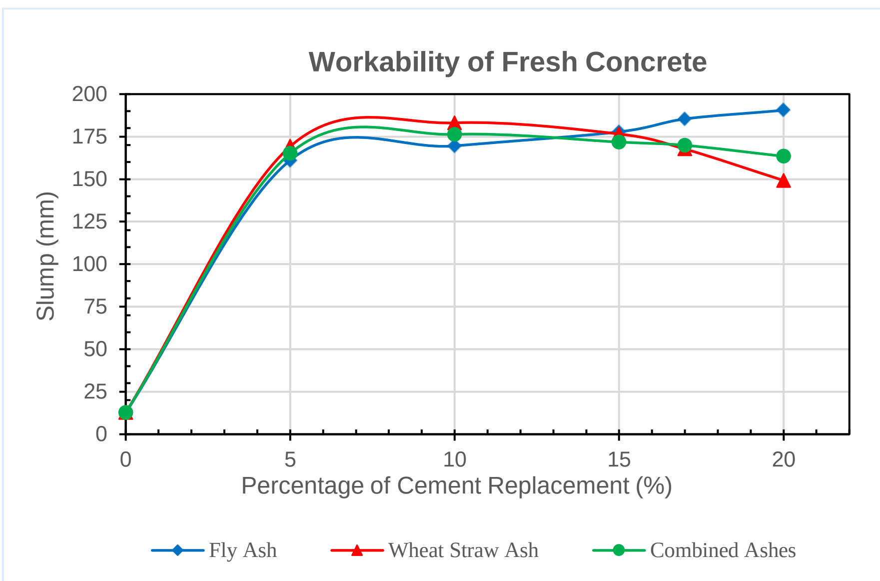


Figure 2: Variation in Workability with Different Ash Replacement Levels

3.2 Compressive Strength

For compressive strength testing, the concrete samples were categorized into three groups: Fly Ash (FA), Wheat Straw Ash (WSA), and a combined FA and WSA group, with varying replacement levels (5%, 10%, 15%, 17%, and 20%). Each replacement group was tested at 3, 14, and 28 days of curing. The average of three samples from each curing interval was used as the result for that specific replacement level. The compressive strength results for FA, WSA, and combined ashes are presented in Figures 3, 4, and 5, respectively.

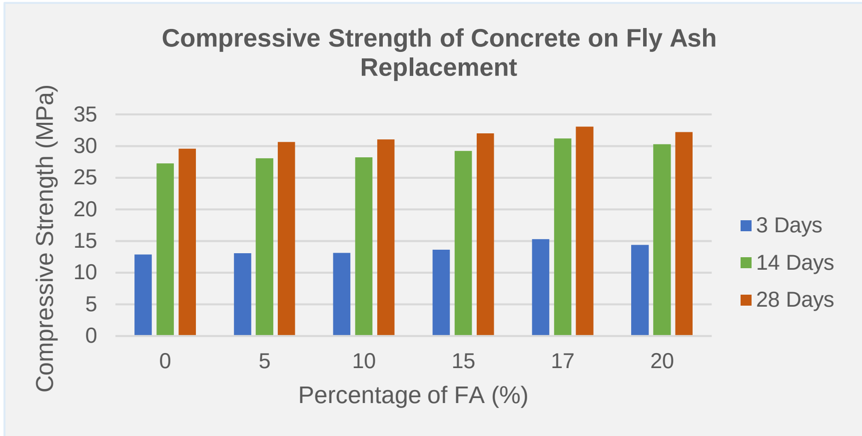


Figure 3: Compressive Strength on Replacement of Fly Ash (FA)

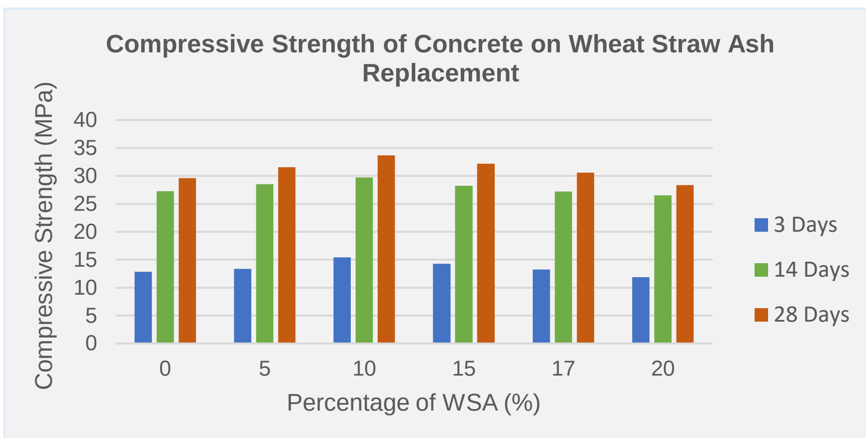


Figure 4: Compressive Strength on Replacement of Wheat Straw Ash (WSA)

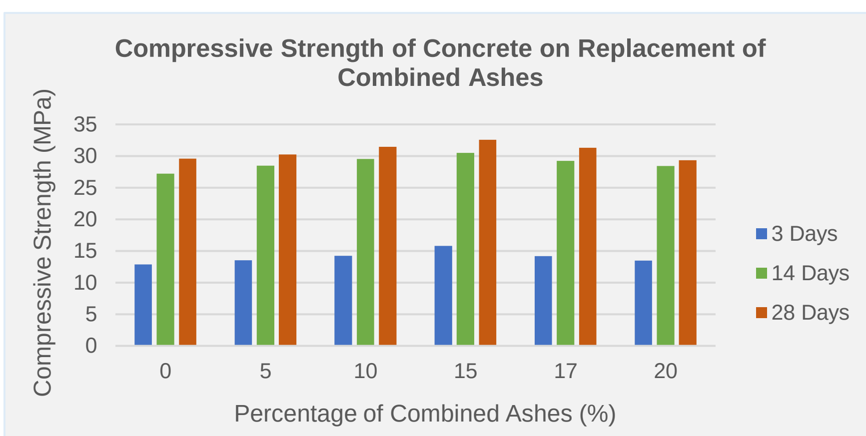


Figure 5: Compressive Strength on Replacement of Combined Ashes (FA + WSA)

Furthermore, Figures 6, 7, and 8 compare the compressive strength of self-compacting concrete with different percentages of ash replacement, providing an overview of the performance variations at different curing ages (3, 14, and 28 days) and replacement levels. These figures help visualize the influence of fly ash, wheat straw ash, and their combined use on strength gain over time. The trends observed support the identification of optimal replacement levels and highlight the practical potential of using these ashes in sustainable concrete applications.

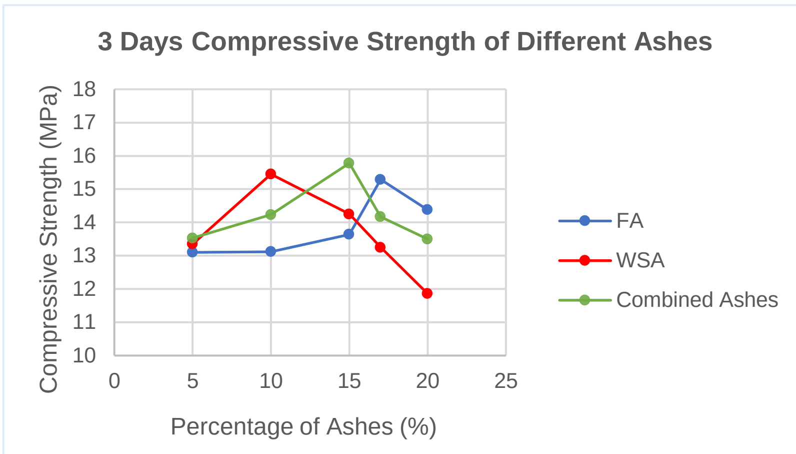


Figure 6: 3-Day Compressive Strength of Self-Compacting Concrete with Varying Ash Contents

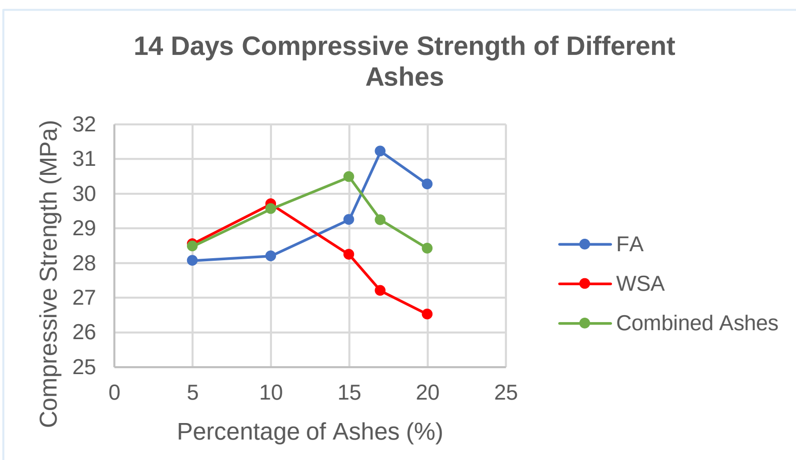


Figure 7: 14-Day Compressive Strength of Self-Compacting Concrete with Varying Ash Contents

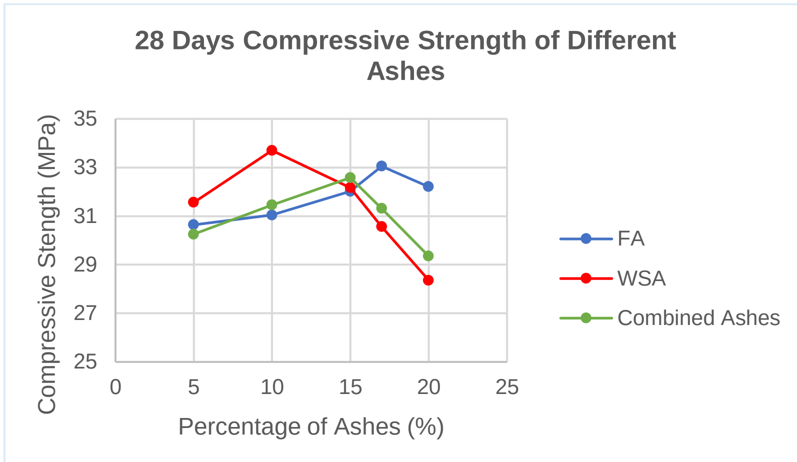


Figure 8: 28-Day Compressive Strength of Self-Compacting Concrete with Varying Ash Contents

The strength improvements observed at 17% fly ash and 10% wheat straw ash can be linked to their pozzolanic activity and filler effects, which refine the concrete matrix. Fly ash helped enhance workability due to its spherical particles, while wheat straw ash contributed to strength by providing reactive silica. When combined, the materials offered a balance of flow and strength, suggesting a mild synergistic behavior beneficial for sustainable mix design.

4 Practical Application

The use of wheat straw ash and fly ash as partial cement replacements offers a practical solution for sustainable construction in Pakistan, where agricultural and industrial waste is widely available. This approach can be adopted in housing projects, rural infrastructure, pavements, and non-structural elements, reducing cement demand and overall construction costs. In regions with limited access to high-quality materials, self-compacting concrete developed with these waste products can improve workability and ease of placement without the need for advanced machinery. Adopting this method supports waste management efforts, lowers carbon emissions, and promotes ecofriendly construction practices aligned with Pakistan's growing need for affordable and sustainable development.

5 Conclusion

This study explored the use of fly ash and wheat straw ash as partial replacements for cement in self-compacting concrete, supported by a polycarboxylate based superplasticizer to maintain workability. Mix designs with varying replacement levels of 5%, 10%, 15%, 17%, and 20% were evaluated. Workability tests revealed that 20 percent fly ash achieved the highest slump flow of 190.5 mm, while 10 percent wheat straw ash and 10 percent combined ash yielded 183.11 mm and 176.33 mm respectively. It was observed that higher contents of wheat straw ash tended to reduce flow. Compressive strength tests conducted at 3, 14, and 28 days showed optimal results at 17 percent fly ash, 10 percent wheat straw ash, and 15 percent combined replacement, with all mixes maintaining strength values comparable to conventional concrete. Based on the results, it is suggested that natural organic wastes such as fly ash and wheat straw ash can be utilized in concrete. As these ashes are hazardous for the environment, so utilization of such wastes in concrete with optimized values will also be beneficial for our environment. The findings confirm that these organic waste materials, when used in appropriate proportions, can produce environmentally friendly concrete without compromising performance.

Future research should focus on exploring the long-term durability and microstructural behavior of concrete containing organic waste ashes. Investigations on resistance to sulfate attack, chloride penetration, and freeze-thaw cycles would help evaluate performance in aggressive environments. Additionally, optimizing mix design for large-scale applications and exploring combinations with other sustainable materials may enhance the potential for broader implementation in green construction.

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