

MECHANICAL PROPERTIES OF GREEN PAVER BLOCK INCORPORATING RAW RIVER WATER TEXTILE DYEING SLUDGE

Goh Wan Inn

Advanced Concrete Material Focus Group, Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, Malaysia

wigoh@uthm.edu.my

Amir Kamarul Izzuddin

Advanced Concrete Material Focus Group, Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, Malaysia

af210063@student.uthm.edu.my

Abstract

This study examines the feasibility of utilizing textile dyeing sludge, a byproduct of the textile industry, to produce a Green Paver Block (GP Block). This study examines the mechanical characteristics of eco-friendly paver blocks. Raw river water sludge will serve as the basis for comparison. The primary objective of this study is to determine the physical properties of GP Block when combined with Raw River Water Sludge (RRWS) and to identify the optimal percentage mix ratio of textile dyeing sludge required to produce GP Block. Due to its greater reliance on natural resources, the building industry also raises questions regarding its environmental effects. Mechanical tests were conducted on blocks with varying RRWS content (2.5%–10%). The results showed that increasing RRWS content led to a decrease in density and compressive strength, and an increase in water absorption due to the fine and organic nature of the sludge. However, blocks with 2.5% RRWS maintained acceptable strength, which is 22.19 MPa, density of 1995.3 kg/m³, and water absorption of 11.25%, making them suitable for non-structural applications. Scanning Electron Microscope with Energy Dispersive X-Ray (SEM-EDX) analysis confirmed the presence of calcium and silicon, supporting RRWS's role as a filler material. The study concludes that 2.5% RRWS is the optimal mix ratio for producing environmentally friendly and structurally reliable GP Blocks, contributing to sustainable construction practices and effective waste management.

Keywords: Raw River Water Sludge, RRWS, Green Paver Block, GP Block

1. INTRODUCTION

Paver blocks, commonly used in construction and landscaping, are traditionally made from cement, sand, and aggregates. Due to environmental concerns such as resource depletion and industrial waste, sustainable alternatives like GP Blocks have been developed. These blocks incorporate recycled materials, including wastewater and textile dyeing sludge, to reduce reliance on cement and sand. Interlocking paving stones originated in the Netherlands in the mid-19th century and gained popularity after World War II due to brick shortages. The shift toward concrete pavers was driven by practicality and material availability (Olofinnade et al., 2021). Research shows that using recycled materials not only reduces environmental impact but can also enhance the strength and durability of paver blocks, making them a viable and eco-friendly option for modern construction.

The construction industry significantly contributes to global economic development but is also a major source of environmental degradation. Concrete production, which relies heavily on cement, water, and aggregates, is both costly and energy-intensive. To address these issues, researchers have explored the use of sludge from water treatment plants as a replacement for fine aggregates. This approach not only reduces construction costs but also helps manage the disposal problem of sludge waste. Reusing sludge in construction can mitigate environmental pollution and health risks associated with improper disposal, as sludge often contains heavy metals like lead and mercury that can contaminate soil and affect its fertility (Ruben et al., 2020).

In this study, GP Blocks incorporating recycled raw water sludge (RRWS) were produced using the ratio method with Ordinary Portland Cement (OPC). The blocks, sized 200mm × 100mm × 60mm, included varying proportions of RRWS as a partial sand replacement, alongside control blocks made with natural sand. After a 28-day curing period, mechanical tests were conducted to evaluate density,

compressive strength, and water absorption. Additionally, SEM analysis was used to examine the surface structure and material interactions.

This research identified their fundamental structure and any interactions. Subsequently, the experimental findings were carefully evaluated to ascertain the ideal RRWS ratios to be added to paver blocks. The purpose of this study was to find effective and sustainable ways to include RRWS into building materials to support environmentally friendly building techniques. Table 1 show the mix proportion of RRWS.

Table 1 The mix proportion of RRWS

Mix Name	% of Raw River Water Sludge
Control	0
RRWS 2.5	2.5
RRWS 5	5
RRWS 7.5	7.5
RRWS 10	10

This study highlights the environmental challenges posed by the cement industry, particularly the extraction and processing of non-renewable minerals like limestone. These activities can severely degrade natural landscapes, disrupt ecosystems, and threaten biodiversity. Additionally, the improper disposal of sludge, especially from the textile industry, contributes to soil and water pollution. By reusing sludge as a component in paver blocks, the study presents a practical and eco-friendly solution that reduces waste and supports sustainable construction practices.

2. MATERIAL

2.1. Raw River Water Sludge

RRWS is a waste product of water treatment processes, which has received significant attention for its possible applications in sustainable construction and environmental management. This review investigates its properties and application with a particular focus on its incorporation into construction materials.

RRWS is composed of organic debris, fine particles, heavy metals, and other pollutants filtered from untreated river water during purification. Its composition varies depending on the river source and impurity levels. Before use, the sludge typically has high moisture content. Chemical analysis reveals significant amounts of oxides such as silica, alumina, and calcium oxide, making RRWS a viable supplementary material in construction. The sludge's density, measured using a pycnometer, is approximately 17.1 kN/m³. These characteristics support its potential for sustainable building applications (Lynn et al., 2015).

(Yan et al., 2024) developed an innovative method to convert textile dyeing sludge into lightweight construction aggregates using a non-sintered process, which is more environmentally friendly than traditional high-heat sintering. The optimal mix included a sludge-to-cement ratio of 2.25, with 5% fly ash and 1% additive, cured over 28 days. This formulation achieved a compressive strength of 6.93 MPa, a bulk density of 753 kg/m³, and a water absorption rate of 17.98% after one hour. The material's strength and durability were attributed to the formation of calcium silicate hydrate (C–S–H) gel and Ettringite during hydration. Additionally, zinc ions present in the sludge reacted to form stable compounds like $\text{Ca}(\text{Zn}(\text{OH})_3)_2 \cdot 2\text{H}_2\text{O}$, which were encapsulated within the C–S–H gel, effectively minimizing the risk of heavy metal pollution. This approach not only promotes the reuse of industrial waste but also supports the production of sustainable building materials aligned with global environmental goals. Figure 1 shows the material of Raw River Water Sludge.



Figure 1: Raw River Water Sludge

2.2. Ordinary Portland Cement (OPC)

Ordinary Portland Cement (OPC) plays a crucial role in the construction of concrete and GP Blocks due to its strong binding properties and widespread availability. In GP Blocks containing RRWS, OPC serves as the primary binder, ensuring structural integrity and durability. Its cost-effectiveness makes it a preferred choice in Malaysian construction. This study emphasizes OPC's interaction with sludge materials, highlighting its importance in maintaining the performance and sustainability of modified paver blocks.

2.3. Sand

Sand is a vital component in the construction of paving blocks, serving as a fine aggregate that enhances mix consistency, compaction, and finishing. It contributes to the density and structural strength of the blocks, ensuring they remain solid and secure after installation. Fine sand, particularly with particle sizes $\leq 2.36\text{mm}$, is preferred for smoother surfaces and better compaction, especially in the top layer of paving stones. Proper selection and proportioning of sand are essential for producing high-quality, durable paving blocks, as supported by BS EN 12620:2002 sieve analysis standards.

2.4. Water

Water plays a crucial role in the paving block mixture, primarily enabling cement hydration to form calcium silicate hydrate which is the key binding agent responsible for strength and durability. Proper water content ensures workability, allowing the mix to be easily moulded and compacted, which eliminates air gaps and results in denser blocks. During curing, water maintains hydration, preventing shrinkage cracks and enhancing the long-term performance of the material. Effective water management improves surface finish, strength, and resistance to wear, weathering, and mechanical stress.

2.5. Coarse Aggregate

To achieve standards the coarse aggregates will be sieved to ensure a maximum particle size of no more than 10 mm. By using 10 mm aggregates this can reduce fractures and gaps in the concrete mixture. For bigger aggregates it is used to increase the overall strength of the paver block. For the weak aggregates, they are kept clean to maintain specimen performance and quality of the paving block.

3. SPECIMEN PREPARATION

3.1. Collection of Material

The materials used in this study included sand, cement, coarse aggregate, and raw river water sludge, which was used as an additive in green paver blocks. Based on the determined ratios, the amount of raw river water sludge was adjusted for each sample.

3.2. Mix Design

Table 2 provides an overview of the material ratio in this investigation, detailing the quantities of cement, sand and water utilized. Additionally, Table 3 outlines the mix proportions for incorporating Raw River Water Sludge as an admixture in Green Paver Blocks. These proportions were formulated in accordance with the specified guidelines of ASTM Standard C902-15.

Table 2 Ratio of Material

Cement : Sand	1 : 3
Water/Binder Ratio	0.80

Table 3 Percentage mix proportion of RRWS added into sand in GP Block

Mix Name	% of Raw River Water Sludge
Control	0
RRWS 2.5	2.5

RRWS 5	5
RRWS 7.5	7.5
RRWS 10	10

3.3. Mould Preparation

Sample specimens were prepared at the Advanced Material Laboratory using moulds measuring 200mm × 100mm × 60mm for compression and water absorption testing. A total of thirty blocks were cast for both the 7-day and 28-day tests. The moulds were kept in place for at least 24 hours to allow initial hardening before the curing process began. The casting procedure involved several steps: moulds were first cleaned and coated with oil to ease demoulding. Materials including sand, cement, and RRWS were measured according to specified ratios and thoroughly mixed. The mixture was then poured into the moulds, which were gently struck to eliminate air pockets. Each sample was labeled with a unique number and date for tracking purposes. After one day, the blocks were removed from the moulds and placed in a curing tank to ensure proper hydration and strength development. This curing phase was essential for enhancing the durability and structural integrity of the paver blocks. Figures 2, 3, and 4 show the casting process of the paver block.



Figure 2: Mixed materials

Figure 3: Casting of paver block

Figure 4: Paver block

4. EXPERIMENTAL TESTS

4.1. Density Test

A density test measures the mass of a GP Block per unit volume. The outcome helps determine the block compactness, porosity, and overall durability. Density testing helps measure the uniformity and consistency of materials such as sand, concrete, and RRWS. The density of a GP Block can determine its strength, durability, thermal properties, and suitability for various applications. Density measurements can identify material variations and weaknesses, enabling adjustments to manufacturing techniques and

material compositions to meet performance requirements. Each sample was weighed using a precise scale and the density was calculated using the formula:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad (1)$$

4.2. Compressive Strength Test

This test was designed to determine the compressive strength of paver blocks. For this reason, paver blocks measuring 200 x 100 x 60 mm were used. After a 24-hour drying and curing period, the samples were removed from the moulds holding the Textile Dyeing Sludge mixture. On days 7 and 28, 30 samples were prepared and analyzed. The guidelines provided in BS EN 12390-3: 2009 were used to evaluate the compressive strength values. Each sample was placed in the compression machine, and the piston was adjusted to contact the surface of the block. The load was gradually applied until cracking occurred, indicating the maximum load capacity. The machine recorded the results in kilonewtons (kN), and the average compressive strength was calculated for all samples. This test provided critical data for assessing the structural integrity and performance of the paver blocks. Figures 5 and 6 show the situation before and after a load is applied to the paver block.



Figure 5: Before load applied



Figure 6: After load applied

4.3. Water Absorption

The water absorption test measured the ability of a paver block to absorb water, which indicated its porosity and durability. The procedure involved drying the paver block in an oven at a specified temperature until a constant weight was achieved, then cooling it to room temperature and weighing it. The block was then immersed in water for a set period, usually 24 hours, after which it was removed, wiped dry, and weighed again. The difference in weight before and after immersion, expressed as a percentage of the dry weight, gave the water absorption rate. This test helped determine the block's resistance to weathering and potential durability in various environmental conditions. The water absorption percentage was calculated using the formula:

$$\text{Water Absorption (\%)} = \frac{\text{Final Weight} - \text{Initial Weight}}{\text{Initial Weight}} \quad (2)$$

4.4. Scanning Electron Microscope with Energy Dispersive X-Ray Analysis

SEM is a complex analytical method that produces high-resolution pictures and detailed surface morphology of materials. By directing a focused beam of electrons onto the specimen surface, SEM significantly surpasses the resolution limits of conventional optical microscopy. This approach enables nanoscale visualization, with resolutions ranging from less than 1 nanometre to several nanometres, making it ideal for microstructural investigations in materials research. During SEM analysis, a focused electron beam scans the sample's surface and collects various signals using specialized detectors. These electrons interact with the atoms in the sample, generating signals that provide insights into surface topography and composition. Real-time imaging is facilitated through software that correlates the beam's position with the intensity of electrons detected. Figure 7 shows the instrument for SEM and EDX testing.



Figure 7: Zeiss Evo LS10

5. RESULTS AND DISCUSSION

5.1. Density

A density test measures the mass of a GP Block per unit volume. The outcome helps determine the block compactness, porosity, and overall durability. Density testing helps measure the uniformity and consistency of materials such as sand, concrete, and RRWS. The density of a GP Block can determine its strength, durability, thermal properties, and suitability for various applications. Density measurements can identify material variations and weaknesses, enabling adjustments to manufacturing techniques and material compositions to meet performance requirements. The calculation and result are presented below, highlighting how these values help in understanding the RRWS characteristics and their potential applications. Table 4 shows the data on the density, and Figure 8 shows the bar chart of the density.

Table 4 Data of Density Test

Type of sample		Density (kg/m ³)
Days	Percentage of RRWS	
7	0	2029.2
	2.5	1992.0
	5	1974.7
	7.5	1936.3
	10	1914.8
28	0	2054.2
	2.5	1995.3
	5	1980.0
	7.5	1961.7
	10	1937.1



Figure 8: Bar chart of Density test

The density of the paver blocks decreased slightly when RRWS was incorporated into the mix. This is because RRWS typically contains organic matter and fine particles, which are less dense than conventional aggregates, leading to a reduction in overall mass per unit volume. Additionally, RRWS introduces more voids due to its fine and irregular particle structure, further contributing to the decrease in the density of the concrete paver blocks. These findings align with previous research by Lynn et al. (2015), which showed that the density of CPB decreases significantly with the increment of RRWS percentage, and also align with previous research by Govedarica et al. (2022), which showed that RRWS may lead to decreases in mechanical strength.

5.2. Water Absorption

The water absorption test was conducted to assess the porosity and potential durability of the paver blocks. This test measures the amount of water absorbed by the blocks, calculated as a percentage of the dry weight. A lower absorption rate indicates a denser and more durable material, better suited to withstand environmental wear and weathering. The results provide valuable insight into the quality and performance of the blocks, with comparisons made against standard values and previous studies to evaluate their effectiveness. Table 5 shows the data of the water absorption, and Figure 9 shows the bar chart of the water absorption.

Table 5 Data of Water Absorption Test

Type of sample			Water Absorption (%)
Days	RRWS Percentage (%)	Weight (kg)	
7	0	10.23	2029.2
	2.5	11.34	1992.0
	5	12.14	1974.7
	7.5	10.75	1936.3
	10	9.36	1914.8
28	0	11.32	2054.2
	2.5	11.25	1995.3
	5	12.31	1980.0
	7.5	12.59	1961.7
	10	11.82	1937.1

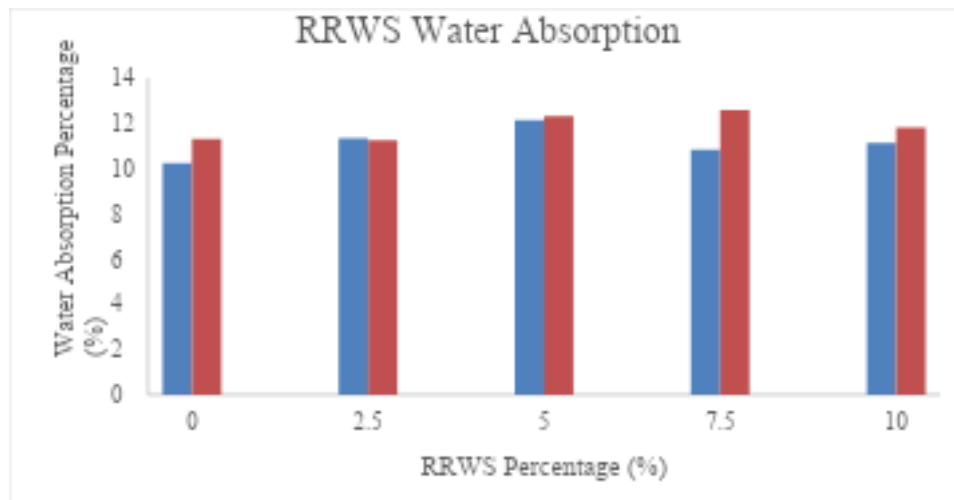


Figure 9: Bar chart of the Water Absorption test

The trend suggests that RRWS increases the water absorption capacity of paver blocks, especially at higher percentages. This is likely due to the organic and fine particulate nature of RRWS, which introduces void into the concrete matrix. These voids allow more water to be absorbed, which can affect the durability and weather resistance of the blocks. However, the non-linear behavior at 7.5% and 10% RRWS indicates that other factors, such as particle distribution, compaction quality, and curing conditions, may influence the results. These findings align with previous research by Kadam et al. (2020), which demonstrated that GP Blocks contain an interconnected void network that enables water to pass through, contributing approximately 15% to 30% of the volume. Table 6 presents the data on compressive strength, and Figure 10 displays the corresponding graph.

5.3. Compressive Strength

The compressive strength test was conducted to evaluate the load-bearing capacity and structural integrity of paver blocks, particularly for applications exposed to heavy loads. Blocks measuring 200 mm × 100 mm × 60 mm were prepared using a mix that included Textile Dyeing Sludge. After a 24-hour drying period, the samples were demoulded and cured, with 30 specimens tested on Day 28 to align with standard concrete curing practices. The test followed the BS EN 12390-3:2009 standard, which ensures consistency and reliability in measuring the compressive strength of hardened concrete. Results were analyzed and compared with standard benchmarks and existing literature to assess the performance of RRWS-incorporated paver blocks.

Table 6 Data of Compressive Strength

Type of sample			Compressive strength (MPa)
Days	RRWS Percentage (%)	Weight (kg)	
7	0	17.5	2029.2
	2.5	16.83	1992.0
	5	13.6	1974.7
	7.5	10.75	1936.3
	10	9.36	1914.8
28	0	23.6	2054.2
	2.5	22.19	1995.3
	5	15.58	1980.0
	7.5	15.44	1961.7
	10	12.37	1937.1

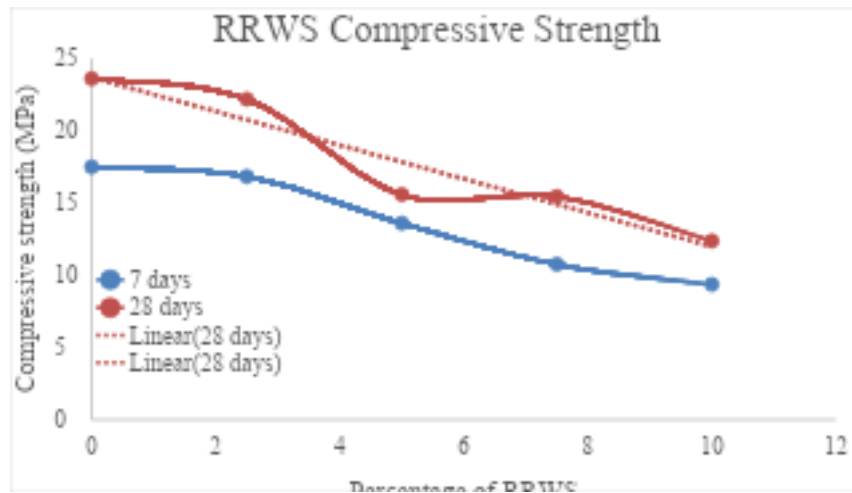


Figure 10: Graph of Compressive Strength test

The compressive strength of paver blocks incorporating varying percentages of RRWS (0% to 10%) was evaluated at 7 and 28 days of curing. Results showed a clear trend: as RRWS content increased, compressive strength decreased. This reduction is attributed to several factors, including interference with cement hydration due to organic compounds in RRWS, increased voids from its fine particle structure, and reduced overall density of the blocks. Despite this decline, the 28-day strength values were consistently higher than the 7-day results, indicating ongoing hydration and strength development over time, albeit at a slower rate in the presence of RRWS.

5.4. Scanning Electron Microscope (SEM) with Energy Dispersive X-Ray Analysis (EDX)

SEM analysis was conducted on RRWS, to examine the concrete's microstructure. The technique provided detailed insights into the RRWS elemental composition, confirming the presence of key elements, assessing homogeneity, and identifying impurities. Figure 11 shows the image of the Sample GP Block incorporating RRWS, while Figure 12 shows the result of EDX. Table 7 shows the surface morphology of RRWS, while Table 8 shows the summary result of EDX for RRWS.

Table 7 Surface Morphology

Material s	RRWS
Surface	Rough, uneven with granular texture and varying particle sizes.
Pattern	Irregular, asymmetrical with no distinct repeating structures, random particle arrangement.
Shape	Irregular, asymmetrical with no distinct repeating structures, random particle arrangement.

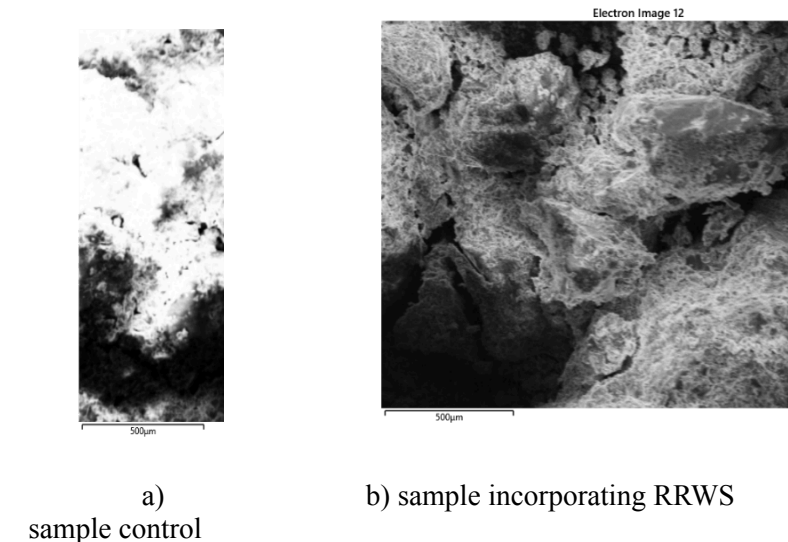


Figure 11: SEM Image for a and b

RRWS material displays a rough, uneven surface with a granular texture and varying particle sizes. This irregular morphology contributes to increased porosity when RRWS is used in paver blocks. The particles are asymmetrical and randomly shaped, lacking any consistent structure, which affects packing density and bonding efficiency within the concrete matrix. These characteristics align with earlier findings that showed reductions in both density and compressive strength when RRWS was incorporated. Despite its non-uniform structure, RRWS can still function effectively as a filler material. However, its influence on mechanical performance necessitates careful control of its content to maintain a balance between sustainability and structural integrity. These observations are consistent with previous research by Lynn et al. (2015), which confirmed RRWS's potential as a filler material in construction applications.

EDX analysis was conducted on RRWS, to examine the concrete's chemical composition. The technique provided detailed insights into the RRWS elemental composition, confirming the presence of key elements, assessing homogeneity, and identifying impurities

Table 8 Summary Result for EDX

Aspect	RRWS
Oxygen Dominance	High organic content, likely from organic binders, or biological matter in the sludge.
Metals Presence	High in calcium
Inorganic Component	Higher oxygen and metal content suggests a mixed origin
Summary	Complex mix of organic and inorganic elements

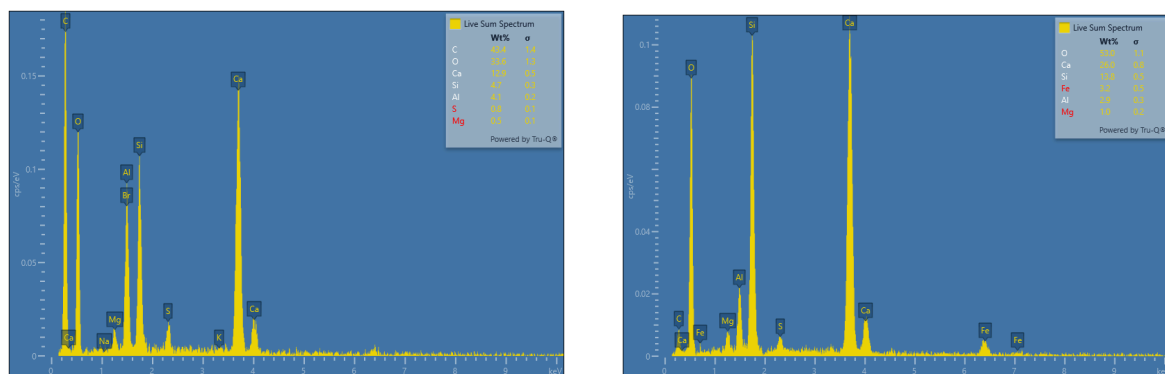


Figure 12: Result Chemical Properties from EDX for a and b

EDX analysis revealed that RRWS is rich in oxygen, indicating a high organic content. In addition, the presence of inorganic elements such as calcium and silicon supports its potential use as a partial cementitious material. However, the elevated organic load may negatively affect the strength and durability of paver blocks. The data also shows that increasing RRWS content raises the organic composition while slightly reducing mineral content, which corresponds with observed decreases in compressive strength and density.

6. CONCLUSION

The study successfully assessed the mechanical and physical properties of GP Blocks incorporating Recycled Raw Water Sludge (RRWS), revealing that increasing RRWS content led to reduced density and compressive strength, along with higher water absorption due to the fine and organic nature of the sludge, which introduced more voids into the concrete matrix. Despite these effects, blocks with 2.5% RRWS maintained acceptable strength (22.19 MPa), density (1995.3 kg/m³), and water absorption (11.25%), making them suitable for non-structural applications like walkways and driveways. SEM-EDX analysis confirmed the presence of calcium and silicon, supporting RRWS's role as a filler material, though its irregular particle shape and high organic content necessitate careful control to balance sustainability with structural integrity. The study recommends a 2.5% RRWS mix ratio as the optimal ratio, supported by proper curing for at least 28 days and leachability testing to ensure safety and durability. Additionally, it encourages further research to refine material characterization and expand RRWS applications in sustainable construction.

7. ACKNOWLEDGEMENTS

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through Multidisciplinary Research Grant (MDR), Vot. Q775.

REFERENCES

- Ahmadi, M., Hakimi, B., Mazaheri, A., & Kioumars, M. (2023). Potential Use of Water Treatment Sludge as Partial Replacement for Clay in Eco-Friendly Fired Clay Bricks. *Sustainability*, 15(12), 9389. <https://doi.org/10.3390/su15129389>
- Czechowska-Kosacka, A. (2019). Application of sewage sludge for the production of construction. *MATEC Web of Conferences*, 252, 05025. <https://doi.org/10.1051/mateconf/201925205025>
- Dharmaraj, R., Manikandan, P., Narayanan, K., Malathy, R., Alagumurugan, R., & Rajalingam, P. (2022). Study of impact of crumb rubber used as an aggregate in concrete mix. *Materials Today: Proceedings*, 68, 2104–2110. <https://doi.org/10.1016/J.MATPR.2022.08.371>
- Kumar, S., & Sharma, U. (2023). Comparative analysis between use of waste glass in rigid pavement and alkali resistant glass fibers for use in paver blocks. *Materials Today: Proceedings*, 93, 57–61. <https://doi.org/10.1016/J.MATPR.2023.06.236>
- Lynn, C. J., Dhir, R. K., Ghataora, G. S., & West, R. P. (2015). Sewage sludge ash characteristics and potential for use in concrete. *Construction and Building Materials*, 98, 767–779. <https://doi.org/10.1016/j.conbuildmat.2015.08.122>
- Mohamad, H. M. (2022). Manufacture of Concrete Paver Block using Waste Materials and by-products: a review. *International Journal of Geomate*, 22(93). <https://doi.org/10.21660/2022.93.j2363>
- Olofinnade, O., Morawo, A., Okedairo, O., & Kim, B. (2021). Solid waste management in developing countries: Reusing of steel slag aggregate in eco-friendly interlocking concrete paving blocks production. *Case Studies in Construction Materials*. <https://doi.org/10.1016/J.CSCM.2021.E00532>
- Soni, A., Rajput, T. S., Sahu, K., & Rajak, S. (2022). Utilization of Waste Plastic in Manufacturing of Paver

- Blocks. International Journal for Research in Applied Science and Engineering Technology, 10(2), 939–942. <https://doi.org/10.22214/ijraset.2022.40410>
- Sumanasooriya, Milani S., and Narayanan Neithalath. (2011) "Pore structure features of pervious concretes proportioned for desired porosities and their performance prediction."Cement and Concrete Composites, pp 778-787. <https://doi.org/10.1016/j.cemconcomp.2011.06.002>
- Yan,X.,Xu,Y.,Shen, X., Zhang, H., & Liu, R. (2024). Environment-friendly convert from waste textile sludge into lightweight aggregates by non-sintered technology: physical properties and mechanism. International Journal of Environmental Science and Technology. <http://doi.org/10.1007/s13762-024-05748-9>