ALKALI-ACTIVATED SELF COMPACTING CONCRETE: A STUDY ON COMPRESSION BEHAVIOUR

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Abstract: Alkaline-Activated Self-Compacting Concrete (AASCC) is an innovative approach that aims to address environmental concerns associated with traditional Portland cement production while enhancing construction efficiency and material performance. This concrete alternative combines the benefits of alkaline activation with self-compacting properties, offering a promising solution for sustainable construction practices. The objective of AASCC is to reduce carbon dioxide emissions by incorporating alkaline activators into partially replaced aluminosilicate precursors such as rice husk ash and silica fume. These materials serve as sustainable alternatives to conventional cement, which has a high carbon footprint due to its manufacturing process. By using aluminosilicate precursors and alkaline activators, AASCC minimizes environmental impact while maintaining structural integrity.

One of the key advantages of AASCC is its self-compacting nature. This property allows the concrete to flow easily into formwork and fill complex shapes without the need for mechanical vibration. As a result, construction processes become more efficient and cost-effective, as manual labor and equipment requirements are reduced. Moreover, AASCC exhibits superior mechanical properties compared to traditional concrete. Its blend of alkali activation and self-compacting characteristics enhances durability, strength, and overall performance, making it suitable for a wide range of applications in construction.

Keywords: Alkali activation, rice husk ash, silica fume, mechanical properties

1. Introduction

Presently, the focus of research revolves around managing environmental pollution. Industrialization, urbanization, and population growth are the primary contributors to environmental pollution. There has been a notable rise in the use of cement, with each person now consuming up to 1 cubic meter of concrete annually to support infrastructure expansion. The increasing demand for concrete is predominantly driven by Ordinary Portland Cement [1]. The increasing desire for concrete made with Ordinary Portland Cement (OPC) has led to significant CO2 emissions (approximately 5% -7%) [2], contributing to ecological imbalances due to the ongoing depletion of natural resources. In the course of cement production [3], half of the emissions stem from the calcination process, while 40% are linked to the pyro-processing unit. The remaining 10% originate from the mining and transportation of raw materials. Simultaneously, safeguarding the environment necessitates preventing the unregulated disposal of waste or by-products. Repurposing these by-products as an alternative cement material offers numerous advantages, such as resource sustainability, environmental conservation, and resolution of disposal challenges.

In 1983 Hajime Okamura [4], who is known as the father of SCC Technology, proposed the utilization of self-compacting concrete (SCC), a specialized type of concrete that gained significant attention in the construction industry due to its unique properties and advantages. SCC is designed [5] to flow and compact under its own weight, without the need for external vibration, making it particularly suitable for complex or congested reinforcement arrangements where traditional concrete placement methods might be challenging. One important aspect of SCC development is the incorporation of alkaline activators. These activators, often based on materials like[6], [7], [8], [9]alkali silicates or alkali hydroxides, are added to the concrete mix to enhance its performance and properties. In terms of fresh properties, alkaline activators play a crucial role in improving the flowability and workability of SCC. They reduce the viscosity of the concrete mixture, allowing it to flow more easily into intricate formwork and around densely packed reinforcement. This results in better consolidation and eliminates the need for mechanical compaction, saving time and labor during construction.

Additionally, alkaline activators contribute to the early strength development of SCC[1] . By promoting the activation of cementitious materials at an early age, they accelerate the hydration process and enhance the overall strength of the concrete. This is particularly beneficial in applications where early formwork removal or rapid construction schedules are required.

Furthermore, the incorporation of alkaline activators in SCC can lead to improved durability characteristics. These activators can mitigate the risk of alkali-silica reaction (ASR) and enhance the resistance of concrete to chemical attacks, thus extending the service life of structures made with SCC.

2. Significance of research

Most research studies focusing on Alkali-Activated Slag or Fly Ash Concrete (AASCC) have primarily examined Fly Ash or Ground Granulated Blast Furnace Slag (GGBFS) as the aluminosilicate source material. However, there is a notable gap in research concerning the use of Ordinary Portland Cement (OPC) as the base material in AASCC investigations. By investigating the use of OPC alongside supplementary materials like rice husk ash and silica fume, it can uncover novel insights into the compatibility, mechanical strength, durability, and environmental sustainability of the alkali-activated concrete systems. The current disposal methods for pozzolanic waste materials, such as burning and dumping, contribute significantly to environmental pollution. Both RHA and silica fume offer valuable opportunities for sustainable waste management practices. The primary goals of this study are to examine how varying percentages of Rice Husk Ash (RHA) impact both the fresh and hardened properties of AASCC when blended with Ordinary Portland Cement (OPC).

3. Material and methods

3.1.Materials

The research used OPC, Silica fume, and RHA sourced locally as the aluminosilicate materials. Fine aggregate came from M-sand meeting IS 383:1987 Zone II standards, with a specific gravity of 2.6 and a fineness modulus of 3.0. Coarse aggregates, locally available and sized between 10 mm to 12.5 mm with a specific gravity of 2.5, were also included. The geopolymerization process relied significantly on an alkaline solution, using sodium hydroxide and sodium silicate. The sodium hydroxide, in flake form and 98% pure, and liquid sodium silicate were obtained from a local supplier. To enhance the workability and flow of fresh concrete, a commercially accessible superplasticizer called Master Glenium Sky 8233 from BASF, based on second-generation polycarboxylic ether and with a relative density of 1.10, was applied.

3.2.Mix proportion

Since there's no established mix design procedure for alkaline-activated self-compacting concrete, the mix design for AASCC follows the EFNARC guidelines for SCC. The target strength for AASCC was set at 30 MPa. Five mixes were prepared: one control mix using OPC and 10% Silica fume as the binder, and four mixes with varying proportions of RHA in addition to the binders with alkaline solution. RHA replaced OPC at 0%, 5%, 10%, and 15% by mass, while maintaining a total binder content of 550 kg/m3. The alkaline solution-to-binder ratio was kept at 0.4 for all mixes except control mix. Sodium hydroxide molarity was set at 12 M, with a sodium silicate to sodium hydroxide ratio of 2. To meet AASCC characteristics per EFNARC guidelines, an additional 25% water and 6% superplasticizer by mass of binder were added. Detailed mix descriptions and ingredient proportions can be found in **Table1**.

TABLE 1. Mix proportion details.

MixSample	OPC kg/m^3	Silica fume kg/m^3	RHA kg/m^3	Coarse aggregate kg/m^3	Fine aggregate kg/m^3	NaOH		Sodium silicate	SP (%)
						kg/m^3	Molarity		
Control mix	495	55	00	681.5	870	-	-	146	6
AASCC1	495	55	00	681.5	870	35.75	12	146	6
AASCC2	467.5	55	27.5	681.5	870	35.75	12	146	6
AASCC3	440	55	55	681.5	870	35.75	12	146	6
AASCC4	412.5	55	82.5	681.5	870	35.75	12	146	6

3.3. Preparation, casting, and curing

Saturated surface-dried aggregates were utilized in the creation of specimens. A sodium hydroxide solution was prepared a day prior to casting and was thoroughly mixed with a sodium silicate solution two hours before combining all components. The process commenced by blending coarse and fine aggregates, then incorporating finely ground materials like OPC, Silica fume, and RHA. After the completion of dry mixing, a uniformly blended liquid mixture comprising an alkaline solution, superplasticizer, and extra water was introduced into the blend. Wet mixing was then conducted for a duration of three minutes to ensure uniformity. Subsequent to this, the freshly blended concrete underwent assessment of its workability in accordance with EFNARC standards. Following the workability assessment, the fresh concrete was re-mixed and poured into molds for cubes, cylinders, and beams without undergoing compaction, relying solely on gravity to fill the molds. Once demolded, the specimen is then subjected to oven curing at a temperature ranging from 70°C to 80°C for 24 hours before being left to undergo ambient curing until the desired strength is achieved.

4. Experimental work

4.1. Fresh properties tests

The concrete mixture would be considered self-compacting concrete (SCC) if it met the standards for filling ability, passing ability, and segregation resistance. Each mixture underwent testing using various techniques specified by EFNARC to evaluate different aspects of workability. **Table 2.** presents the different assessment methods for filling ability, passing ability, and segregation resistance, along with their respective acceptable values according to European guidelines established by EFNARC. In this study, tests such as the slump flow test, V-funnel test, and J-Ring tests were conducted to assess the fresh properties of the mixtures.

Table 2. Acceptable values based on the European guidelines established by EFNARC.

Test method	Minimum value	Maximum value	Unit	Property
Slump flow	650	800	mm	Filling ability
V-Funnel	6	12	s	Filling ability
J-Ring	0	10	mm	Passing ability

4.2. Hardened properties tests

AASCC specimens were tested for compressive strength, splitting tensile strength, and flexural strength at 7 and 28-day intervals under ambient curing conditions. For each age group, at least three specimens from different batches were cast for testing.

4.2.1. Compressive strength test

The compressive strength of AASCC samples was evaluated following the IS:516 standard, using 150 mm cubes tested on a Universal Compression Testing Machine. To avoid premature flow or cracking, the ends of the specimens were capped with a material stronger than the concrete core. The cubes were positioned in the machine so that the load was applied to opposite sides, ensuring the cube's axis aligned with the center of the platen's thrust. The load was gradually increased until the specimen failed, and the maximum load at failure was recorded to determine the compressive strength.

4.2.2. Split tensile strength test

The tensile splitting strength test was conducted according to IS:5816 standards on cylindrical specimens measuring 150mm by 300mm. The test utilized a compression testing machine equipped with a steel loading plate between the machine's platens. The specimen was centrally positioned with packing strips and loading pieces parallel to its top and bottom surfaces. A uniform loading rate of 1.2N/mm^2/min was applied until failure, and the maximum load at failure was recorded.

4.2.3. Flexural strength test

Flexural strength testing was conducted on beam samples measuring 100mm x 100mm x 500mm, following the procedure outlined in IS:516. The bearing surfaces of the supports and rollers were meticulously cleaned. The beam sample was placed such that the load was applied to its top surface, as originally molded, with two lines spaced 20.0 cm apart. The axis of the specimen was aligned with the loading device, and no extra material was added between the bearing surfaces and rollers. The load was gradually increased without sudden impact until the beam failed. The maximum load at the failure point was recorded to determine the flexural strength.

5. Result and discussion

5.1. Fresh properties

Fig 1., **Fig 2.**, and **Fig 3**. illustrate an examination of the impact of various levels of RHA (ranging from 0% to 15%) on the fresh properties of AASCC blends. The utilization of RHA as a partial replacement for OPC led to a decline in workability, as demonstrated by the 720 mm slump flow value achieved by the reference mix. The increased specific surface area of RHA induced water absorption on the surface, resulting in a decrease in mortar flowability due to a reduction in the amount of water available for lubrication. Mixtures with higher proportions of RHA displayed improved cohesion, decreased slump flow values, reduced mix segregation, and higher plastic viscosity. The most favorable workability results were observed in blends composed of 85% OPC, 10% silica fume, and 5% RHA.

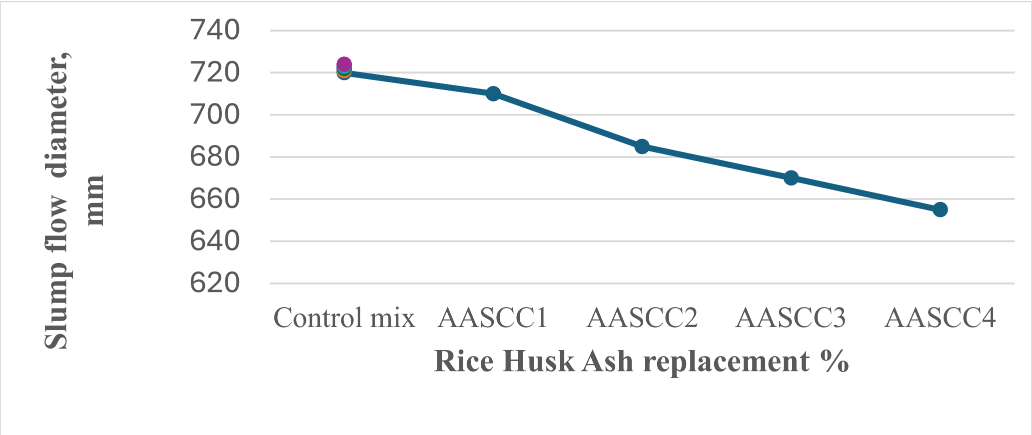

Fig 1. The slump flow test graph

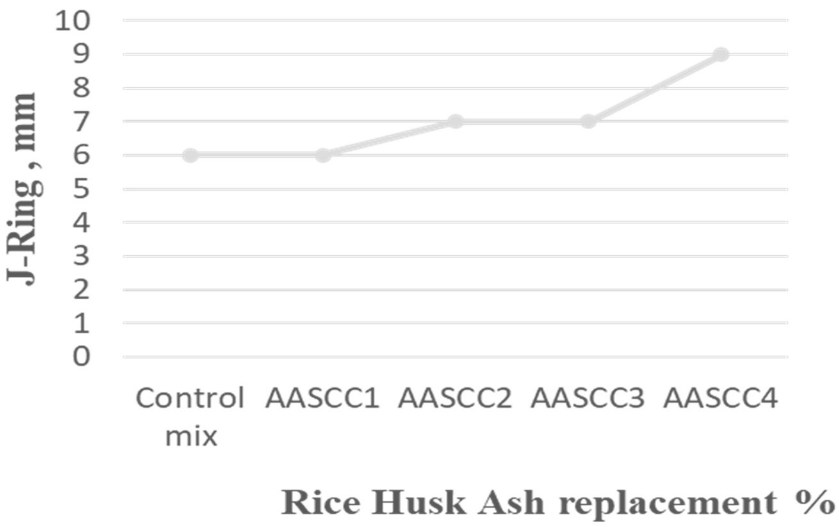

Fig 2. The J-Ring test graph

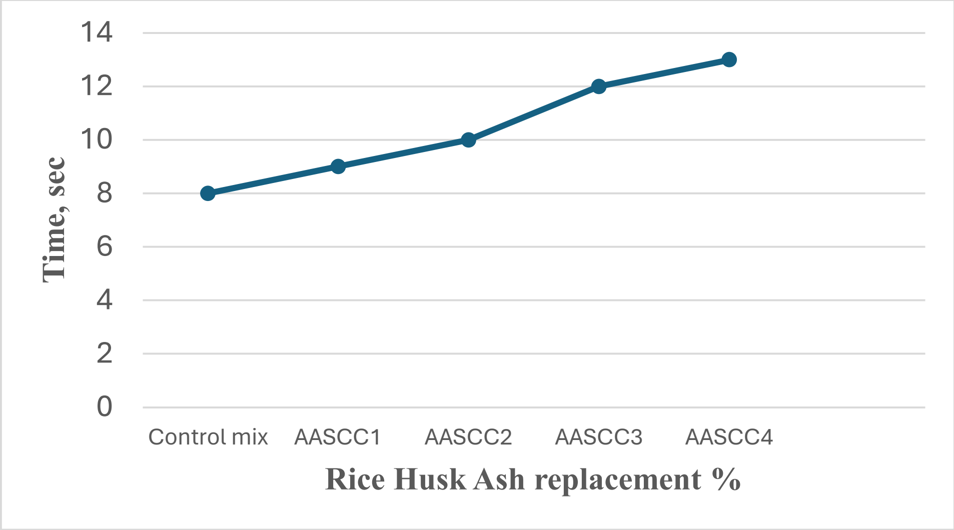

Fig 3. The V-Funnel test graph

5.2.Hardened properties

5.2.1. Compressive strength

The results of the compressive strength test for AASCC at 7 and 28 days are illustrated in **Fig 4**., where the AASCC mixture comprising 90% OPC and 10% silica fume is regarded as the reference mixture. As shown in **Fig 4.**, the compressive strength of AASCC based on OPC with varying percentages of RHA (0%, 5%, 10%, and 15%) surpasses that of the reference mix at all testing stages.

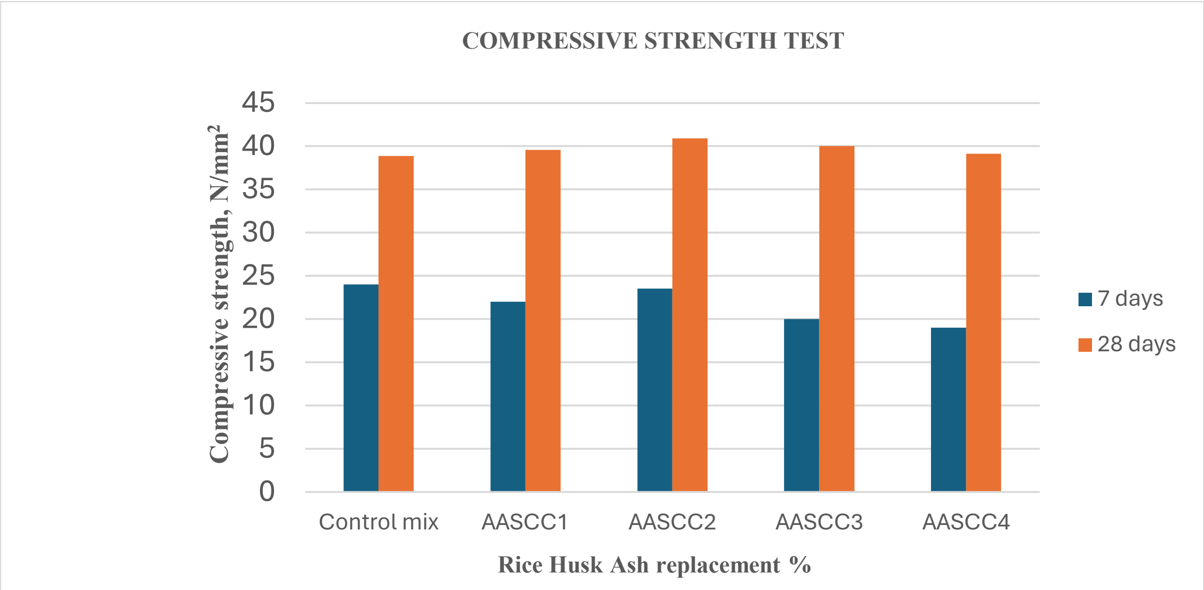

Fig 4. The compressive strength test graph

5.2.2. Flexural strength test result

During the testing of flexural strength, standardized beams of the AASCC mixture are exposed to a bending load until failure ensues. This procedure aids in determining the material's capacity to endure bending forces. The findings of the flexural strength test for AASCC at 7 and 28 days are presented in **Fig 5**, where the AASCC mix comprising 90% OPC and 10% silica fume is regarded as the control mix. Similar to compressive strength, the inclusion of RHA enhanced the flexural strength of AASCC by fostering enhanced interfacial bonding between the paste and aggregates. The highest flexural strength was recorded for mix AASCC2 (5% RHA) after 7 days. Nevertheless, with an escalation in RHA content to 10% and 15%, there was a decline in flexural strength.

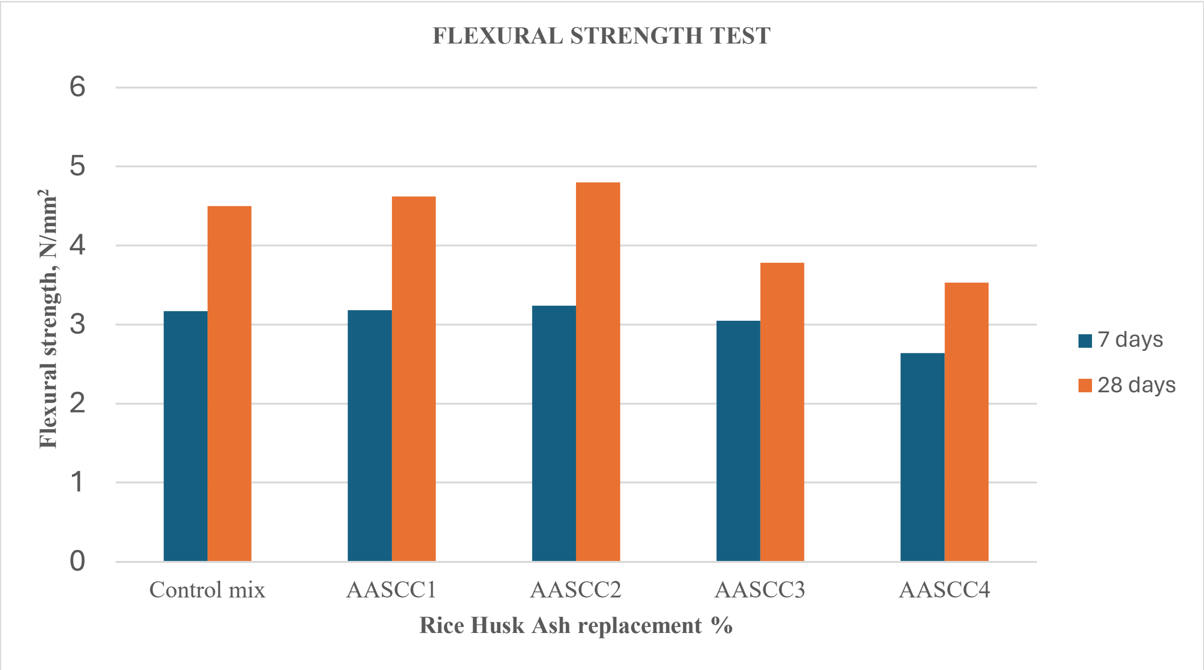

Fig 5. The flexural strength test graph

5.2.3. Split tensile strength test result

The structural design philosophy, encompassing aspects such as shear and anchorage of steel reinforcement, plays a pivotal role in the realm of construction. The outcomes of splitting tensile strength for Alkali -Activated Self-Compacting Concrete (AASCC) blends are delineated in **Fig 6.** An observable reduction in split tensile strength is noted with an escalation in the proportion of RHA in AASCC.

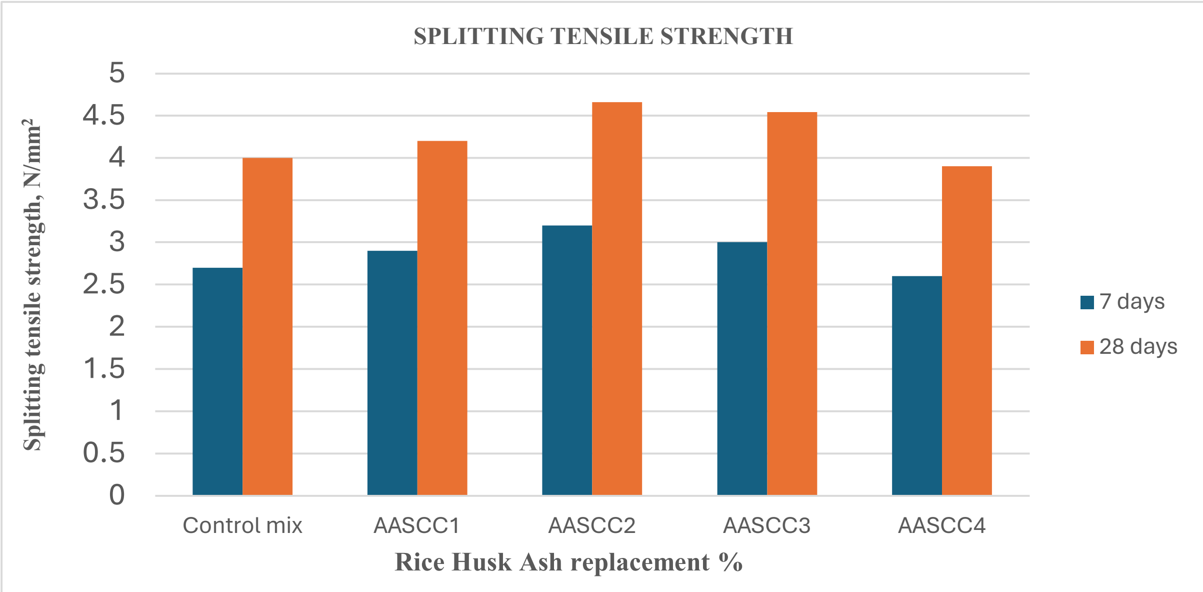

Fig 6. The split tensile strength test graph

6. Conclusion

The study investigated the impact of combining Rice Husk Ash (RHA) with Ground Ordinary Portland Cement and silica fume in Alkali-Activated Self-Compacting Concrete (ASSCC) mixes at room temperature, using experimental analysis. The following conclusions were drawn from the study:

1. The efficacy of the suggested AASCCs was assessed through an analysis of workability. Enhancing the workability performance of the AASCCs was achieved by increasing the substitution of OPC 53 and silica fume with RHA within the range of 0 % to 15 %.
2. The workability of all mixes falls within acceptable EFNARC limits. However, as the RHA percentage increases from 0% to 15%, the fluidity and flowability of AASCC mixes decrease due to increased paste volume and higher water demand from the porous structure of RHA.
3. The replacement of up to 5% of RHA significantly improves the compressive strength, split tensile strength, and flexural strength of AASCC compared to the control mix at all ages.

4. Developing AASCC using OPC, silica fume and RHA as aluminosilicate source is viable and results in substantial strength at room temperature. This approach also addresses disposal issues associated with silica fume and RHA, thereby contributing to environmental preservation by reducing land and air pollution through decreased CO_2 emissions.

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