Feasibility of Utilizing Rice Husk Biochar as a Supplementary cementitious material in Concrete Blocks

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Abstract. Rice husk is one of the major byproducts of agriculture. This research is conducted to evaluate the feasibility of rice husk biochar (RHB) integrated concrete blocks and normal M30 grade concrete blocks through compressive strength test performance. RHB is used in this research as a supplementary cementitious material (SCM) in concrete blocks. The rice husk was pyrolyzed by burning in a muffle furnace with limited or no oxygen conditions under 700°C temperature. Blocks with the dimensions of 150mm×150mm×150mm were made according to the BS 1881-108 1983 standard. The RHB integrated blocks were made by replacing 1 wt.% of the weight of cement with RHB. Three RHB integrated blocks and three normal concrete blocks (as control blocks) were made. The concrete blocks were made using M30 Grade with a volume ratio of cement: sand: coarse aggregate, 1:1:2 accordingly, and the cement to water weight ratio was taken as 1:0.5. One of each control concrete block and RHB integrated concrete block were put into a water bath to cure for 7, 14 and 28 days accordingly. Then the compressive strength test was performed on each block. Although the compressive strengths of RHB integrated blocks were lower compared to normal concrete blocks, the compressive strength of 7, 14 and 28 days cured blocks had acceptable compressive strength above 30MPa.

Keywords: Supplementary cementitious material (SCM), Rice husk Biochar (RHB), Concrete blocks, Pyrolysis, Ordinary Portland Cement (OPC)

1 Introduction

Cement is considered a highly sought-after material in development and infrastructure due to its accessibility, reasonable price, and strength. According to research, the global cement production has reached approximately 4.28 billion tons [1]. Although it is found that the cement industry directly represents 7-8% of the CO_2 emissions associated with human activities [2]. CO_2 is a major greenhouse gas (GHG) which contributes to climate change due to its ability to trap heat in Earth's atmosphere. Demand for cement is increasing due to economic growth, rapid industrialization, and urbanization in the world. Therefore, the cement industry is actively working to reduce its carbon footprint, aligning with the UN's sustainable development goals (SDGs), particularly SDG 12 (responsible consumption & production) and SDG 13 (Climate action), through various policies, regulations and initiatives focused on sustainability [3]. Therefore, complying with SDG 13 (Climate Action), the industry is acknowledged to decarbonize processes, including reducing CO_2 emissions per ton of cement by 30% by 2030 and to achieve net-zero emissions by 2050 according to the Global Cement and Concrete Association (GCCA) [4]. To mitigate this issue, several solutions have been suggested in the literature, such as the addition of biomass and waste materials, ashes to replace cement products and the development of alkali-activated materials to get rid of Portland cement in concrete and mortars. Cost-effective, sustainable solutions can be limited to the use of bio-based materials (as raw or ash) the main composition of mortar or concrete.

a. Biochar

Biochar is a unique carbon-neutral solution among bio-renewable materials has recently gained much attention in the construction field as a supplementary cementitious material (SCMs) for Portland cement as it can reduce CO_2 emissions from cement production [5]. Biochar is a carbon-rich, porous material which is produced by pyrolyzing agricultural waste residues (bagasse, corn husk, rice husk ash, etc.) using a muffle furnace under zero or reduced oxygen conditions. The qualities of the biochar, such as the yield, physicochemical and microstructural properties, are dependent upon conditions of biochar production, which are;

- Temperature range
- Heating rate
- Residence time.

High temperature pyrolysis (500-700°C), Biochar undergoes thermal cracking, which releases volatiles from its pores and leaves behind a carbon skeleton [6]. Also, pyrolysis performed at a temperature higher than 500°C produces hydrophilic biochar due to the removal of labile aliphatic functional groups existing on the surface of biochar, resulting in the formation of high porosity [7].

There are two types of pyrolysis types that can be separated according to the heating rate they are slow pyrolysis and fast/flash pyrolysis. Slow pyrolysis, which is usually performed over several hours, is normally associated with higher yield of biochar and low flammability of the produced char compared with fast and flash pyrolysis, which are typically performed over seconds [8].

b. Rice Husk Biochar

The annual production of rice is more than 750 million tons of rice grain, according to research conducted in 2024. Rice husk is a predominant agricultural waste residue generated by rice mills in rice-cultivating countries. The elemental composition of Rice husk has been tested in research using energy dispersive X-ray analysis and found to be include 9.55- 18.74% Carbon, 30.90 -35.51% Oxygen, 43.17-58.19% silica and 1.36-1.66% Potassium by weight. Also, in 2022 Chen found that rice husk comprises 25-33% cellulose, 25-31% lignin, 18-21% hemicellulose, 15% pentosans, and minerals with 16% silica compositions [9].

Rice husk biochar (RHB) is generated by pyrolyzing the rice husk using a muffle furnace at limited or zero oxygen conditions. RHB is found to consist of 87-97% silica in the form of non-crystalline or amorphous silica with small quantities of inorganic salts [10], [11]. The amorphous portion is a crucial factor in determining the contribution of a particular biochar in the pozzolanic reaction. Pozzolanic materials react with Calcium Hydroxide during cement hydration, which results in the formation of calcium silicate hydrate (C-S-H) gel, which is a key component responsible for the strength and cohesion of cementitious structures [12]. The amorphous nature of silica enhances the surface area and increases contact points, which facilitates the formation of C-S-H gel and promotes the densification of the material microstructure [13], [14].

According to ASTM 2019, a pozzolan must be a siliceous or aluminous material that reacts chemically with calcium hydroxide $Ca(OH)_2$ at ambient temperatures. Natural pozzolan should have a combined total of at least 70% silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3), while the magnesium oxide (MgO) content should not exceed 5% [15]. RHB meets this requirement, because it has a combined total of SiO_2, Fe_2O_3 and Al_2O_3 greater than 70%. Therefore, RHB can be considered a good natural pozzolan that can be used to replace cement.

c. RHB as a Supplementary Cementitious Material

Due to pozzolanic properties and environmental benefit, RHB has gained attention as a potential SCM. Supplementary cementitious materials (SCMs) are materials that contribute to the hydration process and enhance the mechanical and durability properties of concrete.

The proximate analysis of rice husk biochar has shown an increased fixed carbon when the temperature was increased to 400°C to 700°C [16]. The amorphous nature of SiO_2

content in RHB at 450°C (33.50%) and 650°C (41.30%) shows higher potential for pozzolanic reactivity compared to crystalline silica [15], [17]. It was found that RHB at 700°C has the highest pozzolanic reactivity, resulting in the highest hydration degrees and highest compressive strength of RHB incorporated cement materials [18].

It was stated in [19] that Biochar pyrolyzed at 700°C had improved the compressive strength of the concrete sample more than that pyrolyzed at 500°C because of the high porosity and large surface area, which facilitates cement hydration. But in contrast, the research conducted by Gupta and Kua in 2018 highlights that the optimum temperature range highly depends on the biomass selection [19].

Incorporation of RHB as an SCM was found to be optimal within the range of 0.085 – 5 wt.%, which has resulted increased strength and enhancement of other properties, and also the same authors have stated that the addition of 1-2 wt.% RHB has significantly reduced water permeability compared to the control mortar, resulting in a 15-18% increase in strength of the cement mortar after 7,42, and 120 days [20]. The same authors also stated that 1 wt.% of RHB increased the hydration rate due to the high specific surface area and smaller particle size of the biochar compared to cement. Another study has reported that incorporating 1wt.% of RHB increased the compressive strength of concrete by 8.9% [21].

2 Methodology

According to the Literature review, the optimal temperature to produce RHB that was used as an SCM in this study was found to be 700°C, and the concrete mixture was determined to be made by replacing 1% of the weight of the ordinary Portland cement (OPC) with RHB.

a. Material preparation

Rice Husk was collected from a rice mill and pyrolyzed to produce RHB at 700°C at Sri Jayawardhanapura University of Sri Lanka. The pyrolyzing conditions are mentioned in Table 1.

Then produced RHB was granulated and sieved to a size between 0.063mm and 2mm. Ordinary Portland Cement (OPC) with SLS 107 has been purchased from a local hardware store. River sand (0.063mm – 2mm) was used as the fine aggregate for the concrete. In this research, 1 wt.% of OPC was replaced with RHB pyrolyzed at 700°C.

Then 10g of river sand was taken to an evaporating dish with a known mass and put into the oven at 105°C and kept for 24 hours. Next, the sample with the evaporating dish was taken out and kept inside a desiccator until it came to the room temperature. Next, it was weighed using an electronic balance. Then it was again put inside the oven at 105°C for 2 hours and was taken out and weighed again. This process was repeated until the sample achieved a constant weight. The moisture content of the river sand was calculated as a percentage, and the amount of water was adjusted using the moisture content accordingly.

Table 1. Pyrolysis Conditions of RHB.

Pyrolysis Conditions	Example
Temperature (°C)	700
Residence Time (hour)	1
Temperature ramp (°C/minutes)	10
Oxygen condition	Low/ Zero

According to BS 1881-108:1983 standard, should incorporate coarse aggregates having a nominal maximum size not exceeding 40mm should be incorporated to build the concrete blocks of 150mm. Gravel was used as the coarse aggregate.

Standard concrete test cube moulds of 150mm×150mm×150mm size were taken from the Civil Engineering Department of the National Engineering Research and Development Centre.

b. Experimental Procedure

According to BS 1881-108:1983 standard, before assembly of the mould, the joints between the sides of the mould, between the sides of the mould and the base plate were thinly coated with oil and grease to prevent water loss. Then the mould was assembled in a manner where the sides of the mould were positively located, and the whole assembly was held rigidly together to prevent leakages from the mould (Fig. 1). The internal faces of the assembled mould were then thinly coated with release agent to prevent adhesion of concrete.

Fig. 1. Oil & grease applied (150×150×150mm) mould

The concrete mixture for 150mm test cubes was made by blending OPC, River sand, and RHB 1wt% from OPC according to the M30 grade volume and weight ratios. The volume ratio between OPC cement, sand, coarse aggregate is 1:1:2 and cement-to-water weight ratio was taken as 1: 0.5. The moisture content of sand should be considered in determining the water amount needed to add to the mixture.

According to the standard, after mixing OPC, sand, RHB, and coarse aggregates, water was added and mixed well. Then the mixture was thoroughly mixed by shoveling it to form a cone on the sampling tray, and then it was turned over with a shovel to form a new cone. This was done three times. When forming the cones, each shovelful of material on the apex of the cone was deposited so that the portions that slides down the sides were distributed evenly, and the Centre of the cone was not displaced.

Fig. 2. Compacting each 50mm layer with a compact bar

Then the 150mm× 150mm × 150mm moulds were placed on a rig of horizontal surface rig and the concrete was filled in a way to remove entrapped air as much as possible. To produce full compaction of the concrete with neither excessive segregation nor laitance, the concrete was placed in layers of approximately 50mm deep and compacted each layer using a compact bar as shown in Fig. 2. Each layer was compacted with evenly distributed 25 strokes as mentioned in the BS 1881-108:1983 standard. After the top layer was compacted, leveled the top surface by using a mason trowel and the outside of the moulds were wiped to clean.

Three 150mm× 150mm × 150mm test cubes were made using this method (Fig. 3). Then the mould with the sample was kept to dry for 24 hours, and then after dried, it was named and transferred to a water bath to cure. One block is kept for 7 days, another for 14 days, and the last test cube for 28 days.

(a) (b)

Fig. 3. (a) Dried RHB 1wt% integrated concrete blocks with mould; (b)Curing water bath.

The same steps that were used to develop the RHB integrated concrete blocks were followed to make the normal concrete block according to the standard of M30 grade concrete blocks without replacing 1% of the weight of cement with RHB.

Compressive strength test

After 7,14, and 28 days, each block was taken out of the water bath and kept until the water dried off. Then the weight of the test cube was measured the weight using an electronic balance. Next, the uniaxial compressive strength of the block was examined using the standard testing instrument (Compression Testing Machine: CTM) with a pace of 6.8 kN/s at the National Engineering Research & Development Centre (Fig. 4).

A few samples of each test cube cured for 7, 14 and 28 were collected and stored in a waterproof bag to test under a Scanning electron microscope (SEM) and a Transmission electron microscope (TEM).

Fig. 4. Compression Testing Machine (CTM)

3 Results and Discussion

Table 2. Compressive Force of Control Concrete Block and RHB 1% incorporated concrete block.

Curing Period	Compression Force (kN)	
	RHB 1% integrated Concrete Block	Control concrete blocks
7	916.5	1015.3
14	968.1	1035.5
28	814.11	1066.2

The 1 wt% RHB replaced test cubes and control test cubes built for M30 grade, which had been cured for 7, 14 and 28 days respectively were subjected to compressive strength test. Table 2 shows the results of the compressive force.

The compressive strength of the concrete blocks was calculated by dividing the compressive force by the area of one concrete cube (0.15m×0.15m). Table 3. shows the compressive strength according to the compression force in Table 2.

Table 3. Compressive strength of Control Concrete Block and RHB 1% incorporated concrete block.

Curing Period	Compressive Strength (MPa)	
	Control Concrete Block	RHB 1% integrated Concrete Block
7	45.12	40.73
14	46.02	43.03
28	47.39	36.18

Compressive strength of RHB incorporated samples is illustrated in Fig. 5. The graph shows that the compressive strength of Biochar incorporated blocks are less than the control concrete test cubes. The blocks are made in accordance with M30 grade. According to the standard, Concrete cubes of M30 grade should have a minimum compressive strength of 30 MPa. When comparing data of the compressive strength test, all compressive strengths were over 30MPa, which is the standard of the M30 grade concrete block. Compared to the RHB 1wt.% integrated block that was cured for 7 days was above 40 MPa, and the compressive strength had increased gradually. However, the compressive strength of the RHB 1wt.% integrated block that was cured for 28 days was decreased. According to research, there can be several reasons that cause this deviation. The three blocks were made by using 1 concrete mixture and therefore, RHB might not have been distributed equally through the mortar mixture. The microstructure analysis of the scanning electron microscope has shown that a homogenous matrix of the test concrete cube is important for the compressive strength, and strength changes could occur due to mechanical interlocking or altered crack patterns [22]. The porous nature of RHB has relatively low load-bearing capacity creating weak zones (like voids) in the concrete, which significantly reduce the mechanical strength of the hardened concrete. While the internal curing nature of RHB can promote cement hydration and increase the formation of hydration products, it is minimal compared to the weakening effect caused by the biochar [23].

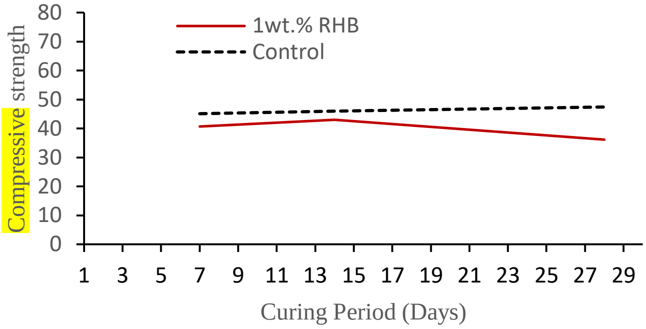

Fig. 5. Compressive strength of Control Concrete block and RHB 1% incorporated concrete block after 7,14 and 28 days of curing

In another research, it has been found that the lower envelope density of RHB, which is lower than cement and sand, results in an overall decrease in the density of the composites. Furthermore, the incorporation of biochar into Ultra-high-performance concrete (UHPC) matrix led to the generation of porosity surrounding its particles, resulting in a decrease in the density of UHPC composites [24].

This research could be further improved to achieve accuracy by building 3 blocks from both control and RHB 1wt% integrated concrete for each 7, 14, and 28 days of curing period. Once the research was done in this way, the random errors will be minimized.

4 Conclusions

This study investigated the potential of rice husk biochar (RHB) as a supplementary cementitious material for 150×150×150mm concrete blocks. Results have shown that concrete blocks with 1wt% of cement replaced with RHB has a compressive strength above 30MPa, which is acceptable for M30 grade concrete blocks. Although the compressive strength of RHB incorporated blocks cured for 7, 14 and 28 days were above 30MPa, the 28-day cured block had a lower compressive strength than the others. The research revealed this deviation might have occurred due to reasons such as significant inconsistencies in the reinforcement properties of RHB due to the unequal distribution throughout the matrix, high porosity, and low load-bearing strength of RHB. This research underscores the importance of homogeneity of matrix, and determining the optimum value of pyrolyzing temperature and weight percentage of specific biochar on material performance. These inconsistencies could be avoided by using at least 3 samples from each block for curing days in future studies.

References

1. Y. Wang, M. Xu, X. Lv, Z. Wen, and C. Chen, The eco-efficiency evaluation in China's cement industry: A city-level study, Science the Total Environment, 865, p. 161132, Mar. 2023, doi: 10.1016/j.scitotenv.2022.161132.
2. B. Massoumi Nejad, S. Enferadi, and R. Andrew, A comprehensive analysis of process-related CO2 emissions from Iran's cement industry, Cleaner Environmental Systems, 16, p. 100251, Mar. 2025, doi: 10.1016/j.cesys.2024.100251.
3. X. Lin, W. Li, Y. Guo, W. Dong, A. Castel, and K. Wang, Biochar-cement concrete toward decarbonisation and sustainability for construction: Characteristic, performance and perspective, J Clean Prod, 419, p. 138219, Sep. 2023, doi: 10.1016/j.jclepro.2023.138219.
4. Global Cement and Concrete Association, Global Cement and Concrete Industry Announces Roadmap to Achieve Groundbreaking 'Net Zero' CO2 Emissions By 2050,
5. Z. Zhao, A. El-Naggar, J. Kau, C. Olson, D. Tomlinson, and S. X. Chang, Biochar affects compressive strength of Portland cement composites: a meta-analysis, Biochar, 6(1), p. 21, Mar. 2024, doi: 10.1007/s42773-024-00309-2.
6. F. Ronsse, S. van Hecke, D. Dickinson, and W. Prins, Production and characterization of slow pyrolysis biochar: influence of feedstock type and pyrolysis conditions, GCB Bioenergy, 5(2), pp. 104–115, Mar. 2013, doi: 10.1111/gcbb.12018.
7. R. Zornoza, F. Moreno-Barriga, J. A. Acosta, M. A. Muñoz, and A. Faz, Stability, nutrient availability and hydrophobicity of biochars derived from manure, crop residues, and municipal solid waste for their use as soil amendments, Chemosphere, 144, pp. 122–130, Feb. 2016, doi: 10.1016/j.chemosphere.2015.08.046.
8. M. Senath and H. Karunanayake, Feasibility of Utilizing Rice Husk Ash as a Reinforcement Material for Soil-Based Roofing Sheets, 2024.
9. R. S. Chen, S. Ahmad, S. Gan, and M. A. Tarawneh, High loading rice husk green composites: Dimensional stability, tensile behavior and prediction, and combustion properties, Journal of Thermoplastic Composite Materials, 33(7), pp. 882–897, Jul. 2020, doi: 10.1177/0892705718815536.
10. Y. Zhang et al., Comparison of the Physicochemical Characteristics of Bio-char Pyrolyzed from Moso Bamboo and Rice Husk with Different Pyrolysis Temperatures, Bioresources, 12(3), May 2017, doi: 10.15376/biores.12.3.4652-4669.

11. R. P. Jaya, M. A. A. Muhamad Nor, Z. A. Ahmad, and Z. Mohd Amin, Properties of mortar containing rice husk ash at different temperature and exposed to aggressive environment, Advanced Materials Research, 2013, pp. 87–93. doi: 10.4028/www.scientific.net/AMR.620.87.
12. K. H. Tan, T. Y. Wang, Z. H. Zhou, and Y. H. Qin, Biochar as a Partial Cement Replacement Material for Developing Sustainable Concrete: An Overview, Journal of Materials in Civil Engineering, 33(12), Dec. 2021, doi: 10.1061/(asce)mt.1943-5533.0003987.
13. K. H. Tan, T. Y. Wang, Z. H. Zhou, and Y. H. Qin, Biochar as a Partial Cement Replacement Material for Developing Sustainable Concrete: An Overview, Journal of Materials in Civil Engineering, 33(12), Dec. 2021, doi: 10.1061/(ASCE)MT.1943-5533.0003987.
14. J. G. S. P. P. Gunawardana, Development of Biochar-Reinforced Low-Cost Roofing Sheet Using Earth Soil & Cement, 2024.
15. N. Claoston, A. Samsuri, M. Ahmad Husni, and M. Mohd Amran, Effects of pyrolysis temperature on the physicochemical properties of empty fruit bunch and rice husk biochars, Waste Management & Research: The Journal for a Sustainable Circular Economy, 32(4), pp. 331–339, Apr. 2014, doi: 10.1177/0734242X14525822.
16. A. Uroić Štefanko and D. Leszczynska, Impact of Biomass Source and Pyrolysis Parameters on Physicochemical Properties of Biochar Manufactured for Innovative Applications, Front Energy Res, 8, Jul. 2020, doi: 10.3389/fenrg.2020.00138.
17. T. M. Myint and N. Tuntiwiwattanapun, Evaluation of pozzolanic activity in rice husk biochar and ash activated by ball milling for enhanced cement-based composites, IOP Conf Ser Earth Environ Sci, 1500(1), p. 012081, May 2025, doi: 10.1088/1755-1315/1500/1/012081.
18. G. Huang et al., Upcycling rice husk biochar into carbon-negative composites, Constr Build Mater, 470, p. 140459, Apr. 2025, doi: 10.1016/j.conbuildmat.2025.140459.
19. S. Gupta and H. W. Kua, Effect of water entrainment by pre-soaked biochar particles on strength and permeability of cement mortar, Constr Build Mater, 159, pp. 107–125, Jan. 2018, doi: 10.1016/j.conbuildmat.2017.10.095.
20. A. M. N. Aman, A. Selvarajoo, T. L. Lau, and W. H. Chen, Biochar as Cement Replacement to Enhance Concrete Composite Properties: A Review, Oct. 01, 2022, MDPI. doi: 10.3390/en15207662.
21. L. Wang et al., Biochar as green additives in cement-based composites with carbon dioxide curing, J Clean Prod, 258, p. 120678, Jun. 2020, doi: 10.1016/j.jclepro.2020.120678.
22. A. Alagesan, V. B. Raju, M. Veerapathran, and P. Arunachalam, Investigation the effects of adding biochar to concrete mixture experimentally on performance properties, Matéria (Rio de Janeiro), 30, 2025, doi: 10.1590/1517-7076-rmat-2024-0965.
23. D. Wang, A. Jantwal, E. Kaynak, G. Sas, and O. Das, Promoting internal curing in concrete by replacing sand with sustainable biochar, Case Studies in Construction Materials, 22, p. e04542, Jul. 2025, doi: 10.1016/j.cscm.2025.e04542.

24. Q. Zhang et al., Investigation of the macro performance and mechanism of biochar modified ultra-high performance concrete, Case Studies in Construction Materials, 21, p. e03595, Dec. 2024, doi: 10.1016/j.cscm.2024.e03595.