Enhancing The Mechanical Properties Of Concrete Using Rice Husk Ash And Crushed Glass As Sustainable Additives

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Abstract:

Concrete is widely known for its high compressive strength but is inherently weak in tension and flexural resistance. To address these limitations and promote sustainable construction practices, this research explores the potential of incorporating Rice Husk Ash (RHA) and Crushed Glass (CG) as partial replacements for cement and fine aggregate, respectively, in concrete mixtures. RHA, a highly reactive pozzolanic by-product of rice milling, was used to replace cement in proportions of 5%, 10%, and 15%, 20% while CG, derived from waste glass, was used to replace fine aggregate at similar levels. The fresh concrete properties were assessed through slump tests to evaluate workability, while the hardened properties were measured using 28-day compressive strength, flexural strength, and split tensile strength tests. Results showed that optimal replacement levels of RHA and CG significantly improved compressive strength and mechanical performance due to enhanced matrix densification and better interparticle bonding. However, increased replacement percentages adversely affected workability, necessitating careful adjustments in water content. This study confirms that the integration of RHA and CG can serve as a viable and eco-friendly alternative in concrete production, contributing to waste reduction, reduced cement usage, and a lower carbon footprint. These findings support the use of agricultural and industrial by-products in sustainable concrete technology, offering both environmental and economic advantages for the construction industry.

Keywords— Rice Husk Ash, Crushed Glass, Compressive Strength, Workability, Flexural Strength, Sustainable Concrete, Waste Materials.

1. Introduction

Concrete is the most widely used construction material across the globe due to its excellent compressive strength, durability, and versatility. However, it is inherently weak in tension and flexure, which limits its performance in certain structural applications. Furthermore, the production of conventional concrete heavily relies on non-renewable resources such as natural aggregates and Portland cement, contributing significantly to environmental degradation through high energy consumption and carbon emissions.

In recent years, rising concerns about the environmental impact of concrete production and the increasing volatility in the cost and availability of raw materials have prompted researchers and industry professionals to explore alternative, sustainable materials. Industrial and agricultural by-products are being increasingly considered as partial replacements for cement and aggregates, not only to reduce costs and promote waste recycling but also to enhance specific properties of concrete.

Among these alternatives, Rice Husk Ash (RHA)—an agricultural by-product obtained from burning rice husks—and Crushed Glass (CG)—recycled from waste glass—have shown promising potential. RHA is rich in amorphous silica, which exhibits pozzolanic properties, making it a viable supplementary cementitious material. Crushed glass, when finely ground, can serve as a partial replacement for fine aggregates and contribute to improved particle packing and reduced porosity in the concrete matrix.

This research focuses on evaluating the mechanical performance and workability of concrete mixes incorporating varying proportions of RHA and CG. The primary aim is to identify the optimal combination that yields enhanced compressive strength while maintaining adequate workability. Standardized laboratory tests, including slump tests and 28-day compressive strength evaluations, are conducted under controlled conditions. While long-term durability assessments are beyond the scope of this study, the short-term results provide critical insights into the feasibility of adopting RHA and CG in sustainable concrete formulations.

The use of these alternative materials offers several benefits: it reduces dependency on natural resources, promotes effective waste management, lowers greenhouse gas emissions, and contributes to a more sustainable and circular construction economy. By demonstrating the practical application and performance of concrete incorporating RHA and CG, this study supports ongoing efforts to make concrete production more eco-friendly and economically viable without compromising on quality or structural integrity.

2. Literature Review

1. Use of Glass Powder and Crushed Glass in Concrete

- Manan Asad (2024) found that using rough and smooth glass powder as partial replacements for sand improved concrete strength, particularly when combined with 5% fly ash. Rough glass powder yielded a maximum compressive strength of 23.26 MPa at 15% replacement.
- Marcela Redondo-Pérez et al. (2024) conducted a meta-review of 157 studies on glass powder in ultra-high-performance concrete (UHPC). Up to 25% replacement of cement with glass powder enhanced hydration and compressive strength (>150 MPa), but higher levels led to strength reduction.
- Samir Saify et al. (2023) reported that replacing 15% of cement with waste glass powder resulted in the highest compressive strength in high-strength concrete—88 MPa at 28 days, also improving density and ultrasonic pulse velocity.
- Peter Ontieri Manyara (2019) demonstrated that replacing 10% river sand with crushed glass and adding 1% blue gum ash yielded 30.1 MPa strength, suggesting its suitability for lightly loaded structural elements.
- MdAzree Othuman Mydin et al. (2024) found that using 20% soda-lime glass bottle waste in foamed concrete improved strength, pore structure, and durability.

2. Use of Rice Husk Ash in Concrete

- Muralidharan Raghav et al. (2021) reviewed supplementary cementitious materials (SCMs) like RHA, highlighting their pozzolanic reactivity and suitability for sustainable concrete. Optimal replacement levels ranged from 15% to 55%, improving durability and resistance to aggressive environments.

- Rahmat Madandoust and Reza Ghavidel (2013) (in 6 SAMPLE.docx) found that combining 10% glass powder and 5% RHA provided the best 28-day compressive strength. This hybrid mix showed increasing strength with age due to enhanced pozzolanic activity.
- Al Mashhadani D. A. et al. (2023) reviewed HPC made with combinations such as 10% RHA + 10% silica fume, reporting increased strength and sustainability. Nanomaterials like nano RHA further improved matrix densification.

3. Combined Use of RHA and Glass Powder

- Studies combining RHA and GP consistently show enhanced interparticle bonding, matrix densification, and mechanical performance, especially at optimized levels of 10–15% replacement each. However, higher replacement levels negatively impact workability, necessitating water content adjustments.
- Md. Munir Hayet Khan et al. (2023) validated that 20% GP yielded optimal strength in self-compacting concrete, while quartz powder reduced workability. Artificial neural networks were also effective in strength prediction models.

4. Environmental and Economic Implications

Utilizing RHA and CG promotes a circular economy, lowers cement demand, and reduces the carbon footprint of concrete. These materials not only serve as effective substitutes but also encourage waste management and cost savings in construction.

5.Conclusion of the Review

The reviewed literature underscores the promising role of RHA and CG as sustainable cement and fine aggregate substitutes in concrete. With appropriate replacement levels, these materials can significantly enhance compressive strength, improve durability, and reduce environmental impact, although careful attention must be paid to their effects on workability and long-term performance.

3. Materials

In this study, Ordinary Portland Cement (OPC 53 Grade) was selected for its proven reliability and widespread use in structural concrete applications. The cement complied with IS 12269:2013 specifications and exhibited key physical properties including a specific gravity of 3.15, fineness of 4.5% (retained on a 90 µm sieve), an initial setting time of 45 minutes, and a final setting time of 280 minutes. These characteristics make it particularly suitable for high-performance and high-strength concrete formulations. The fine aggregate used was natural river sand classified under Zone II as per IS 383:2016, with a specific gravity of 2.65, water absorption of 1.2%, bulk density of 1640 kg/m^3, and a fineness modulus of 2.62, all of which contribute to improved workability, cohesive behavior, and a stable mix. For coarse aggregate, well-graded crushed granite with a maximum size of 20 mm was employed, also conforming to IS 383:2016 standards. It had a specific gravity of 2.75, water absorption of 0.6%, an aggregate crushing value of 22.5%, and an impact value of 21.2%, indicating excellent load-bearing capacity and resistance to mechanical degradation.

As a sustainable pozzolanic additive, Rice Husk Ash (RHA) was introduced as a partial replacement for cement. The RHA, obtained from controlled combustion of rice husk, had a specific gravity of 2.4, silica content of approximately 85%, and fineness of 8.5% retained on a 90 µm sieve. These parameters reflect its high reactivity and potential to significantly enhance strength and durability through secondary C-S-H formation. Additionally, Crushed Glass (CG) derived from post-consumer waste glass was utilized as a partial fine aggregate substitute. The recycled glass was finely ground to ensure particle compatibility and demonstrated a specific gravity of 2.55, water absorption of 3.5%, bulk density of 1580 kg/m³, and fineness of 9.8%, making it suitable for sustainable mix designs that reduce reliance on natural resources. Finally, potable water conforming to IS 456:2000 was used for both mixing and curing operations. The water had a pH of 7.4, chloride content of 120 mg/L, and sulfate content of 150 mg/L, with no evidence of harmful alkalinity, thus ensuring its compatibility for concrete production and hydration processes.

4. Mixtures

This study presents a detailed experimental investigation into the incorporation of Rice Husk Ash (RHA) and Crushed Glass (CG) as sustainable supplementary materials in concrete, with the objective of enhancing compressive strength, workability, and reducing the environmental footprint of conventional concrete. The materials used in this research included Ordinary Portland Cement (OPC 53 Grade), natural river sand, crushed granite coarse aggregate, potable water, RHA, and CG. OPC complied with IS 12269:2013, featuring a specific gravity of 3.15, a fineness of 4.5% (retained on a 90 µm sieve), and setting times of 45 minutes (initial) and 280 minutes (final), making it ideal for high-strength applications. The fine aggregate—Zone II natural river sand—had a specific gravity of 2.65, water absorption of 1.2%, bulk density of 1640 kg/m³, and a fineness modulus of 2.62. Crushed granite with a maximum size of 20 mm met IS 383:2016 requirements and exhibited a specific gravity of 2.75, water absorption of 0.6%, aggregate crushing value of 22.5%, and an impact value of 21.2%, ensuring its suitability for durable concrete. The RHA, sourced from the controlled combustion of rice husks, was used as a partial cement replacement and had a specific gravity of 2.4, silica content of 85%, and fineness of 8.5%. Crushed Glass (CG), obtained from recycled waste glass, was ground to a suitable size and used as a fine aggregate substitute, possessing a specific gravity of 2.55, water absorption of 3.5%, bulk density of 1580 kg/m³, and fineness of 9.8%. The mixing water met IS 456:2000 standards, with a pH of 7.4, chloride content of 120 mg/L, sulfate content of 150 mg/L, and no harmful alkalinity. RHA and CG were incorporated at replacement levels of 5%, 10%, 15%, and 20% by weight, maintaining a constant water-to-cement ratio of 0.45 across all mixes. A control mix comprising 100% OPC and conventional aggregates served as a reference. This comprehensive mix design was executed to evaluate the fresh and hardened properties of the modified concrete, such as slump, compressive strength, flexural strength, and split tensile strength, and to identify the optimum blend of RHA and CG for producing high-performance, eco-friendly concrete.

Table 1: Mix Proportions Of Concrete For Different Mix Design

Mix Design	Cement (kg/m³)	RHA (kg/m³)	Fine Aggregate (kg/m³)	CG (kg/m³)	Coarse Aggregate (kg/m³)	Water (L)
Control Mix (0% RHA + 0% CG)	350	0	700	0	1200	175

Mix 1 (5% RHA + 5% CG)	332.5	17.5	665	35	1200	175
Mix 2 (10% RHA + 10% CG)	315	35	630	70	1200	175
Mix 3 (15% RHA + 15% CG)	297.5	52.5	595	105	1200	175
Mix 4 (20% RHA + 20% CG)	280	70	560	140	1200	175

5. Test Methods

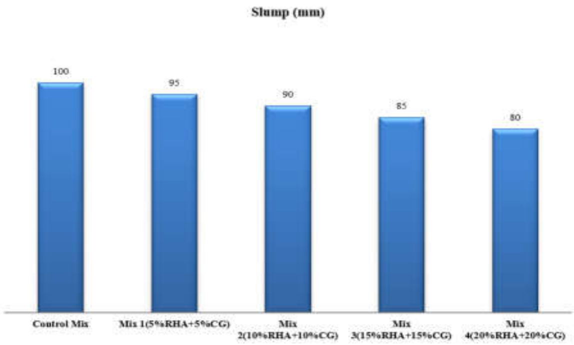
The experimental program was designed to systematically investigate the influence of Rice Husk Ash (RHA) and Crushed Glass (CG) on the mechanical and workability properties of concrete. Ordinary Portland Cement (OPC 53 Grade), compliant with IS 12269:2013, was used as the primary binder, while natural river sand (Zone II) and 20 mm crushed granite served as fine and coarse aggregates, respectively. RHA, with a specific gravity of 2.4 and silica content of 85%, and CG, with a specific gravity of 2.55 and fineness of 9.8%, were used as partial replacements for cement and fine aggregate. A full factorial experimental design was adopted, incorporating RHA and CG replacement levels of 5%, 10%, 15%, and 20%. Concrete mixes were prepared using a mechanical mixer to ensure uniform dispersion of materials. For each mix, 150 mm cube moulds were cast for compressive strength testing, while 150 × 300 mm cylindrical moulds were used for flexural and split tensile strength assessments. The specimens were carefully compacted using vibration and cured in potable water (as per IS 456:2000 standards) for 7, 14, and 28 days to ensure proper hydration.

Workability was assessed immediately after mixing using the slump cone test, which provided a measure of the mix's consistency and ease of placement, and the flow table test, which evaluated the spread and cohesion of the mixes—particularly important for RHA and CG-containing blends known to influence fluidity. Mechanical performance was evaluated using compressive strength tests at all three curing intervals, following standard procedures to ensure reliable results. All tests were conducted in triplicate for each mix variation to ensure statistical reliability and reproducibility. This comprehensive setup enabled a detailed analysis of how varying dosages of sustainable additives influenced concrete's fresh and hardened properties.

6. Results and Discussion

6.1 Workability Test

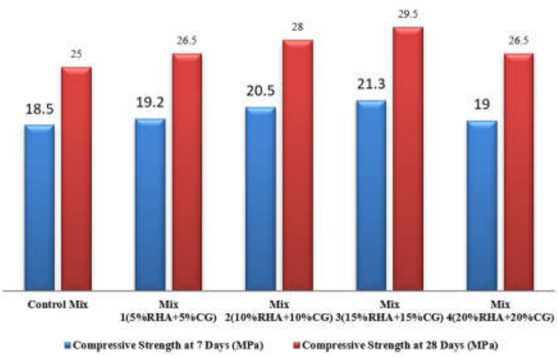
Workability, a vital characteristic of fresh concrete, was assessed in this study using both the slump test and the flow table test to evaluate consistency and flowability, respectively. The incorporation of Rice Husk Ash (RHA) and Crushed Glass (CG) as partial replacements for cement and fine aggregate showed a clear trend of decreasing workability with increasing replacement levels. The control mix exhibited the highest slump value of 100 mm, indicating excellent flow characteristics, while mixes with increasing proportions of RHA and CG showed progressively lower slump values—95 mm for 5% replacement, 90 mm for 10%, 85 mm for 15%, and the lowest, 80 mm, for 20% replacement. This reduction is primarily due to the high water absorption capacity of RHA, resulting from its porous structure, and the angular, irregular shape of CG particles, which increases internal friction and hinders flow. Nevertheless, all mixes remained within acceptable workability limits, demonstrating that RHA and CG can be effectively used in concrete without compromising fresh concrete performance. However, to maintain the desired consistency, especially at higher replacement levels, modifications such as increased water content or the use of chemical admixtures may be necessary.



Graph 1: Workability Test Results

6.2 Compressive Strength Test

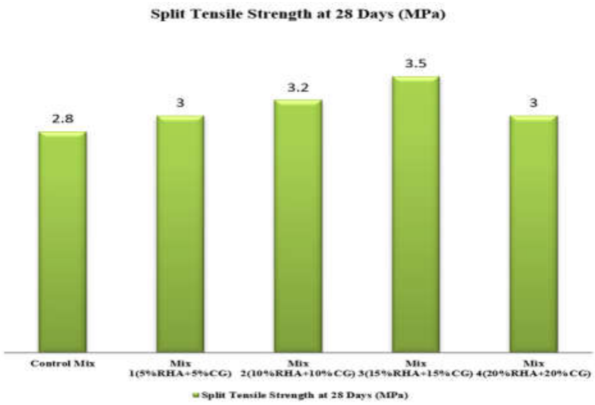
Compressive strength, a fundamental measure of concrete's structural performance, was evaluated at 7 and 28 days using standard cube tests. The results revealed a clear enhancement in strength with the incorporation of Rice Husk Ash (RHA) and Crushed Glass (CG), particularly at moderate replacement levels. The control mix (0% RHA and CG) exhibited strengths of 18.5 MPa and 25.0 MPa at 7 and 28 days, respectively. Mixes with increasing proportions of RHA and CG showed progressive improvements, with Mix 1 (5% RHA + 5% CG) reaching 19.2 MPa and 26.5 MPa, and Mix 2 (10% RHA + 10% CG) achieving 20.5 MPa and 28.0 MPa at the same intervals. The highest strength was observed in Mix 3 (15% RHA + 15% CG), which attained 21.3 MPa at 7 days and 29.5 MPa at 28 days. These gains are attributed to the pozzolanic reactivity of RHA, which enhances C-S-H gel formation, and the filler effect of CG, which improves packing density and reduces voids. However, Mix 4 (20% RHA + 20% CG) demonstrated a decline in strength (19.0 MPa at 7 days and 26.5 MPa at 28 days), suggesting that excessive replacement levels may impair hydration and bonding due to high water absorption and reduced cement content. Overall, the findings indicate that a balanced replacement of 10–15% RHA and CG offers optimal compressive strength, while higher proportions may lead to diminishing returns and structural inefficiencies.



Graph 2: Compressive Strength Test Results

6.3 Split Tensile Strength Test

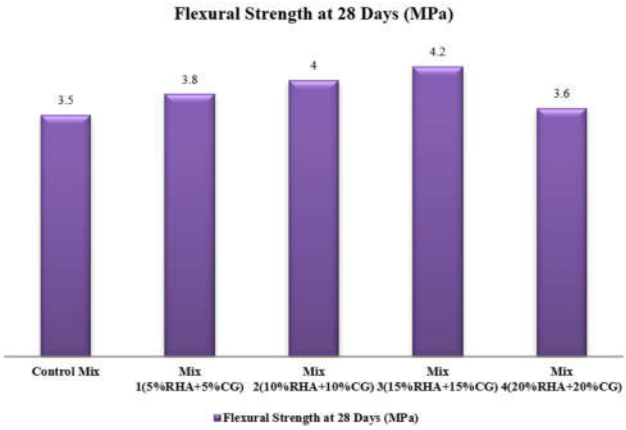
The split tensile strength of concrete, evaluated at 28 days using cylindrical specimens, demonstrated a clear improvement with the incorporation of rice husk ash (RHA) and crushed glass (CG). The control mix exhibited a strength of 2.8 MPa, which increased progressively to 3.5 MPa at the optimal replacement level of 15% RHA and 15% CG. This enhancement is mainly due to the pozzolanic activity of RHA, promoting additional C-S-H formation and improved bonding, combined with the angular texture of CG that enhances aggregate interlocking. However, at higher replacement levels (20% RHA and CG), the tensile strength declined to 3.0 MPa, likely because of increased water absorption and reduced cementitious material, which adversely affect hydration and bonding. These findings suggest that moderate replacement levels of 10–15% RHA and CG provide the best balance for strengthening concrete's tensile resistance without compromising its overall performance.



Graph 3: Split Tensile Strength Test Results

6.4 Flexural strength Test

The flexural strength of concrete, assessed at 28 days using the three-point loading test, demonstrated notable improvements with the incorporation of Rice Husk Ash (RHA) and Crushed Glass (CG) as partial replacements for cement and fine aggregate. The control mix recorded a baseline strength of 3.5 MPa, while mixes with combined RHA and CG replacements of 5%, 10%, and 15% achieved enhanced strengths of 3.8 MPa, 4.0 MPa, and a peak of 4.2 MPa, respectively. This improvement is attributed to the pozzolanic reactivity of RHA and the angular particle shape of CG, which together enhance matrix densification, interparticle bonding, and internal friction. However, at 20% replacement, the strength decreased to 3.6 MPa, likely due to increased porosity and reduced cohesiveness in the mix. These results indicate that flexural performance can be significantly enhanced through moderate RHA and CG usage, with 15% replacement emerging as the optimal level before diminishing returns are observed.



Graph 4: Flexural Strength Test Results

7. Conclusion

The study revealed that as Rice Husk Ash (RHA) and Crushed Glass (CG) content increased, slump values decreased progressively, indicating reduced workability. The control mix had the highest slump of 100 mm, while mixes with RHA and CG showed a decline from 95 mm to 80 mm, primarily due to RHA's water absorption and CG's angular shape increasing internal friction. Despite this, all mixes remained within workable limits, suggesting that slight adjustments to water content or admixtures could maintain the desired consistency. Compressive strength increased with RHA and CG, reaching a peak of 29.5 MPa in Mix 3 (15% RHA + 15% CG) at 28 days, surpassing the control mix's 25.0 MPa. However, higher replacement levels (20%) led to a decrease in strength, suggesting that moderate replacement levels (10–15%) offer the best performance. Flexural strength also improved, peaking at 4.2 MPa in Mix 3, but dropped to 3.6 MPa at 20% replacement, likely due to excess porosity and reduced cohesiveness. Split tensile strength showed a similar trend, increasing to 3.5 MPa in Mix 3, with a decrease to 3.0 MPa in Mix 4, further indicating that excessive replacement levels reduce the mix's effectiveness. Overall, moderate replacement levels (10–15%) optimize both strength and workability.

7.1 Recommendation for Future Use

For future use, research should focus on refining the replacement levels of Rice Husk Ash (RHA) and Crushed Glass (CG), ideally between 10% and 15%, to achieve an optimal balance between workability and strength. Higher replacement levels (20%) should be avoided due to diminishing returns in both strength and workability. To mitigate the reduction in workability, the incorporation of water-reducing admixtures or superplasticizers can help maintain the desired consistency in concrete mixes. Additionally, further studies are needed to assess the long-term durability of concrete containing RHA and CG, particularly in terms of resistance to chloride penetration, sulfate attack, and freeze-thaw cycles. Expanding the research to include other critical properties such as shrinkage, creep, and fire resistance will offer a more comprehensive understanding of the effects of these materials on concrete. A life cycle assessment (LCA) is also recommended to evaluate the environmental benefits, such as reduced energy consumption and CO_2 emissions, highlighting the sustainability of using RHA and CG in concrete. Lastly, assessing the scalability and cost-effectiveness of RHA and CG for commercial production is essential for their widespread industrial adoption, ensuring both environmental and economic advantages.

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