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Mechanical Properties of Green Paver Block with Textile Dyeing Effluent Sludge Admixture

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Abstract

The rapid growth of the construction industry has increased the demand for paving blocks, raising concerns about the depletion of natural resources. This study explores the use of Textile Dyeing Effluent Sludge (TDES) in green paver blocks to assess its mechanical properties—density, compressive strength, water absorption, and initial rate of absorption—and to determine the optimum mix ratio. Paver blocks with varying TDES content (5%, 10%, 15%, and 20%) were compared to control blocks made with natural sand and Ordinary Portland Cement (OPC). Results showed that increasing TDES content reduced density and compressive strength due to the lightweight and porous nature of TDES. The TDS 5TDES mix, containing 5% TDES, demonstrated the best performance, achieving a compressive strength of 17.13 MPa and a density of 2161 kg/m^3 at 28 days, compared to the control mix with 52.65 MPa and 2216 kg/m^3. Water absorption and permeability increased with higher TDES content, with TDS 5TDES maintaining moderate absorption levels. These findings identify TDS 5TDES as a viable option for non-structural applications, promoting sustainable construction while addressing waste management in the textile industry. Further research is recommended to enhance mechanical properties and broaden the applicability of TDES-based materials.

Keywords

Textile, Waste Material, TDES, Textile Dyeing Effluent Sludge, Paver Block

1. Introduction

The construction industry is experiencing rapid growth, driving the demand for construction materials like paver blocks. While this progress is significant, it also raises concerns regarding natural resource conservation and sustainability. Malaysia, as an emerging economy, is promoting eco-friendly construction practices by adopting sustainable materials and methods. Paver blocks, traditionally made of Portland cement and natural aggregates, have long been used in various applications such as sidewalks, parking lots, and industrial settings due to their strength and versatility [1].

One such alternative approach is the use of industrial waste, such as Textile Dyeing Effluent Sludge (TDES), which offers the potential as a sustainable admixture in paver block production. TDES, a byproduct of the textile dyeing industry, contains a complex mix of chemical compounds and poses significant environmental challenges due to its hazardous composition [2]. Improper disposal methods, such as landfilling, further exacerbate environmental pollution and harm nearby ecosystems [3]. Incorporating TDES into paver blocks helps to address waste management issues, which can also help in minimizing the environmental pollution.

This research aims to evaluate the feasibility of using TDES in green paver blocks by analyzing their mechanical properties, including density, compressive strength, water absorption, and the initial rate of absorption, in compliance with IS 15658:2021, BS EN 12390-3:2009, and ASTM C1585 standards. Based on **Table 1**, the study also investigates the optimum mix ratios of TDES (5%, 10%, 15%, and 20%) in a design mix of 1:3:4 (Cement:Sand:Coarse aggregate). A total of 60 samples, measuring 215 mm × 100 mm × 65 mm, were prepared and cured for up to 28 days. Comparative analyses were conducted to evaluate the performance of modified paver blocks against control samples made with natural sand and Ordinary Portland Cement (OPC).

Table 1. Mix proportion of TDES to be admixture in green paver block.

Mix Name	% of TDES
TDS 0TDES (Control)	0%
TDS 5TDES	5%
TDS 10TDES	10%
TDS 15TDES	15%
TDS 20TDES	20%

This study holds significant environmental and industrial relevance, providing a sustainable solution for managing industrial waste while promoting eco-friendly construction practices. The integration of TDES into green paver blocks offers a novel approach to waste management, reduces environmental pollution, and advances circular economies within the construction industry. By optimizing TDES mix ratios, this research contributes to the development of durable and efficient materials, paving the way for sustainable construction solutions [1].

2. Material

2.1. Textile Dyeing Effluent Sludge (TDES)

Textile Dyeing Effluent Sludge (TDES) is a waste byproduct generated from wastewater treatment in textile manufacturing. It contains a mix of organic and inorganic substances, including residual dyes, heavy metals, salts, and various chemical additives [4]. If not properly managed, TDES can contribute to environmental pollution due to its complex composition [5]. Conventional disposal methods, such as landfilling and incineration, pose several challenges, including high moisture retention, potential leaching of contaminants, and air pollution from burning. An alternative and more sustainable approach involves repurposing TDES in the production of paver blocks. By adding TDES in the production can help in reducing environment pollution. While TDES possesses a low specific gravity of 0.87 which can be classified as a lightweight material. It presents limitations in structural applications such as paver blocks, where high strength and stability are required. However, its potential can be explored in surface treatments to improve water resistance and promote sustainable waste repurpose. SEM analysis of TDES indicates structural similarities with industrial by-products like fly ash and bottom ash due to agglomeration and phase transformations during wastewater treatment. This process results in a highly porous structure with a large surface area, influencing its chemical behavior and making it a viable material for specific sustainable construction applications. **Figure 1** shows the material of Textile Dyeing Effluent Sludge.

Figure 1. Textile dyeing effluent sludge.

2.2. Ordinary Portland Cement (OPC)

Ordinary Portland Cement was utilized as the primary binding material due to its widespread availability and cost-effectiveness in the Malaysian construction industry [6]. Its reliable performance and accessibility made it a preferred choice for various structural applications. To maintain its quality and workability, the cement was stored in a dry environment, protected from moisture and air exposure

[8]. Proper storage was crucial to preventing premature hydration, ensuring that cement retained its intended properties for optimal performance in construction applications.

2.3. Sand

Sand played a crucial role in the production of paver blocks by serving as a fine aggregate in the concrete mix. Its primary function was to enhance the strength and durability of the blocks by filling the voids between larger aggregates, ensuring a well-compacted and stable structure. Additionally, sand contributed to the workability of the mix, making it easier to handle, mold, and cast. It also helped achieve a smooth and uniform surface finish, improving the aesthetic quality of the paver blocks. Sand with a maximum particle size of 2.36 mm was used, following IS 15658:2021 standards, ensuring an optimal mix for enhanced performance and consistency in paver block production.

2.4. Coarse Aggregate

Compliance with IS 15658:2021 standards, coarse aggregates maintaining a maximum particle size of 12.5 mm. The selection was made to minimize voids and potential cracks within the concrete matrix, thereby improving the overall structural integrity of the paver blocks. This contributed to enhanced strength and durability, making the blocks more resistant to external loads [7] [8]. Additionally, weaker aggregates were excluded to maintain the quality and performance of the final product, ensuring long-term reliability in construction applications.

2.5. Superplasticizer (SP)

Commonly referred to as high-range water reducers, incorporated into the concrete mix to enhance its flowability, ensuring efficient filling of molds and reinforced sections. Their inclusion allowed for a significant reduction in the water-cement ratio while maintaining workability, ultimately improving the early strength and durability of the paver blocks [9]. Additionally, superplasticizers accelerated the initial setting time, contributing to a more efficient curing process. This admixture played a crucial role in minimizing shrinkage and enhancing the overall mechanical performance of the concrete [10]. In this study, the use of superplasticizers effectively improved the workability of the mix while adapting to the specific cement composition, ambient conditions, and mix design, resulting in high-quality, durable paver blocks.

3. Specimen Preparation

3.1. Collection of Materials

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

3.2. Mix Proportion

Table 2 provides an overview of the mix composition employed in this investigation, detailing the quantities of cement, sand, and water utilized. Also, **Table 3** delineates the mix proportions for incorporating Textile Dyeing Effluent Sludge as admixture in Green Paver Blocks. These proportions were formulated following the specified guidelines of IS 15658:2021.

Table 2. Mix ratio.

Cement:Sand:Coarse aggregate	Water	Superplasticizer
1:3:4	1.00	2% of cement weight

Table 3. Mix proportion of TDES and other materials.

Mix Name	Cement (kg/m^3)	Sand (kg/m^3)	Coarse Aggregate (kg/m^3)	TDES (kg/m^3)	Water (kg/m^3)	Superplasticizer (kg/m^3)
Control (0%)	221	793	1200	0	221	4.42
TDS 5TDES	221	793	1200	39.65	221	4.42
TDS 10TDES	221	793	1200	79.30	221	4.42
TDS 15TDES	221	793	1200	118.95	221	4.42
TDS 20TDES	221	793	1200	158.60	221	4.42

3.3. Mold Preparation

Paver block samples were prepared using molds with dimensions of 215 mm × 100 mm × 65 mm for compression testing. A total of 60 blocks were cast, with designated samples scheduled for testing at 7 and 28 days. To facilitate smooth demolding, the molds were thoroughly cleaned and coated with a thin layer of oil. The concrete mixture, consisting of sand, cement, water, coarse aggregate, Textile Dyeing Effluent Sludge (TDES), and a superplasticizer, were carefully measured and mixed according to specified proportions. The prepared mixture was then poured into the molds, manually compacted to eliminate trapped air, and labeled with sample numbers and test dates for identification. After molding, the blocks were allowed to harden for at least 24 hours before being demolded and placed in a curing tank. This curing process ensured adequate hydration, enhancing the durability and strength of the paver blocks. Following a structured preparation method ensured consistency and reliability in the samples for subsequent mechanical testing. **Figure 2** and **Figure 3** show the casting process of paver block.

3.4. Curing Process

The samples underwent water curing for the entire duration necessary to reach maturity. All samples, including the paver blocks up to the 28th day, were monitored to ensure the required concrete aging occurred. **Figure 4** indicates the curing process for paver block production.

Figure 2. Casting of paver block.

Figure 3. Paver block.

Figure 4. Curing process.

4. Laboratory Testing

4.1. Density Test

Density test was conducted to determine the mass per unit volume of green paver blocks, providing insights into their compactness, porosity, and structural integrity. This test is essential for evaluating material uniformity, consistency, and the overall performance characteristics of blocks, such as strength, durability, and thermal properties. A total of 30 clean, dry samples were prepared, and their volume was determined using an appropriate method. Each sample was weighed using a precise scale, and the density was calculated using the formula:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \tag{1}$$

4.2. Compressive Strength Test

Compressive strength test was conducted to evaluate the load-bearing capacity of green paver blocks incorporating Textile Dyeing Effluent Sludge (TDES). Blocks measuring 215 × 100 × 65 mm were used, with a total of 30 samples tested after 7 and 28 days of curing. The procedure followed BS EN 12390-3:2009 guidelines. Prior to testing, all equipment was inspected to ensure no foreign objects were present. 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.

4.3. Water Absorption Test

Water absorption test was conducted to evaluate the paver blocks' capacity to absorb water, providing insights into their porosity, permeability, and resistance to moisture infiltration—critical factors for assessing durability and suitability for construction applications. A total of 30 clean and dry samples were prepared and weighed to record their initial weights. The samples were then fully submerged in water at room temperature for a predetermined duration. After immersion, excess surface water was wiped off, and the samples were immediately weighed to determine their wet weights. The water absorption percentage was calculated using the formula:

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

The results provided valuable data on the material's moisture resistance and assisted in quality control and material selection for construction projects.

4.4. Initial Rate of Absorption Test

The Initial Rate of Absorption (IRA) test is a critical procedure to evaluate the surface water absorption capacity of concrete paver blocks during early moisture contact, providing insights into their porosity, permeability, and durability. The test involves drying the paver block to a constant mass at 105°C, cooling it to room temperature, and recording its dry weight (M1). The sample is then partially submerged in water (3 - 5 mm depth) for one minute, after which excess water is gently blotted, and the wet weight (M2) is measured. The IRA value is calculated using the formula:

$$\text{IRA} = \frac{M_2\left(\text{Mass after absorption}\right) - M_1\left(\text{Mass Initial}\right)}{\text{Area}} \tag{3}$$

This test ensures the paver block meets quality standards by identifying potential issues such as high absorption, which can affect bonding, durability, and resistance to weathering.

5. Results and Discussion

5.1. Density

According to **Figure 5**, the control mix (0% TDES) recorded the highest density of 2216 kg/m³, serving as the baseline for comparison. As TDES content increased, the density decreased, with TDS 5TDES (5% TDES) achieving 2161 kg/m³, TDS 10TDES (10% TDES) at 2018 kg/m³, and TDS 15TDES (15% TDES) at 1965 kg/m³. Interestingly, TDS 20TDES (20% TDES) showed a slight increase to 2023 kg/m³, though it remained lower than the control.

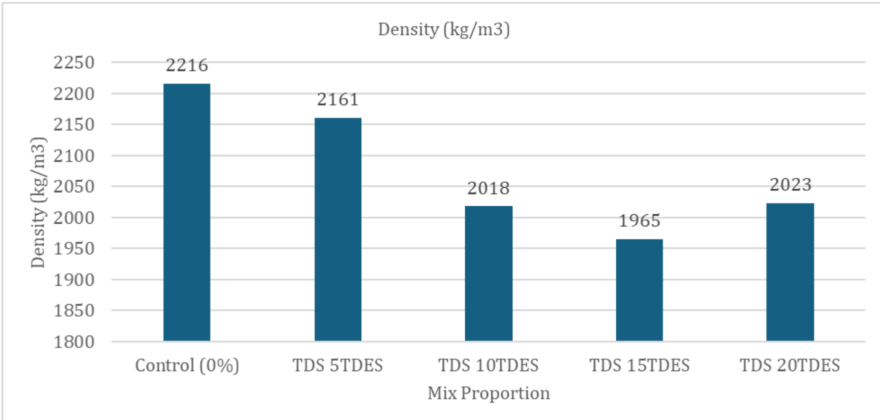

Figure 5. Average Density (kg/m³).

Table 4. Density results of green paver block.

Mix Proportion	Density (kg/m³)
TDS 0TDES (Control)	2216
TDS 5TDES	2161
TDS 10TDES	2018
TDS 15TDES	1965
TDS 20TDES	2023

The reduction in density (see **Table 4**) is attributed to the lightweight, porous nature of TDES, which replaces denser materials like fine aggregates. TDES particles, with irregular shapes and high porosity, create air voids in the matrix, further reducing density. Increased porosity at higher TDES levels also limits compaction efficiency during production. Additionally, the low specific gravity of 0.87 contributes to the overall density reduction, as it indicates the material's lower mass relative to water. This low specific gravity suggests a high air content within the particles, further exacerbating the reduction in overall density. The slight recovery in density for TDES 20 may result from particle rearrangement during curing, though it does not offset the overall decreasing trend.

5.2. Compressive Strength

Based on **Figure 6**, the control mix demonstrated the highest compressive strength, measuring 35.67 MPa at 7 days and 52.65 MPa at 28 days, establishing a benchmark for comparison. The TDS 5TDES mix (5% TDES) exhibited a significant reduction, achieving only 13.53 MPa at 7 days and 17.13 MPa at 28 days, representing a 62% and 67% decline, respectively. With higher TDES content (10%, 15%, and 20%), compressive strength continued to decrease sharply, reaching as low as 3.88 MPa at 28 days.

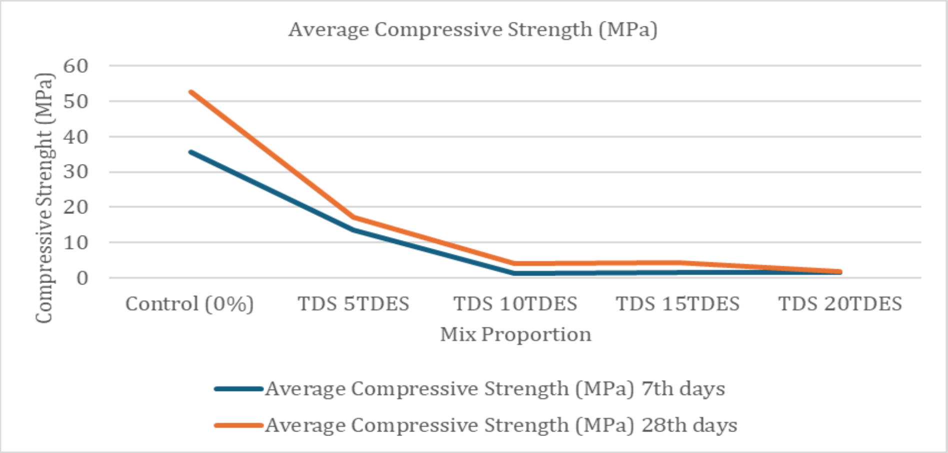

Figure 6. Average compressive strength (MPa).

Table 5. Compressive strength results of green paver block.

Mix Proportion	Compressive Strength (MPa)	
	7th days	28th days
TDS 0TDES (Control)	33.67	52.65
TDS 5TDES	13.53	17.13
TDS 10TDES	1.15	4.04
TDS 15TDES	1.38	4.14
TDS 20TDES	1.36	1.80

The reduction in compressive strength (see **Table 5**) is primarily attributed to the lightweight and porous nature of TDES, which weakens the cementitious matrix by introducing voids and reducing bonding capacity. Additionally, the uneven distribution of TDES particles during mixing created inconsistencies within the concrete structure, further compromising strength. At higher TDES levels, increased porosity and particle clustering hindered the hydration process, limiting the formation of calcium silicate hydrate (C-S-H), which is crucial for strength development. While the TDS 5TDES mix maintained acceptable strength for low-structural applications, higher TDES content significantly impaired performance, emphasizing the need to optimize mix design, compaction, and curing processes to mitigate its negative effects.

5.3. Water Absorption

Water absorption test, conducted in accordance with IS 15658:2021 standards, evaluated the performance of 30 green paver block samples containing varying proportions of Textile Dyeing Effluent Sludge (TDES).

From **Figure 7**, the control mix demonstrated the lowest water absorption rates, with 4.03% at 7 days and 2.48% at 28 days, reflecting its dense and impermeable structure, ideal for structural applications. As TDES content increased, water absorption rates rose due to the porous and lightweight nature of TDES, which introduced micro-voids and reduced the blocks' density and impermeability. TDS 5TDES (5% TDES) showed moderate absorption rates of 5.63% at 7 days and 5.87% at 28 days, a 28% and 81% increase compared to the control. Higher TDES content, such as in TDS 10TDES, resulted in the highest absorption rates (8.64% at 7 days and 8.50% at 28 days), attributed to increased voids and irregularities in the matrix. Slightly lower absorption rates in TDS 15TDES and TDS 20TDES were observed, potentially due to partial densification during curing. However, the porous nature of TDES and challenges like uneven particle distribution and inconsistence curing further elevated water absorption across all TDES mixes.

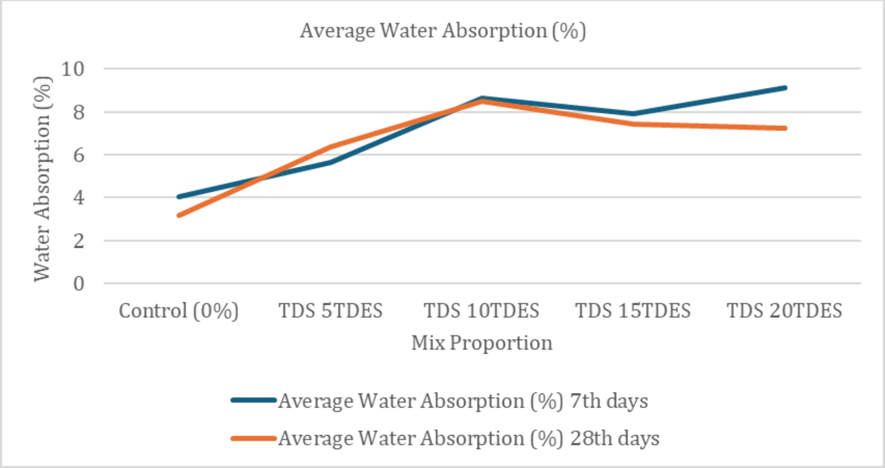

Figure 7. Average water absorption (%).

These results from **Table 6** highlight that while TDES enhance sustainability, higher proportions may limit paver blocks' applications in environments requiring high durability and low permeability.

Table 6. Water absorption results of green paver block.

Mix Proportion	Water Absorption (%)	
	7th days	28th days
TDS 0TDES (Control)	4.03	3.17
TDS 5TDES	5.63	6.39
TDS 10TDES	8.64	8.50
TDS 15TDES	7.93	7.41
TDS 20TDES	9.10	7.24

5.4. Initial Rate of Absorption

The Initial Rate of Absorption (IRA) test, conducted in accordance with ASTM C1585 standards, assessed the surface porosity and permeability of green paver blocks with varying Textile Dyeing Effluent Sludge (TDES) content.

From **Figure 8**, the control sample (0% TDES) exhibited the lowest and most consistent IRA values, with 0.08 g/cm²/min at 7 days and 0.05 g/cm²/min at 28 days, reflecting its dense and impermeable structure. TDS 5TDES (5% TDES) showed comparable performance, with IRA values of 0.06 g/cm²/min at both 7 and 28 days, indicating minor porosity attributed to TDES but relatively stable results due to effective bonding and particle packing aided by a naphthalene-based superplasticizer.

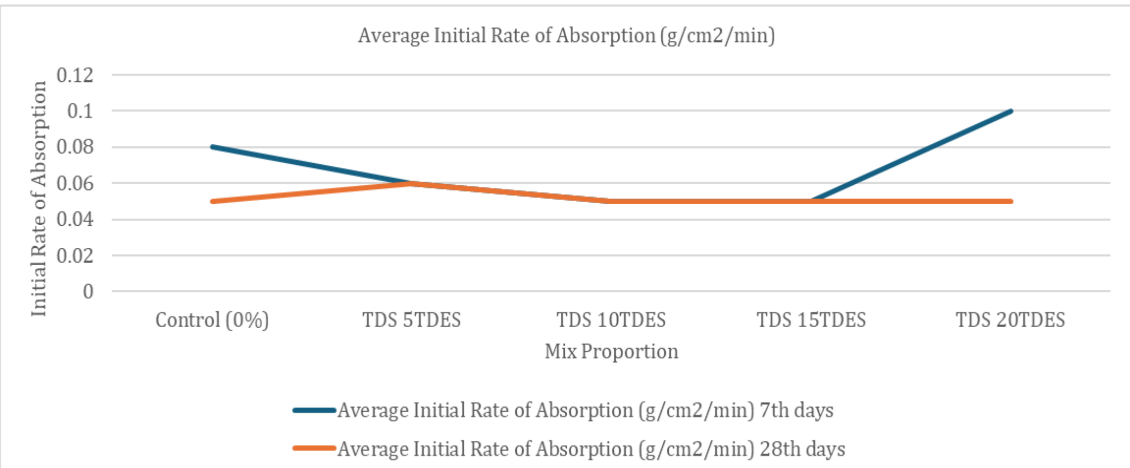

Figure 8. Average initial rate of absorption (g/cm²/min).

Table 7 highlights the variations in the Initial Rate of Absorption (IRA) among different TDES mix proportions. The TDS 10TDES (10% TDES) mix showed a significant decline in IRA to 0.03 g/cm²/min at 7 days, indicating that microvoids were partially filled, leading to reduced surface permeability. However, at 28 days, the IRA remained similar to the control mix, suggesting minimal additional densification over time. In contrast, TDS 15TDES (15% TDES) recorded the highest IRA at 7 days, reaching 0.19 g/cm²/min—an 81% increase compared to the control. This spike was likely due to uneven particle distribution and the formation of surface voids. Over time, with extended curing, partial particle rearrangement occurred, reducing the IRA to 0.03 g/cm^2/min at 28 days. Meanwhile, TDS 20TDES (20% TDES) demonstrated stable IRA values of 0.06 g/cm^2/min at 7 days and 0.05 g/cm^2/min at 28 days. This suggests a balance between the increased porosity introduced by the TDES and the gradual densification during curing, contributing to a more consistent absorption behavior over time.

These results highlight the impact of TDES properties, such as irregular particle shapes and porosity, on absorption behaviour, with lower TDES content maintaining stable IRA values and higher content introducing irregularities and elevated absorption rates.

Table 7. Initial rate of absorption results of green paver block.

Mix Proportion	Initial Rate of Absorption (g/cm^2/min)	
	7th days	28th days
TDS 0TDES (Control)	0.08	0.05
TDS 5TDES	0.06	0.06
TDS 10TDES	0.05	0.05
TDS 15TDES	0.05	0.05
TDS 20TDES	0.10	0.05

6. Conclusion

The study concludes that incorporating Textile Dyeing Effluent Sludge (TDES) into green paver blocks offers a sustainable solution for construction materials, with TDS 5TDES (5% TDES) emerging as the optimal mix. This mix achieved a balance between density, compressive strength, and water absorption, demonstrating satisfactory performance for non-structural applications such as decorative and landscaping uses. Higher TDES proportions (10% - 20%) resulted in significant reductions in mechanical properties due to increased porosity, weak bonding, and interference with the hydration process. While TDS 5TDES offers a viable option for promoting sustainability and addressing waste management challenges in the textile industry, further research is recommended to refine its formulation, improve mechanical properties, and expand its applications.

7. Recommendations

Future research on incorporating Textile Dyeing Effluent Sludge (TDES) into paver blocks should focus on long-term durability, environmental impact, and optimizing mix designs. Key areas include evaluating resistance to environmental stress, chemical degradation, and energy consumption through comprehensive life cycle assessments. Exploring broader ratios and additives like superplasticizers can enhance mechanical properties; while studying the interaction between TDES and superplasticizers can improve structural integrity. These efforts aim to refine TDES-based formulations and advance sustainable construction materials.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Rathee, M. and Singh, N. (2022) Durability Properties of Copper Slag and Coal Bottom Ash Based I-Shaped Geopolymer Paver Blocks. *Construction and Building Materials*, **347**, 128461. https://doi.org/10.1016/j.conbuildmat.2022.128461

[2] Wang, Y., Qiu, L., Hu, Y., Chen, S. and Liu, Y. (2023) Influential Factors on Mechanical Properties and Microscopic Characteristics of Underwater 3D Printing Concrete. *Journal of Building Engineering*, **77**, 107571. https://doi.org/10.1016/j.jobe.2023.107571

[3] Kanmani, S., Anandaraj, S., Shankar, D., Remya, P.R., Vijaymohan, S., Miruthun, G., et al. (2022) A Novel Approach on Usage of Waste Sludge from Textile Dyeing Units in Paver Block Manufacturing. *Materials Today: Proceedings*, **52**, 1952-1958. https://doi.org/10.1016/j.matpr.2021.11.599

[4] Raju, L. and Vasanth Kumar, D. (2025) Biological Sludge from Textile Dyeing Effluent Treatment Plant—Characterization, Combustion Simulation and Its Impact on Air Pollution. *Results in Engineering*, **25**, 103850. https://doi.org/10.1016/j.rineng.2024.103850

[5] Pan, K., Qian, Z., Guo, T., Chen, Y., Li, F., Ding, M., et al. (2024) Stability and Performance of Aerobic Granular Sludge for Treatment of Textile-Dyeing Wastewater. *Journal of Water Process Engineering*, **63**, 105401. https://doi.org/10.1016/j.jwpe.2024.105401

[6] Meng, L., Yi, H., Park, K., Lin, R. and Wang, X. (2025) Partial Replacement of Ordinary Portland Cement with Belite-Rich Cement to Produce Limestone Calcined Clay Cement to Regulate the Hydration Process, Improve Strength, and Reduce Carbon Emissions. *Construction and Building Materials*, **460**, 139865. https://doi.org/10.1016/j.conbuildmat.2025.139865

[7] Kojima, K., Luo, X., Kim, J. and Hama, Y. (2024) Effects of Drying and Wetting on the Microstructure of Ordinary Portland Cement and Blast Furnace Slag Cement during Drying-Wetting Cycles. *Construction and Building Materials*, **457**, 139539. https://doi.org/10.1016/j.conbuildmat.2024.139539

[8] Li, C., Qiao, A., Song, X., Ma, K., Yin, W. and Long, G. (2025) Influence of Coarse Aggregate Morphology on Stacking Voidage and Its Numerical Calculation. *Structures*, **71**, 108101. https://doi.org/10.1016/j.istruc.2024.108101

[9] Erdem, E., Aydın, G.M. and Kılınçarslan, R. (2024) Production of High Strength and Colored Concrete Using Textile Waste Reactive Dyestuffs as Superplasticizers. *Construction and Building Materials*, **418**, 135382. https://doi.org/10.1016/j.conbuildmat.2024.135382

[10] Das, R., Panda, S., Saumendra Sahoo, A. and Kumar Panigrahi, S. (2024) Effect of Superplasticizer Types and Dosage on the Flow Characteristics of GGBFS Based Self-Compacting Geopolymer Concrete. *Materials Today: Proceedings*, **103**, 11-21. https://doi.org/10.1016/j.matpr.2023.06.339