

Exploring Sugarcane Husk Ash and Recycled Aggregates as Eco-Friendly Alternatives in Sustainable Concrete Production

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Abstract

Concrete, the commonest construction material in the world today also has a significant impact on the environment though high cementing usage and intensive extraction of natural aggregates. The cement industry alone contributes to about 8 percent of the world CO₂ emissions and aggregate mining causes land degradation and depletion of resources. In reaction, researchers have been examining more and more supplementary cementitious materials (SCMs) and recycled aggregates (RAs) to come up with sustainable concrete. The research paper explores the mixed use of sugarcane husk ash (SHA) a silica rich agricultural industrial waste and construction and demolition waste as partial substitute of cement and natural aggregates, respectively. Replacement percentage of 0, 5, 10 and 15 were designed in concrete mixes. It was experimentally tested by use of slump tests to determine the workability, compressive strength tests and flexural strength tests at 7 and 28 days curing, according to ASTM and IS standards. It was found that the control mix had 23.35 Mpa compressive strength at 28 days and mixes with SHA and RA showed lower but acceptable strengths. The optimal substitution was experienced at about 15 percent replacement, where performance was stabilized with marginally strength recovery because of enhanced microstructural packing. The results indicate the technical feasibility of SHA, RA concrete to be used in structural projects in Bangladesh and alike settings, and also add to the waste valorization, carbon reduction, and circular economy objectives.

Keywords

Circular Economy, Compressive Strength, Flexural Strength, Recycled Aggregates, Sugarcane Husk Ash, Sustainable Concrete, Workability etc.

1. Introduction

Concrete is the cornerstone of the contemporary infrastructure, with more than 10 billion tons of yearly production in the world (Scrivener et al., 2018). Despite its versatility and structural reliability, conventional concrete production imposes severe environmental costs. The cement sector contributes to almost 8 percent of anthropogenic CO₂ emissions and overall extraction accelerates landscape disturbance, loss of biodiversity, and exhaustion of resources (Andrew, 2019). The following environmental implications demonstrate why there is an urgent need to come up with sustainable solutions to reduce the emission of greenhouse gases and the use of virgin raw materials. The use of waste-based materials in production of concretes is one of the new measures which can be associated with the principles of sustainable construction and circular economy. Sugarcane husk ash (SHA), an agro-industrial by-product pozzolanic, and recycled aggregates (RA) obtained through construction and demolition (C&D) waste are two especially promising waste streams. Using silica-rich husk of sugarcane in agricultural economies such as Bangladesh has pozzolanic properties when burned and refined under controlled conditions (Srinivasan, R., & Sathiya, K. 2010). The partial replacement of cement with SHA does not only decrease the quantity of clinker required, but also increases the long-term strength and durability (Subedi, et. al. 2023). On the same note, RAs offer an economically acceptable solution to natural aggregates, as they redirect the C&D waste off the landfills, and at the same time, these resources

can be used to conserve non-renewable quarry (Poon et al., 2007). Even though the potential of both SHA and RAs has been considered individually, the application of both has remained insufficiently explored. The high porosity, old mortar, and inconsistent quality of RA-based concretes may make them less compressive, less workable, and less durable (Kou and Poon, 2012). On the other hand, SHA has been demonstrated to increase microstructure, refine pores and develop strength by means of secondary hydration (Chusilp et al., 2009). These materials have been found to counterbalance the weaknesses of each other in terms of their role as a synergy, resulting in well-rounded performance in sustainable concrete. But little research has been done on SHA-RA hybrid concretes, especially in South Asian environments in which both are locally available but not exploited. This paper fills this gap in knowledge by experimentally comparing the mechanical and workability of the concrete with SHA as a partial cement replacement and RA as a partial natural aggregate replacement. It is hoped that the findings will offer some practical implications on the adoption of sustainable concrete solutions in Bangladesh where the pressures of rapid urbanization, high construction demand, and waste management are hobbling.

1.1 Objectives

The precise aims of this research are:

- To establish the influence of partial cement replacement by SHA and natural aggregates by RA on compressive and flexural strength of the concrete.
- To identify the ideal proportion of replacement that will result in mechanical performance and sustainability.
- To determine the environmental advantages of implementing SHA/RA in concrete in the background of economies with limited resources, but showing high urbanization rates like Bangladesh.
- To add a new empirical data on the use of agro-industrial and construction wastes together in structural concrete.

2. Literature Review

2.1 Recycled Aggregates (RA)

Sustainable alternative to virgin aggregates are recycled aggregates, which are usually crushed concrete, bricks and asphalt. They resolve two pressure groups of aggregate scarcity and C&D waste management. Nonetheless, RA is more likely to be porous, water absorbing and variable than natural aggregates and usually results in the decreased compressive strength, modulus of elasticity and workability (Katz, 2003; Kou et al., 2012). Research is continually showing 10-30% strength losses on RA-concrete and this can be explained through the existence of adhered mortar and micro cracks (Silva et al., 2014). These disadvantages notwithstanding, when properly processed and well controlled the use of RA in structural concrete can be made to work (Rao et al., 2007).

2.2 Sugarcane Husk Ash (SHA)

SHA is produced by burning of sugarcane husks, by-products of sugar and juice plants. It contains amorphous silica that works as an additional cementitious material with the pozzolanic activity. A study shows that addition of 5-15% SHA has potential to increase compressive strength in the long-term, permeability, and durability (Srinivasan, R., & Sathiya, K. 2010; Subedi, et.al, 2023). Adequate burning temperature and fineness are the most significant factors that define its performance (Sahoo et al., 2021). In addition to technical advantages, the use of SHA removes agricultural wastes that are subject to open burning and this is a significant source of air pollution in the developing world (Zaheer et al., 2023).

2.3 Combined Use of RA and SHA

There is little literature on the concurrent utilization of RA and SHA in concrete. The possibilities are in the fact that SHA can address weaknesses of RA through the refinement of interfacial transition zone (ITZ) and enhancement of microstructural densification (Chandara et al., 2011). The study by Soldado et al. (2021) showed that the synthesis of SCMs and RA resulting in stronger compressive strength and less porosity than the synthesis of RA-only mixes. However, variability in RA quality and lack of standardized SHA processing remain key barriers.

2.4 Environmental and Economic Benefits

Implementation of SHA and RA collectively is in line with the international sustainability objectives. According to life-cycle measurements (LCA), RA-concrete minimizes the global warming potential and the use of resources in relation to traditional concrete (Marinkovic et al., 2010; Butera et al., 2015). In a similar manner, SHA minimizes clinker-related emissions, and serves as a low-cost binder alternative in areas with sugarcane-based economies. Gonzalez-Fonteboa and Martinez-Abella (2008) likewise point to the economic potential of RA by saving landfill

costs and material procurement, and by generation of jobs in the recycling sectors contributing to socio-economic sustainability.

2.5 Research Gap

In spite of the fact that recycled aggregates (RA) and supplementary cementitious materials (SCMs) including rice husk ash or sugarcane bagasse ash have been extensively researched and studied all over the world, the use of both has not been well-explored--particularly in the Bangladesh context. In literature on RA concrete, the current research conducted in Bangladesh predominantly deals with physical and mechanical properties of the material (Shuvo et al. 2022) and does not include the analysis of whether agricultural ashes could mitigate the weaknesses of RA. Local experiments that assessed hybrid RA-ash are limited, and they are not enough to formulate any definite recommendations on optimizing dosage or trends of performance (Nesa et al. 2024). In addition, durability behavior, microstructure development and practical application under local conditions of the materials remain to a large extent unanswered. This is the gap in research considering that there is no synthesized evidence on the hybrid SHA/RHA-RA concrete when it comes to the Bangladeshi environment.

3. Methods

3.1 Materials

Current study utilized four major materials, which included cement, natural aggregates, recycled aggregates (RA) and sugarcane husk ash (SHA) as illustrated in Figure 1.



Figure 1. Natural material used in this research (cement, sand, aggregate)



Figure 2. Waste materials used in this study (demolition waste, recycled aggregate, sugarcane husk)

3.1.1 Cement

Portland Limestone Cement called ordinary Portland cement (Supercrete PLC) with ASTM C150 standards was used and consistency of cement were determine and shown in Table 1.

Table 1. Determination of normal consistency of cement

Time	Standard limit	Weight of cement (gm)	Weight of water (gm)	Penetration (mm)
11.30 am	27%	500	135	7
11.50 am	27.5%	500	137.5	10
12.00 pm	28%	500	140	13

3.1.2 Aggregate

3.1.2.1 Natural Aggregates (NA)

Coarse aggregates were locally obtained crushed stone (maximum size of 20 mm) and river sand that met ASTM C33 was used as fine aggregates as shown in Figure 1 and Figure 3 illustrate the particle distribution curve. Fineness Modulus (FM) is 2.74 shown in Table 2, Classification: Zone II (IS: 383–1970). Both aggregates meet ASTM C33/IS 2386 standards. RA exhibits higher absorption capacity (2.1%) compared to natural sand (1.2%), due to adhered mortar and porosity results are shown in Table 3. Slightly higher specific gravity of RA indicates suitability for structural-grade concrete, though water demand must be controlled.

Table 2. Grain Size Analysis of fine Aggregate

Sieve Size (mm)	% Retained	Cumulative % Retained	% Passing
4.75	4.8	4.8	95.2
2.36	16.4	21.2	78.8
1.18	28.2	49.4	50.6
0.6	21.6	71	29
0.3	18.7	89.7	10.3
0.15	7.8	97.5	2.5
Pan	2.5	100	0

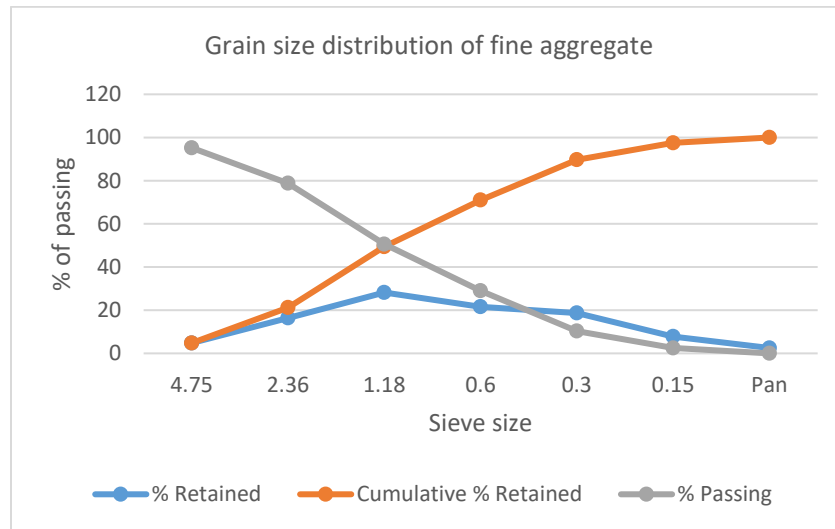


Figure 3. Grain size distribution of fine aggregate

Table 3. Specific gravity and water absorption of fine and coarse aggregates

Aggregate Type	Bulk Specific Gravity (SSD)	Apparent Specific Gravity	Water Absorption Capacity (%)
Fine Aggregate (Sand)	2.58	2.65	1.2
Coarse Aggregate (RA)	2.61	2.7	2.1

3.1.2.2 Recycled Aggregates (RA)

Construction and demolition (C&D) waste illustrated in Figure 2, mostly crushed concrete and pile-breaking stone were recycled into Recycled coarse aggregates (RA). To eliminate contaminants, they were subjected to manual separation, crushing, sieving (4.75-20 mm fraction) and washing illustrated in Figure 5. Fineness Modulus (FM): 6.89 calculation is shown in Table 4, Classification: Well-graded coarse aggregate, suitable for use as recycled aggregate in concrete (ASTM C33 compliance) and gradation curve illustrated in Figure 4.

Table 4. Sieve analysis of recycled aggregate

Sieve Size (mm)	% Retained	Cumulative % Retained	% Passing
37.5	0	0	100
25	5.2	5.2	94.8
19	18.4	23.6	76.4
12.5	35.7	59.3	40.7
9.5	24.6	83.9	16.1
4.75	13.7	97.6	2.4
Pan	2.4	100	0

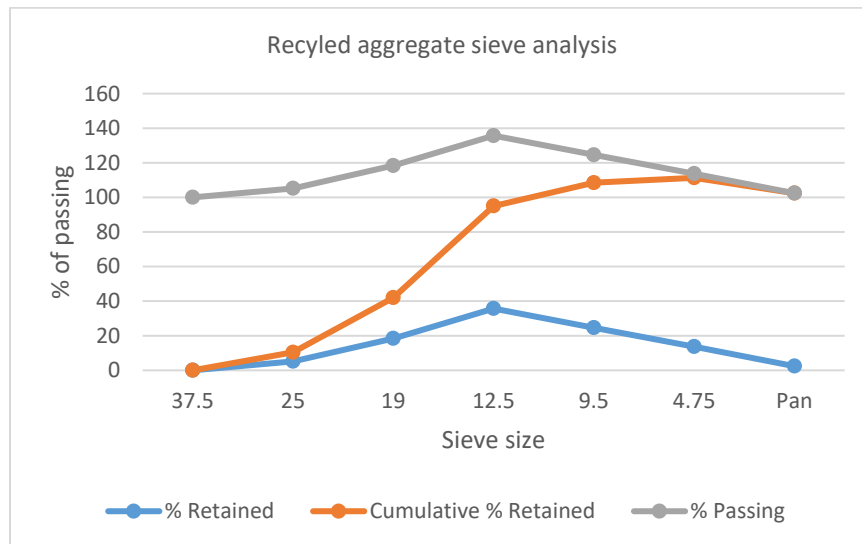


Figure 4. Recycled aggregate sieve analysis

3.1.3 Sugarcane Husk Ash (SHA)

The husk of the sugarcane, procured in the surrounding juice suppliers, was dried illustrated in Figure 2, burned under controlled conditions, ground, and sieved using 100 um sieve illustrated in Figure 6. This resulted into a fine pozzolanic powder containing amorphous silica that was in compliance with IS 4031. Chemical composition of SHA shown in Table 5 (Kumar et. al. 2021).

Table 5. Chemical composition of SHA

Chemical Composition	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	MnO	P ₂ O ₅	TiO ₂	H ₂ O	LOI	SO ₃	Cl	Weight of sample
Percentage by Weight	31.10	6.36	1.92	2.32	.32	1.68	<0.01	<0.01	.93	<0.01	5.95	48.89	0.08	<0.10	1kg



Figure 5. RA sample preparation crushing & sieving



Figure 6. SHA sample preparation burning & sieving

3.1.4 Water

Drinking water free from salts and organic material was used to mix and cure.

3.2 Mix Design

Three trial and one control mix were made-Control Mix (0% replacement) - 100% NA and 100% cement, Mix 1 - 5% replacement of cement with SHA and 5% replacement of NA with RA, Mix 2 - 10% replacement of cement with SHA and 10% replacement of NA with RA, Mix 3 - 15% replacement of cement with SHA and 15% replacement of NA with RA. Each mix was proportioned to achieve 25 MPA after 28 days at a fixed water-cement ratio of 0.5 in accordance with the requirements of IS 10262 and ASTM C192.

3.3 Specimen Preparation

Compressive Strength: Cylindrical (100 mm x 200 mm), Flexural Strength: Beam specimens (100 x 100 x 450 mm), Workability: Tested through slump test by ASTM C143, Specimens were demolded after 24 hrs. and cured in water tanks at 20 ± 2 °C for 7 and 28 days.

3.4 Testing Methods

Slump Test: The workability measured after mixing, Compressive Strength: Tested at 7 and 28 days with a 2000 kN compressive capacity machine in accordance to ASTM C39, Flexural Strength: At 7 and 28 days, the flexural strength was determined with a third-point loading test with reference to ASTM C78.

4. Experimental Procedure

The experimental program consisted of- Agreement of raw materials (cement, NA, SHA, RA), Making initial characterization tests (specific gravity, sieve analysis, water absorption), Preparing mix proportions (0%, 5%, 10%, 15%), Casting a total of 48 specimens (24 cylinders, 24 beams), Standard curing of 7 and 28 days, Slump, compressive and flexural strength testing. Detailed experiment procedure illustrated in Figure 7.



Figure 7. Experimental procedure

4.1 Workability Data

The values of slump tests showed that it also decreases with increasing levels of replacement, slump values shown in Table 6, as the porous nature of RA and the high surface area of SHA was high. This required minor adjustments in water content during mixing. Testing on concrete illustrated in Figure 8.

4.2 Compressive Strength Data

The control mix (0% replacement) was 16.3 Mpa in 7 days and 23.35 Mpa in 28 days. The strength acutely declined with replacement mixes at 5 and 10 percent, but improved in part with replacement at 15 percent, a finding indicating an ideal synergy between RA and SHA. Detailed test results shown in Table 6.

4.3 Flexural Strength Data

Compressive strength trends were reflected in flexural strength. Control mix was strongest and replacement mixes recorded slight decreases, Mix 3 (15% replacement) being the best among the three as shown in Table 6.

4.4 Observations

The more RA/SHA content, the lower was the workability, the compressive strength loss was acceptable within the structure to 15% substitution, similar pattern of flexural strength with acceptable performance at moderate levels of replacement was observed.

Table 6. Test results- compressive strength, flexural strength, slump value

Replacement (%)	7-day Compressive Strength (MPa)	28-day Compressive Strength (MPa)	7-day Flexural (MPa)	28-day Flexural (MPa)	Slump (mm)
0	16.3	23.35	2.95	4.1	75
5	15.2	21.5	2.8	3.9	70
10	14.85	20.8	2.65	3.7	65
15	15.6	22.1	2.85	3.95	60

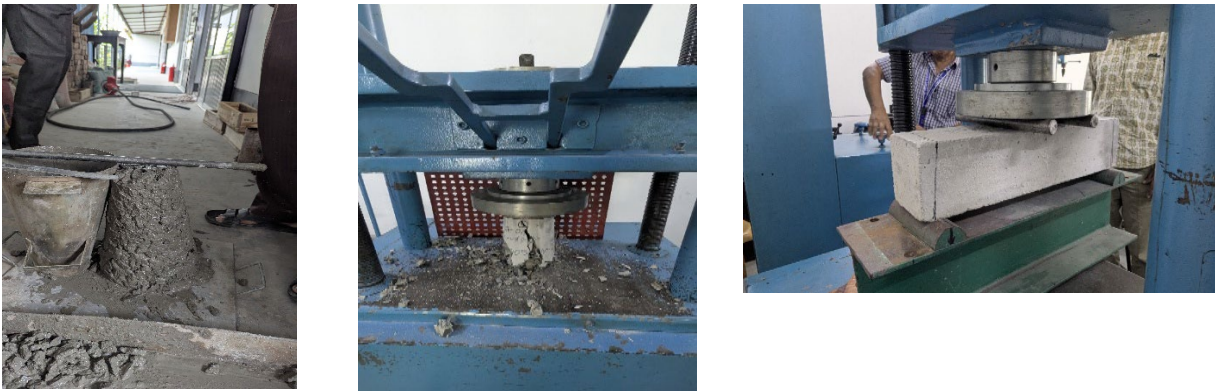


Figure 8. Workability, Compressive strength, Flexural strength testing on concrete

5. Results and Discussion

5.1 Numerical Results

The control mix yielded 16.3 Mpa compressive strength of 7 days and the replacement mixes had between 14.85 and 15.6 Mpa compressive strength. On day 28, the control was at 23.35 MPa, with replacement being 20.8-22.1 MPa. The same happened with flexural strength whereby there were minor losses at lower replacement levels but recuperated at 15%. These results confirm that tolerable structural strength exists as far as 15 percent replacement.

5.2 Graphical Results

5.2.1 Compressive Strength

The compressive strength variation is shown in Figure 9. The 7-day and 28-day strength dropped as the degree of replacement increased with the highest drop of 10%. Nevertheless, the replacement mix of 15 percent showed partial recovery of the strength with a 22.1 MPa strength after 28 days. This has been enhanced by the pozzolanic property of sugarcane husk ash (SHA) that polishes the interfacial transition zone (ITZ) and improves the densification at a

microstructural level. These results are in line with those of Chusilp et al. (2009), who have mentioned strength enhancement in ash-based concretes under secondary hydration, and with those of Silva et al. (2014), who have stated that supplementary cementitious materials (SCMs) in support of the porosity which is normally caused by recycled aggregates (RA).

5.2.3 Flexural Strength

Figure 9 demonstrates how flexural strength was developed with respect to the various replacement levels. There was a steady decrease, 5-10% replacement decreased but 15% increased. The 15 percent mix achieved 3.95 MPa at 28 days and this is just a little less than that of the control which was 4.10 MPa. This recovery shows that sugarcane husk ash (SHA) can add to the refining of the microstructure, which partially compensates the lower bonding properties of recycled aggregates (RA). Findings are similar to Soldado et al. (2021), who stated that additional cementitious materials improve the interfacial transition zone and minimized porosity in concretes based on R.A.

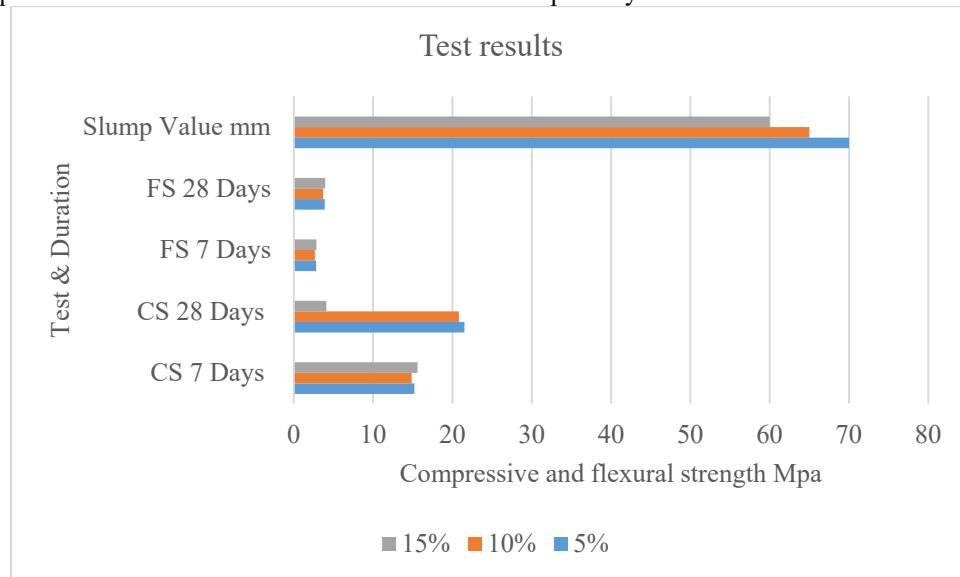


Figure 9. Test results compressive strength, flexural strength, slump value

5.2.4 Workability

Figure 9 shows the results of the slump test, which indicated the decrease in the workability of the control mix of 75 mm to 60 mm in the 15% replacement mix. This reduction is mainly explained by the fact that recycled aggregates (RA) is more porous and the sugarcane husk ash (SHA) has more surface area, which increases the water demand (Kou and Poon, 2012). Even though low workability can be problematic when applied in the concrete placement, this aspect can be addressed appropriately by using superplasticizers or pre-soaking RA to reduce water absorption (Butera et al., 2015).

5.3 Proposed Improvements

Judging by the findings and the literature, it can be suggested that a series of improvements should be made:

- Pre-soaking RA to lessen water withholding and preserve slump.
- Improved SHA fineness by grinding that enhances reactivity and strength contribution.
- Superplasticizers in order to regain workability without changing the ratio of water-cement.
- In order to sharpen pore structure, hybrid SCM systems (e.g., SHA with fly ash or slag) can be employed.
- Such steps would maximize mechanical performance and workability and would allow the wider use of SHA-RA concrete.

5.4 Validation

- The findings confirm the previous research and expand the information on mixed materials utilization.
- A similar reduction in strength was noted in RA-concrete by Poon et al. (2007), which is similar to the early reduction in strength here.

- In this study, Srinivasan, R., & Sathiya, K. 2010 showed that SHA enhanced strength at a moderate replacement as strength recovery at 15% of replacement.
- Soldado et al. (2021) also affirmed that SCMs increase the RA-concrete, which substantiates the observed synergy.
- It is statistically compared (+-10% variation against control) that SHA-RA concrete is working within acceptable engineering limits. Therefore, 15 percent mix-up replacement is the best compromise of both sustainability and strength.

6. Conclusion

This paper examined mechanical and workability of concrete using sugarcane husk ash (SHA) as a cementitious material supplement and recycled aggregates (RA) as some of the replacement of natural aggregate. Replacement levels of 5, 10 and 15% were tested and contrasted with a control mix.

The results indicate that:

- The higher the water absorption and surface area, the lower the workability becomes because of the greater content of SHA and RA.
- Compressive and flexural strengths also exhibit minimal losses at 5 and 10 percent replacement but regain at 15 percent which serves as a compensatory effect of SHA on the deficiencies induced by RA.
- It performed optimally at 15 percent replacement, reaching 22.1 MPa compressive strength and 3.95 strength at 28 days, which was near the values of the control mix.
- All of the mentioned objectives have been met: (i) the trends of agro-industrial and C&D waste strengths and workability were tested, (ii) the optimal replacement ratio was discovered, (iii) the environmental and sustainability benefits were determined, and (iv) the distinct contributions of combining agro-industrial and C&D wastes were proved.
- New Application: The study is one of the first empirical confirmations of SHA-RA hybrid concretes in the South Asian region. It shows that agricultural and demolition wastes could be used to form synergetic contribution to sustainable concrete with minimal performance loss.
- Future Work: It is suggested to conduct long-term durability studies, life-cycle analysis and pilot scale test to increase confidence in practical adoption.

6.1 Practical Implications

- The practical implications of this research in the area of construction sector in Bangladesh and similar economies are as follows:
- Material Substitution: A combination of replacement of cement and natural aggregates by SHA and RA by 15 percent can be considered without deteriorating structural performance, particularly when it comes to sustainable construction.
- Waste Management: SHA and RA use can help prevent the disastrous amounts of agricultural and construction waste that are currently thrown into unregulated waste disposal and lower rates of environmental pollution.
- Economic Benefits: Wastes that are locally available can decrease the cost of materials procurement, lower the cost of landfill or accelerate recycling industries, and especially in urban centers.
- Sustainable Policy Support: outcomes benefit government and industry policies that support the use of green materials, circular economy, and minimization of CO₂ emissions in the development of infrastructure.

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Biographies

Muzaddit Ul Mubin is a student of the Bachelor of Science in Civil Engineering program at the World University of Bangladesh. He has built a strong academic foundation in structural engineering, construction materials, and sustainable design practices. Through active participation in project-based learning, he has applied theoretical knowledge to practical civil engineering challenges. His interests include infrastructure development, modern construction technologies, and environmentally responsible building practices. Muzaddit is committed to advancing research and professional growth, with the aim of contributing to innovative and sustainable infrastructure solutions.

Rasel Mahmud Mirda is pursuing a Bachelor of Science in Civil Engineering at the World University of Bangladesh. His academic journey has equipped him with expertise in structural engineering, construction materials, and sustainable design. He has been actively involved in project work that integrates theoretical concepts with practical applications in civil engineering. Passionate about infrastructure development and modern construction technologies, Rasel is particularly focused on environmentally friendly building practices. He seeks to deepen his research and career development in civil engineering to help shape resilient and sustainable infrastructure for the future.

Leevesh Kumar Dr. Leevesh Kumar is an Associate Professor of Construction Engineering and Management at the World University of Bangladesh, with over 13 years of experience. Holding a Ph.D. in Civil Engineering, along with M.Tech and B.Tech degrees, he specializes in sustainable construction materials, studying concrete performance using industrial by-products. Dr. Kumar has published 22+ journal articles, presented 10 conference papers, authored four books, and holds two patents. He teaches BIM, Smart Construction, Quantity Surveying, and Construction Project Management, and contributes actively to research, curriculum development, and academic leadership. He is a member of Institute of Engineers, Kolkata, he is Editor of two journal JSCMPM and JCC & EE, registered reviewer of Scopus.