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Investigating the Effect of Rice Husk Biochar on Mechanical Properties and Chemical Resistance of Concrete

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Abstract. Sustainable use of rice husk is a subject of many recent researches. This study aims to determine the effect of rice husk biochar on the mechanical properties and chemical resistance of concrete. Methodology includes comprehensive literature review, followed by experimental investigations where Rice Husk Biochar (RHB) was partially replaced with cement in concrete at percentages ranging from 1% to 3.5 %. The results reveal that incorporating RHB into concrete enhances the compressive strengths, tensile strength, and durability, along with providing excellent resistance to chloride and sulfate solution. The results show that RHB has excellent potential to be used as a sustainable RHB used in replacement of cementin making environmentally friendly concrete by utilization of agricultural waste.

Keywords: Rice husk biochar, concrete, mechanical properties, chemical resistance, sustainability.

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1. Introduction

Concrete is currently the most widely used construction material in the world due to its versatility, strength, and durability. Where, cement takes the more significant percentage of concrete composition, which is produced through a process that significantly contributes to global environmental concerns because of emission of CO_2.

Concrete is a heterogeneous material in which the bond between cement pastes and aggregate decides the strength of concrete and the resistance against different chemicals attacks (such as sulphates and chlorides). But the problem lies with the usage of cement, if cement content increases the shrinkage and different unwanted effects increases, which needs to be resolved using difference admixtures or RHB used in replacement of cements, but cost of available admixtures or RHB used in replacement of cements are high and can be uneconomical.

On the other hand, 750 million Ton rice is produced every year globally with a byproduct of 120 million Ton Rice Husk (Suryaprakash Shailendrakumar Shukla, 2022). Burning of this byproduct in South Asian countries cause smog & Global warming, which is injurious to health. A better way is required to use this byproduct in sustainable manner (Mehta, 2023). In the quest to reduce the environmental impact of construction materials, the use of biochar, specifically rice husk biochar (RHB), has emerged as a promising solution. Rice husk is an abundantly produced by-product of rice milling, its traditional disposal methods include burning which contribute to air pollution and greenhouse gas emissions (Nair, J., Shika, S., & Sreedharan, V., 2020).

However, when subjected to pyrolysis, rice husks can be converted into biochar, a stable form of carbon that can be utilized as an RHB used in replacement of cement in concrete (Cuthbertson, D., Berardi, U., Briens, C., & Berruti, F., 2019). This process not only mitigates environmental pollution but also enhances the properties of concrete. The objective of this study is to investigate the effect of Rice Husk bio char (RHB) on the mechanical properties and chemical resistance of concrete.

The findings of this research could provide a way to reduce the carbon footprint within the construction industry as part of a global response against climate change. The use of rice husk biochar in concrete allows for managing the waste in the areas where rice is produced viz-a-viz more desirable mechanical and durability properties of concrete could be achieved in concrete.

2. Literature Review

Increasing attention to the use of rice husk biochar, (RHB), by-product of rice processing, a sustainable material to develop better properties for concrete has been received recently. The RHBC is incorporated in the concrete mixture to enhance certain valuable aspects: mechanical strength, durability, and chemical resistance (Dixit, A., Gupta, S., Pang, S., & Kua, H., 2019).

Usage of RHB has proved to increase the compressive strength of concrete. However, the optimum replacement value differs from study to study; 0.1% to 10% RHB replacement has been reported. For example, rice husk biochar at 0.1% replacement showed a marginal increase in compressive strength over the controlled specimens (Akhtar & Sarmah, 2018).

Incorporation of RHB has been demonstrated to raise its flexural strength by up to 20% and slightly improve splitting tensile strength towards the betterment of structural performance (Akhtar & Sarmah, 2018). RHB improves concrete durability in that its resistance to attacks by chloride and sulfate is significantly enhanced. With RHB addition, the concrete becomes less permeable, lowering the mass gain rate in the sodium chloride absorption process, which, in turn, brings about a higher strength retention after long-term exposure to aggressive environments (Gupta et al., 2020).

The adding of rice husk biochar positively affects dynamic viscoelasticity, creep resistance, and stress relaxation properties of concrete composites, although these properties may decrease with increasing temperature (Zhang et al., 2017).

2.1 Chemical Resistance of Concrete with Rice Husk Biochar

RHB has been found to reduce chloride penetration greatly and thus improve the long-term durability of concrete structures exposed to marine environments or de-icing salts (Gastaldini et al., 2007). The addition of RHB at different percentages produced enhanced sulfate resistance, where a remarkable decrease in the loss of strength due to the sulfate attack can be seen.

This happens because the amorphous silica contained in the RHB offers a pozzolanic reaction, thereby improving the microstructure of the concrete (Kannan & Ganesan, 2016). The concrete mixtures containing RHB have lower carbonation coefficients than traditional concrete, thus showing more excellent resistance to degradation due to carbonation (Gastaldini et al., 2007).

2.2 Microstructural Enhancements

RHB helps to achieve a more waterproof structure because of a higher porosity and, as a result, smaller permeability ensures higher durability. According to SEM analysis it has been revealed that RHB fits into micro-pores closely within the cement matrix enhancing mechanical attributes as well as chemical attacks (Madandoustet al., 2011).

RHB is rich in silica that also enhances the pozzolanic reactions, leading to enhanced concrete microstructure and mechanical performances. Several works discuss that due to high porosity and large surface area, RHB enables these advantageous reactions (Endale et al., 2022).

2.3 Environmental and Economic Benefits

When used in concrete, RHB improves the concrete properties as well as has environmental advantages of cutting down the usage of PC and providing a suitable solution for better management of agriculture residues.

This leads to a closed loop economy to be achieved in the construction sector which help in reducing material wastage (Endale et al., 2022).

3. Research Methodology

3.1 Introduction

Since RHB is cheap and locally sourced then its use as the supplementary cementitious material would help cut down the constructing cost yet at the same time the results shows that its performance gives or even enhances the concrete performance (Le et al., 2014). This chapter provides an overview of the research method used in the study to determine the impact of rice husk biochar on the mechanical properties and chemical resistance on concrete.

The Research methodology starts with the literature review and subsequent sample preparation. From the fine aggregate, coarse aggregate, water/cement ratio, and also content of biochar content is computed. The percentage of biochar content is at 1%, 1.5%, 2%, 2.5%, 3%, and 3.5% tests performed to determine the optimum ratio of biochar for improving concrete properties.

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3.2 Experiment Design

The experimental design for the current study aims to clearly demonstrate the effects of different proportions of RHB on the concrete characteristics. The major factors include, the cement is replaced with different proportion of RHB by the weight, which are placed at 1%, 1. 5%, 2%, 2. 5%, 3%, and 3. 5%. These prepared samples are compared with control mix to establish the effect of RHB. The experimental design is summarized in the flowchart given in Fig-1 and the Table 1 present the detail of mix proportion.

The table-1 summarizes various properties of concrete mixes containing different percentages of RHB. The mixes are labeled from 0% to 3.5%, indicating increasing proportions of the RHB. Testing in the first phase of the research is conducted at 7 days after casting the specimens. In the next phase, they will be tested at 28 days and 56 days.

For compressive strength, two samples are tested for each mix at all three durations, totaling 42 samples. This allows researchers to assess how the compressive strength of the concrete evolves over time with varying RHB used in replacement of cement concentrations. Additionally, compressive strength under chloride (Cl-) and sulfate (SO42-) exposure conditions is evaluated with one sample tested under each condition, ensuring a total of 42 samples across all mixes and durations.

Splitting tensile strength is tested with one sample per mix at 7, 28, and 56 days, totalling 14 samples, providing insights into the concrete's resistance to tensile stresses. Water absorption characteristics are evaluated with one sample per mix at 7days, totalling 7 samples, to understand how much water the concrete absorbs over time.

Lastly, shrinkage is measured with one sample per mix at 7 days, also totalling 7 samples, to assess changes in dimensional stability.

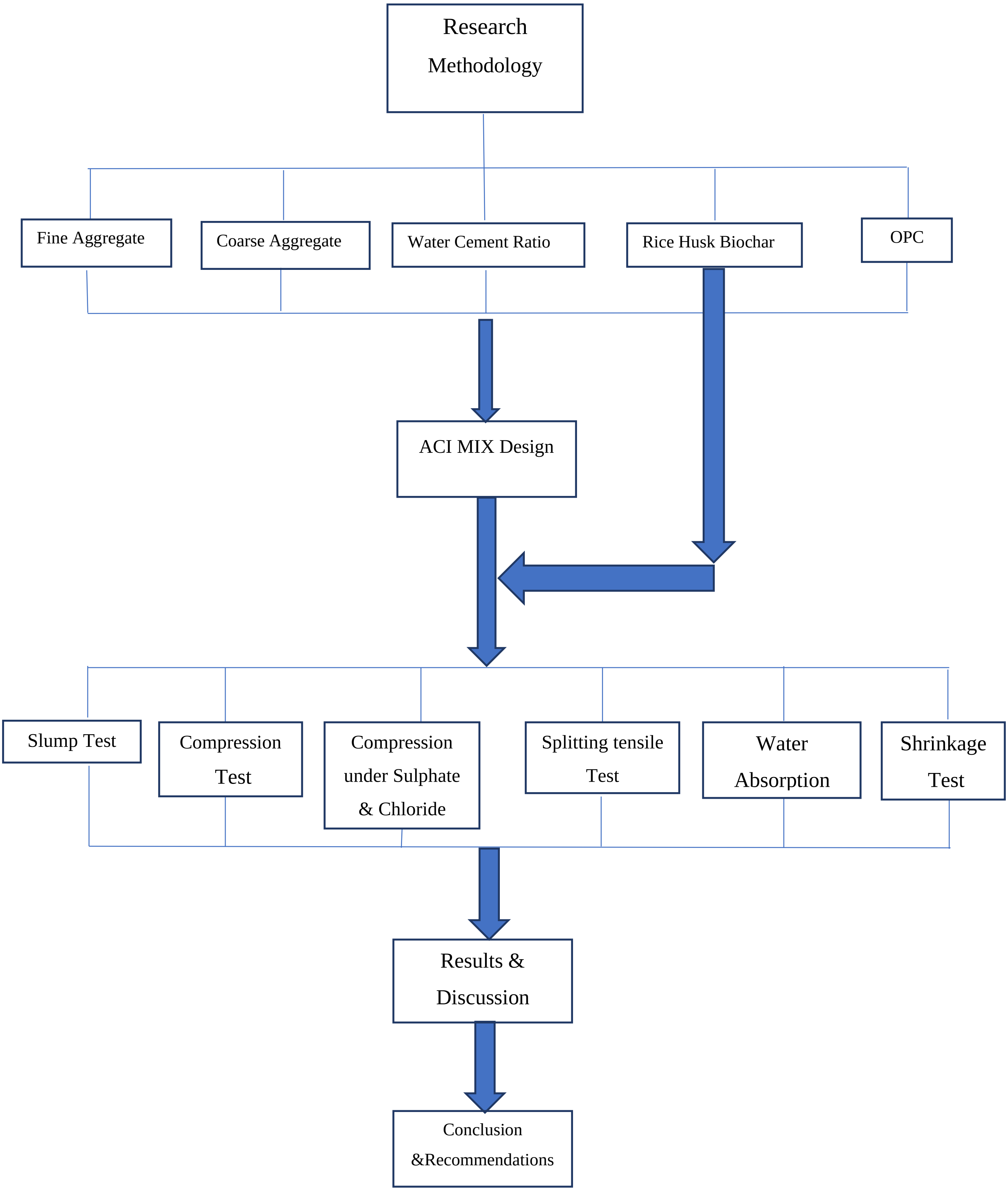

Table 1. Mix Proportions

Testing	Mixes							Testing Durations			
	Mix 0%	Mix 1%	Mix 1.5%	Mix 2%	Mix 2.5%	Mix 3%	Mix 3.5%	7 Days	28 Days	56 Days	Total No of Sample
Compressive Strength (2 samples)	√	√	√	√	√	√	√	√	√	√	42

Compressive Strength Under Cl^- & SO_4^{2-} (1+1 sample)	√	√	√	√	√	√	√	√	√	√	42
Splitting Tensile (01 sample)	√	√	√	√	√	√	√	√	√	X	14
Water Absorption (01 sample)	√	√	√	√	√	√	√	√	X	X	7
Shrinkage (01 sample)	√	√	√	√	√	√	√	√	X	X	7

3.3 Materials

The materials used in this study include:

i. **Ordinary Portland Cement (OPC):** Lucky cement used as the primary binding material.

ii. **Fine Aggregate:** Chenab sand with a Finess Modulus 2.2.

iii. **Coarse Aggregate:** Sakhi Sarwar crush with maximum size **20mm.**

iv. **Rice Husk Biochar (RHB):** Produced through the pyrolysis of rice husks at temperatures between 450°C and 550°C.

v. **Water:** Clean, potable water for mixing and curing.

Table 2 provides a detailed breakdown of the materials used in each mix proportion.

Table 2 Materials

Mixes	**Materials**				
	OPC	**Fine Aggregate**	**Coarse Aggregate**	**Water**	**RHB**
Mix 0%	√	√	√	√	**X**
Mix 1%	√	√	√	√	√
Mix 1.5%	√	√	√	√	√
Mix 2%	√	√	√	√	√
Mix 2.5%	√	√	√	√	√
Mix 3%	√	√	√	√	√
Mix 3.5%	√	√	√	√	√

Preparation of Rice Husk Biochar

Rice husk biochar is prepared through a controlled pyrolysis process. The rice husks are heated in an oxygen-limited environment to temperatures between 450°C and 550°C. The biochar produced is then ground and sieved obtain a consistent particle size suitable for concrete mixing.

3.5 Mix Proportion

The mix proportions for the concrete samples are calculated based on the American Concrete Institute (ACI) mix design method for a target strength of 30 MPa. Mix proportions are given in the table 3. The RHB replaces a portion of the cement by weight in the proportions of 1%, 1.5%, 2%, 2.5%, 3%, and 3.5%.

3.6 Sample Preparation

The concrete mixes are prepared by first dry mixing the aggregates, cement, and RHB. Water is then added gradually while mixing until a homogeneous mixture is achieved. The fresh concrete is poured into molds and compacted to remove any air voids. The samples are demolded after 24 hours and cured in water at 20°C until the testing age.

3.7 Testing Procedures

The testing procedures are designed to evaluate both the mechanical properties and chemical resistance of the concrete mixes.

Compressive Strength

Concrete cubes with dimensions of 100 mm x 100 mm x 100 mm used for testing. Testing occurs at ages of 7, 28, and 56 days to assess the compressive strength development over time. However, in the first part of this study, the 7-days results will be considered and evaluated. The procedure involves subjecting the cube to uniaxial compression using a compression testing machine. During testing, the maximum load applied to each cube until failure is recorded.

Splitting Tensile Strength Test:

Concrete cylindrical specimens with dimensions of 100mm diameter and 200mm height were used for testing. Testing occurs at ages of 7, 28, and 56 days to assess the Splitting Tensile strength development over time. However, in the first part of this study, the 7-days results will be considered and evaluated. The specimens are placed horizontally between the loading platens of a testing machine and loaded along their diameter until failure.

Compressive Strength Test under Chloride Solution (24 hr. in sodium chloride solution):

Concrete cubes with dimensions of 100 mm x 100 mm x 100 mm used for testing. Cubes are placed in a 5% sodium chloride solution for 24 hours. Testing occurs at ages of 7, 28, and 56 days to assess the compressive strength development over time. However, in the first part of this study, the 7-days results will be considered and evaluated. The procedure involves subjecting the cube to uniaxial compression using a compression testing machine. During testing, the maximum load applied to each cube until failure is recorded.

Compressive Strength Test Under Sulphate Solution (24 hr in sodium sulphate solution):

Concrete cubes with dimensions of 100 mm x 100 mm x 100 mm used for testing. Cubes are placed in a 5% sodium sulphate solution for 24 hours. Testing occurs at ages of 7, 28, and 56 days to assess the compressive strength development over time. However, in the first part of this study, the 7-days results will be considered and evaluated. The procedure involves subjecting the cube to uniaxial compression using a compression testing machine. During testing, the maximum load applied to each cube until failure is recorded.

Water Absorption Test

Concrete cubes measuring 100 mm x 100 mm x 100 mm are used. The testing is conducted at a designated age of 7 days. The procedure begins with the initial drying and weighing of the cubes. Subsequently, the specimens are immersed in water for a period of 24 hours to ensure thorough saturation. After immersion, the cubes are removed, dried to eliminate surface moisture, and weighed again to determine the increase in weight, which directly reflects the amount of water absorbed.

Shrinkage Test

Concrete prisms measuring 100 mm x 100 mm x 300 mm are used. The testing is conducted at a specific age of 7 days, a critical period when concrete undergoes significant early-age shrinkage. The procedure involves measuring the linear shrinkage of the prisms over a designated period of time. Initially, the prisms are carefully cast and left to cure under standard laboratory conditions. After the curing period, measurements of the dimensions are taken periodically to monitor any changes in length.

Table 2 Mix Proportions

Material	CEMENT	SAND	AGGREGATE	W/C RATIO
Proportion	1	1.75	3.18	0.55

3.8 Limitations

Several limitations were identified in the methodology: Variability in Biochar Quality: Differences in the properties of biochar based on production conditions could affect the consistency of results. Sample Size: Limited sample sizes might restrict the generalizability of the findings. Long-Term Durability: The study primarily focuses on short to medium-term effects; long-term durability needs further investigation.

4. Results and Discussion

The results are analyzed to evaluate the impact of rice husk biochar (RHB) on the mechanical properties and chemical resistance of concrete.

4.1 RHB Effect on Compressive Strength

The compressive strength of the concrete samples was tested at 7days. The results are summarized in Table 4. Fig-2 shows the increase in7-days compressive strength with the addition of the RHB as partial replacement to cement, peaking at 27.8 MPa for the 2% mix. The control mix, which does not contain the RHB used in replacement of cement, has the lowest compressive strength at 25.4 MPa. Even the smallest percentage of the RHB used in replacement of cement (1%) enhances the compressive strength to 26.2 MPa. As the percentage of the RHB used in replacement of cement increases, the compressive strength continues to rise, reaching its maximum at 2%. However, beyond 2%, the compressive strength slightly declines but remains higher than the control mix. The mixes with 2.5%, 3%, and 3.5% of the RHB used in replacement of cement show compressive strengths of 27.6 MPa, 27.3 MPa, and 27.1 MPa, respectively. This pattern suggests that while the RHB used in replacement of cement significantly improves the compressive strength of concrete, there is an optimal percentage (2%) beyond which the benefits diminish. The slight decline in strength, if goes beyond 2%, it might be due to the low effectiveness of higher addend concentrations or there will be negative effects added to the rubber compounds.

4.2 Effect of RHB on Splitting Tensile Strength

The results are summarized in Table 5. Fig-3 demonstrates the splitting tensile strength in megapascals (MPa) for various concrete mixes, containing a control and mixes with different percentages of an RHB used in replacement of cement, measured after 07 days. The data exposes a trend of increasing tensile strength with the addition of the RHB used in replacement of cement, summiting at 2.6 MPa for the 2% mix. The control mix, which does not contain any RHB used in replacement of cement, has the lowest tensile strength at 2.2 MPa. Even a small addition of the RHB used in replacement of cement, such as 1%, enhances the tensile strength to 2.3 MPa. As the percentage of the RHB used in replacement of cement increases, the tensile strength continues to rise, reaching its maximum at 2%. Beyond this optimal percentage, the tensile strength slightly declines but remains higher than the control. Specifically, mixes with 2.5%, 3%, and 3.5% of the RHB used in replacement of cement show tensile strengths of 2.5 MPa, 2.4 MPa, and 2.3 MPa, respectively. This pattern indicates that while the RHB used in replacement of cement effectively improves the splitting tensile strength of concrete, there is an optimal concentration (2%) after which the benefits start to diminish. The slight decrease in strength beyond 2% suggests diminishing returns or potential adverse effects of higher RHB used in replacement of cement concentrations.

Table 3 Compressive Strength

Mix	7 Days (MPa)
Control	25.4
Mix 1%	26.2
Mix 1.5%	27.0
Mix 2%	27.8

Mix 2.5%	27.6
Mix 3%	27.3
Mix 3.5%	27.1

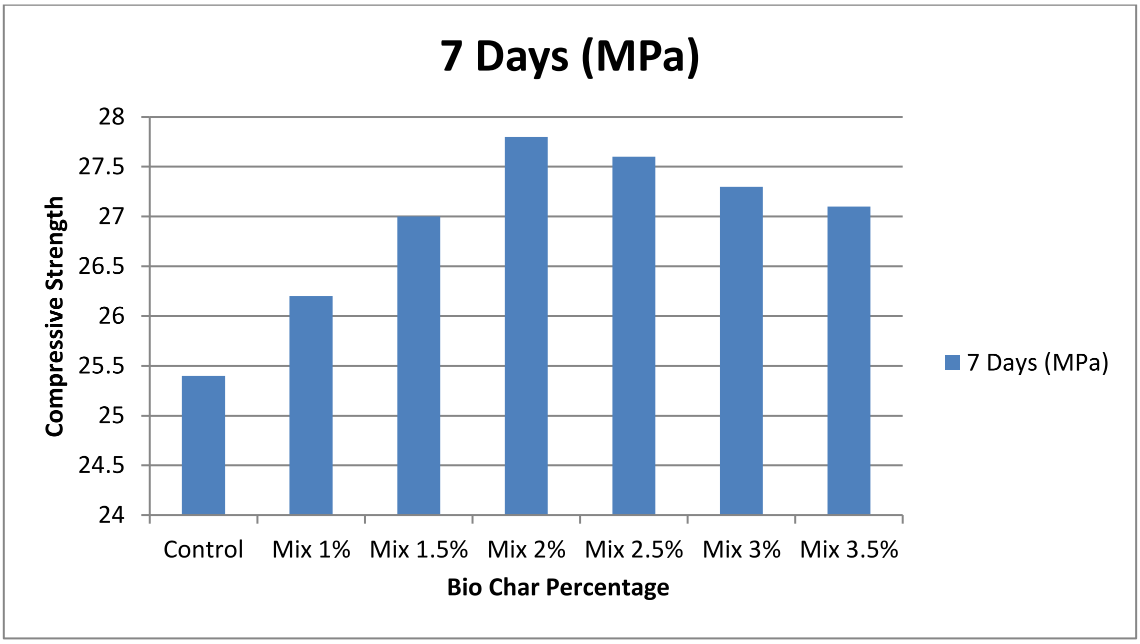

Figure 1 Compressive Strength Chart

Table 4 Splitting Tensile Strength

Mix	7 Days (MPa)
Control	2.2
Mix 1%	2.3
Mix 1.5%	2.4
Mix 2%	2.6
Mix 2.5%	2.5
Mix 3%	2.4
Mix 3.5%	2.3

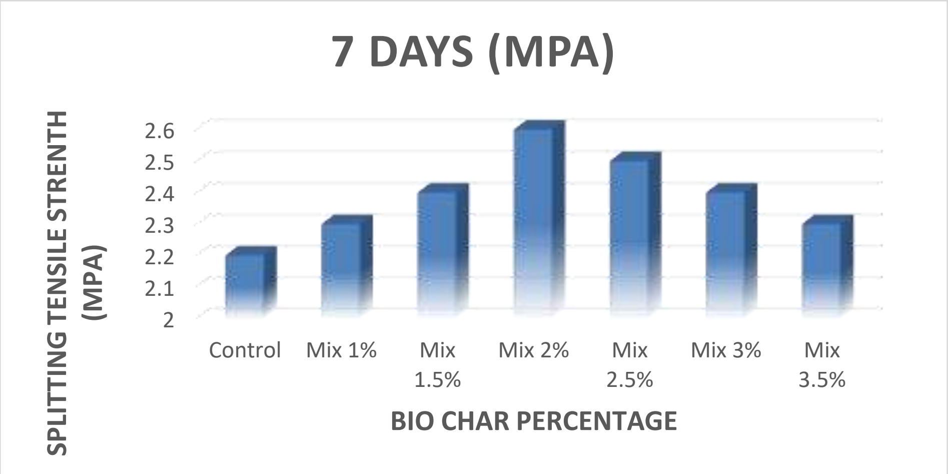

Figure 2 Splitting Tensile strength Chart

4.3 Effect of RHB on Compressive strength under chloride solution (sample placement time 24hrs)

Compressive strength results for samples placed in chloride solution for 24 hours. The results are summarized in Table 6. The compressive strength test results for concrete samples exposed to chloride solution for 24 hours were evaluated at 7 days to understand the early-age performance of rice husk biochar (RHB) as an RHB used in replacement of cement. The results showed in Fig.4 shows that the control mix, without any RHB, had a compressive strength of 26.7 MPa at 7 days. On the other hand, the mixes with RHB used in replacement of cement recorded higher values of the compressive strength of the concrete as compared to plain mixes. RHB mix of 1%, it has a strength of 27.8. It was observed that the highest early-age strength was associated with 2% RHB mix and had a compressive strength of 28. 9 MPa. This improvement is due to the pozzolanic character of the RHB, which reacts with the calcium hydroxide of cement to produce the formation of more C-S-H and strengthening of the concrete matrix. Mixes containing higher RHB content (2. 5%, 3%, and 3. 5%) exhibits slightly changes with 7days compressive strength of the range 28.7 MPa, 28. 5 MPa, and 28. 2 MPa, respectively. On the basis of these outcomes, it can be found out that the early-age densification of RHB has almost a very optimistic influence on the Compressive Strength of Concrete, but at the same time, up to a particular ratio there is a little bit beneficial beyond which the strength enhancing effect starts declining. Overall, the 7-day compressive strength highlight the beneficial impact of RHB on the early-age performance of concrete in chloride-rich environments. The enhanced strength at early ages suggests that RHB can contribute to the durability and robustness of concrete structures, particularly in aggressive conditions. Further experimental validation and exploration of long-term performance are necessary to fully establish the benefits of RHB in concrete applications.

4.4 Effect of RHB on 7-Day Compressive Strength under Sulfate Attack (sample placement time 24hrs)

The resistance to sulfate attack was evaluated by immersing the specimens in a sulfate solution for 24hrs and then we checked its compressive strength. The results are summarized in Table 7. Fig. 5 results indicate that the compressive strength of concrete samples decreases after exposure to sulfate solutions for 24 hours. This initial reduction is consistent with findings from the literature, which highlight the damaging effects of sulfate ions on the concrete matrix. Rice husk biochar (RHB) modified concrete showed better resilience compared to the control mix, with lesser reductions in compressive strength. The mix with 2% RHB displayed the highest resistance to sulfate attack, maintaining a 7-day compressive strength of 25.0 MPa after sulfate exposure.

Table 5 Compressive Strength under Chloride Solution

Mix	7 Days Compressive Strength (MPa)
Control	26.7
Mix 1%	27.8
Mix 1.5%	28.4
Mix 2%	28.9
Mix 2.5%	28.7
Mix 3%	28.5
Mix 3.5%	28.2

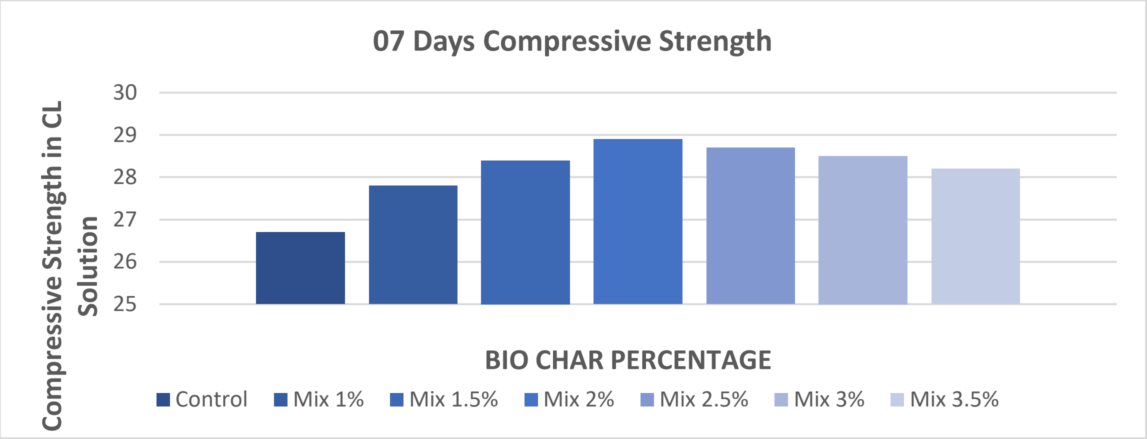

Figure 3 Compressive Strength under Chloride Solution

Table 6 Compressive Strength under Sulphate Solution

Mix	7 Days Mpa
Control	22.9
Mix 1%	23.6
Mix 1.5%	24.3
Mix 2%	25
Mix 2.5%	24.8
Mix 3%	26.6
Mix 3.5%	24.4

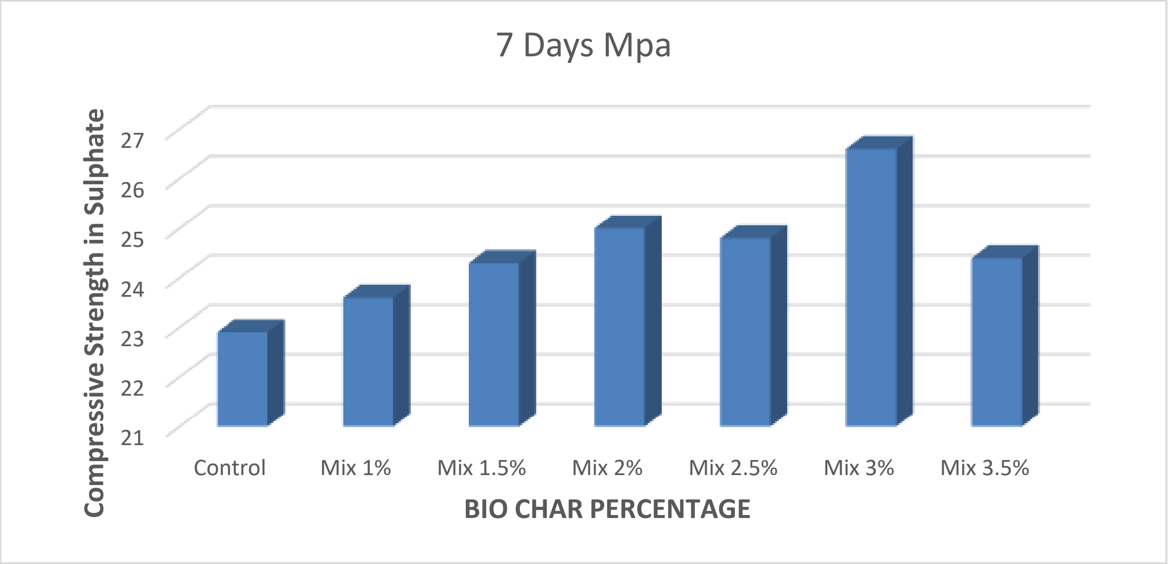

Figure 4 Compressive Strength under Sulphate Solution

4.5 Effect of RHB on Water Absorption

The water absorption test was done for 7 days. The results are brief in Table 8. The results in Fig.6 of the water absorption test performed for 7 days are useful in understanding the early-age water absorption behavior of the concrete mixes. This implies that the control mix had the highest water absorption at 5. 1%, which shows a trend of more porosity and less density relative to the RHB-modified mixes. As the percentage of RHB increase, the water absorption was comparatively reduced till the mix containing 2% of RHB which was registered minor water absorption of 4%. 9%. This is the trend which indicates that through participation in forming the concrete matrix microstructure, RHB amplifies the measured impermeability of concrete at early-ages. Based on pozzolanicity reactions made with the silica rich RHB & cement paste calcium hydroxide, there is also the formation of C-S-H gel involving more coverage to the pores which in turn reduces water absorption. However, it is pertinent to suggest here that, although for all the RHB mixes gradually the quantity of water absorbed but the extent of water absorption is quite lesser, which shows that after certain percentage level of RHB has already enhanced the water absorption capacity of the cement conclusively. These outcomes point to the effectiveness of RHB in enhancing the early-age characteristics of concrete, its reduced permeability and increased resistance to water penetration as factors that can lead to recommendable levels of sustainability and durability of concrete structures.

4.6 Effect of RHB on Shrinkage

The shrinkage of the concrete samples was determined at 7 days. The results are brief in Table 9. The density of the concrete samples was also tested after 7 days to determine how far the RHB positively contributed to the low shrinkage rate of concrete. A significant decrease in shrinkage effects was observed in Fig.7 the mixes containing RHB compared to the control mixes for both the 7-day shrinkage results. As for the control mix, it was 4 units less than before, indicating that the amount of control needed reduced. 05%, respectively The FC with RHB displayed contracting or shrinkage values as follows; minimum at 2% and 2. Also, 5% RHB, both at 0. 03%. From these conclusions, it becomes apparent that the incorporation of RHB can be attributed to lesser shrinkage whereby it helps in reduction of the drying shrinkage effects since it gives a means of cause to enable slow evaporation which makes enough space within the concrete matrix.

Table 7 Water Absorption

Mix	7 Days Water Absorption (%)
Control	5.1
Mix 1%	5.0
Mix 1.5%	4.9
Mix 2%	4.9
Mix 2.5%	4.9
Mix 3%	4.9
Mix 3.5%	5.0

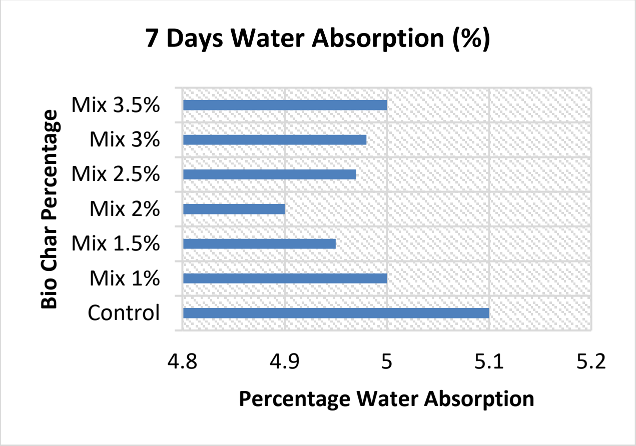

Figure 5 Water Absorption Results

Table 8 Shrinkage

Mix	7 Days Shrinkage (%)
Control	0.0375
Mix 1%	0.0300
Mix 1.5%	0.0300
Mix 2%	0.0225
Mix 2.5%	0.0225
Mix 3%	0.0300
Mix 3.5%	0.0300

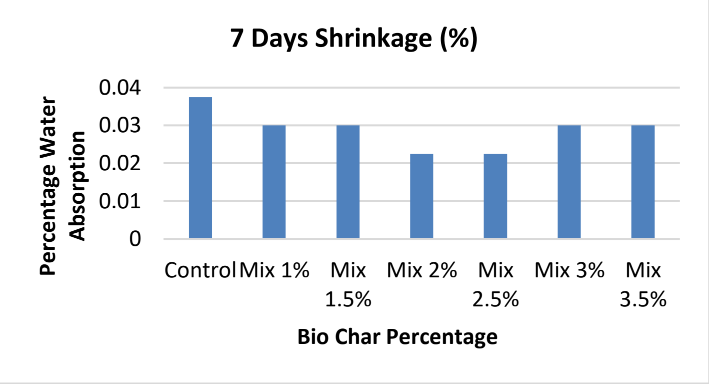

Figure 6 Shrinkage Results

5. Conclusion

The findings from the experimental section show that the incorporation of RHB in concrete causes an enhancement in its compressive strength, tensile strength and chemical resistance where the highest performance is, realized at 2% RHB dosage. These enhancements are directly caused by contributions of pozzolanic reactions and specifically the nature of the concrete matrix. RHB also plays its part in sustainability, such as the use of agricultural waste and the reduction of carbon emissions of concrete production.

The use of RHB used in replacement of cements in concrete is essential to improve the mechanical characteristics besides achieving a sustainable construction material and hence Rice husk biochar (RHB) can be used as an excellent candidate for concrete. The current research was intended to assess how RHB influenced the performance of concrete, especially on the mechanical properties as well as the chemical resistance. Different ratios of RHB were incorporated in concrete then tested through several tests. The following are the reflections of the relevant findings made from the present study:

- Compressive Strength: The incorporation of RHB at a maximum of 2 percent of cement weight enhanced the strength of concrete in terms of its compressive strength. This was the highest value obtained from the specimens with the optimal mix which is 2% RHB was observed to have a 07-day compressive strength of 27. 8 MPa with is 9.44% high than control mix.
- Tensile Strength: The splitting tensile strength also benefited from the inclusion of RHB, peaking at 2% with a tensile strength of 2.6 MPa at 07 days which is 18.18 % high in comparison to control mix. This indicates better stress distribution and bonding within the concrete matrix.
- Compressive strength in chloride solution: RHB enhanced the concrete's resistance to chloride and enhanced durability. In comparison, the mixes containing RHB exhibited higher compressive strengths. The 1% RHB mix achieved a strength of 27.8 MPa, while the 1.5% RHB mix reached 28.4 MPa. The highest early-age strength was observed in the 2% RHB mix, which recorded a compressive strength of 28.9 MPa.
- Compressive strength in Sulphate solution: Rice husk biochar (RHB) modified concrete showed better resilience compared to the control mix, with lesser reductions in compressive strength. The mix with 2% RHB displayed the highest resistance to sulfate attack, maintaining a 7-day compressive strength of 25.0 MPa after sulfate exposure.
- Water Absorption and Shrinkage: The water absorption and shrinkage tests revealed that RHB reduces water absorption and shrinkage, contributing to a denser, more stable concrete structure.

Discussion

The positive influence of RHB on concrete properties can be attributed to several factors:

- Pozzolanic Reaction: Since RHB contains high silica content the calcium hydroxide in the cement is converted back to form more C-S-H resulting in better concrete matrix.
- Microstructure Improvement: The porous nature of RHB improves the internal microstructure of concrete, reducing voids and enhancing density.
- Chemical Stability: The incorporation of RHB increases the chemical stability of concrete, providing better resistance to environmental degradation.
- These findings underscore the potential of RHB to improve concrete performance while promoting sustainability by utilizing agricultural waste. The use of RHB not only enhances the mechanical properties of concrete but also aligns with global efforts to reduce carbon footprints and promote eco-friendly construction practices.
- To this end, incorporating this method of concrete production will create more sustainable construction. Through this waste management, the conventional cement can be replaced partially with compacted agricultural wastes to minimize the emissions of CO_2 to the atmosphere. The function of carbon sequestration increases the environmental benefit of the biochar for the concrete containing RHB modification making it a green solution for the

construction industry (He, Z., Hu, L., Li, Y., Hu, J., & Shao, Y. (2018).

- Reduction in CO2 Emissions: By partially replacing cement with RHB, the overall carbon footprint of concrete production can be significantly reduced.
- Waste Utilization: Utilizing rice husk, a byproduct of rice milling, for biochar production promotes waste recycling and contributes to a circular economy.
- Enhanced Durability: The improved durability of RHB-modified concrete can lead to longer-lasting structures, reducing the need for frequent repairs and replacements.
- The advancement in mechanical properties led to better chemical stability, and considerable saving on environmental impacts place RHB as a strong candidate in the construction industry for an RHB used in replacement of cement.
- Overcoming the limitations of traditional concrete through the reuse of agricultural waste in material composition, economical cost can be reduced generating more durable structures while also promoting a sustainable future

Despite the promising results, there are several challenges and considerations for the widespread adoption of RHB in concrete:

- Standardization: There is a need for standardized procedures for producing and incorporating RHB into concrete to ensure consistent quality and performance.
- Economic Feasibility: The cost of producing high-quality biochar and its economic feasibility at a large scale need to be thoroughly evaluated.
- Long-term Performance: Further studies are needed to evaluate the daily use, effectiveness, and sustainability of RHB-modified concrete after it has been subjected to the natural environment.

Reference

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