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Research Article

Potential and production of pervious concrete incorporating rice husk as a partial aggregate replacement

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ABSTRACT

Pervious concrete is produced by utilising cement, coarse aggregate, and water. Industrial or agricultural waste products contribute significantly to environmental problems, such as air pollution and carbon dioxide emissions. Therefore, these waste products should be reused or recycled within construction or infrastructure activities to reduce their impacts on the environment. To address environmental problems, this study investigates an agricultural waste product, particularly rice husk (RH), in order to replace natural coarse aggregate in pervious concrete. This research addresses the research gap of employing unprocessed RH as a direct coarse aggregate replacement in pervious concrete. Its novel contribution is the empirical identification of a suitable replacement percentage that balances environmental waste valorisation with the preservation of structural integrity. Pervious concrete was prepared with a proportion of 1:3 (cement to coarse aggregate) and a water–cement ratio of 0.5, with RH replacing coarse aggregate by weight at 2%, 4%, 6%, and 8%. This study aims to investigate the potential of RH as a partial aggregate replacement by producing pervious concrete and assessing its behaviour. Two main experimental activities were conducted: RH surface morphology and elemental analysis, as well as analysis of compressive strength of pervious concrete cubes at 7, 28, and 40 days, with a total of 45 specimens. The design standards for determining the compressive strength were in accordance with BS EN 12390-3. The results indicated that the specimen with 2% RH replacement exhibited the highest compressive strength among all specimens, achieving 13.4 MPa at 7 days, 16.3 MPa at 28 days, and 18.0 MPa at 40 days. Overall, the compressive strength of pervious concrete decreased as the proportion of coarse aggregate replaced by RH increased. Therefore, it can be concluded that RH has the potential to replace coarse aggregate at proportions of less than 4% in pervious concrete based on the testing.

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1. Introduction

This section provides a brief discussion on pervious concrete, problem statement, rice husk (RH), RH as both a cement and aggregate replacement, and coarse aggregate replacement in pervious concrete. Additionally, this section addresses the objective of the study.

The rapid expansion of impermeable urban surfaces has markedly disturbed natural hydrological cycles, resulting in heightened stormwater runoff, groundwater depletion and frequent waterlogging. For mitigating and addressing these environmental challenges, pervious concrete has emerged as a critical component of sustainable infrastructure. Pervious concrete is categorised as a

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special concrete produced using cement or binder, coarse aggregate, and water, either without or with minimum use of sand. It contains a high volume of air voids or porosity, allowing water to flow or penetrate. Pervious concrete is also referred to as water-permeable concrete, porous concrete, or no-fines concrete, and is commonly used in pavement applications. Shende et al. (2019) highlighted the use of pervious concrete in pavement construction, which typically helps to replenish groundwater and reduce waterlogging; however, such pavements are unsuitable for heavy loads. Due to its low compressive strength, pervious concrete is typically employed in sidewalks, low-load parking areas, pathways, and driveways. Kováč and Sičáková (2018) reported that impermeable surfaces, especially concrete surfaces, hinder natural water movement through the surface and underlying soil during heavy rainfall, resulting in water runoff, stormwater accumulation, and snow melting. According to Lo et al. (2021), pervious concrete is classified as green infrastructure for managing stormwater runoff in urban environments, with compressive strengths ranging from 2.8 to 28 MPa in cube shape. Talsania et al. (2015) highlighted concerns regarding the ease with which pervious concrete disperses stormwater compared to conventional concrete, the restoration of groundwater that eliminates the need for retention ponds or other stormwater management systems, and the costs associated with manufacturing pipe systems. According to previous research, pervious concrete is gaining popularity as it is more durable, flexible, and less expensive to build and maintain.

Agricultural waste products, such as crop residues and animal waste from husbandry, are a major source of waste products in developing countries or those with agriculture-based economies. Most countries in the Association of Southeast Asian Nations (ASEAN), including Malaysia, Thailand, and Vietnam, are well known for their agricultural sectors, which employ various technologies that contribute to national income. However, waste management processes in these countries are still lacking. Typically, these waste products are either incinerated or deposited in certain dumpsites or landfills for disposal. The burning of agricultural waste causes numerous problems, such as human health problems, as well as emissions of carbon dioxide (CO_2), toxic chemicals, and nitrogen oxides. Sahoo et al. (2021) noted that rice harvesting requires a large area for disposal, while burning this waste leads to air and soil pollution. Chabi et al. (2018) reported that producing concrete using agricultural waste products has garnered considerable interest and awareness, as these materials are renewable and generate lower CO_2 emissions. Currently, the primary goal of innovation, invention, and research in building and construction materials is to promote the use of materials that enhance energy efficiency and environmental performance, such as locally sourced renewable materials.

Rice husk (RH) is a by-product of rice milling, consisting of the shells produced during paddy husking, and is classified as agricultural waste. Winarno (2019) stated that RH, also known as rice hull, has a hard surface composed of lignin and silica, which protects the seed during its growth. Due to its structural arrangement of silica-

cellulose and its non-biodegradable nature, RH exhibits several benefits, including resistance to flaring or smouldering (Chabannes et al. 2014). Additionally, RH has a wide range of applications, such as thermal insulation, fuel production, removal of phenols from water, and absorption of pigments, heavy metal ions, and dyes from wastewater (Chen et al. 2018). Rice husk is used in concrete or mortar as a cement replacement when processed into ash; however, there is limited information regarding the use of RH as a replacement for fine or coarse aggregate. In general, RH is processed by burning at a certain temperature to produce small, fine particles. The production of RH has increased in line with population growth in ASEAN countries. Nowadays, many researchers have studied RH as a biomass resource and a cement replacement in concrete. Patil et al. (2020) reported that RH had not previously been utilised in concrete manufacturing and described RH as a dried, thin coating covering rice seeds. Chabannes et al. (2014) noted that the utilisation of raw RH in concrete without prior burning is considered a research limitation. In earlier research, Chabannes et al. (2016) added whole raw RH with other materials, such as lime-based binders, in concrete.

Rice husk undergoes various processes to alter its shape, colour, and condition, using a grinder and furnace to produce rice husk ash (RHA). The ash is ground and burned at high temperatures, approximately 900–1,000 °C, to produce RHA with a high presence of silicon dioxide (SiO_2). Rice husk ash is used as a partial or full replacement for cement in concrete, and is sometimes combined with other waste products as a blended material for cement replacement or as other concrete components, such as aggregate replacement. The ash is also utilised as a cement replacement in various types of concrete. Rattanachu et al. (2020) discussed the use of RH ground to cement size and replaced 20–50% cement by weight with the ground RH in concrete, followed by the determination of strength and chloride penetration depth. Reddy et al. (2021) evaluated the comprehensive strength properties at 7 and 28 days of concrete age, especially compressive, tensile, and flexural strength, by incorporating RHA as a partial cement replacement in proportions of 5%, 7.5%, 10%, 12.5%, and 15%, along with the addition of a superplasticiser.

Rice husk ash is used as a cement replacement and is combined with other waste products, such as agricultural waste and industrial waste. Shende et al. (2019) assessed the compressive strength and permeability of pervious concrete using RHA as a partial cement replacement at 8% and 10%, in addition to glass fibre content of 0%, 0.2%, 0.4%, and 0.6%. Maryoto and Sudibyo (2019) noted that approximately 2.825 million tons of RH are produced annually in Indonesia, which are usually used for producing bricks and lightweight concrete. Rice husk contains about 90% SiO_2 , with the remaining percentages comprising other chemicals such as ferric oxide, aluminium oxide, and calcium oxide (Maryoto and Sudibyo 2019). Chetan and Aravindan (2020) tested the compressive and tensile strength of concrete using RHA as a partial cement replacement at proportions of 0%, 5%, 10%, 15%, and 20%, together with robo sand as a sand replacement. Based on their observation, the compres-

sive and tensile strength increased by 3.12% and 5.63%, respectively, when using 10% RHA as a cement replacement for 28 days. Varadharajan et al. (2020) investigated concrete made with RHA as a partial cement replacement with proportions of 0–20%, marble waste powder (MWP) as a partial sand replacement with proportions of 0–30%, and hooked steel fibre (HSF) at 1.5% by weight of cement to determine its mechanical properties. They reported that the concrete prepared with 15% RHA, 30% MWP, and 1.5% HSF achieved optimal mechanical performance.

Rice husk is used as an aggregate replacement in normal or specialised concrete, either in the form of RHA or RH in various shapes or conditions. Fernandes et al. (2019) reported the compressive strength of concrete containing glass foam pellets as a partial replacement for coarse aggregate at 10%, 20%, and 30%, produced using RHA, soda-lime glass waste, and calcium carbonate, which was measured at 3, 7, 28, 56, and 90 days. Samantaray et al. (2016) found that concrete strength increased when incorporating 10–30% RHA as a partial fine aggregate replacement, but decreased when using 40–50% RHA. Obilade (2014) investigated the use of RH as a sand replacement in concrete by weight and volume at 0%, 5%, 10%, 15%, 20%, and 25%, utilising a mix design ratio of 1:2:4. The study showed that a 5% sand replacement by both weight and volume yielded the highest compressive strength of the concrete. Winarno (2019) studied RH with particle widths of 2–4 mm, a maximum length of 10 mm, and a density of 690 kg/m³ as a sand replacement in concrete blocks, with Portland cement-to-RH weight ratios of 0.67–2.00. The literature consistently demonstrates that RHA enhances concrete performance due to its high silica content and pozzolanic activity at replacement percentages up to 20%. In contrast, the use of raw RH waste presents a more strict structural limitation, generally restricted to 5% or less due to its lower density and inferior bonding properties.

Several studies have investigated pervious concrete with coarse aggregate replacement for producing sustainable materials, improving mechanical properties, and reducing the environmental impact. The coarse aggregate replacement materials can be divided into two groups: industrial waste and agricultural waste. Two types of coarse aggregate (limestone with an angular shape (size of 6.35 mm) and pea gravel with a rounded shape (size of 9.54 mm)) were used to produce pervious concrete (Torres et al., 2020). Lopez et al. (2019) reported the physical and mechanical properties of pervious concrete made using high-density polyethylene pellets as a partial coarse aggregate replacement, with various sizes and ratios. Chen et al. (2024) studied the crushing morphology, durability, and strength of pervious concrete using corn cob as a coarse aggregate replacement at 0%, 25%, 50%, 75%, and 100%, and determined that 50% replacement yielded the best compressive strength at 28 and 50 days of curing. Supit and Priyono (2022) evaluated the effect of using polyethylene terephthalate plastic waste as a 5% coarse aggregate replacement, with sizes of 5–10 mm and 10–20 mm, across three mix proportions (cement–aggregate ratios of 1:2, 1:3, and 1:4). Wang et al. (2024) evaluated the compres-

sive strength and effective porosity of pervious concrete made with recycled coarse aggregate of different gradings (5–15 mm, 15–20 mm, and 20–25 mm) and water–cement ratios (0.4, 0.45, and 0.5). Tijani et al. (2022) reported on the production of pervious concrete using sorghum husk ash as a cement replacement and palm kernel shell as a coarse aggregate replacement at 20%, 40%, 60%, 80%, and 100% by weight, noting that 20% and 40% of palm kernel shell replacements met the required minimum compressive strength of 2 N/mm². Torres et al. (2020) highlighted the production of pervious concrete with high compressive strength by considering several factors, such as specimen compaction, type and size of coarse aggregate, water–cement ratio, and the use of superplasticiser.

The current literature reveals considerable variation in the optimal replacement percentage, ranging from 5% to 50%, highlighting the sensitivity of pervious concrete to the distinct morphology and chemical properties of different waste materials. This inconsistency suggests that a strategy or approach is unfeasible, as the structural performance of the mixes depends entirely on the specific physical properties of the selected industrial or agricultural by-product. This study addresses the research gap concerning the limited exploration of raw or unprocessed agricultural waste as a direct alternative to mineral coarse aggregates in pervious concrete, given that most existing literature focuses on processed ashes rather than the bulk physical husk. Although pervious concrete is conventionally optimised for high void connectivity using gravel, there is a lack of empirical data about the impact of the cellular morphology and organic surface of RH on the mechanical structure of certain mix designs. The novel contribution of this study is the identification of a specific percentage of RH as gravel replacement, establishing a precise baseline for waste valorisation that balances environmental mitigation with functional load-bearing requirements. The main objective of this study was to produce pervious concrete with partial coarse aggregate replacement using RH and determine the behaviour of pervious concrete, especially its compressive strength. Besides, the objective is to determine an accurate baseline for the replacement percentage that balances environmental waste valorisation with the functional demands of compressive strength.

2. Material Preparation and Experimental Setup

The methodology of this study is divided into two parts: the production of pervious concrete and the evaluation of its behaviour.

2.1. Materials and characteristics

This study utilised RH, with the chemical composition data referenced from a previous study. The RH was stored in a plastic sack for 3 months prior to use. It was then cleaned to remove dirt, dust, and foreign matter that could weaken the bonding between the RH and other concrete materials. Chabi et al. (2018) reported that the size of RH ranged between 1 and 4 mm, and siev-

ing was conducted using a 1-mm sieve to remove impurities, such as sand, silt, and clay. The chemical composition of RH was observed and compared with ground RHA, raw RHA, ordinary Portland cement, and natural aggregate from previous studies, as shown in Table 1. This initial comparative study is important to identify the major chemical components to avoid adverse effects on concrete behaviour. Additionally, the incorporation of both raw RH and its ash derivatives (RH) is scientifically essential to demonstrate the substantial chemical transformation that occurs during thermal processing

which directly informs the focus of the study on raw waste valorisation. The comparison of key chemical compositions is illustrated in Fig. 1. Shang et al. (2024) reported the elemental content of RH as follows: carbon (C) 35.42%, nitrogen (N) 0.36%, hydrogen (H) 5.34%, and oxygen (O) 58.88%. Rice husk is an organic, carbon-based material whose surface consists of complex cellulose and silica, which can chemically inhibit the setting of cement. Ordinary Portland cement is a reactive binder based on lime, while natural aggregates are stable minerals like silica or limestone.

Table 1. Chemical composition of RH in different conditions.

Chemical composition (%)	Rice husk (Mareya et al. 2023)	Ground rice husk ash (Rattanachu et al. 2020)	Raw rice husk ash (Alomayri et al. 2021)	Ordinary portland cement (Alyami et al. 2023)	Natural aggregate (Shariati et al. 2023)
Silicon dioxide (SiO ₂)	13.91	93.5	96.70	22.75	19.42
Aluminium oxide (Al ₂ O ₃)	0.04	0.2	0.30	5.58	0.83
Iron oxide (Fe ₂ O ₃)	0.04	0.4	1.26	3.87	0.55
Calcium oxide (CaO)	0.36	0.9	0.57	59.94	31.12
Sulphur trioxide (SO ₃)	0.07	0.2	–	2.14	0.03
Magnesium oxide (MgO)	0.07	0.4	0.27	2.32	9.64
Sodium oxide (Na ₂ O)	0.01	–	0.05	0.86	0.98
Potassium oxide (K ₂ O)	1.19	3.3	0.45	0.75	1.19

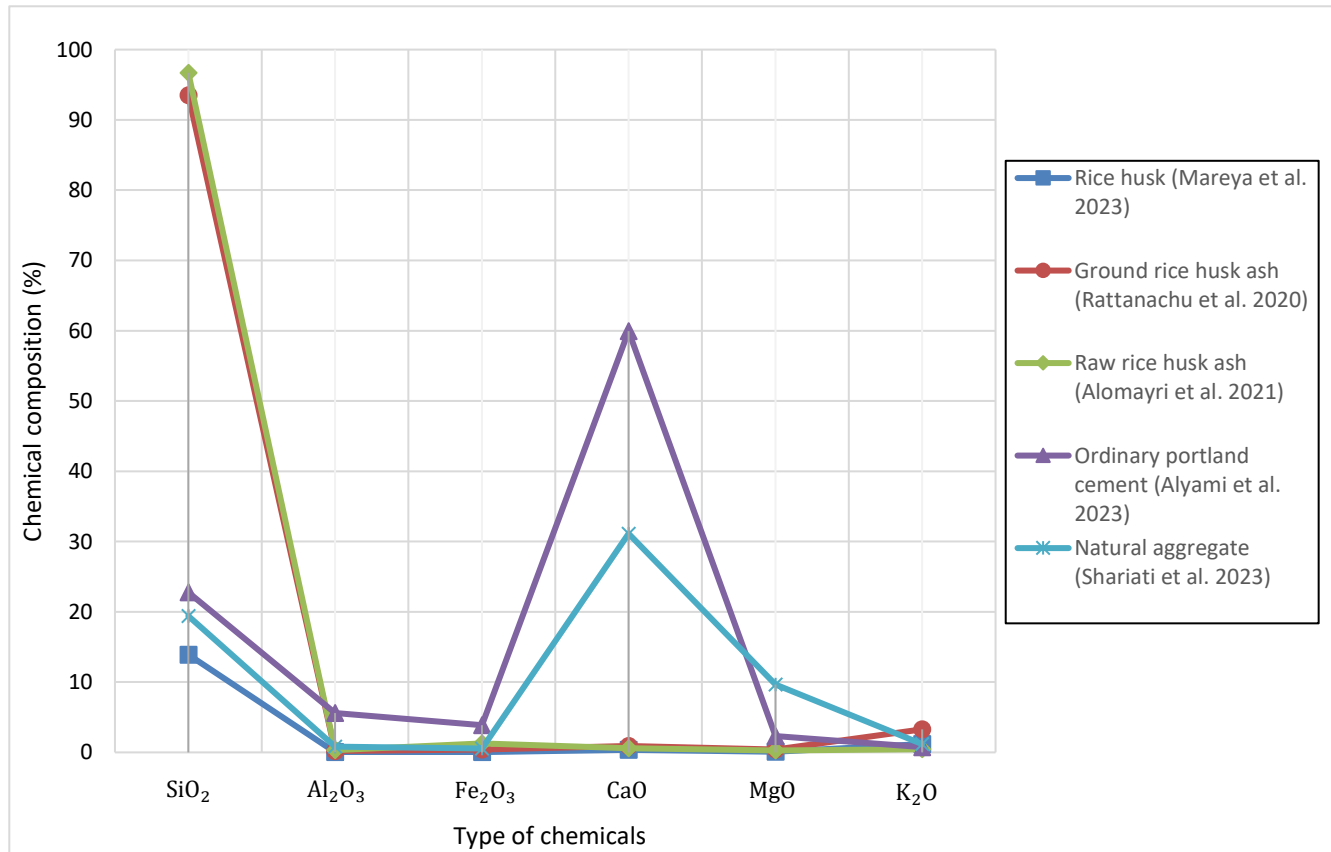


Fig. 1. A comparison study on the importance of chemical composition.

Although the synthesis of strength-giving silicates in Portland cement requires a precise calcium oxide (CaO) concentration of 60% to 65%, raw RH and gravel are chemically unable to replenish this lime content due to their minimal calcium profiles. The suitability of RH in pervious concrete is determined by its physical geometry and silica-rich surface which offer a lightweight, porous scaffold that increases the chemical binding energy of the cement paste without participating in the primary hydraulic reaction, rather than by its role as a chemical donor. Calcium oxide, sometimes referred to as lime, has the ability to increase strength and reduce cracking. The percentage differences in CaO content between RH and ground RHA, raw RHA, ordinary Portland cement, and natural aggregate are 60%, 36.84%, 99.40%, and 98.84%, respectively. Secondly, an important chemical in cement is SiO₂, commonly known as silica, which helps to impart strength. However, an excess of silica can affect the setting time of cement. The SiO₂ content of RH was recorded as 85.12%, 85.62%, 38.86%, and 28.37% when compared to ground RHA, raw RHA, ordinary Portland cement, and natural aggregate, respectively. Although RH has a low SiO₂ content of 13.91%, the comparison study indicates that post-combustion of SiO₂ concentrations increases to over 90%, transforming the function of the material from a physical aggregate replacement to a reactive pozzolanic binder. By presenting this profile, the data provides a necessary chemical justification for the research gap. It highlights that while processed RHA is chemically optimised for cementitious reactivity, the RH employed in this study functions under a different mechanical mechanism, thus requiring a separate investigation of its performance as a coarse aggregate replacement. The chemical composition of SiO₂ is reported to have the lowest percentage compared to that of other specimens. Thirdly, Al₂O₃, or alumina, facilitates the rapid setting of cement. The combination of RH, aggregate, and ordinary Portland cement is suitable within the range of 2–8%. The comparative percentage of RH relative to other specimens ranges from 80% to 99%. Chen et al. (2018) reported that the chemical composition of RH varies depending on weather patterns, geography, and fertilisers used during paddy cultivation. Observations indicate that the ash component of RH has a high SiO₂ content, making it suitable as a source for silicon compounds. Rice husk is appropriate for use as an additive or aggregate replacement in concrete because its chemical composition, especially CaO and SiO₂, is sufficient and not excessively high. The chemical composition of RH provides a critical baseline for its utilisation as a coarse aggregate replacement. This comparison is also essential because RH acts as a physical filler that reduces the overall density and thermal conductivity of the mix. A thorough understanding of its elemental makeup is necessary to balance the trade-off between the resulting structural voids in the concrete and its compressive strength.

In this study, RH was analysed using scanning electron microscopy (SEM) to determine its surface morphology, and energy-dispersive X-ray spectroscopy (EDS) was employed to carry out elemental analysis. The SEM and EDS analyses were conducted using a thermal field emission scanning electron microscope at an accelerating voltage of 20 kV, providing the necessary beam

energy for high-resolution morphological imaging and characteristic X-ray excitation. Samples were prepared by mounting them on aluminium stubs and sputter-coating to ensure surface conductivity. Morphological analysis was conducted in secondary electron mode, with magnifications ranging from 100× to 5,000× at a working distance of approximately 14.5 mm. The EDS map sum spectrum was utilised to quantify elemental distribution, providing a chemical depth of field that complements the structural insights obtained from SEM micrographs alone. Chabannes et al. (2014) noted that RH contains very small pores with a size less than 0.1 µm, and from the SEM images, RH with appropriate shape and size could be used as aggregates or fibres in concrete. Chabi et al. (2018) reported that SEM observations revealed a high concentration of silica on the surface of RH grains. Subsequently, RH was tested for its physical properties, including density, void content, and sieve size, before being used in the mixing process of pervious concrete.

2.2. Mix design and specimen preparation

Pervious concrete was produced using gravel (coarse aggregate), RH, cement, and water, as shown in Fig. 2. The proportion of cement to gravel (coarse aggregate) in the pervious concrete was 1:3, with a water–cement ratio of 0.5. The coarse aggregate used in the concrete mix was well graded with a size below 20 mm. For pervious concrete, a water–cement ratio of 0.5 is often considered high, where numerous designs range from 0.27 to 0.35. Outside this range, the paste may possess sufficient fluidity to flow off the gravel and RH, which accumulate at the bottom of the mould and form an impermeable layer. A cement–gravel ratio of 1:3 and a water–cement ratio of 0.5 are commonly chosen as they offer the best compromise between strength and paste thickness required to coat the gravel without blocking voids. The mix is designed and formulated to achieve a target theoretical void ratio of 22%, where pervious concrete is normally designed for a void content of 18–35% (Obla 2010) and 15–30% (Firouzi et al. 2012). The void content in pervious concrete is determined by the synergistic interaction among aggregate structure, material composition, and paste rheology. The utilisation of larger, consistently graded aggregates creates the primary skeletal framework for open pores, while the 1:3 mix design ensures sufficient cementitious paste to cover these particles without obstructing the established air channels. Furthermore, the selection of the cement–gravel ratio of 1:3 is based on studies by Malayali and Chokkalingam (2018) and Abd Rahman et al. (2019).

Rice husk replaced the coarse aggregate by weight at proportions of 2%, 4%, 6%, and 8%, with one specimen without RH serving as a control mix. A complete description is provided in Table 2. These percentages are commonly used in exploratory studies as they represent low to moderate replacement levels, allowing for gradual observation of the effects on strength, bonding, and void connectivity, while minimising the risk of mixture instability or excessive clogging. The replacement of gravel with RH was carried out on a weight-to-weight basis to ensure a consistent mass–cement ratio and to improve precision during batching. The approach was chosen to

reduce errors associated with the bulking effect of organic materials, which often causes volumetric measurements to be inconsistent under varying moisture conditions. Regarding the achievement of the required compressive strength, weight-based mixing is more accurate than volume-based mixing. This is because the latter method can be affected by changes in material density and compaction, whereas the former method guarantees consistent material proportions. Finally, the decision to replace coarse aggregate by weight is based on the stud-

ies by Singh and Singh (2020), Supit and Priyono (2022), and Bhujel et al. (2025), which used lightweight materials in pervious concrete. Although the RH replacement is based on weight percentage, the volumetric implications of the density mismatch have been thoroughly determined. The density ratio between coarse aggregate and RH is approximately 15, and a 2% replacement by weight results in a 19.6% increase in solid volume, leading to a measurable increase in void ratio and a decrease in packing density.

Table 2. Mix design information and description.

Specimen label	Description	Coarse aggregate (kg/m ³)	Rice husk (kg/m ³)	Cement (kg/m ³)	Water (kg/m ³)
RH0 (control)	Mix without rice husk (RH)	1050	0		
RH2	Mix with gravel replacement of 2% by weight of RH	1029	21		
RH4	Mix with gravel replacement of 4% by weight of RH	1008	42	350	175
RH6	Mix with gravel replacement of 6% by weight of RH	987	63		
RH8	Mix with gravel replacement of 8% by weight of RH	966	84		

This study provides a direct evaluation of the impact of low-density organic fibres on the overall mechanical properties and density of pervious concrete mixes by maintaining uniform weight across all mixes. To achieve a homogeneous mix, the gravel and cement were thoroughly mixed before adding RH and water to the mixer to prevent segregation. This study deliberately omits superplasticiser to establish a baseline performance for a simplified 1:3 mix design intended for low-tech applications and also to evaluate the fundamental behaviour of the cement–aggregate bond. Fig. 3(a) shows the mixing process before the addition of water, while Fig. 3(b) illustrates the completed mixing process. The fully mixed specimen, which was mixed for approximately 8–10 min,

was placed in a concrete mould of 100 mm × 100 mm × 100 mm and compacted using a vibrating table for 3 s. The specimen was then left at room temperature for rapid hardening, as shown in Fig. 4. After removal from the mould, the cube specimen was placed in a curing tank for 7, 28, and 40 days. Lastly, the cube specimen was tested to determine the compressive strength of the pervious concrete in accordance with BS EN 12390-3 (2019).

A total of 45 specimens were prepared across all mixes for the compressive strength test. Fig. 5 illustrates the hardened cube specimens with 8% RH. A clear flowchart of the material preparation and experimental setup activities is illustrated in Fig. 6.



Fig. 2. The basic ingredient of pervious concrete with RH.



Fig. 3. Pervious concrete mixing: (a) Before adding water; (b) Completing the mixing process.



Fig. 4. The process of moulding of pervious concrete on the vibrator table.



Fig. 5. The cube specimen with 8% of RH in pervious concrete.

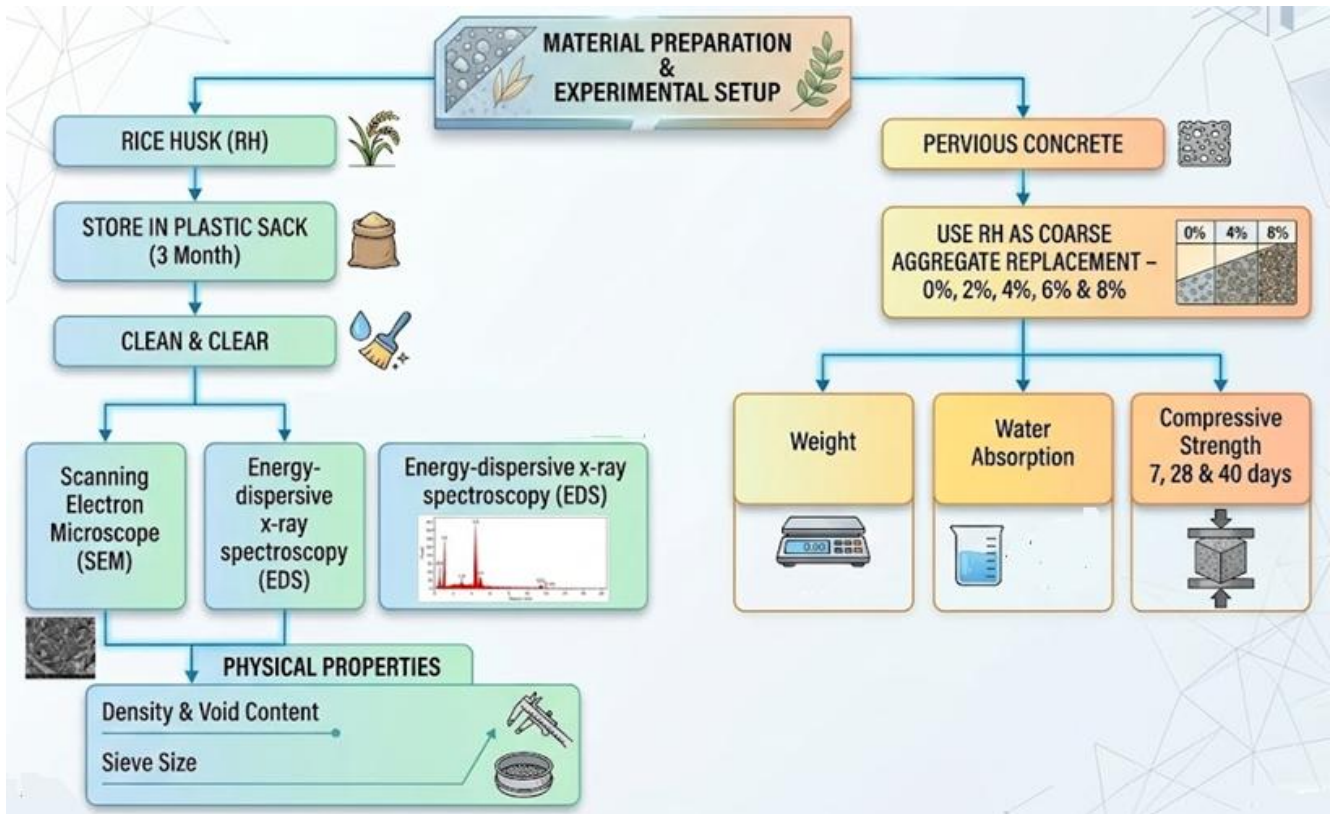


Fig. 6. The material preparation and experimental setup flowchart.

3. Results and Discussion

This section is composed of four parts: surface morphology and elemental analysis of RH, physical properties of RH, water absorption of hardened pervious concrete, and compressive strength of hardened pervious concrete.

3.1. Surface morphology and elemental analysis of rice husk

In this section, SEM micrographs were used to study the surface morphology of RH, with high-resolution images providing a comprehensive report on the examination of the RH surface. Nevertheless, it is acknowledged that EDS analysis offers more insights into the surface material compared to SEM analysis. The SEM micrograph of the RH surface was recorded and illustrated in Fig. 7, exhibiting properties similar to the study of Naraththa et al. (2024). From the observation, the curved region on the RH surface was detected, exhibiting wavy, furrowed, and conical borders. Furthermore, the surface displays well-organised micro-bumps, while the outermost layer is irregular, featuring a highly ridged structure along with protrusions that contribute to frictional properties. Consequently, the surface of RH, characterised by a combination of bumps and voids, is very suitable for being filled with coarse aggregate to create a strong surface upon the hardening of the concrete.

Fig. 8 presents the EDS elemental analysis for the RH surface, and the major elements recorded are tabulated in Table 3. Across the four locations, the major elements with high percentages are O (42–52%), Ca (13–27%),

and C (11–32%). Conversely, the major elements with low percentages are potassium (K, 0–1.2%), iron (Fe, 0–1.4%), and aluminium (Al, 0–2.0%). The percentage differences between the highest experimental values and the data from Sudhir et al. (2024) are 2.42% for O, 74.61% for Si, 85.07% for C, and 17.28% for K. Similarly, the percentage differences between the lowest experimental values and the data from Sudhir et al. (2024) for O, Si, C, and K are 19.99%, 90.31%, 56.93%, and 23.58%, respectively. The surface morphology analysis helps determine the bonding and packing of RH particles within the pervious concrete structure, while the elemental analysis verifies material consistency and identifies factors potentially affecting durability. These assessments ensure that RH is an appropriate and reliable replacement for gravel.

3.2. Physical properties of rice husk

The physical properties of RH, particularly the density, void content, and sieve size, were analysed and reported in this section. The density of RH was determined to be 140 kg/m³. This value was compared with densities reported in previous studies, including those by Sreesvarna et al. (2019) with 14.29% difference, Yuzer et al. (2013) with 12.86% difference, and Chabannes et al. (2014) with 26.29% difference. An explicit evaluation of material density differences was performed by comparing RH with several other low-density coarse aggregate replacements documented in the literature such as raw corn cobs (Chen et al. 2024), unmodified bamboo (Wang et al., 2024), and oil palm kernel shell (Khankhaje et al. 2016). The density of RH is approximately 7.16%

less than that of raw corn cobs, indicating that both materials are within a comparable lightweight range. In contrast, RH has a significantly greater density gap compared to unmodified bamboo, which is around 65% denser than RH, and oil palm kernel shell which is roughly 78.66% denser than RH. These comparisons highlight that, among often examined agricultural or biomass-based aggregates, Rh is situated at the lowest end of the density spectrum. This underscores the importance of properly addressing volumetric equivalence, packing

behaviour and mix proportioning when replacing RH in concrete mix. The void content of RH was measured to be 85.83%. The sieve size of RH is presented in Table 4. The highest percentage retained corresponds to a sieve pan size of 2.00 mm, and the highest percentage passing corresponds to a sieve pan size of 300 μm . The fineness modulus of RH was calculated as 3.31, classifying it as a coarse material. The fineness modulus affects concrete mix design by reducing workability, enhancing strength potential, and reducing blending and shrinkage.

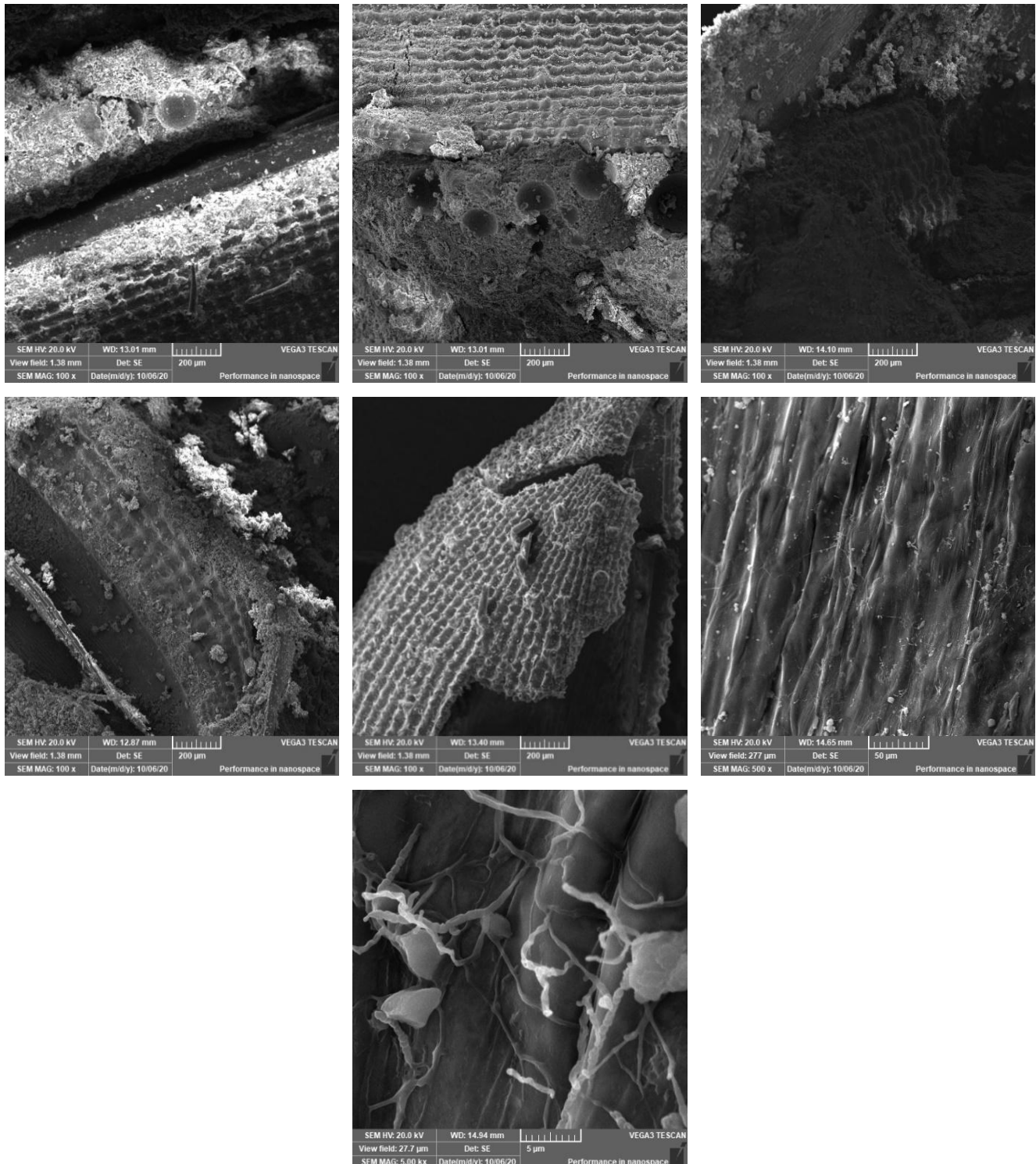


Fig. 7. The surface morphology of rice husk with 200 μm , 50 μm , and 5 μm .

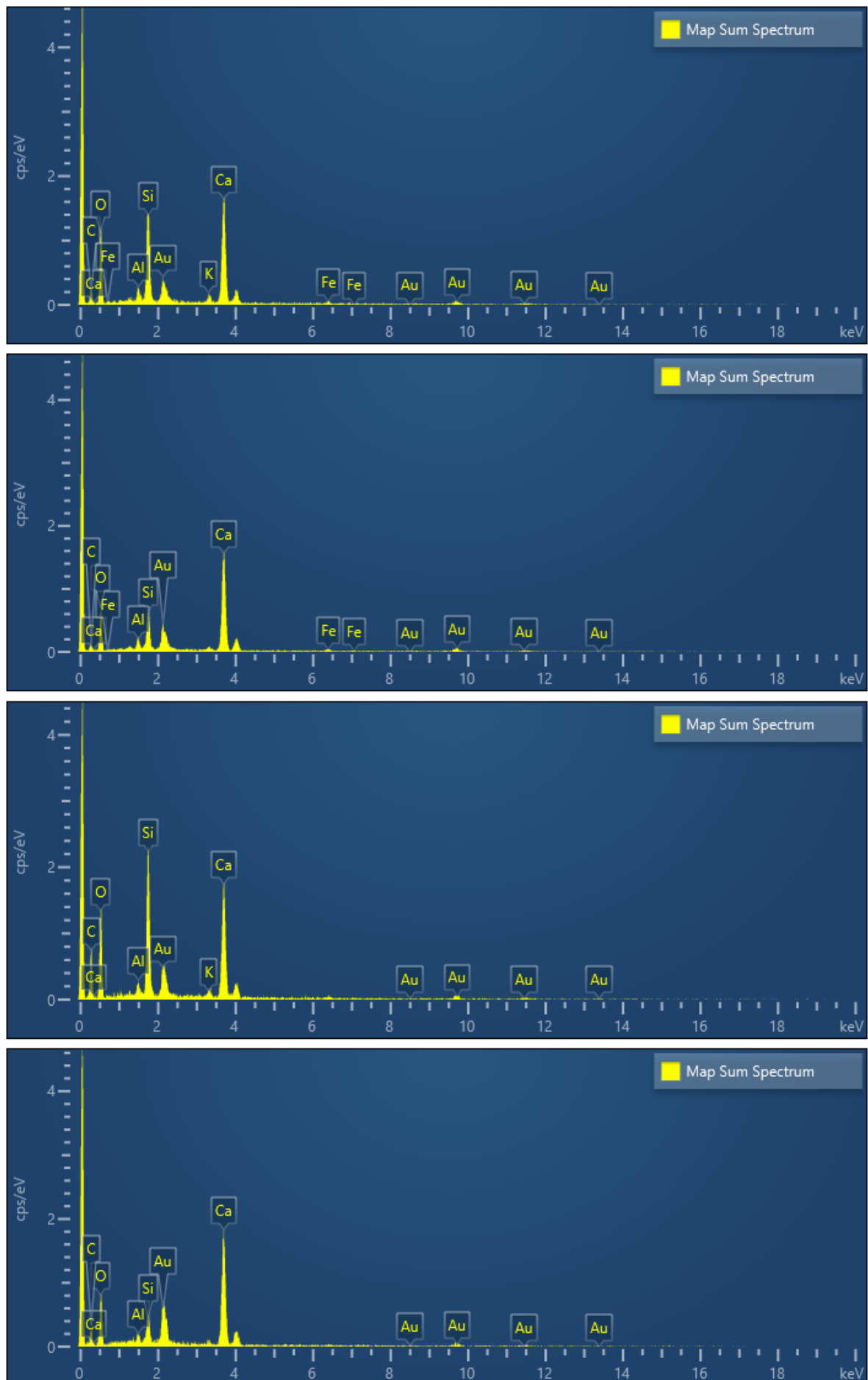


Fig. 8. EDS elemental analysis graph for the RH surface in four locations.

Table 3. The major element from the EDS elemental analysis graph.

Element	Weight (%)	Weight (%)	Weight (%)	Weight (%)	Weight (%) (Sudhir et al. 2024)
Oxygen, O ₂	52.38	51.23	42.95	51.18	53.68
Silicon, Si	9.54	6.02	9.31	3.64	37.57
Calcium, Ca	19.01	27.84	13.25	25.19	–
Aluminium, Al	1.47	2.08	0.79	1.45	–
Carbon, C	15.12	11.40	32.89	18.54	4.91
Potassium, K	1.20	0	0.81	0	1.06
Iron, Fe	1.28	1.44	0	0	–

Table 4. The sieve size analysis of the rice husk.

Sieve pan size	Percentage retained (%)	Percentage passing (%)
5.00 mm	0	100
3.35 mm	0	100
2.00 mm	48.72	51.28
1.18 mm	38.46	61.54
600 µm	7.69	92.31
300 µm	5.13	94.87
150 µm	0	100
75 µm	0	100
0	0	100

3.3. Weight and water absorption of hardened pervious concrete

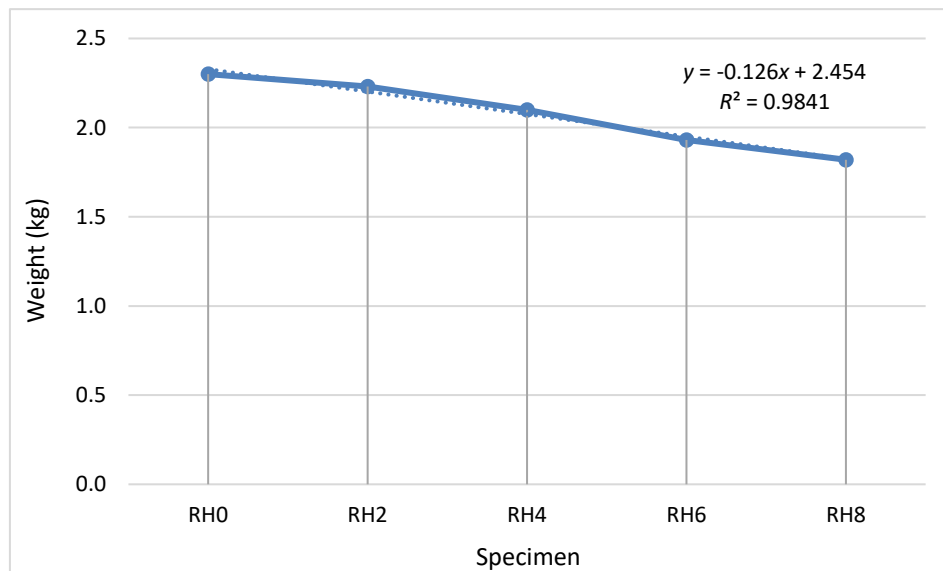
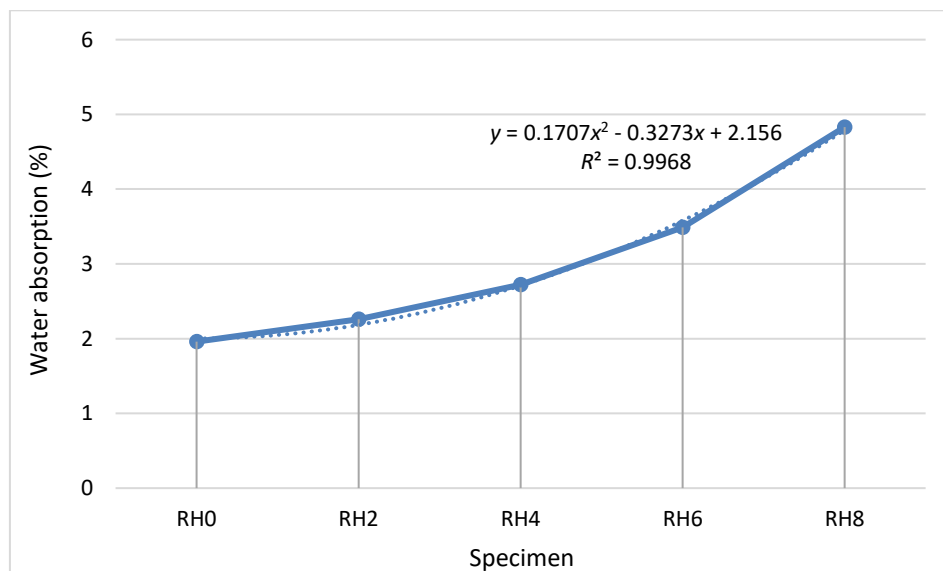
Table 5 presents the average amount of water that pervious concrete can absorb at atmospheric pressure, along with the average weight of the specimens. The relationship between specimen type and weight is illustrated in Fig. 9. The specimen weight decreased as the percentage of RH in pervious concrete increased, as previously noted, since RH is lighter than coarse aggregate. The percentage weight differences are as follows: 3.04% (between RH0 and RH2), 8.70% (between RH0 and RH4), 16.09% (between RH0 and RH6), and 20.87% (between RH0 and RH8). The weight percentage difference between the highest and lowest values, comparing RH2 and RH8, is 18.39%. The line graph in Fig. 9 shows a clear and consistent inverse relationship between specimen type and corresponding weight. The weight steadily decreased from approximately 2.3 kg for RH0 to about 1.8 kg for RH8. The high coefficient of determination (R^2) value of 0.9841 indicates that the linear regression model provides a good fit for the observed data points, reflecting a strong linear trend.

In the previous study, the percentage of water absorption increased with the increase of RH proportion due to its high water-absorption capacity. In addition, the water absorption percentages of all specimens are relatively low because pervious concrete typically facilitates the movement of water through its solid body and is characterised by a porous structure. The percentage differences in water absorption between RH0 and RH2, RH4,

RH6, and RH8 are 13.27%, 27.94%, 43.84%, and 59.42%, respectively. The relationship between water absorption and the pervious concrete specimens is shown in Fig. 10. Water absorption values vary by approximately 53.21% between RH8, which has the highest absorption, and RH2, which has the lowest absorption. Furthermore, the percentage difference in water absorption between RH2 and RH4 is 16.91%, and between RH2 and RH6 is 35.24%. According to Golewski (2023), normal concrete with water absorption of 4–6% is considered to have excellent durability, while normal concrete with water absorption below 5% is regarded as high quality. This study uses water absorption exclusively to observe the moisture uptake behaviour associated with RH rather than to assess durability. Pervious concrete, unlike normal concrete, features substantial interconnecting voids, rendering conventional durability standards unsuitable. The increasing absorption values indicate the high porosity of RH and its effect on the internal moisture absorption of the mix rather than a lack of durability. Based on the water absorption values, RH8 is classified as having good durability, and all specimens are classified as good quality. In conclusion, when considering the relationship between weight and water absorption, the weight of the specimen decreases as the percentage of water absorption increases. Fig. 10 illustrates an R^2 value of 0.9968, indicating an almost perfect fit of data and suggesting that the modification represented by the RH specimen systematically enhances capillary action or increases the internal surface area available for water retention.

Table 5. The weight and water absorption of every specimen.

Specimen	Weight (kg)	Water absorption (%)
RH0	2.30	1.96
RH2	2.23	2.26
RH4	2.10	2.72
RH6	1.93	3.49
RH8	1.82	4.83

**Fig. 9.** The relationship of weight and the specimens of coarse aggregate replacement.**Fig. 10.** The relationship of water absorption and specimens with different amounts of coarse aggregate replacement.

3.4. Compressive strength of hardened pervious concrete

The compressive strength and maximum load of the pervious concrete specimens for 7, 28, and 40 days were recorded and presented in Table 6. Both compressive strength and maximum load increased with curing age, reflecting the strength development of pervious con-

crete from its initial to mature state. All specimens exhibited lower compressive strength and maximum load compared to RH0, the control mix. The highest compressive strength values at 7, 28, and 40 were observed in RH2, while the lowest values were recorded for RH8. When comparing the highest and lowest compressive strength values, reductions of 81.21% at 7 days, 84.08% at 28 days, and 83.80% at 40 days were noted. Relative

to the control mix, the early compressive strength (7 days) of RH2, RH4, and RH6 was 10.07%, 34.23%, and 60.40%, respectively. At the mature age of 28 days, the percentage differences in compressive strength between the control mix and other specimens were 18.91% for RH2, 38.81% for RH4, and 70.15% for RH6. Fig. 11 illus-

trates the relationship between compressive strength and curing age of pervious concrete. Based on the results, a 2% replacement is identified as the optimum value when compared with other replacement percentages in terms of the compressive strength of pervious concrete.

Table 6. The compressive strength and maximum load of pervious concrete for 7 days, 28 days, and 40 days.

Specimen	Maximum load (N)	Compressive strength (MPa)	Maximum load (N)	Compressive strength (MPa)	Maximum load (N)	Compressive strength (MPa)
	7 days		28 days		40 days	
RH0	148.80	14.9	201.23	20.1	216.3	21.6
RH2	133.70	13.4	163.00	16.3	180.2	18.0
RH4	98.26	9.8	123.30	12.3	124.0	12.4
RH6	58.69	5.9	60.47	6.0	61.25	6.1
RH8	27.83	2.8	31.82	3.2	34.97	3.5

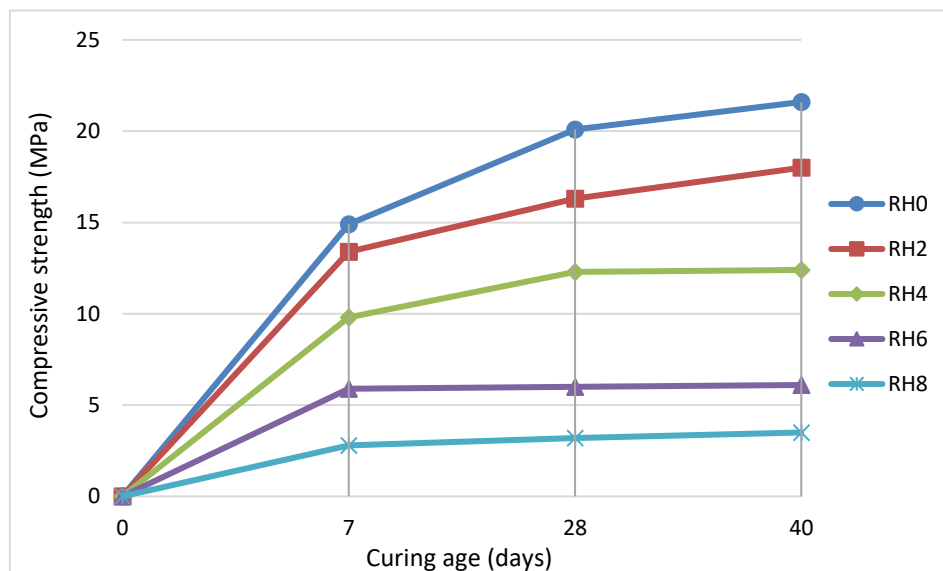


Fig. 11. The relationship of compressive strength and curing age for pervious concrete specimens.

If the relationship between compressive strength and specimens is examined with respect to curing age, as shown in Fig. 12, the compressive strength values for RH6 and RH8 are close to each other at 7, 28, and 40 days. Thus, pervious concrete with reasonable compressive strength is suitable for replacing coarse aggregate with RH at levels below 4%. Moura et al. (2021) reported that the compressive strength of pervious concrete using waste glass powder as a cement replacement by mass ranged from 11.1 to 23.0 MPa, which is within the standard of the compressive strength for pervious concrete (4–28 MPa) for cube specimens, and exceeds the Brazilian and American Concrete Institute standard of 20 MPa. However, according to Moura et al. (2021), all specimens met the standard except for the RH8 specimen. The compressive strength of pervious concrete decreased as the percentage of coarse aggregate replacement increased for all curing ages. This is because using a high percentage of RH for substituting coarse aggregate affects the bonding among RH, coarse aggregate, and cement, whereas using a low percentage of coarse aggregate results in poor compressive strength.

The failure pattern of the high RH utilisation in pervious concrete specimens differs from that of normal concrete, as shown in Fig. 13. Normal concrete generally demonstrates a brittle, clean fracture characterised by well-defined cracks due to its dense matrix and strong aggregate interlock. Conversely, the RH specimens exhibit irregular, crumbly and fibrous disintegration after testing, with loose RH particles and poorly bonded regions. This behaviour demonstrates the low density, porous structure and insufficient stiffness of the RH specimen which disrupts the aggregate framework and reduces load-transfer efficiency. The figure shows a specimen after being tested or compressed, demonstrating that it is not brittle, unlike the control mix. Although it is well known that adding or replacing RH in pervious concrete may reduce compressive strength due to its lightweight and porous nature, this study is important not only to confirm this trend but also to determine the degree of reduction, understand the influence on pore structure, and identify the optimum replacement level that balances compressive strength with enhanced sustainability or material efficiency.

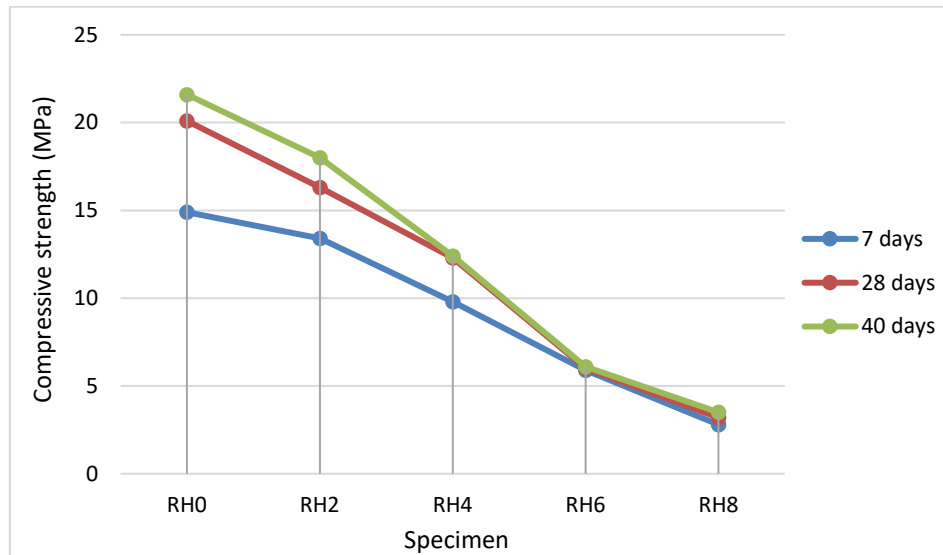


Fig. 12. The compressive strength values according to curing age.



Fig. 13. Photographs of the specimens after testing.

The study specifically concentrated on the structural integrity and material durability phases to determine the maximum gravel replacement limit of RH that preserves the mechanical properties and functionality. The focus on compressive strength is essential because RH, as an organic material, tends to weaken the interfacial transition zone, whereas water absorption serves as an initial indicator of the microporosity of the material. Furthermore, the study primarily examined the waste valorisation potential of agricultural by-products as a replacement for coarse aggregate. Although porosity and permeability are essential metrics for pervious concrete, these properties will be optimised in future phases after determining the viable mix proportions. Rice husk shows potential as a sustainable alternative in pervious concrete; however, its effectiveness is limited to replacement levels below 4%, as higher concentrations cause a significant reduction in compressive strength due to inadequate mechanical bonding between the organic fibres and the cement matrix.

4. Conclusions

From the experimental activity and analysis, the following comprehensive conclusions can be drawn:

- The surface morphology analysis demonstrates that RH is suitable for replacing coarse aggregate due to its rough surface texture, which is irregular and wavy rather than smooth. Moreover, elemental analysis revealed that RH has three major elements: O, Ca, and C.
- The weight of pervious concrete decreases as the percentage of RH, which is used as a coarse aggregate replacement, increases; while the water absorption of the pervious concrete increases with higher RH content. The water absorption of pervious concrete remains relatively low because water easily seeps through the porous solid parts of the concrete.
- The compressive strength of the pervious concrete decreases as the proportion of coarse aggregate replaced by RH increases. Additionally, the percentage difference in compressive strength at 28 days between the control mix and the other specimens ranges from 18% to 70%. Thus, pervious concrete containing 2% RH as a replacement for coarse aggregate exhibits the highest compressive strength at 7, 28, and 40 days. Therefore, RH2 is classified as a potential replacement for coarse aggregate in the production of pervious concrete.

By limiting the study to the compressive strength and water absorption of pervious concrete, other physical

and mechanical properties should also be tested to obtain comprehensive data. Several adjustments and further chemical processes are required (e.g., the addition of a superplasticiser) to improve the water absorption and compressive strength of the pervious concrete. Furthermore, the potential of RH as a replacement for concrete materials, especially as an aggregate in specialised concrete, should be studied and investigated. Finally, future studies should expand upon the preliminary findings regarding mechanical properties by incorporating standardised porosity and permeability tests to comprehensively evaluate the hydraulic performance of RH-integrated pervious concrete.

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Conflict of Interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available but are available from the corresponding author upon reasonable request.

AI Assistance

No AI-based tools were used in the preparation of this manuscript.

Author Contributions

All authors made substantial contributions to the conception and design of the study, acquisition of data, analysis and interpretation of data; drafted or critically revised the manuscript for important intellectual content; and approved the final version to be published.

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