Mustansiriyah Journal of Materials Engineering and Sustainability
Volume 01, No. 01, 2025, Pages 20-26
https://mjmes.uomustansiriyah.edu.iq/
Research Article

DOI: https://doi.org/10.31272/kqpssf20
ISSN: 3079-9899 (Print)
ISSN: 3079-9902 (Online)

Hybrid Pervious Concrete Incorporating Micro Rice Husk Ash for Improved Mechanical Properties and Ecological Benefits

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Article Info

Received	20/05/2025
Revised	21/06/2025
Accepted	24/06/2025
Published	01/07/2025

Abstract

To improve mechanical qualities and sustainability, this study explores the creation of hybrid pervious concrete that partially substitutes micro-rice husk ash (MRHA) for ordinary Portland cement (OPC). MRHA replacement levels of 0, 5, 10, and 15% by weight of cement were used to create four different concrete mixtures. At 10% MRHA, the compressive strength improved by 16%, from 36.5 MPa (control) to a maximum of 42.3 MPa. At 10% MRHA, water permeability dropped from 5.8×10^{-7} m/s (control) to 4.7×10^{-7} m/s, suggesting better matrix densification. At 15% MRHA, the water absorption decreased by 15.4% from 7.8% to 6.6%. As MRHA has a lower specific gravity, the hardened density at 15% MRHA decreased slightly from 2340 kg/m³ (control) to 2298 kg/m³. The results showed that 10% MRHA replacement offers the best results in terms of strength, permeability, durability, and environmental benefits. Thus, MRHA is a viable sustainable material for environment-friendly concrete applications.

Keywords: Cement, Rice husk ash, Permeability, Sustainability.

1. Introduction

Today's building industry is facing increasing challenges, impacted by the continuous increase of the global population and calling for original solutions to maintain the sustainability of materials. As concrete is the primary medium of construction, the industry is reliant on cement, which requires a large amount of energy in production and releases large amounts of carbon dioxide. Traditional concrete is impervious and helps to create urban flooding and heat islands by preventing storm and ground water from recharging the water table. Permeable concrete (pervious concrete) is now utilized as a sustainable approach for stormwater management due to its ability to let water penetrate through, via its interconnected voids. However, despite its potential benefits to the environment, permeable concrete possesses a relatively low mechanical strength, particularly compressive strength, attributed to lack of fine aggregates and porous framework [1]. In order to improve this trade-off between permeability and strength by replacement of the PC it has to be investigated for several SCMs. Rice husk ash (RHA), a waste of rice plants, obtained after milling rice, [has also been used as] an eco friendly pozzolan. RHA is an abundant source of amorphous silica and in fine ground form as micro rice husk ash (MRHA) has ability to be a reactive pozzolana material, which reacts with CH during the cement hydration process leading to the formation of extra C-S-H gel [2]. This leads to densification of matrix, and better ITZ and mechanical properties [3]. The innovation of hybrid permeable concrete with MRHA not just possesses the strength enhancing effect, but keeping its permeability to be sufficient. Moreover, use of MRHA has an edge on the environmental issue of agro-waste utilization process, which decreases the extent of landfill and emission of CO_2 during production of the Portland cement [4]. These actions are consistent with the objectives of green construction and the construction industry's principle of the circular economy [5]. It was reported in the earlier works that the partial substitution of RHA up to the level of 10% by weight of cement greatly enhances the compressive and flexural strengths of RCA mixtures and that the porosity is not unduly affected when it is carefully designed [6]. Furthermore, pozzolanic reaction of MRHA also enhances resistance to chloride, decreases water absorption, and improves the durability in severe environmental condition[7].

The impact of using rice husk ash (RHA) instead of cement in the production of lightweight aerated concrete was examined by Ali et al. [8]. Type I Portland cement, fine aggregate, and aluminum powder were used in this study as aerating agents. Aluminum powder was added at 0.5% by weight of binder during mixing, and RHA was added at different replacement levels (0, 2.5, 5, 7.5, 10, 12.5, and 15% by weight of cement). The results indicated that adding 10% RHA as a partial replacement for cement in aerated concrete improved the strength and durability of concrete. The test covered physical, mechanical, and durability aspects (such as density, compressive strength, split tensile strength, and flexural strength of concrete cured for 3, 7, 28, and 90 days, as well as corrosion analysis and sulfate attack at 28 days of curing). The chemical makeup of rice husk ash (RHA) and its impact on the properties of concrete were investigated by Abdulazeez et al. [9]. In comparison to the control mix, concrete mixes containing different proportions of RHA as a partial cement replacement (up to 30%) were tested. According to the results, the ideal cement replacement level was 10% RHA, which produced a compressive strength of 26.8 N/mm², which was similar to that of the control concrete (26.9 N/mm²). Consequently, the study concluded that rice husk ash can be used as an effective cement substitute in concrete. Al-Alwan et al. examined the impact of using rice husk ash (RHA) in concrete as a partial cement substitute. [10]. Their research concentrated on the effects of different RHA proportions (0%, 7%, and 14%), water-to-cement ratios (0.3, 0.5, and 0.7), and curing times (10, 20, and 30 days) on the strength, durability, and resistance to corrosion of the concrete.The researchers came to the conclusion that employing fine RHA particles effectively lowers chloride ion penetration over time while also greatly increasing flexural, compressive, and tensile strengths. Additionally, they found that higher water-to-cement ratios had a negative impact, which they attributed to the increased porosity of concrete. The use of bagasse ash (BA) and rice husk ash (RHA) as cement substitutes up to 30% was examined by Dhanalakshmi et al. [11]. To increase the strength and durability of high-performance concrete and support sustainable building practices, they discovered that the ideal replacement ratio was 70% cement, 20% RHA, and 10% BA.

In this study, the use of micro rice Husk as cementitious material replacement (partial) in the development of hybrid permeable concrete had been focused in improving the mechanical properties, environmental considerations, and urban water management system. The results are anticipated to help develop sustainable pavement systems for sidewalks, parking lots and low volume roads.

2. Materials and Methodology

The present experimental study investigates the mechanical and durability performance of hybrid permeable concrete with micro rice husk ash (MRHA) as a partial replacement for Ordinary Portland Cement (OPC). It is intended to create a structurally stable and responsive environmental permeable concrete tool with better compressive strength and water management. Portland cement (PC) Type I, according to ASTM C150, was used as the primary hydraulic binder for all concrete mixes. Entry of a constant cementitious content of 300 kg/m3 was used to provide consistency and also to enable direct performance comparisons from MRHA to MRHA replacement levels. OPC Type I was chosen for its moderate hydration and stable strength gain to be used as reference material to investigate the pozzolanic effect of MRHA. Micro rice husk ash (MRHA) as a supplementary cementitious material (SCM): It is obtained by controlled burning of rice husk and fine grinding to have larger surface area and increase reactivity. The MRHA used in this research contains a high proportion of an amorphous silica phase meaning it is applicable for pozollan reaction with CH produced as a result of cement hydration. The fly ash was employed as a substitute for cement partially at 5%, 10%, and 15% in weight of cement. The replacement interval was selected according to a number of previous studies indicating that the best strength and durability property could be obtained at a certain percentage of MRHA addition. The coarse aggregates were clean well graded crushed stones up to 12.5 mm of nominal size and conforming to ASTM C33. Same total dosage of 1200 kg/m³ for all of the mixes was kept to keep the porosity and permeability constant and below values of 1400 kg/m³ for porous concretes for load-bearing application including pervious concrete. The mixing water was drinkable water without impurities, provided at a fixed dosage of 150 kg/m³; the resulting ,w/cm" varied from 0.50 to 0.60 depending on the MRHA dosage. This interval was chosen such that sufficient hydration was imparted to that system while fulfilling the desired workability permeability parameters. To compensate the reduction in workability which is typically observed with pozzolanic materials like MRHA, a polycarboxylate based HRWRA, also known as superplasticizer, was added at 5 kg/m³ dose. This was done to achieve consistent flowability and compaction in all concrete mixtures, a key issue especially for applications of pervious concrete where even void structure has to be preserved. All the materials used were evaluated for their chemical and physical properties before usage. The MRHA met the requirements as per ASTM C618 for pozzolanic materials with 50% SiO_2 and LOI. Compositional and Physical properties of OPC and MRHA are presented in Tables 1 and 2. The mix proportions for Permeable Concrete with MRHA are presented in Table 3. Pan mixer was used for mixing concrete batches. Dry ingredients were initially mixed for 2 min, and then addition of water plus superplasticizer solution was done gradually. The poured concrete was vibrated to be compact with standard moulds withdrawing. Specimens were cured under water saturated condition for 28 days at 23 ± 2 degree Celsius and test was performed as per ASTM standards for compressive strength and permeability. This model was developed to investigate the influence of MRHA on mechanical indices, helping to identify an MRHA based permeable concrete mix, which can provide both mechanical strength and environmental compatibility.

Table 1. Chemical Composition of Cement and Supplementary Materials.

Component	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	LOI (%)
OPC	20.5	4.9	3.1	63.2	2.5	2.8	1.8
MRHA	89.4	0.7	0.5	1.1	0.8	0.1	4.2

Table 2. Physical Properties of Cement and MRHA.

Property	OPC	MRHA
Specific Gravity	3.15	2.10
Blaine Fineness (m²/kg)	320	840
Mean Particle Size (µm)	10–15	<5
Color	Gray	Light gray
Max. Aggregate Size (mm)	—	—
Water Absorption (%)	—	12.5
Bulk Density (kg/m³)	—	390

Table 3. Mix Proportions for Permeable Concrete with MRHA

Mix ID	Cement (kg/m³)	MRHA (% replacement)	MRHA (kg/m³)	Coarse Aggregate (kg/m³)	Water (kg/m³)	Superplasticizer (kg/m³)
PC-0	300	0	0	1200	150	5
PC-5MRHA	285	5	15	1200	150	5
PC-10MRHA	270	10	30	1200	150	5
PC-15MRHA	255	15	45	1200	150	5

2.1. Experimental work

By partially substituting Ordinary Portland Cement (OPC) with micro rice husk ash (MRHA), the experimental program sought to determine how the mechanical characteristics, permeability, and water absorption behavior of hybrid permeable concrete were affected. Before being ground with a mechanical grinder to a particle size of approximately 150 µm, the rice husk ash used in this study was burned under controlled conditions for two hours at 600°C. As shown in Table 3, four concrete mix designs were created: one control mix (PC-0) with 0% MRHA, and three modified mixes (PC-5, PC-10, and PC-15) with MRHA added at replacement levels of 5%, 10%, and 15% by weight of cement, respectively. An experimental design was created to determine the ideal replacement percentage of MRHA that would improve the strength and durability characteristics of concrete while preserving sufficient permeability. To completely comprehend the impact of MRHA incorporation, extensive testing of the compressive strength, hardened density, water permeability, and water absorption was performed to assess the performance of permeable concrete mixtures.

2.2.1 Compressive Strength

Compressive strength tests followed EN 12390-3 and cubes of 150 mm 3 150 mm 3 150 mm size were cast. The specimens were removed from the moulds after 24 h and then cured in water at 23 ± 2 °C until the test age. Tests were also placed at 28 days of curing age targeting to study the effect of MRHA content on compressive strength of CKD at various ages. The specimens were uniaxially compressed using a calibrated universal testing machine (UTM). Load was applied at a steady rate of 0.5 MPa/sec and without an impact, until the time of failure. Three samples were tested for all mixture proportions (0%, 5%, 10% and 15% MRHA replacement levels) and an average compressive strength was considered for statistical relevance and for reduction of experimental error. The findings were employed to assess the pozzolanic potential of MRHA and its beneficial effect on the strength of permeable concrete systems.

2.2.2 Density

The hardened density of the concrete mixes was measured according to ASTM C642 to evaluate whether the addition of MRHA imparts on the closeness and mass to volume ratio of the cured concrete. 150 mm × 150 mm × 150 mm cubic specimens were tested. The samples were surface-dried after 28 days water curing to remove surface water, and air dried before weighing in air with digital balance (precision, ±0.01g). The volume of each sample was calculated from the measured dimension, and hardened density (kg/m³) was obtained from the following equation.

$$\text{Density} = \frac{\text{Mass (kg)}}{Volume\ (m^3)} \ldots \qquad \ldots\ldots\ldots\ldots(1)$$

Three specimens were tested for each mixture design (0%, 5%, 10%, and 15% MRHA), and average density value was used for calculation. This test sought to establish whether the addition of fine MRHA increases the bulk density of permeable concrete due to increased particle packing and matrix density enhancements.

2.2.3 Water Permeability

The water permeability of the hybrid permeable concrete mixes containing MRHA was tested to determine the resistance of material to the flow of water under pressure which is an important property to evaluate long-term durability and the performance in pavement and drainage system. An adapted version of DIN 1048 Part 5 has been used for the test, which is appropriate for the determination of the saturated porous material ST of a concrete in the perfusion under hydraulic gradient. Cylindrical specimens of 150 mm diameter and 300 mm height were cast for each dose of MRHA (0%, 5%, 10% and 15%) and cured under water at 23 ± 2°C for 28 days. After the curing process was completed, all the specimens were pressurized with a constant hydrostatic pressure of 5 bar (0.5 MPa) for 72 hours in a laboratory permeability cell, which was equipped to ensure constant pressure exerted upon a circular exposed profile. After the completion of test, the specimens were cut longitudinally, and the maximum penetration depth of water along the fracture surface was measured with a graduated ruler with a precision of 1 mm. The average of penetration depths (mm) in three specimens of each mix were calculated and reported as water penetration index. This approach was chosen to approximate the in-service hydraulic environment and to investigate the MRHA influence on the concrete pore structure. The high silica content and the pozzolanic activity of MRHA is anticipated to improve matrix densification, reduce the number of interconnected capillary pores, and therefore enhance impermeability. Accordingly, this test is a good manner of measuring the water-seepage level of hybrid permeable concretes.

2.1.4 Water Absorption Reduction

Water absorption test under pressure (ASTM C642) Test was carried out to examine the resistance of concrete to moisture penetration. The samples were oven-dried at 105 ± 5°C for 24 hours, cooled in a desiccator, and subsequently soaked for 48 hours in water. The mass gain was recorded and water uptake (%) was calculated by the following equation:

$$\text{Absorption}(\%) = \frac{\text{Wsat} - \text{Wdry}}{\text{Wdry}} x100$$

Where:

Wsat = saturated weight

Wdry = oven-dried weight

This test helped to understand the applicability of MRHA in modifying pore structure and water repellency.

3. Results and Discussion

3.1 Compressive Strength

From the compressive strength results (Table 4 and Figure 1), it may be concluded that with the addition of MRHA, the mechanical properties of hybrid pervious concrete are significantly enhanced. To confirm the reliability of these findings, statistical analysis was performed on the replicate samples. The standard deviation for each mix was within ±1.2 MPa, indicating that the observed increases in compressive strength, especially at the 10% MRHA level, are statistically significant and not due to normal variation alone. The control blend, PC-0 (no pozzolanic replacement), developed a compressive strength of 36.5 MPa at 28 days of age. This is consistent with the fact that OPC has its natural limitation in pervious concrete and the structure of the pores is not modified to add secondary binder or to induce other binding phases. When 5% of cement was substituted with MRHA (PC-5MRHA), 39.8 MPa, the strength was enhanced, due to the high content of amorphous silica and fine particles of MRHA. MRHA particles act as both a reactive pozzolan and microfiller, which decreases pore volume and generates more calcium silicate hydrate (C–S–H) by secondary reaction of hydration. This is in line with the results of Ganesan et al. (2008) which explained that fine ground rice husk ash addition enhanced the strength by the filler effect and pozzolanic reactivity [12]. The compressive strength was 42.3 MPa at 10% substitution level (PC-10MRHA), which was the highest compressive strength compared with the other mixtures. The high point is reached due to the optimised balance between the cementitious content and the reactivity of the MRHA and a relatively well-packed and chemically reactive matrix. The large specific surface area of MRHA supplies nucleation sites for C–S–H in the case of the latter, which refines the pores structure and greatly densifies the ITZ. Habeeb and Mahmud (2010) also noticed the highest gain of strength at 10% RHA for better pozzolanic reaction and more efficiency particle distribution [13],[14]. However, the 15% higher content of MRHA (PC-15MRHA) showed a slight decrease to 41.2 MPa. This small decrease implies that the dilution effect of cement becomes larger than any additional benefit from pozzolanic reaction beyond a certain replacement level. Added MRHA may also induce a lack of CH available for reaction and resulting diminished matrix strength. Wishing for replacement of greater proportions of OPC was reported by some investigators and RHA addition of more than 10 -15 % of was observed to have a detrimental effect on compressive strength due to over-replacement of OPC[15]. Consistent with this finding, this study shows that moderate MRHA contents (approximately 10%) have potential to significantly enhance the mechanical properties of porous concrete. This is in accordance with the literature which states that 10% is the best percentage to achieve strength efficiencies using highly reactive pozzolans such as micro rice husk ash [16],[17].

Table 4. The all test results for hybrid concrete assembled with micro rice husk ash.

Mix ID	PC-0	PC-5MRHA	PC-10MRHA	PC-15MRHA
Compressive Strength MPa	36.5	39.8	42.3	41.2
Density (kg/m³)	2340	2325	2310	2298
Water Permeability ($\times 10^{-7}$ m/s)	5.8	5.2	4.7	4.8
Water Absorption (%)	7.8	7.1	6.7	6.6
Reduction (%)	0.0	9.0	14.1	15.4

Among all the mixes tested, the 10% MRHA mix performed the best overall, producing the best combination of high strength, low permeability, and reduced water absorption, as shown in Table 4.

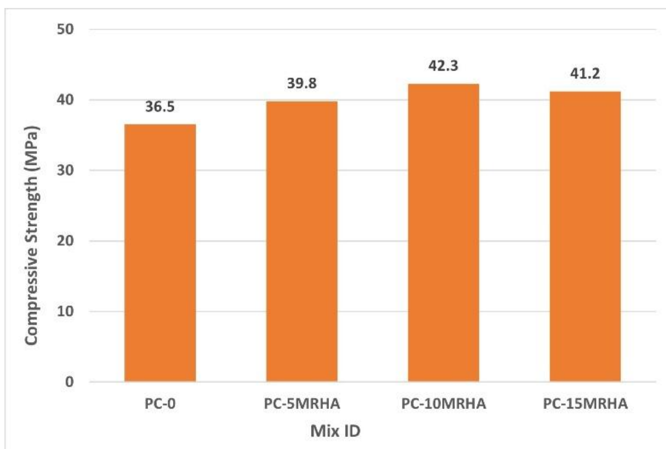

Figure 1. Compressive Strength results of Hybrid Concrete with MRHA.

3.2 Density

The hardened density results of hybrid concrete mixtures containing MRHA are given in Table 4 and Figure 2. The values show a tendency of decreasing density with increased contents of MRHA which are in agreement with the physical properties of rice husk ash and its effect on the microstructure of the concrete. The control composition (PC-0), harboring no MRHA, had a density of 2340 kg/m³. This is the typical value for plain concrete with ordinary Portland cement (OPC) and normal aggregates. The corresponding densities reduced to 2325 kg/m³, 2310 kg/m³ and 2298 kg/m³ as the MRHA replacement level rose up to 5%, 10% and 15% respectively. These relatively small decreases are explained by two main reasons. First, the apparent specific gravity of MRHA (2.10) is very much lower than that of OPC (3.15), leading to direct reduction of mass per unit volume of the cementitious matrix when a portion of the cement is replaced by MRHA[12],[18]. This phenomenon has been widely reported in cases in which lightweight or low density pozzolanic materials are used as partial replacement for Portland cement [19]. Second, MRHA at moderate blending dosages can densify the matrix thanks to pozzolanic reaction and filling effect, but may also cause to a slight increase in entrapped air or internal porosity at higher levels of replacement, e.g. 15%. The reason behind it is probably related to the fineness and the higher water demand of MRHA, which would influence the compaction and the dispersion of the particles under mixing. Habeeb and Mahmud (2010) reported the same behavior, they found that as RHA content was higher than 10% there was a decrease in density, which might have been explained by the greater internal porosity[13]. Although the densities reduced, they are still competitive for structural grade concrete and proved to be an environmentally favorable compromise between weight reduction and mechanical performances. The findings in this study suggest that MRHA is a prospective lightweight binder, at-room hardening, towards environmentally friendly binder, without too much loss in mechanical properties, when blended two or less 10% by mass of cement. Concrete still satisfies the specifications for structural applications and offers adequate load-bearing capacity for pavements and low-volume roads despite this minor density decrease.

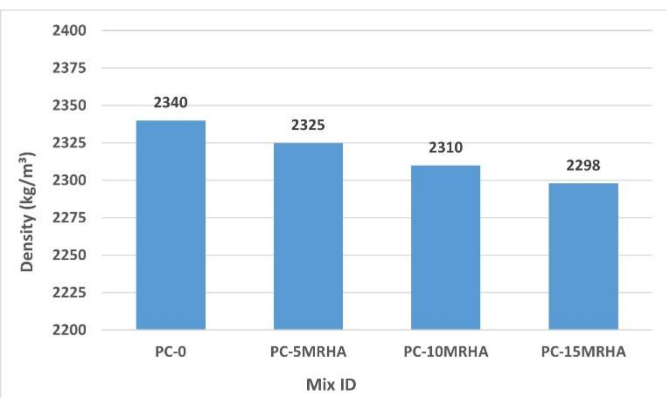

Figure 2. Density results of Hybrid Concrete with MRHA.

3.3 Water Permeability

The water permeability characteristics of the hybrid permeable concrete containing MRHA are given in Table 4 and Figure 3. The results clearly exhibit that permeability decreases as MRHA dosage changes from 0% to 10%, and then slightly increases at replacement level of 15%. These findings reveal the double role of MRHA in the pore structure and the total impermeability of the concrete matrix. The control mix (PC-0) of 0% for pozzolanic replacement has the highest permeability value (5.8×10^{-7} m/s), which is related to the open and linked capillary pores of the porous concrete systems without matrix densification. In these applications, the low amount of finest reactive material leaves largely empty capillary voids, and thus increased permeability and ability to let water into the material. The permeability decreased markedly to 5.2×10^{-7} m/s after replacing 5% OPC with MRHA (PC-5MRHA), which is attributed to the pozzolanic reaction of MRHA, consuming calcium hydroxide and producing extra calcium silicate hydrate (C–S–H) that results in increased matrix densification and pore blocking. The microfil1er effect of MRHA due to its superfine particle size is also significantly effective in occluding the capillary pores [20]. The best performance was from the 10% MRHA level (PC-10MRHA) which showed a water permeability minimum of 4.7×10^{-7} m/s, this proportion is likely to produce an optimum trade-off between the pozzolanic reactivity and the matrix cohesion of the binder. A similar observation was stated by Ganesan et al. (2008) where equal replacement with 10 percentage to RHA yield minimum permeability and higher durability performance. Interestingly, a PC-15MRHA sample experienced a minimal rise of permeability to about 4.8×10^{-7} m/s, which should be taken as a sign that too high a degree of substitution starts to affect the binding capacity and uniformity of the cementitious matrix, probably a result of a diminished content of calcium hydroxide left for pozzolanic reaction and increased need of water of dispersion. Excessive over-replacement results or can result in insufficient C–S–H formation and increased internal porosity as previously reported by Habeeb and Mahmud (2010) [13]. In summary, by both chemical (pozzolanic) and physical (filler) effect, MRHA addition increases the impermeability of hybrid concrete. The best results are found with 10% substitution, coupled with current studies for permeability reduction and durability improvement using rice husk ash in cementing regime. This demonstrates that the 10% MRHA mix achieves the best balance between permeability and strength, which is essential for guaranteeing both structural performance and efficient storm water management.

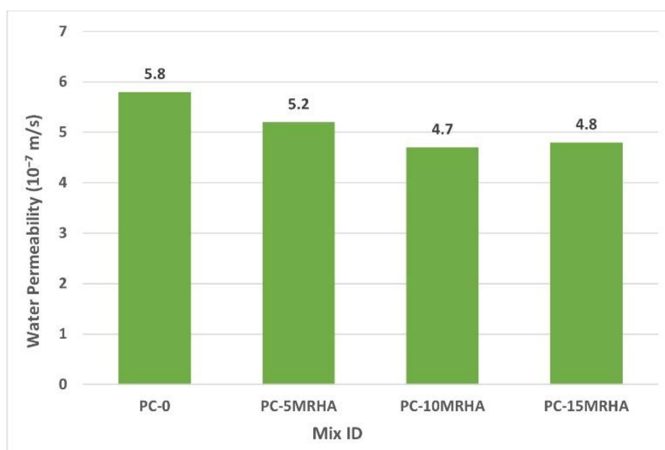

Figure 3. Water Permeability Results of Hybrid Concrete with MRHA

3.4 Water Absorption

The water absorption test results in Table 4 and Figure 4 show a decrease in percentage of absorbed water for all MRHA dosages. These findings are important because they demonstrate the material's resistance to moisture attack, which is an important consideration for improvements in durability of concrete, specifically permeable systems. The water absorption was greatest in the control mix (PC-0) and it was on the order of 7.8%, as should be expected in pervious concrete without pozzolanic materials and microstructural densification. This high absorption is due to a relatively open pore structure and no fillers covering capillary pores. For PC-5MRHA, in which MRHA was incorporated at 5%, absorption was lowered to 7.1% due to the decrease by 9.0% over the cystosepiment. Such the enhancement is attributed to micro-filler effect and pozzolanic reactivity of MRHA for not only making the pore structure denser but also improving the binding matrix because of forming additional calcium silicate hydrate (C–S–H) gel[13]. At 10% MRHA (PC-10MRHA) the absorption further decreased to 6.7% showing an additional 14.1% decrease. This dose seems to be the most suitable to enhance moisture resistance since the packing density is increased and the chemical reactivity is highly improved. Ganesan et al. (2008) found a comparable result; 10% RHA replacement causes a considerable reduction of absorption because of the effective closure of water paths in concrete[12]. Fig. 3c reveals that as the MRHA amount increased to 15% (PC-15MRHA) the water uptake decreased further down to 6.6%, achieving an overal >15.4% drop. This indicates that there is still improvement of water resistance with increasing MRHA dosage up to a certain level. But the literature also cautions against too high replacement levels, which may lead to a decrease of workability and dispersion, which in turn may jeopardize compaction and result in pores being bunched together [20]. In the present study, the MRHA seemed to be dispersed enough to maintain a low rate of absorption even at 15%. These results support the advantageous function of MRHA of limiting water absorption and improving moisture resistance notably in pervious concrete systems for which restrictive fluid flow is a key feature of long lasting service. By reducing moisture intrusion and related damage processes, such as corrosion and freeze-thaw cycles, lower water absorption also increases durability.

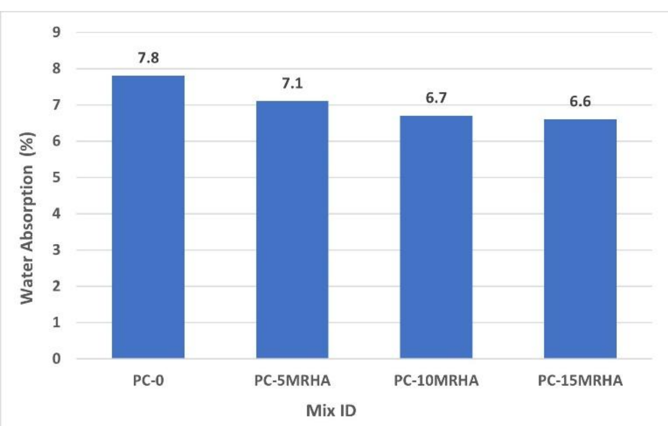

Figure 4. Water Absorption results of Hybrid Concrete with MRHA

4. Conclusion

This study examined the partial substitution of micro-rice husk ash (MRHA) for Ordinary Portland Cement (OPC) in hybrid pervious concrete. 10% was determined to be the ideal replacement level, resulting in a 16% increase in compressive strength (42.3 MPa), decreased permeability (4.7×10^{-7} m/s), and enhanced density and water absorption properties. These improvements demonstrate that MRHA has the potential to be a practical and sustainable substitute for cement in the production of pervious concrete.

Based on the practical implications of the findings, MRHA-enhanced pervious concrete can be used successfully in low-volume roads, parking lots, sidewalks, and urban pavement systems, where both structural integrity and water drainage are necessary. Utilizing MRHA also helps to value waste, lessens the environmental impact of cement production, and promotes circular economy.

Future research is advised to assess the long-term durability of MRHA-based pervious concrete under actual environmental exposure conditions and to investigate its behavior under heavy traffic loads, chemical attacks, and freeze-thaw cycles. It may be possible to improve the performance and expand its applicability in the development of sustainable infrastructure by examining the use of additional agro-waste pozzolanic materials or by mixing MRHA with fibers or nanomaterials.

Acknowledgements

The authors would like to thank Mustansiriyah University (www.uomustansiriyah.edu.iq) Baghdad – Iraq for its support in the present work.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Y.K. Ibrahim, S.A. Ahmad, and A.S. Abbas: proposed the research problem.

Y.K. Ibrahim and S.A. Ahmad: developed the theory and performed the computations.

Abdalqadir and A.S. Abbas: verified the analytical methods

All authors discussed the results and contributed to the final manuscript.

AI Declaration Statement

The authors confirm that the manuscript has been written without the assistance of generative AI or AI-based writing tools.

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