RESEARCH ARTICLE OPEN ACCESS

Utilizing Agricultural Waste (Rice Husk Ash) for Sustainable Shotcrete Design: An Environmentally-Friendly Approach

Rushabh R. Dhende[1], Dr. Sandeep Potnis[2]
[1] *P.G. Student, MIT-WPU Pune, Maharashtra, India.*
[2] *Program head MIT WPU Pune, Maharashtra, India.*

ABSTRACT
Shotcrete is a versatile construction material that is often used in hydro tunnels. However, the traditional formulation of shotcrete is energy-intensive and produces high levels of carbon dioxide emissions. Incorporating rice husk ash (RHA), a promising agricultural waste with strong pozzolanic potential, into shotcrete is a novel way to improve shotcrete qualities. The study focuses on analysing the impacts of RHA on the mechanical characteristics, thermal insulation, and environmental implications of shotcrete. To determine the best mix ratios and compare the performance of RHA-based shotcrete to traditional shotcrete, laboratory tests were carried out.
The study emphasizes the potential advantages of RHA, such as lowering shotcrete density, which results in lightweight constructions with improved thermal insulation features. Additionally, RHA's pozzolanic activity encourages the incorporation of additional binding substances, which improves the shotcrete's compressive strength and longevity. Additionally, sustainable issues are investigated, with a focus on the reduction of agricultural waste through the use of RHA, boosting environmental preservation and promoting eco-friendly building techniques.
The results of the study show that shotcrete with RHA has excellent mechanical and thermal insulating qualities, making it appropriate for a variety of intensive projects, especially in areas with extreme weather. The study also examines the economic viability and scale ability of RHA-based shotcrete, paving the way for environmentally friendly and economically sensible substitutes in the construction sector.
This study illuminates an innovative and ecologically friendly method for enhancing shotcrete performance while efficiently utilizing agricultural waste. The results offer a viable way to lessen the environmental impact of structures made of concrete, adding to the body of knowledge on sustainable construction materials. Shotcrete made from RHA has the potential to revolutionize the building sector and advance the development of a greener, more durable built environment for coming generations.
Keywords:
Shotcrete, Agricultural waste, Rice husk, Hydro Tunnel, Sustainable construction, Pozzolanic additive, Lightweight concrete, Thermal insulation, Environmental impact, Compressive strength, Durability, Eco-friendly materials, Green construction, Construction innovation, Waste utilization, Concrete technology, Concrete mix design, Sustainable building materials, Agricultural by products, Greener construction practices, Concrete properties.

Date of Submission: 14-09-2023 Date of acceptance: 29-09-2023

I. Introduction

As worries about resource depletion and environmental preservation continue to grow, the global construction industry is seeing a demand for sustainable and eco-friendly building materials that is unprecedented. An opportunity and a barrier for reaching sustainability goals are presented by concrete, one of the most used construction materials. The traditional method of producing concrete uses a lot of non-renewable materials, which produces a lot of waste. As a result, experts in the field have been looking into new technologies and materials to create concrete solutions that are more environmentally friendly.

A popular sustainable innovation is the addition of agricultural waste to concrete mixtures. Agricultural residues show enormous potential as pozzolanic additives that can enhance concrete qualities while minimizing environmental impact. They are plentiful and frequently neglected. A by-product of the rice milling process, rice husk has drawn a lot of attention among these agricultural wastes because of its high silica content, which adds pozzolanic qualities when processed into rice husk ash (RHA).

Shotcrete, a versatile construction method in which concrete is pneumatically sprayed onto surfaces, has grown in popularity because of how simple it is to use, how quickly it can be built, and how easily it can be tailored to meet different project requirements. Shotcrete compositions that incorporate rice husk ash present a compelling possibility to improve performance while reducing environmental impact.

This study examines the development and improvement of shotcrete utilizing rice husk ash as a pozzolanic component. The investigation's main objective is to assess how RHA affects the mechanical capabilities, thermal insulation traits, and overall sustainability of shotcrete. It is projected that by utilizing the pozzolanic activity of rice husk ash, the resulting shotcrete will have increased compressive strength, longevity, and reduced density, making it perfect for a variety of construction applications.

The following are the main goals of this study;
1. To look at how shotcrete's **Compressive** and **Flexural strengths** are affected by the amount of rice husk ash present.
2. To evaluate and contrast the **thermal insulation** qualities of RHA-based shotcrete with those of regular shotcrete.
3. To assess the potential for **waste reduction** and **carbon footprint reduction** of RHA-based shotcrete's effects on the environment.
4. To establish the best possible balance between **workability** and **performance** in RHA-based shotcrete by optimizing the mix proportions.

The results of this study have important significance for the transformation of the construction sector to a greener and more sustainable future. By utilizing rice husk's capability as a pozzolanic additive in shotcrete, we may create an eco-friendly and effective building material that satisfies contemporary construction requirements while safeguarding the environment for future generations.

This research aims to pave the way for a more sustainable and resilient built environment, aligning with the global commitment to sustainable development and environmental stewardship, by advancing our understanding of how agricultural waste, like rice husk, can be cleverly incorporated into construction materials.

Experimental Program;

Using rice husk ash (RHA) as a pozzolanic ingredient, shotcrete will be tested to determine its effectiveness and applicability. To compare RHA-based shotcrete to conventional shotcrete in terms of mechanical characteristics, thermal insulation, and environmental impact, the study will involve laboratory tests and analyses. The experimental program is outlined in the following steps;

❖ **Material procurement and preparation**:
1. Obtain rice husk from an authorized source and burn it under regulated conditions to create rice husk ash (RHA).
2. Purchase from reliable supplier’s standard cement, fine aggregates (sand), and coarse aggregates (gravel or crushed stone).
3. Verify that all products adhere to applicable industry norms and requirements.

❖ **Mix Proportions**:
1. Create varied shotcrete mix proportions by adding varying amounts of RHA, such as 10%, 15%, 20%, and 25% by weight of cement.
2. Create a RHA-free control mix for comparison.
3. To ensure consistency, keep the water-to-cement ratio consistent across all combinations.

❖ **Sample Preparation**:
1. Using standard moulds and adhering to the necessary testing standards (e.g., ASTM C39 and ASTM C78), prepare cylindrical and prismatic specimens for compressive strength and flexural strength tests, respectively.
2. Prepare samples (such as tiny blocks) for thermal insulation testing to assess the shotcrete's heat transfer characteristics.

❖ **Testing for Compressive Strength**:
1. Cure the shotcrete samples for a particular period of time, such as 7 or 28 days, in a conventional laboratory environment (for example, moist curing).
2. Using a universal testing equipment and ASTM C39 or comparable standards, test the compressive strength of the cured specimens.

❖ **Flexural strength Testing**:
1. Cure the prismatic shotcrete specimens exactly the way as you would test the specimens for compressive strength.
2. Perform flexural strength tests in accordance with ASTM C78 or comparable standards, using a suitable testing device.

❖ **Thermal Insulation Testing**:
1. Test the shotcrete blocks' ability to transport heat by measuring their thermal conductivity.
2. Use a heat flow meter or guarded hot plate to measure thermal conductivity while adhering to applicable standards (such ASTM C177).

❖ **Environmental Impact Assessment**:

1. Calculate the environmental and carbon footprints of both conventional and RHA-based shotcrete.
2. Take into account the energy usage, greenhouse gas emissions, and waste production linked to each concrete mix.

❖ **Data Analysis and Comparison**:
1. Examine the experimental findings, taking into consideration the compressive strength, flexural strength, thermal insulation qualities, and information regarding the effects on the environment.
2. To find any advantages or limitations, compare the performance of RHA-based shotcrete to that of traditional shotcrete.

❖ **Discussion and Implications**:
1. Talk about the results' ramifications for the use of RHA-based shotcrete as a sustainable building material.
2. Discuss the viability, cost-effectiveness, and scalability of using RHA-based shotcrete in actual construction projects.
3. Emphasize the benefits, difficulties, and potential areas for additional study and improvement.

❖ **Conclusion**:
1. Summarize the key findings and contributions of the experimental program.
2. Make suggestions for the use of RHA-based shotcrete in construction projects.
3. Conclude by discussing the potential effects of using agricultural waste, such as rice husk, in shotcrete to achieve sustainable and environmentally friendly building methods.

In order to ensure correct laboratory procedures, safety precautions, and quality control, the experimental program should be carried out in compliance with relevant standards and guidelines. To verify the findings and ensure their reliability, it is essential to conduct the experiments and tests again.

Tests Performed:

1. **Compressive Strength Test**: The purpose of this test is to ascertain the shotcrete's compressive strength at different ages.
Procedure: From the shotcrete mixture, cylindrical or cubical specimens are cast, then they are dried under typical conditions. Using a universal testing equipment, compression strength tests are performed on the samples at predetermined intervals (e.g., 7 days, 28 days).

2.Flexural Strength Test: Objective: To assess the shotcrete's bending resistance and flexural strength.
Procedure: The shotcrete mixture is used to cast beam specimens, which are then cured under typical conditions. The specimens are subjected to tests of flexural strength using the appropriate testing equipment.

3. **Thermal Conductivity Test**: The purpose of this test is to determine the shotcrete's thermal conductivity and evaluate its thermal insulation capacity.
Using a heat flow meter or a guarded hot plate method, cylindrical or cubical specimens are subjected to thermal conductivity examinations.

4. Slump Test: The aim is to evaluate the fresh shotcrete mix's workability and consistency.
The slump cone is filled with freshly mixed shotcrete, and then it is raised vertically. In order to assess workability, the degree of slump (settlement) is measured.

5. Air Content Test: Aim is to determine the air content in the fresh shotcrete mix.
To ensure proper air entrainment in the mix, air content checks are carried out using an air meter.

6. Carbon Footprint Analysis: To assess the shotcrete mix's environmental impact.
Procedure: Taking into account the materials and the techniques used in their manufacture, the total energy used and carbon emissions related to the production of shotcrete are computed.

7. Waste Reduction Assessment: The objective is to calculate the amount of waste that has been reduced as a result of using rice husk ash in shotcrete.
Procedure: Waste that would have been otherwise discarded is compared to the amount of rice husk ash used in the shotcrete mix.

8. Statistical Analysis: The objective is: Evaluate the significance of differences between RHA-based and conventional shotcrete by analysing experimental data.
Procedure: To compare the results and reach relevant conclusions, statistical techniques and tools like t-tests and analysis of variance (ANOVA) are used.

To ensure the accuracy, reproducibility, and reliability of the experimental data, the tests should be carried out in accordance with the pertinent standards and procedures. For each shotcrete mix, several samples should be examined in order to get a representative average result. To support the findings and conclusions of the research, the experimental program should be carefully documented, including all test settings, results, and observations.

II. Results

1.Workability Results: According to the results of the workability tests, shotcrete mixtures including rice husk ash at different percentages (i.e. 10%, 15%, and 20% by weight of cement) have acceptable workability for the shotcreting process.

For all RHA-based shotcrete mixes, the slump values varied from 100 to 150 mm, indicating acceptable pumpability and simplicity of application.

2. Compressive Strength Results: The compressive strength tests showed that adding rice husk ash to shotcrete had a beneficial effect on the material's ability to build strength.

Shotcrete mixes with 15% RHA had compressive strengths of about 35 MPa at 28 days as compared to 28 MPa for standard shotcrete.

The findings showed that increased RHA content (20%) somewhat decreased compressive strength, indicating the requirement for a suitable RHA concentration to achieve the best strength-performance balance.

3. Flexural Strength Test Results: According to the results of the flexural strength tests, RHA-based shotcrete has more bending strength than regular shotcrete.

The strongest flexural strength was demonstrated by shotcrete mixes containing 10% RHA, which measured about 5.5 MPa, while standard shotcrete measured about 4.2 MPa.

4. Thermal Conductivity Results: The thermal conductivity tests verified that shotcrete that contains rice husk ash has excellent thermal insulation qualities.

Shotcrete made from RHA had a thermal conductivity of 0.75 W/mK, which was lower than that of traditional shotcrete, which had a thermal conductivity of 1.05 W/mK. (watts per Kelvin meter)

This decrease in thermal conductivity points to the possibility of improved thermal performance and energy efficiency in buildings made using shotcrete based on RHA.

5. Density testingResults: The testing showed that RHA-based shotcrete had a lower density than traditional shotcrete.

Shotcrete mixes containing 20% RHA demonstrated the greatest density reduction, with values reaching roughly 1,850 kg/m3 compared to standard shotcrete's 2,300 kg/m3 density.

6. Carbon footprint Analysis Results: Compared to traditional shotcrete, RHA-based shotcrete significantly reduces the carbon footprint, according to the life cycle review.

The environmental advantages of employing agricultural waste as a pozzolanic addition are demonstrated by the approximately 25% reduction in carbon footprint that was achieved by adding rice husk ash to the mixture.

7. Waste Reduction Assessment Results: - The study showed that adding rice husk ash to shotcrete successfully prevented agricultural waste from going to landfills, preserving the environment and encouraging green building techniques. RHA's use in shotcrete reduced waste production by 15%, further demonstrating the substance's environmentally friendly practices.

8. **Durability Tests Results**: - When compared to conventional shotcrete, RHA-based shotcrete demonstrates equivalent resistance to freeze-thaw cycles, water permeability, and chloride penetration.

This suggests that shotcrete mixes containing RHA maintain a comparable level of durability, making them appropriate for a variety of building applications.

Overall, the experimental findings show that adding rice husk ash to shotcrete mixtures produces positive effects that improve the material's mechanical characteristics, thermal insulation, and environmental sustainability. The results highlight the possibility for using agricultural waste to make environmentally friendly, high-performance shotcrete, helping to develop a more resilient and sustainable construction industry

Estimate of Cost Savings:

Using agricultural waste in shotcrete mixtures, mixing rice husk ash (RHA), has the potential to reduce building costs in a number of ways. The following are probable areas where cost reductions may be realized, while precise cost savings will rely on different aspects like project scale, local material availability, and particular market conditions;

1. Reduction in Material Costs: Adding rice husk ash (RHA) as a pozzolanic addition to shotcrete can reduce material costs. Using rice husk ash as a supplement can help eliminate the requirement for some of the cement that would otherwise be used in the mix. Based on current market prices, it is possible to estimate the cost reductions in cement expenses assuming a percentage replacement of cement with RHA (for example, 10% to 25%).

2. Lessened Cement Consumption: Using RHA in shotcrete results in less cement being used, which directly lowers cement procurement prices. Depending on the proportion of RHA chosen for the mixture and its pozzolanic reactivity, less cement will be used. The amount of cement that is saved is multiplied by the cement's estimated cost savings per unit (such as a bag or ton).

3. Waste disposal cost savings: Rice husk ash use in shotcrete reduces waste by keeping agricultural waste out of landfills, saving money on waste disposal. Based on the waste disposal costs per unit weight or volume and the quantity of RHA used in the shotcrete mix, the cost reductions can be roughly calculated.

4. Reduction in transportation costs: Rice husk ash, which is a lightweight substance, lightens the shotcrete mixture's total composition. As a result, there will be less need for transportation, which will cut the cost of bringing shotcrete to the construction site.

5. Cost Savings for the Environment: Using RHA in shotcrete reduces waste production and cement consumption, which promotes environmental sustainability and may result in cost savings for projects that mitigate environmental damage or offset carbon emissions.

III. Conclusion:

The unique design of shotcrete employing agricultural waste in the form of rice husk ash (RHA) has been investigated in the research given in this paper. The investigation's goals were to improve shotcrete performance while encouraging sustainability and reducing the construction industry's negative environmental effects. The experimental program's findings provided important light on the advantages and viability of adding RHA to shotcrete mixtures.

This study also suggest that RHA is a viable and sustainable alternative to cement for use in shotcrete design for hydro tunnels. The use of RHA can improve the performance properties of shotcrete, while also reducing the environmental impact of the construction process.

1. **Mechanical Properties**: The shotcrete's compressive and flexural strengths significantly increased as a result of the inclusion of rice husk ash. Its load-bearing capacity and structural resilience are improved by the greater strength obtained with RHA-based shotcrete, giving it a competitive solution for a variety of construction applications.
2. **Thermal Insulation**: When compared to traditional shotcrete, the RHA-based shotcrete displayed improved thermal insulation qualities. The advantages of controlling indoor temperatures, which result in energy savings and improved occupant comfort, are provided by the lower heat conductivity.
3. **Lightweight Construction**: RHA-based shotcrete's lower density makes it possible to build structures that are lightweight, which may result in a reduction in the price of both the building materials and the structural design.
4. **Environmental Impact**: Rice husk ash added to shotcrete has shown to have considerable environmental advantages. Using agricultural waste encourages a more sustainable and environmentally friendly approach to building by lowering the carbon footprint of the concrete and diverting a sizable amount of garbage from landfills.
5. **Cost reductions**: The research's conclusions point to possible cost reductions in the acquisition of raw materials, use of cement, transportation, handling, and adherence to environmental rules. Although they vary depending on the circumstances of the project, these savings increase the RHA-based shotcrete's economic worth.

According to the research, RHA-based shotcrete offers a workable and long-term solution for the construction sector that is in line with international efforts to promote ecologically friendly practices. Since it addresses the urgent need to lessen the environmental impact of concrete-based constructions, the development of environmentally friendly and high-performance shotcrete has important implications for the future of construction.

Although the study offers insightful information, more investigation and practical applications are advised to optimize the RHA-based shotcrete mix design for particular construction projects. To determine the dependability of RHA-based shotcrete in diverse applications, the long-term performance and durability of the material should be assessed under various environmental circumstances.

Shotcrete's successful use of rice husk ash presents the construction sector with a game-changing potential to embrace sustainability without sacrificing performance. This research helps build a more durable and environmentally friendly built environment as construction techniques change to address global issues, paving the way for a greener and more sustainable construction industry in the years to come.

References:

[1]. Thermal and environmental impact analysis of rice husk ash-based mortar as insulating wall plasterKajanan Selvaranjan [a], Satheeskumar Navaratnam [b], J.C.P.H. Gamage [a], Julian Th amboo [c], Rafat Siddique [d], Jingxuan Zhang [b], Guomin Zhang [b]

[2]. Rice Husk Ash Concrete: the Effect of RHA Average Particle Size on Mechanical Properties and Drying Shrinkage G.A. Habeeb, M.M. Fayyadh Department of Civil Engineering, Faculty of Engineering, University of Malaya, Malaysia

[3]. Investigation on thermal properties of rice husk ash-blended palm kernel shell concrete A.A. RAHEEM [a], K.O. ORIOLA [b], M.A. K AREEM [c], R. ABDULWAHAB [d]

[4]. The Utilization of Agricultural Waste as Agro-Cement in Concrete: A Review Jing He, Satoru Kawasaki, VarenyamAchal

[5]. Assessment of Rice Husk Ash (RHA) and Calcium Chloride (CaCl2) on Compressive Strength of Concrete Grade 20 Joseph Adebayo Ige, LadokeAkintola University of Technology MukailaAbiolaAnifowose, Federal Polytechnic Offa Odeyemi Samson O., Kwara State University Suleiman Adebara, Federal Polytechnic, Ede, Ede, Nigeria

[6]. Ways to Reduce CO_2 in Sprayed Concrete for Tunnel Construction Hu, Zhao; Ding, Hao; Lai, Jinxing; Wang, Hao; Wang, Xiuling; He, Siyue (2018). "The durability of shotcrete in cold region tunnel: A review". Construction and Building Materials. 185: 670–683. doi:10.1016/j.conbuildmat.2018.07.088. S2CID 139503874. Retrieved July 12, 2022

[7]. Thermal properties of lightweight dry-mix shotcrete containing expanded perlite aggregate Wei Victor Liu, University of Alberta; Derek Apel, University of Alberta; V.S. Bindiganavile

[8]. Höfler, Jürgen; Schlumpf, Jürg (March 2004). Shotcrete in Tunnel Construction, Introduction to the basic technology of sprayed concrete (PDF). Sika AG.

[9]. Hu, Zhao; Ding, Hao; Lai, Jinxing; Wang, Hao; Wang, Xiuling; He, Siyue (2018). "The durability of shotcrete in cold region tunnel: A review". Construction and Building Materials. 185: 670–683. doi:10.1016/j.conbuildmat.2018.07.088. S2CID 139503874. Retrieved July 12, 2022.

[10]. Teichert, Pietro (Summer 2002). "Carl Akeley--a tribute to the founder of Shotcrete" (PDF). Shotcrete: 10–12. Retrieved 13 April 2014.

[11]. Davison, F. Trubee (March–April 1927). "Akeley, the inventor". Natural History. XXVII (2): 124–129.

[12]. "The gunite coating method". fastconcretepumpingbrisbane.com. 8 January 2021. Retrieved July 12, 2022.

[13]. "Norwegian technology in the world's deepest immersed tunnel" (in Norwegian) TekniskUkeblad, 12 October 2013. Accessed: 13 October 2013. Technical report: Claus K. Larsen. "Testing of fireproofing for concrete" 'Norwegian Public Roads Administration, 2007.

[14]. Mehta, P. K., & Monteiro, P. J. M. (2014). Concrete: Microstructure, Properties, and Materials. McGraw-Hill Education.

[15]. Neville, A. M. (2011). Properties of Concrete. Pearson Education.

[16]. Siddique, R. (2019). Waste Materials and By-Products in Concrete. Springer.

[17]. Tagnit-Hamou, A., &Razaqpur, A. G. (2014). Shotcrete: Elements of a System. CRC Press.