The Mechanical Properties of Concrete Containing Glass Waste as Fine Aggregates and Rice Husk Ash as Cementitious Material

Sajjad Ali Mangi
Department of Civil Engineering, SZAB Campus, Khairpur Mirs, Mehran University of Engineering & Technology Sindh, Pakistan
sajjad.nec@muetkhp.edu.pk (corresponding author)

Shahid Ali Shaikh
Department of Civil Engineering, SZAB Campus, Khairpur Mirs, Mehran University of Engineering & Technology, Sindh, Pakistan
shahid.huawei155@gmail.com

Madhusudhan Bangalore Ramu
Department of Civil and Construction Engineering, College of Engineering, A'Sharqiyah University, Ibra, Oman
madhusudhan.ramu@asu.edu.om (corresponding author)

Ahsan Said
Quaid-E-Awam University of Engineering Science and Technology, Shaheed Benazir Abad, Sindh, Pakistan
ahsansaid411@gmail.com

Saeed Ahmed Soomro
Department of Civil Engineering, DHA Suffa University, Karachi, Sindh, Pakistan
engr.saeed@dsu.edu.pk

Ram Kumar
Department of Civil Engineering, SZAB Campus, Khairpur Mirs, Mehran University of Engineering & Technology, Sindh, Pakistan
ramkukreja555@gmail.com

Received: 1 June 2025 | Revised: 23 June 2025 and 30 June 2025 | Accepted: 7 July 2025

ABSTRACT

The increase in the urban population has created a greater demand for infrastructure development. As a result, the use of construction materials, such as cement and fine aggregates, has significantly increased. Cement, a key component of concrete, is not only costly due to its high energy consumption, but also contributes substantially to environmental pollution through the emission of CO_2 during production. Similarly, fine aggregates are widely utilized as fillers in concrete and are also expensive. In response to these challenges, researchers are investigating sustainable, eco-friendly, and cost-effective alternatives to reduce the environmental impact of construction. This research aims to assess the performance of concrete by partially substituting Ordinary Portland Cement (OPC) with Rice Husk Ash (RHA) and replacing fine aggregates with Glass Waste (WG) in varying proportions of 10%, 20%, and 30%. Ten concrete mixtures were prepared using M15 grade concrete with a 1:2:4 mix ratio and a water-cement ratio of 0.55. These included a control mix, individual mixes with RHA and GW, and combined mixes with equal proportions of both materials. The concrete samples were tested for workability, compressive strength, and split tensile

strength. The results showed that RHA decreased the workability, while GW improved it. The compressive strength was optimal at 20% RHA and at a combined 10% RHA and 10% GW. GW alone also performed well at 20% replacement. The tensile strength was the highest with 10% RHA, 10% GW, and their 10% combination after 7 days and 28 days of curing. These findings confirm the potential of RHA and GW to serve as sustainable alternatives in concrete, helping to manage the solid waste, reduce the landfill use, lower the material costs, conserve the natural resources, and support environmentally friendly construction practices.

Keywords-glass waste; rice husk ash; workability; compressive strength; splitting tensile strength

I. INTRODUCTION

The environmental sustainability of the cement and concrete production sectors has become a concern for researchers and scientists [1]. A key area of focus is the exploration of waste materials that could potentially replace cement or serve as fine aggregates in concrete mixtures. Concrete is recognized as the second most widely used material on Earth, surpassed only by water [2], with its global production exceeding 10 billion tons annually. As cement is a primary component of concrete, its worldwide consumption was projected to have reached 4.42 billion tons by 2021, with an annual growth rate of approximately 2.96% between 2018 and 2021 [3]. Furthermore, the global cement industry is expected to have grown to a market value of around USD 401.10 billion by 2025, with an anticipated annual growth rate of 5.10%. Data indicate that China alone is responsible for producing nearly 50% of the world's cement. It has also been forecast that global cement production will have risen to approximately 4.83 billion metric tons by 2030 [4]. Cement production contributes to 8% of the global CO_2 emissions due to the energy-intensive clinker production process, which also releases other harmful gases, like SOx, NOx, and mercury [5]. To reduce these emissions, recycling industrial by-products and using alternative materials is required. RHA, rich in silica (90–96%), is a promising eco-friendly material with strong pozzolanic properties that can replace cement and help cut the CO_2 emissions [6]. Similarly, natural sand, one of the most used resources, can be substituted with GW, which has similar physical and chemical properties. Both RHA and GW offer sustainable solutions by reducing emissions and landfill waste. However, limited research exists on their combined use in concrete. The current study addresses this gap, promoting sustainable construction through the use of these recycled materials [7].

RHA is a fine powder produced from the combustion of rice husks, which are the outer coverings of rice grains. Owing to its rich silica content and pozzolanic behavior, RHA is frequently utilized as a supplementary cementing material in concrete mixtures [8]. Its inclusion can improve concrete's mechanical strength, durability, and resistance to aggressive agents, such as acids and sulfates. As an environmentally friendly alternative, RHA contributes to minimizing the negative impact of rice husk disposal and reducing the carbon footprint of the cement industry. Additionally, it promotes sustainable construction by transforming the agricultural waste into valuable building material [9].

GW is a sustainable material for construction that helps reduce pollution and conserve natural resources. It comes from sources like bottles, construction waste, CRTs, automotive glass, and e-waste. GW has similar properties to natural sand, making it a good replacement for fine aggregate in concrete. Using GW lowers the landfill waste and decreases the need for sand mining, supporting eco-friendly and cost-effective building practices [10].

It has been indicated that the combined use of GW and RHA could enhance the strength performance of concrete [20]. Therefore, this study considered GW as a partial replacement of fine aggregate and RHA as supplementary cementitious materials.

II. MATERIALS AND METHODS

In this research, OPC served as the primary binding material, while RHA was prepared from rice husk at a controlled temperature of 700°C in a furnace. After cooling down, the ash was passed through a 45-micron sieve and incorporated as a supplementary cementitious component in selected concrete mixtures. Ground GW, sieved to pass through a 4.75 mm sieve, was used to partially replace the natural sand. A total of ten concrete mixtures were designed to achieve an M15 compressive strength, using a standard 1:2:4 mix proportion with a water-cement ratio of 0.50. In these mixes, OPC was substituted with RHA, and natural sand was replaced with GW at replacement levels of 10%, 20%, and 30%. Standard-sized concrete specimens, including cubes (150 mm × 150 mm × 150 mm) and cylinders (100 mm × 200 mm), were cast for mechanical testing.

Rice husks, as shown in Figure 1, were collected from various rice mills located in the Sukkur District. These husks were subjected to a controlled incineration process, converting them into ash. Following combustion, the resulting ash was further processed using a Los Angeles abrasion machine, where it was ground continuously for 1 h. To enhance the fineness and ensure that the material possessed the desired pozzolanic characteristics, the ground ash was sieved using a 45-micron sieve. The fine RHA obtained using this procedure, as shown in Figure 3, was subsequently utilized as a partial replacement for OPC in concrete by weight. The GW was obtained from local recycling sources, specifically informal scrap vendors, commonly referred to as Junkyard. The collected glass materials, as depicted in Figure 2, were manually broken into smaller fragments using basic tools, such as a hammer and pestle. The labor-intensive process, as illustrated in Figure 4, produced crushed glass, which was then passed through a 4.75 mm sieve to obtain particles that closely resembled the grain size of conventional fine aggregates. The processed GW was then used to partially replace natural river sand or other standard fine aggregates in concrete mixes by weight, aiming to enhance the sustainability and promote the use of recycled materials in construction.

Fig. 1. Dried rice husk before incineration.

Fig. 2. Recycled bolted glass before crushing.

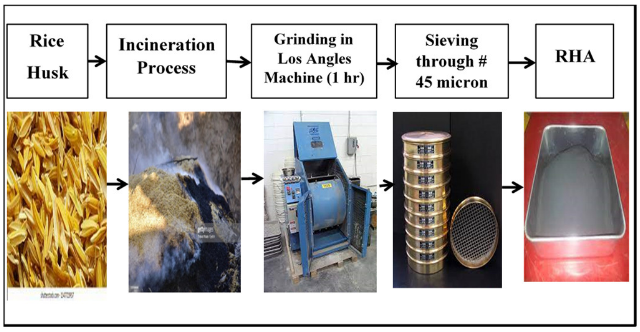

Fig. 3. Process flow for the preparation of RHA.

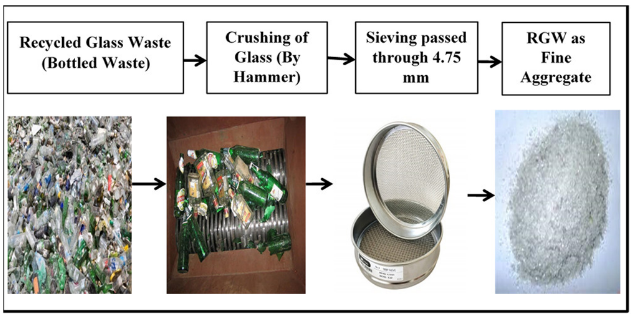

Fig. 4. Process flow for the preparation of recycled GW.

In this experimental study, a range of standardized laboratory tests were performed to assess the suitability of the materials and to evaluate the properties of both fresh and hardened concrete. The sieve analysis, carried out according to ASTM C136 and ASTM C33/C33M, determines the particle size distribution of the fine and coarse aggregates, which is critical for ensuring proper grading and achieving optimal concrete performance. Specific gravity tests were conducted following ASTM C150/C150M-21[10] for OPC and RHA, and ASTM C128-15 [11] and ASTM C127-01 [12] for the fine and coarse aggregates, respectively, to measure the density of the materials, an important parameter for an accurate mix proportioning. The workability of fresh concrete was assessed using the slump test (ASTM C143-78) [13], which evaluates the consistency and flowability of the concrete mix, helping to predict its ease of placement and compaction. The compressive strength of the concrete was determined following BS EN 12390-3 [14], providing a measure of the concrete's capacity to resist the axial loads and overall durability.

Additionally, the splitting tensile strength was measured as per ASTM C496/C496M-04 [15]. These tests are specifically designed to assess the concrete's capacity to endure tensile stresses, which are often responsible for the development of cracks and the eventual structural failure. By thoroughly evaluating the tensile strength, engineers can predict how the concrete will perform under various stress conditions that typically cause damage over time. Collectively, these tests play a crucial role in verifying that both the individual materials used and the final concrete mixtures comply with established engineering standards. This ensures that the concrete will exhibit the necessary structural integrity, long-term durability, and overall reliability required for safe and effective construction.

TABLE I. SPECIMEN DETAILS

Mix notation	(OPC) (%)	Fine aggregate (%)	Coarse aggregate (%)	Replacement materials (%)	
				RHA (%)	GW (%)
B0	100.00	100.00	100.00	-	-
B1	90.00	100.00	100.00	10.00	-
B2	80.00	100.00	100.00	20.00	-
B3	70.00	100.00	100.00	30.00	-
B4	100.00	90.00	100.00	-	10.00
B5	100.00	80.00	100.00	-	20.00
B6	100.00	70.00	100.00	-	30.00
B7	90.00	90.00	100.00	10.00	10.00
B8	80.00	80.00	100.00	20.00	20.00
B9	70.00	70.00	100.00	30.00	30.00

In this study, ten different concrete mix designs (labeled B0-B9) were prepared. Each mix was subjected to both compressive and tensile strength evaluations. For the compressive strength testing, three cubic samples measuring 150 mm × 150 mm × 150 mm were tested at 7 days, and another three at 28 days, making a total of six specimens per mix. Similarly, for the tensile strength assessment, three cylindrical specimens (100 mm diameter and 200 mm height) were tested at 7 days and an additional three at 28 days, also totaling six specimens per mix. Consequently, each mix had 12 specimens tested, leading to an overall count of 120 specimens examined for compressive and tensile strength across all mixes.

III. RESULTS AND DISCUSSION

A. Sieve Analysis

The gradation of both natural hill sand and GW was determined through sieve analysis following ASTM

C33/C33M-13 (2016) [9]. The fine aggregate sample was oven-dried and sourced locally, while the GW was collected from a junkyard, manually crushed, and sieved to achieve the required particle size distribution. As illustrated in Figure 5, a similar pattern of particle sizes was observed from the graphical data during the sieve analysis of fine aggregates and GW.

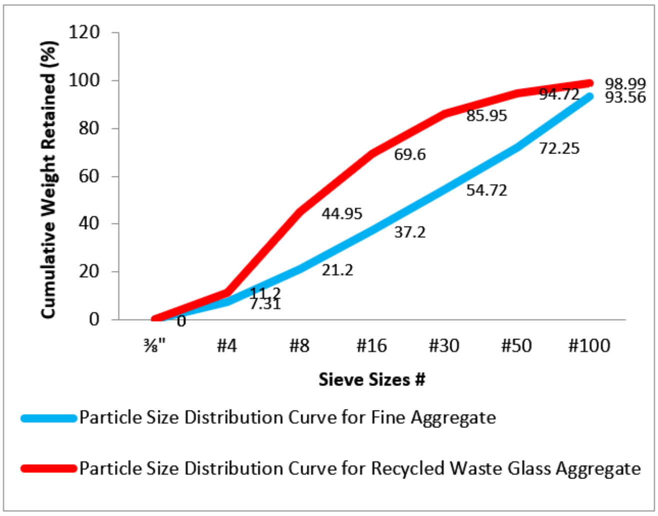

Fig. 5. Comparison of particle size distribution curves for fine aggregate and GW.

B. *Workability (Slump Values)*

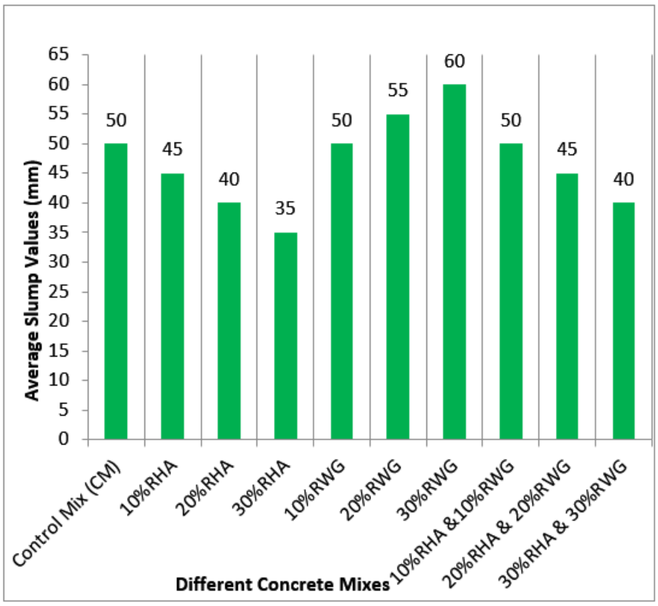

Fig. 6. Comparison of average slump values of different concrete mixes.

Slump tests were performed on various concrete mixes containing different proportions of RHA as a cementitious substitute and GW as a partial replacement for fine aggregate, alongside a control mix. The control mix (B0), which contained no recycled materials, was used as a baseline. As displayed in Figure 6, for mixes B1, B2, and B3, incorporating 10%, 20%, and 30% RHA, respectively, a noticeable decrease in slump was observed, dropping from 45 mm to 35 mm. This reduction is attributed to the higher surface area and lower specific gravity of RHA, which also leads to increased water absorption [16, 17]. Conversely, mixes B4, B5, and B6, which included 10%, 20%, and 30% GW as a fine aggregate replacement, exhibited enhanced slump values, rising from 50 mm to 60 mm. Combined mixes B7, B8, and B9 with equal RHA and GW substitutions (10%–30%) showed decreasing slump, with B7 comparable to the control mix, while B8 and B9 had low slumps despite increasing the water-cement ratio, due to high water absorption.

C. *Compressive Strength*

A total of sixty concrete cube specimens were prepared for testing. Each of these test samples had dimensions of 150 mm in length, 150 mm in width, and 150 mm in height. The preparation and casting of these specimens were carried out in strict accordance with the procedures specified in ASTM C39/C39M-21 (2021) [18], which provides the standard test method for the compressive strength of cylindrical concrete specimens, but is also commonly applied to cube testing in many regions. Following the mixing and casting process, all specimens were subjected to curing, and the compressive strength tests were subsequently conducted after two different curing durations—specifically at 7 days and 28 days—to assess the development of strength over time under axial loading conditions.

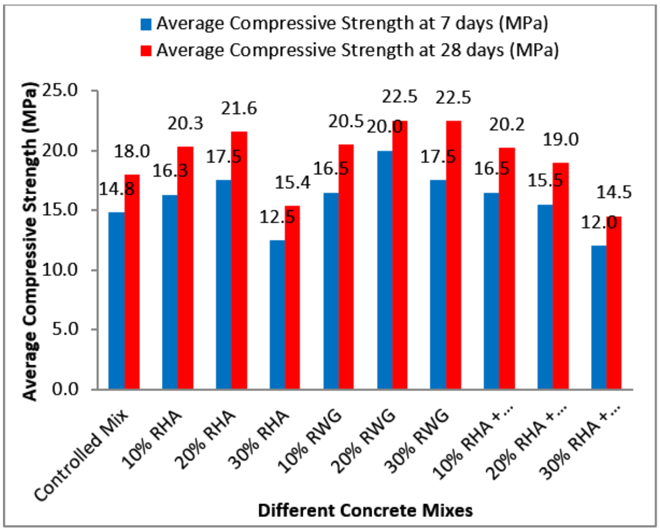

Fig. 7. Compressive strength of cubical specimen (MPa).

The graphical data, as presented in Figure 7, indicate a noticeable enhancement in the compressive strength with 10% and 20% replacement of RHA, whereas a reduction in strength was noted at 30% RHA for both curing durations. The maximum strength was observed at 20% RHA, with an increase of 18.24% after 7 days and 20% after 28 days compared to the control mix. However, the strength decreased significantly with 30% RHA, recording 12.5 MPa and 15.4 MPa at the same curing intervals, confirming the findings in

[19]. These results suggest that 20% RHA is the optimum level for enhancing the compressive strength without compromising the concrete quality.

D. Splitting Tensile Strength

A total of sixty (60) cylindrical test specimens were prepared in accordance with ASTM standards, specifically following the standard procedure for determining the splitting tensile strength of cylindrical concrete specimens, ASTM C496/C496M-04 [15]. The results of the splitting tensile strength test are portrayed in Figure 8.

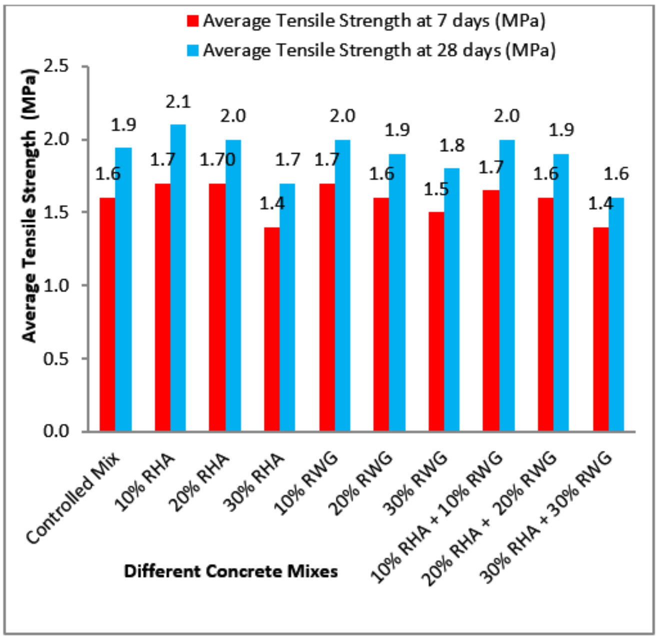

Fig. 8. Splitting tensile strength of cylindrical specimens (MPa).

Each specimen measured 100 mm in diameter and 200 mm in height. Replacing 10% of cement with RHA in the concrete mix resulted in the highest split tensile strengths of 1.7 MPa and 2.1 MPa after 7 and 28 days, respectively. This represented an improvement of 6.3% and 10.52% compared to the control mix. At a 20% RHA replacement, the tensile strength after 7 days was almost unchanged, but a decrease was observed after 28 days. A notable drop in the tensile strength occurred with 30% RHA replacement, showing reductions of 12.5% and 10.5% at 7 and 28 days, likely due to the porous characteristics of RHA causing lower packing density and diminished strength [18]. When GW was used to partially replace the fine aggregate, the best split tensile strengths of 1.7 MPa and 2.0 MPa were observed at 10% GW, corresponding to increases of 6.3% and 5.3% compared to the control. At 20% GW, the tensile strength remained largely unchanged, while a 30% replacement resulted in decreased strength.

For the mixes in which both RHA and GW were incorporated at equal proportions, an overall decrease in the split tensile strength was noted as the replacement levels increased. The 10% RHA + 10% GW mix showed a slightly improved strength compared to the control, while the 20% + 20% mix had similar values to the control. The lowest tensile strengths were recorded at the combined 30% replacement level for both materials. In summary, the highest split tensile strength was achieved with 10% RHA alone, 1.7 MPa and 2.1 MPa after 7 and 28 days, respectively, while the lowest strengths of 1.4 MPa and 1.6 MPa were observed at the 30% RHA and GW combined replacement.

IV. CONCLUSION AND RECOMMENDATIONS

This study evaluated the strength and durability of concrete incorporating Rice Husk Ash (RHA) as a partial cement replacement and Glass Waste (GW) as a partial fine aggregate substitute. RHA and GW were each used at 10%, 20%, and 30% replacement levels. Based on the experimental results, the following key conclusions were drawn regarding their performance in concrete mixes:

- Increasing RHA as a cementitious material reduces the slump due to its higher water absorption from the increased surface area. At 10% RHA, the slump was 45 mm (10% less than the conventional), still acceptable for structural element casting.
- Replacing the fine aggregate with GW increases the slump because GW absorbs less water than the natural aggregate. At 20% GW, the slump reached 40 mm, which is 11% higher than the conventional concrete.
- The combined mixes with 10% RHA and 10% GW showed a slump similar to the conventional concrete (50 mm), while higher substitutions (20%-30%) lowered the slump due to the increased water demand by RHA.
- The compressive strength increased with 10% and 20% RHA, peaking at 20% (21.6 MPa at 28 days), but declined at 30% replacement.
- Replacing the fine aggregate with GW improved the compressive strength at 10% and 20% replacement levels, with 20% showing the best results. However, the strength declined at 30% GW replacement.
- A combined mix of 10% RHA and 10% GW showed higher compressive strengths than the control, reaching 16.5 MPa at 7 days and 20.2 MPa at 28 days—an increase of about 11%–12%. Higher combined replacement levels led to decreased strength.
- The optimal tensile strength was observed with 10% RHA, achieving 1.75 MPa at 7 days and 2.1 MPa at 28 days, indicating improved performance at this level.
- RHA can be effectively used up to 20% replacement, GW up to 20%, and combined RHA + GW up to 10% each for good strength performance; even 20% combined replacements met the target compressive strength.

The experimental results of the study suggest that RHA and GW can be effectively used in concrete as a partial replacements for cement and fine aggregate, respectively. This substitution helps reduce both the construction costs and CO_2 emissions by decreasing the cement usage.

It is proposed that GW be used for up to a 20% replacement level for fine aggregates without significantly affecting the concrete performance, offering a sustainable solution to slow the depletion of natural resources. The study proposes considering durability aspects, such as permeability, exposure to salt solutions, and exposure to elevated temperatures in future research.

ACKNOWLEDGMENT

The Researchers express their gratitude for the support provided by Mehran University of Engineering & Technology, SZAB Campus Khairpur Mir's, Sindh, Pakistan. The authors would like to acknowledge the financial support provided by A'Sharqiyah University, Oman, for the publication of the paper.

REFERENCES

[1] B. Tayebani, A. Said, and A. Memari, "Less Carbon Producing Sustainable Concrete from Environmental and Performance perspectives: A review," *Construction and Building Materials*, vol. 404, Nov. 2023, Art. no. 133234, https://doi.org/10.1016/j.conbuildmat.2023.133234.

[2] J. Watts, "Concrete: The Most Destructive Material on Earth," *the Guardian*, Feb. 2019. https://www.theguardian.com/cities/2019/feb/25/concrete-the-most-destructive-material-on-earth.

[3] "Global Cement Market (Production, Consumption, Imports & Exports): Insight, Trends and Forecast (2019-2021)," *Research and Markets*. https://www.researchandmarkets.com/reports/4871690/global-cement-market-production-consumption.

[4] "Datis Export Group," *Datis Export Group*, July 2020. https://datis-inc.com/blog/worldwide-cement-production-from-2015-to-2019.

[5] C. Chen, G. Habert, Y. Bouzidi, and A. Jullien, "Environmental Impact of Cement Production: Detail of the Different Processes and Cement Plant Variability Evaluation," *Journal of Cleaner Production*, vol. 18, no. 5, pp. 478–485, Mar. 2010, https://doi.org/10.1016/j.jclepro.2009.12.014.

[6] S. H. Channa, S. A. Mangi, N. Bheel, F. A. Soomro, and S. H. Khahro, "Short-term Analysis on the Combined Use of Sugarcane Bagasse Ash and Rice Husk Ash as Supplementary Cementitious Material in Concrete Production," *Environmental Science and Pollution Research*, vol. 29, pp. 3555–3564, Aug. 2021.

[7] K. Bisht and P. V. Ramana, "Sustainable Production of Concrete Containing Discarded Beverage Glass as Fine Aggregate," *Construction and Building Materials*, vol. 177, pp. 116–124, July 2018, https://doi.org/10.1016/j.conbuildmat.2018.05.119.

[8] N. Bheel, A. W. Abro, I. A. Shar, A. A. Dayo, S. Shaikh, and Z. H. Shaikh, "Use of Rice Husk Ash as Cementitious Material in Concrete," *Engineering, Technology & Applied Science Research*, vol. 9, no. 3, pp. 4209–4212, June 2019, https://doi.org/10.48084/etasr.2746.

[9] M. Anwar, T. Miyagawa, and M. Gaweesh, "Using Rice Husk Ash as a Cement Replacement Material in Concrete," in *Waste Management Series*, vol. 1, Elsevier, 2000, pp. 671–684.

[10] W. Song, D. Zou, T. Liu, J. Teng, and L. Li, "Effects of Recycled CRT Glass Fine Aggregate Size and Content on Mechanical and Damping Properties of Concrete," *Construction and Building Materials*, vol. 202, pp. 332–340, Mar. 2019, https://doi.org/10.1016/j.conbuildmat.2019.01.033.

[11] *Specification for Concrete Aggregates* ASTM C-33/C-33M-13, ASTM International, West Conshohocken, PA, USA, 2016.

[12] *Specification for Portland Cement* ASTM C150/C150M-21, ASTM International, West Conshohocken, PA, USA, 2021.

[13] *Test Method for Relative Density (specific Gravity) and Absorption of Fine Aggregate* ASTM C128-15, ASTM International, West Conshohocken, PA, USA, 2016.

[14] *Test Method for Relative Density (specific Gravity) and Absorption of Coarse Aggregate* ASTM C-127-01, ASTM International, West Conshohocken, PA, USA, 2017.

[15] *Test Method for Slump of Portland Cement Concrete* ASTM C143-78, ASTM International, West Conshohocken, PA, USA, 2017.

[16] *Testing Hardened Concrete. Part 3, Compressive Strength of Test Specimens* BS EN 12390-3:2002, BSI, London, UK, 2002.

[17] *Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens* ASTM C496/C496M-04, ASTM International, West Conshohocken, PA, USA, 2017.

[18] *Test Method for Compressive Strength of Cylindrical Concrete Specimens* ASTM International, West Conshohocken, PA, USA, 2021.

[19] O. Zaid, J. Ahmad, M. S. Siddique, and F. Aslam, "Effect of Incorporation of Rice Husk Ash Instead of Cement on the Performance of Steel Fibers Reinforced Concrete," *Frontiers in Materials*, vol. 8, June 2021, Art. no. 665625, https://doi.org/10.3389/fmats.2021.665625.

[20] B. S. Thomas, "Green Concrete Partially Comprised of Rice Husk Ash as a Supplementary Cementitious Material – A Comprehensive Review," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 3913–3923, Feb. 2018, https://doi.org/10.1016/j.rser.2017.10.081.