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EFFECT OF RICE HUSK ASH ON COMPRESSIVE STRENGTH AND WORKABILITY OF CONCRETE

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Abstract

Concrete is the most widely used construction material globally, but its production relies heavily on Portland cement, contributing to significant CO_2 emissions and creating a substantial environmental burden. Rice husk ash (RHA), an abundant agricultural by-product with high silica content and pozzolanic potential, presents a promising opportunity for partial cement replacement, offering environmental and economic benefits. This study investigates the partial replacement of cement with RHA in concrete mixes, evaluating its effect on compressive strength and workability. Replacement levels were limited to 0%, 2%, 4%, and 6% by weight, as higher RHA contents require increased burning to produce sufficient ash, raising processing costs and offsetting the economic benefits of this substitution. Concrete specimens were cast at each replacement level and tested for compressive strength at 7 and 28 days. Compressive strength decreased gradually with increasing RHA content: the 28-day strength for control, 2%, 4%, and 6% replacement levels was 21.73 MPa, 20.03 MPa, 19.39 MPa, and 19.1 MPa, respectively. Workability also declined slightly, with slump values of 45 mm, 43 mm, 41 mm, and 40 mm for the same replacement levels. Despite this reduction, the results suggest that RHA substitution up to 6% is a technically viable strategy, offering meaningful reductions in cement consumption and associated CO_2 emissions, along with the beneficial reuse of agricultural waste, while maintaining acceptable mechanical performance.

INTRODUCTION

The worldwide usage of concrete has grown exponentially, even if its production takes a hefty toll on the environment by relying on Portland cement, which accounts for a massive percentage of CO_2 emissions (Vijaya, Jagadeeswari, and Srinivas 2020)(Zareei et al. 2017)(Bixapathi and Saravanan 2022).Concerned about the sustainability of the construction industry, the limited use of cement due to its pozzolanic properties is being actively researched (Vijaya, Jagadeeswari, and Srinivas 2020)(Cavalcante et al. 2018). Incorporating such materials certainly advances the industry in terms of sustainability since it decreases cement usage as well as the cement industry's carbon footprint (Jayaraman et al. 2023)(Zareei et al. 2017). As an agricultural by-product, rice husk ash (RHA) has even more potential use as an admixture to concrete due to its high pozzolanic silica content, availability, and global production (Lo, Lee, and Lo 2021)(Ozturk et al. 2020)(Rajashekhar Reddy, Harihanandh, and Murali 2021). The use of RHA, which is a by-product of the open burning of rice husks, will help in environmental sustainability of concrete production as well as RHA's carbon negative status (Alex, Dhanalakshmi, and Ambedkar 2016)(Zareei et al. 2017). This practice minimizes the use of cement which in turn lowers the emission of CO_2, using agro-waste like RHA, and converting a useless product into a useful one which reduces waste in landfills (Vijaya, Jagadeeswari, and Srinivas 2020)(Mayooran, Ragavan, and Sathiparan 2017) (Alex, Dhanalakshmi, and Ambedkar 2016). From an environmental perspective, the cement industry's CO_2 emissions and the subsequent production of concrete remains an environmental concern (Zareei et al. 2017)(Ali et al. 2021). This is because the construction industry remains overdependent on cement, which has a high carbon footprint (Mayooran, Ragavan, and Sathiparan 2017) (Zareei et al. 2017)(Tutur et al. 2023). This is of particular importance of developing countries, since RHA can be a low-cost, locally available alternative (Mayooran, Ragavan, and Sathiparan 2017)(Jayaraman et al. 2023)(Igba et al. 2019). For developing countries, this contributes to waste elimination and CO_2 emissions (Wang and Lee 2020) (Tutur et al. 2023). In addition, the concrete's mechanical performance may be compromised, since little is known regarding RHA's optimal replacement levels (Ouypornprasert, Traitruengtatsana, and Kamollertvara 2018). RHA use helps reduce CO_2 cement production and has been said to provide "economic and environmental benefits that encourage the use of high-carbon RHA" (Mayooran, Ragavan, and Sathiparan 2017) (Zareei et al. 2017).

Some prior studies did recognize the characteristics of RHA regarding its chemical, physical, and particle size properties, confirming its pozzolanic reactivity (Vijaya, Jagadeeswari, and Srinivas 2020) (Alex, Dhanalakshmi, and Ambedkar 2016)(Chia et al. 2020).RHA has 8590% amorphous silica, demonstrating its pozzolanic reactivity ability (Zareei et al. 2017) (Bixapathi and Saravanan 2022).An example of RHA having high silica content is 96.44% SiO_2 at calcination of 550°C, with high amorphous silica further enhancing pozzolanic reactions as well as C-S-H gel formation (Lo, Lee, and Lo 2021)(Hussein et al. 2025)(Samad et al. 2022).The pozzolanic activity of RHA enables the formation of C-S-H gel, which enhances strength, durability, and reduces the voids (Chia et al. 2020)(Samad et al. 2022).A number of studies have documented the improvements on compressive strength attributed to RHA and the partial replacement of cement, typically around the 10% replacement mark which resulted in strength enhancements of 19.6% at 28 days (Hussein et al. 2025)(Krishna, Sandeep, and Mini 2016).Moreover, other researchers report optimal replacement values to be between 5% and 15% (Zareei et al. 2017)(Fapohunda, Akinbile, and Shittu 2017).As an example, one study confirmed that a 10% RHA replacement increased compressive strength, while replacements beyond 10% led to a reduction due to a porous structure (Ozturk et al. 2020). Research on paver blocks similarly confirms that an optimal RHA content of 10–15% can improve strength while maintaining performance (Kumar and Gopi 2022).Reported benefits include improved compressive strength at optimal partial replacement levels and a reduced heat of hydration (Wang and Lee 2020)(Chia et al. 2020). Moreover, the current state of the art incorporates contradictions at the empirical level of high replacement and the exploration of the 'ever-lasting' literature at the performance and durability levels in the following studies(Ma et al. 2023)(Syahida Adnan et al. 2021).The prominent gap and limitation of the research done is explaining RHA, in all its forms, above higher replacement levels, as the results are inconsistent starting above 10-20% in the literature (Mayooran, Ragavan, and Sathiparan 2017)(Hussein et al. 2025) (Ouypornprasert, Traitruengtatsana, and Kamollertvara 2018).The absence of a broader performance range and prolonged durability respectively, in the literature is noticed as most studies have been done with the 7/28 day curing and hence not field-based studies (Vijaya, Jagadeeswari, and Srinivas 2020) (Lo, Lee, and Lo 2021)(Ma et al. 2024) (Tutur et al. 2023).Significant research topics have been insufficiently covered, notably the durability and long-range performance of a concrete or compound, as most research is confined to certain concrete grades and/or relatively brief testing periods(Bixapathi and Saravanan 2022) (Rajashekhar Reddy, Harihanandh, and Murali 2021)(Igba et al. 2019).Furthermore, there is a lack of consensus on sustainable replacement thresholds that do not compromise concrete performance, particularly concerning the trade-off between strength gain and potential permeability reduction at higher replacement levels(Hussein et al. 2025)(Khankhaje et al. 2025). Many studies are limited to specific concrete grades or lack long-term durability data, such as tests for sulfate attack or freeze-thaw cycles, and some research is focused on specialized applications like radiation shielding or evaluating fresh properties for 3D printing concrete without assessing compressive strength, leaving a gap in comprehensive mechanical property analysis for standard structural concrete(Jayaraman et al. 2023)(Alrowaili et al. 2024)(Syahida Adnan et al. 2021)(Samad et al. 2022). A significant research gap identified is the limited data on reinforced concrete behavior, such as the shear or bending responses of RHA beams and slabs, necessitating further research (Fapohunda, Akinbile, and Shittu 2017). Furthermore, numerous investigations concluded that a key limitation is the lack of clarity on the behavior of RHA at higher replacement levels, with studies showing a linear strength reduction beyond 10-15%(Krishna, Sandeep, and Mini 2016)(Igba et al. 2019). This results in no clear consensus on sustainable replacement thresholds that do not compromise concrete performance (Hussein et al. 2025) (Ma et al. 2023). This study aims to contribute to filling this gap by assessing the effects of various RHA replacement levels on the compressive strength of concrete. The aim of the current study is to assess the effects of RHA replacement levels specifically 0%, 5%, 10%, 15%, and 20%—on the compressive strength of concrete (Cavalcante et al. 2018). The scope is laboratory-based, focusing on tests for 7-day and 28-day compressive strength only, with durability, shrinkage, and field performance excluded (Bixapathi and Saravanan 2022) (Ouypornprasert, Traitruengtatsana, and Kamollertvara 2018) (Igba et al. 2019). The ultimate goal is to identify the optimal sustainable replacement level of RHA in cement without compromising strength, thereby contributing to cost savings, waste utilization, and reduced environmental impact(Vijaya, Jagadeeswari, and Srinivas 2020) (Krishna, Sandeep, and Mini 2016).

METHODOLOGY

1. Materials and Methods

The materials utilized in this study were:

- Ordinary Portland Cement (OPC)
- Rice Husk Ash (RHA)
- Fine Aggregate (Bolhari Pakistan)
- Coarse Aggregate
- Water

All materials rice husk, cement, aggregates (coarse and fine), and water were procured from the local market in Karachi, Pakistan. The OPC used met the specifications of ASTM C150 Type-I. Rice husk was calcined at 600°C to produce RHA, which was used to replace cement by weight at 0%, 2%, 4%, and 6% substitution levels. For each mix, cement (with the corresponding RHA replacement) and sand were first combined, followed by the addition of coarse aggregate and water at a water-cement ratio of 0.5, using a mix ratio of 1:2:4 for normal concrete. The mixture was cast into 150 mm cube specimens, with 24 cubes prepared per replacement level for each curing age. Specimens were cured for periods of 7 and 28 days and subsequently tested for compressive strength using a compressive testing machine, in accordance with BS 1881.

Table 1. Mix Composition Rice husk Ash

Mix ID	Cement %	RHA %	Aggregate %	W/C Ratio
RHA-0	100	00	100	0.5
RHA-2	98	02	100	0.5

RHA-4	96	04	100	0.5
RHA-6	94	06	100	0.5

RESULTS AND DISCUSSION

1. Energy Dispersive Spectrometry (EDS) analysis

An Energy Dispersive Spectrometry (EDS) examination was conducted to classify and determine the primary and secondary components present in Rice husk ash.

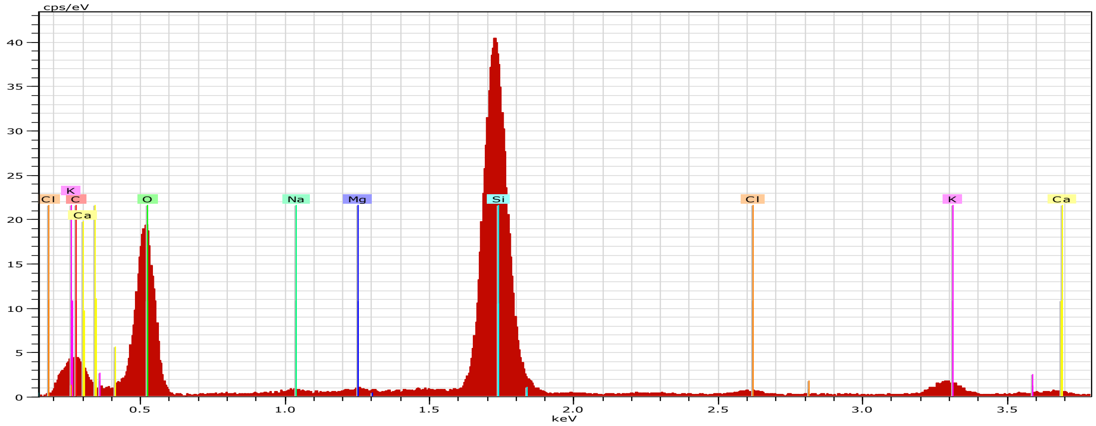

Figure 1: Energy Dispersive Spectrometer EDS of RHA at 600 C-2hr

Table 2. Weight % of elements in RHA(600ºC-2hr)

Elements	Series	wt %age	Error %age
Silicon	K-series	35.7	0.6
Aluminium	K-series	0.79	0.3
Magnesium	K-series	0.53	0.1
Calcium	K-series	1.78	0.4
Sodium	K-series	0.47	0.1
Potassium	K-series	3.17	0.1

2. Scanning Electron Microscopy (SEM)

The morphological properties of the Rice husk ash were detected using Scanning Electron Microscopy (SEM) images at a temperature of 600°C and a duration of 2 hours.

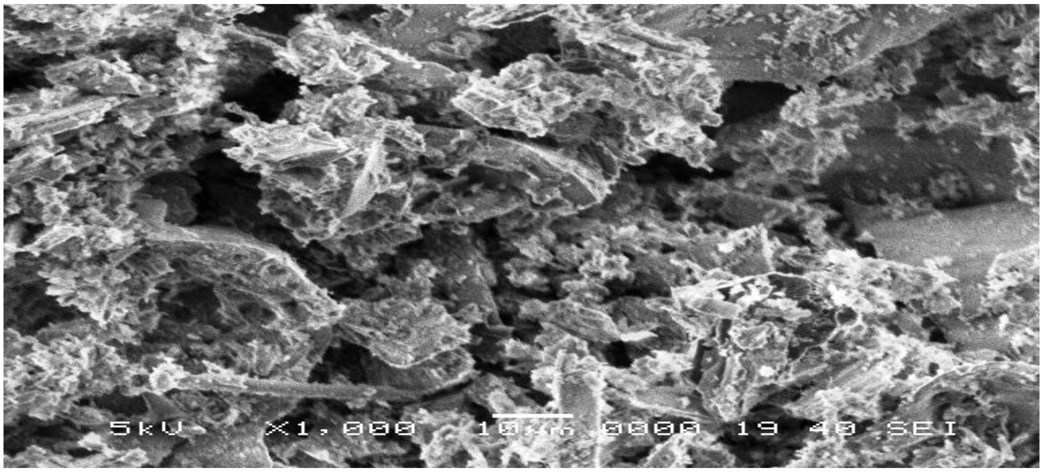

Figure 2: SEM at 10 kV X1000 10µm

3. Workability

Workability refers to the ease with which a concrete mix can be handled and placed, and is commonly assessed using the slump test. Figure 3 illustrates the workability of concrete mixes with varying proportions of Rice Husk Ash (RHA) as a partial replacement for cement. Slump values decreased progressively with increasing RHA content, from 45 mm at 0% RHA (control) to 43 mm, 41 mm, and 40 mm at 2%, 4%, and 6% RHA replacement, respectively. This reduction in workability can be attributed to the high surface area and porous structure of RHA particles, which increase water demand within the mix. Despite this decline, the slump values across all replacement levels remained within an acceptable range for normal construction applications.

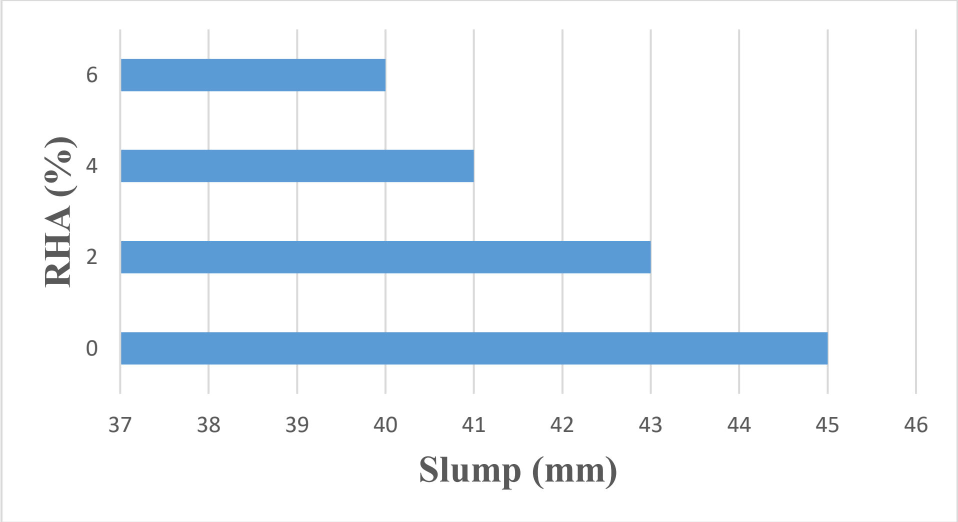

Figure 3: Slump vs RHA (%)

4. Compressive Strength

Figure 4 presents the results of laboratory compressive strength tests conducted at curing periods of 7 and 28 days. The results show that cube strength decreases as the percentage of Rice Husk Ash (RHA) increases. The highest strength, 21.72 MPa, was recorded at 28 days with 0% RHA, while the lowest, 14.7 MPa, was observed at

7 days with 6% RHA. Despite this reduction in strength at higher RHA content, the results indicate that substituting up to 6% of cement with RHA remains a viable option, as strength retention stays close to that of the control mix. Based on the compressive strength results, RHA is recommended for use in concrete at a maximum of 6% replacement for applications such as floors and walls not subject to high load or stress.

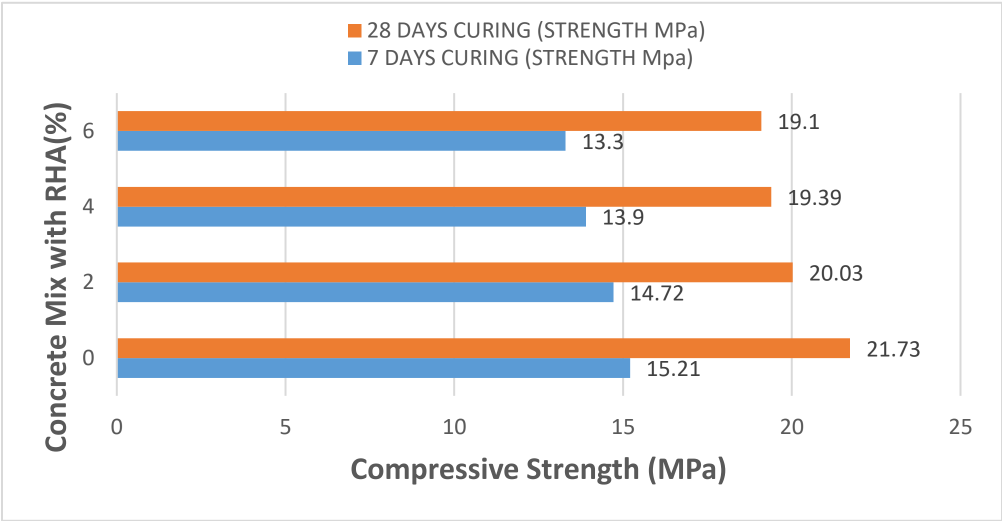

Figure 4: Compressive Strength of RHA Concrete Mixes at 7 and 28 Days

CONCLUSION

Based on the findings of this investigation, the following conclusions were drawn:

- The research revealed that rice husk ash, a waste material, can be effectively utilized in concrete preparation.
- Cubes made with 0% RHA showed the highest compressive strength after 28 days of curing, while strength decreased progressively with increasing RHA content, reaching 19.1 MPa at 6% RHA replacement a reduction of approximately 12% relative to the control.
- Despite this reduction, concrete containing up to 6% RHA can be effectively utilized for specific floor and wall applications not subject to high load or stress.
- Workability decreased slightly with increasing RHA content but remained within an acceptable range for practical use.

This research indicates that incorporating waste materials such as RHA in concrete production can achieve two important outcomes: conserving cement resources and mitigating environmental harm by reducing CO_2 emissions from cement production. Additionally, it offers a method for the safe utilization of agricultural solid waste.

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