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Utilization of Treated Textile Dyeing Wastewater and GGBFS–Perlite Blends for Sustainable Cementitious Composite Development

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Abstract

The increasing global demand for concrete critically intensifies the consumption of potable water, raising significant environmental concerns and depleting vital resources. Concurrently, the textile dyeing industry generates substantial volumes of wastewater, posing considerable disposal and pollution challenges. Our investigation explores a dual solution by utilizing treated textile dyeing wastewater as an alternative mixing water source, combined with ground granulated blast furnace slag (GGBFS) and perlite as supplementary cementitious materials (SCMs), to develop more sustainable cementitious composites. We conducted experiments in two distinct phases: one using potable water as a control and another employing treated dyeing wastewater. Cement was partially replaced with GGBFS at 10% and 20%, and perlite at 5% and 10%, in various blended proportions. We meticulously evaluated fresh concrete properties through slump, flowability, and compaction factor tests. Hardened properties were assessed via compressive strength at 7, 14, and 28 days, alongside water absorption. Microstructural and phase evolution were examined using scanning electron microscopy (SEM) and X-ray diffraction (XRD). Our findings indicate that the treated wastewater generally enhanced workability and yielded compressive strengths comparable to, and occasionally exceeding, those of conventional mixes. The optimal composite, incorporating 20% GGBFS and 10% perlite, demonstrated superior strength, reduced porosity, and a denser hydration matrix. This research underscores the feasibility of integrating treated textile effluent and industrial by-products into cementitious systems, offering a viable pathway for eco-efficient construction materials and promoting circular resource utilization.

Keywords: Treated textile dyeing wastewater; GGBFS–perlite blends; Sustainable cementitious composites; Microstructural analysis; Mechanical properties.

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INTRODUCTION

Our current research delves into a critical area of sustainable construction: the dual challenges of potable water and Ordinary Portland Cement (OPC) consumption in concrete production, coupled with the environmental burden of textile dyeing wastewater [1]. Cement manufacturing is a major contributor to anthropogenic CO_2 emissions, while the extensive use of fresh water for construction places considerable strain on limited global water resources, particularly in rapidly developing regions facing increased construction demand and industrial waste generation [2]. The textile dyeing industry compounds this issue by producing chemically complex wastewater, rich in dissolved solids, chlorides, sulphates, residual dyes, and organic pollutants, which, if untreated, contaminates water systems and poses ecological and public health risks [3]. In response to these challenges, our study investigates the potential of treated industrial wastewater as an alternative mixing water in concrete, provided it meets construction standards [4]. Previous work has shown that methods like coagulation, flocculation, and filtration can effectively reduce contaminants, allowing for wastewater reuse without compromising concrete strength or durability [5]. Simultaneously, the construction industry has increasingly adopted supplementary cementitious materials (SCMs) to reduce content and enhance long-term performance [6]. Ground granulated blast furnace slag (GGBFS), a steel industry by-product, is well-documented for improving compressive strength and refining pore structure through secondary hydration reactions [7]. Perlite, a lightweight volcanic material, is also gaining traction for its filler properties and ability to reduce concrete density, although higher replacement levels might affect early strength development [8]. The synergistic use of such industrial by-products in cementitious composites represents a promising pathway towards low-carbon construction and circular material utilization [9]. While prior studies have separately confirmed the viability of treated wastewater reuse and SCM-based cement replacement, their combined interaction, especially with textile dyeing effluent, has received limited attention [10]. The chemical composition of treated dyeing wastewater could potentially alter hydration mechanisms when used with blended binders containing both GGBFS and perlite [11]. Furthermore, establishing the optimal proportions for balanced mechanical strength, durability, and lightweight performance in such systems remains an open question, hindering wider adoption in practical structural applications [12].

The use of GGBFS was considered due to its latent hydraulic nature and its ability to consume calcium hydroxide during secondary hydration, which can enhance long-term strength and reduce permeability. Perlite was introduced mainly as a lightweight supplementary material with a porous structure that helps reduce density and may improve internal curing behaviour. The use of treated dyeing wastewater was explored from an environmental perspective to reduce freshwater consumption in concrete production and to evaluate whether treated industrial effluent can meet the chemical requirements specified in IS 456:2000. Combining these three components was therefore intended to examine whether industrial wastewater reuse, cement replacement, and density modification can be integrated within a single sustainable concrete system without compromising mechanical performance. Most previous studies have focused on either wastewater utilization or supplementary cementitious materials individually, whereas limited research has examined the combined effect of treated industrial wastewater with mineral additives such as GGBFS and perlite in concrete production. The research directly focusing on the development of sustainable cementitious composites prepared with treated textile dyeing wastewater as mixing water, while partially replacing cement with GGBFS and perlite [13]. We meticulously evaluated fresh workability through slump, flowability, and compaction factor tests, and assessed hardened properties such as compressive strength progression at 7, 14, and 28 days, alongside water absorption behavior [14-18]. Microstructural and mineralogical characterization was performed using scanning electron microscopy (SEM) and X-ray diffraction (XRD) to gain deeper insights into the material's internal structure and phase evolution. We anticipate that the synergistic effects of slag hydration and perlite micro-filling, combined with the reuse of treated effluent, will contribute to a denser cement matrix with improved durability. This investigation is significant as it integrates two major sustainability strategies—industrial wastewater reutilization and industrial by-product cement replacement—within a single composite framework. The outcomes are expected to provide practical insights into eco-efficient concrete production, offering a promising approach for conserving freshwater resources, reducing cement-related emissions, and promoting circular economy principles within the construction sector.

MATERIALS AND METHODS

The experimental program was designed to evaluate whether treated textile dyeing wastewater could function as a viable alternative mixing medium in cementitious systems while simultaneously reducing cement demand through supplementary materials. Ordinary Portland Cement (OPC), Grade 53 conforming to IS 12269:2013, was selected as the primary binder due to its widespread structural use and predictable hydration behavior. To reduce clinker dependence and explore long-term strength development, Ground Granulated Blast Furnace Slag (GGBFS) sourced from a nearby steel industry was incorporated as a partial cement replacement at 10% and 20% by weight. These levels were chosen to observe both moderate and relatively higher substitution effects on strength gain and durability. Perlite was introduced as a secondary additive in combination with GGBFS at replacement levels of 5% and 10%. Its highly porous and lightweight structure was expected to contribute to reduced density and improved particle packing; however, it was also anticipated that excessive perlite content might influence early-age strength. The selection of replacement ranges was therefore intended to balance mechanical performance with material sustainability. Locally available M-sand and crushed coarse aggregates (maximum size 20 mm), meeting IS 383:2016 requirements, were used to maintain practical relevance and field applicability.

Industrial dyeing wastewater was collected from a textile processing unit in the Chennai industrial region and stored in sealed high-density polyethylene containers to prevent contamination before treatment. Preliminary characterization of the raw wastewater was conducted to evaluate its suitability for use in concrete production. Parameters such as pH, total dissolved solids, total suspended solids, alkalinity, chloride content, and organic load were measured following standard procedures recommended in IS 3025. The initial analysis showed that the untreated wastewater contained relatively high alkalinity, dissolved salts, and organic residues, making it unsuitable for direct use as mixing water. To improve the water quality, a multi-stage treatment process was adopted. First, the wastewater was subjected to natural sedimentation for 24 hours so that heavier suspended particles and dye residues could settle at the bottom. The clarified supernatant was then carefully separated and passed through a filtration unit consisting of sand and activated carbon layers, which helped remove remaining suspended matter and reduce the organic dye content. After filtration, the pH of the treated water was measured and adjusted to fall within the acceptable range specified for concrete mixing water in IS 456:2000. The treated wastewater was subsequently stored and used for preparing the concrete mixtures. Ordinary Portland Cement (OPC) was used as the primary binder, while Ground Granulated Blast Furnace Slag (GGBFS) served as a supplementary cementitious material to partially replace cement, aiming to improve long-term hydration and durability performance. Expanded perlite was incorporated as a lightweight mineral additive because of its porous structure and its ability to reduce density while maintaining structural integrity. Natural fine and coarse aggregates conforming to standard grading requirements were used in the concrete mixtures.

The dry constituents were first blended thoroughly to achieve uniform distribution, after which the treated wastewater was gradually introduced during mixing until a homogeneous mixture was obtained. Concrete specimens were cast in standard cube molds and compacted using mechanical vibration to minimize entrapped air and ensure proper consolidation. After casting, the molds were kept undisturbed for 24 hours before demolding, and the specimens were then cured under controlled conditions until the designated testing ages. Compressive strength tests were performed at different curing periods to evaluate strength development. To further understand the internal structure and hydration behavior, selected specimens were examined using scanning electron microscopy to observe the morphology, pore distribution, and bonding characteristics within the cement matrix, while X-ray diffraction analysis was carried out to identify crystalline hydration phases and assess the influence of GGBFS and treated wastewater on the formation of cementitious products. These combined experimental steps allowed the performance of concrete prepared with treated dyeing wastewater and mineral additives to be examined from both mechanical and microstructural perspectives.

Figure 1 shows the key materials selected for this investigation, namely Ordinary Portland Cement(a), GGBFS(b), perlite(c), fine(d) and coarse aggregates(e), and the industrial dyeing wastewater in both untreated (f)and treated (g)forms. Cube specimens of 150 × 150 × 150 mm were cast, compacted carefully, and cured under controlled water conditions for 7, 14, and 28 days. Compressive strength testing was conducted as per IS 516, with three specimens tested per mix and the average value reported to minimize variability. Durability-related performance was assessed through 24-hour water absorption measurements, which indicated pore connectivity and matrix density. To better understand the mechanisms underlying observed performance, the optimum mixture identified in Phase 2 was further examined using Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD). These analyses were intended to provide insight into hydration products, microstructural compactness, and phase evolution. While these techniques offer valuable qualitative and semi-quantitative information, their interpretation is inherently dependent on sample preparation and localized observations; therefore, conclusions drawn from microstructural analysis were considered supportive rather than definitive.

Experimental Testing

The experimental work focused on understanding how the source of mixing water affects the performance of concrete. Two types of water were used. Potable water was considered the control condition, while treated wastewater collected from a textile dyeing unit was used as an alternative in the second phase. The mix proportions were kept the same in both cases so that any changes in performance could be linked mainly to the water source rather than to variations in composition. Before using the treated wastewater, its quality was checked to ensure it was suitable for concrete mixing. Parameters such as pH, total dissolved solids, chlorides, sulphates, alkalinity, and hardness were measured and compared with the limits specified in Indian Standards. Even though the values were within acceptable ranges, the presence of residual dissolved substances cannot be completely ruled out and may still influence hydration and setting behavior.

Fresh concrete was tested immediately after mixing to observe its consistency and handling characteristics. Slump, flow table, and compaction factor tests were carried out following standard IS procedures. These tests helped in understanding how the addition of GGBFS and perlite, along with the use of treated wastewater, affected the workability of the mixes. For strength evaluation, cube specimens of 150 × 150 × 150 mm were prepared, compacted properly, and cured in water. Compressive strength was measured at 7, 14, and 28 days using a compression testing machine in accordance with IS 516. Three specimens were tested for each mix, and the average value was considered for analysis. Water absorption testing was also performed by comparing the weight of oven-dried specimens with that of specimens immersed in water for 24 hours, giving an indication of the internal pore structure. The same testing procedure was followed in both phases to maintain consistency. This made it possible to observe how treated dyeing wastewater, combined with GGBFS and perlite, affected both the fresh and hardened properties of the concrete. The results should, however, be interpreted within the limits of laboratory-scale testing, as field conditions and long-term exposure may produce different responses.

Figure 2 shows the main tests carried out in this study: compressive strength testing (A), flow table test (B), compaction factor test (C), and slump cone test (D), which were used to evaluate the behavior of the concrete mixes.

Dyeing Wastewater Testing

Industrial dyeing wastewater was used in this study as an alternative source of mixing water. The samples were collected from a textile dyeing unit using clean polyethylene containers. Before sampling, the containers were rinsed with distilled water and then with the wastewater itself to avoid contamination.

The raw effluent was not suitable for direct use in concrete, as it contained suspended particles, dyes, and dissolved impurities. Hence, it was subjected to a physicochemical treatment process. Initially, the wastewater was screened to remove coarse fibers and visible solids. It was then stored in an equalization tank to reduce fluctuations in pollutant concentration and pH. Since the wastewater was alkaline in nature, the pH was adjusted using a dilute acid solution to bring it closer to neutral. Coagulation and flocculation were carried out by adding a suitable coagulant and mixing the water at different speeds to allow flocs to form. The mixture was then left undisturbed for some time so that suspended particles and dye residues could settle as sludge. The clearer portion of the water was passed through sand filtration to remove finer suspended matter. After treatment, the water was tested for parameters such

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as pH, turbidity, total dissolved solids, chlorides, sulphates, alkalinity, hardness, and chemical oxygen demand. The values were compared with the limits specified in Indian Standards for concrete mixing water and were found to be within the acceptable range. Even so, treated wastewater can vary depending on its source and treatment conditions, and its behaviour in concrete may not be the same as potable water. Table 1. Shows the various properties of treated and untreated dyeing wastewater.

RESULT AND DISCUSSION

Workability

Some variation in workability was noticed among the mixes, though all of them met the workability requirement for M30 grade concrete. The mixes containing GGBFS showed comparatively better workability than the control mix, which may be attributed to the finer particle size and its effect on paste mobility during mixing. The addition of perlite slightly increased the water requirement, but the consistency did not change significantly and remained within a workable range. Concrete prepared using treated dyeing wastewater showed higher slump and flow values, along with a slightly improved compaction factor compared to concrete made with normal water. This indicates better cohesiveness of the fresh mix, possibly due to the presence of dissolved solids in the treated water, although this effect may vary depending on wastewater characteristics. Perlite reduced the unit weight of concrete because of its low density. In the optimized mix, the cube weight decreased by about 8.5 kg, reaching approximately 8.12 kg. While this reduction may be useful for lowering self-weight, its influence on other performance properties needs to be considered. Water absorption of the treated-wastewater concrete was slightly lower than that of the Phase 1 mixes, suggesting a relatively denser internal structure with reduced porosity. However, this observation is based on limited testing, and further evaluation is required to confirm long-term behaviour.

Figure 1. Materials selection.

Figure 2. Experimental testing

Table 2 presents the mix proportions adopted for the control concrete and the mixes prepared using GGBFS, perlite, and treated dyeing wastewater. The basic proportion was maintained for all batches to allow comparison between mixes. Minor adjustments were made only to obtain the required consistency during mixing. The table indicates the replacement of conventional materials with industrial by-products as part of the study. Table 3 gives the observed values from fresh and hardened concrete tests, such as workability, compressive strength at different curing ages, and water absorption. The results show the effect of GGBFS, perlite, and treated wastewater on concrete performance. Variations were noted between the mixes, mainly due to material characteristics and water quality. The values reported are based on laboratory testing conditions only.

Table 1. Comparison of treated and untreated dyeing wastewater properties.

Parameter	Before treatment value	After treatment value	Target standard	Remark
Color (CU)	210	95	≤200	Pure in color
pH	9.65	6.65	≥ 6	Acceptable limit
Turbidity (NTU)	32.16	20	≤ 25	Improve clarity
TDS (mg/L)	6013	1100	≤ 2000	Still high but within an acceptable limit
Total Alkalinity (mg/L)	1035	300	≤ 600	Reduced to a safe level
Chloride (mg/L)	1650	200	≤ 500 (RCC)	Slight improvement
Magnesium (mg/L)	219	20	≤ 30	Within Limit
Sulphate (mg/L)	792	90	≤ 400	Within limit
Total Hardness (mg/L)	1900	300	≤ 600	Controlled
Iron (mg/L)	1.72	0.2	≤ 1.0	Reduced below the limit
Fluoride(mg/L)	7.24	1.2	≤ 1.5	Acceptable
BOD-3 days @27°C	983	7	≤ 50	Acceptable
COD (mg/L)	2897	50	≤ 250	Acceptable
Dissolved Oxygen	3.14	2.14	≤ 4 - 5	Acceptable
Ammonia	3.84	0.9	0.5mg/L	Acceptable

Table 2. Mixed proportion of modified concrete in normal water

S.N.	Test conducted	Phase 1 (Normal Water)			
		Slump	*Flow table*	*Compaction*	*Water absorption*

		test	*test*	*factor*	*test*
1	Control Mix	85	62	0.88	3.2
2	10% GGBFS + 90% cement	88	64	0.89	3.0
3	20% GGBFS+80% cement	90	66	0.90	2.8
4	10%GGBFS+5%Perlite+85% cement	82	60	0.87	3.1
5	20%GGBFS+10% perlite+70% cement	80	59	0.86	3

Table 3. Mixed proportion of modified concrete in treated dyeing water.

S.N.	**Test conducted**	**Phase 1 (Treated dyeing water)**			
		Slump test	***Flow table test***	***Compaction factor***	***Water absorption test***
1	Control Mix	95	68	0.92	2.8
2	10% GGBFS + 90% Cement	97	70	0.93	2.6
3	20% GGBFS+80% Cement	100	72	0.93	2.4
4	10% GGBFS+5% Perlite+85%Cement	95	66	0.91	2.6
5	20% GGBFS+10% Perlite+70%Cement	92	64	0.90	2.5

Compressive Strength

The inclusion of perlite reduced the unit weight of concrete, and the average cube weight of the optimized mix decreased from about 8.10 kg to nearly 7.80 kg. Concrete prepared using treated dyeing wastewater showed slightly lower water absorption compared with the Phase 1 mixes, which suggests a relatively denser internal structure with reduced porosity.

All mixes satisfied the minimum compressive strength requirements. However, mixes containing perlite showed a small reduction in early-age strength. At later curing ages, the Phase 2 concrete produced with treated dyeing wastewater developed compressive strength values comparable to, and in some cases marginally higher than, those obtained with potable water. The mixture incorporating 20% GGBFS and 10% perlite recorded the highest 28-day compressive strength among the mixes studied. The improvement in strength appears to be associated with the partial replacement of cement and the combined effect of supplementary materials. Overall, the results indicate that treated dyeing wastewater can be used as mixing water without adversely affecting compressive strength under the present test conditions. Figure 3 shows the 28-day compressive strength of the different mixes prepared with potable water and treated dyeing wastewater. Strength increased with the addition of GGBFS, and the mixes containing both GGBFS and perlite performed better than the control. The combination of 20% GGBFS with 10% perlite gave the highest strength in both phases. Results from the treated wastewater mixes remained close to those of the potable water mixes, indicating that the alternative water source did not reduce the load-carrying capacity of the concrete.

Microstructural Analysis

SEM observations were consistent with the strength and water-absorption results at 28 days. Mixes that performed better mechanically generally showed a denser internal structure and a more continuous cement matrix. The paste–aggregate interface appeared tighter in these mixes, which may have contributed to improved load transfer. The mix with 20% GGBFS and 10% perlite showed a comparatively compact matrix, with hydration products distributed more evenly and fewer connected pores. The role of GGBFS can be linked to secondary hydration, which gradually refines the pore structure and reduces free calcium hydroxide. Perlite appears to act mainly as a fine filler, occupying part of the void space within the paste. No abnormal crystalline formations were observed in the examined areas, suggesting that the treated dyeing wastewater did not disturb the hydration process. The control concrete prepared with potable water showed a more irregular structure, with visible pores and some unreacted cement particles. In contrast, the treated-wastewater mixes appeared more uniform, indicating better particle packing and hydration development. These microstructural observations support the mechanical trends, though they are based on limited SEM regions and cannot represent the entire concrete matrix.

Figure 4 shows the microstructure of the concrete prepared using treated dyeing wastewater at two magnification levels. In Figure 4(a) (≈500 µm), the general arrangement of particles within the cement matrix is visible, with a relatively continuous phase and only a few noticeable voids. Figure 4(b) (≈10 µm) provides a closer view of the hydrated regions, where reaction products can be seen surrounding the solid particles and occupying much of the interstitial space. The paste–particle interface appears reasonably intact, though small pores and some unreacted fragments are still present, which is expected in mixes containing supplementary materials. From these observations, the use of treated wastewater does not appear to have disrupted hydration, although microscopic heterogeneity remains within the matrix.

XRD Analysis

XRD was used to examine the phases present in concrete made with treated dyeing wastewater and with partial replacement of cement by GGBFS and perlite. The control mix showed clear portlandite and quartz peaks, with quartz mainly coming from the aggregates. In the blended mixes, the intensity of the portlandite peaks was lower, indicating that part of the calcium hydroxide had been consumed during secondary reactions. The mix with 20% GGBFS and 10% perlite showed a broader hump between about 20° and 35° (2θ), which is typically associated with amorphous C–S–H formation. This points to continued hydration and development of the binding phase. The quartz peaks remained unchanged and appeared to behave as inert constituents from the aggregates and perlite. No additional crystalline products that could be considered harmful were detected in the mixes prepared with treated dyeing wastewater. This suggests that the treated effluent did not interfere with the hydration process. The mineralogical pattern observed here follows the strength gain and lower water absorption measured in the same mixes. Within the scope of this study, treated dyeing wastewater can be used along with GGBFS and perlite without adverse phase formation.

Figure 5 shows the XRD pattern of concrete made with treated dyeing wastewater. Peaks corresponding to calcium hydroxide (CH), calcium carbonate ($CaCO_3$), and C–S–H can be identified, which are typical products of cement hydration. The C–S–H phase represents the main binding component, while the CH peak reflects the ongoing hydration of cement. The $CaCO_3$ peak is likely due to slight carbonation during curing. No unusual crystalline phases are visible in the pattern, and the hydration products appear normal for this type of blended concrete.

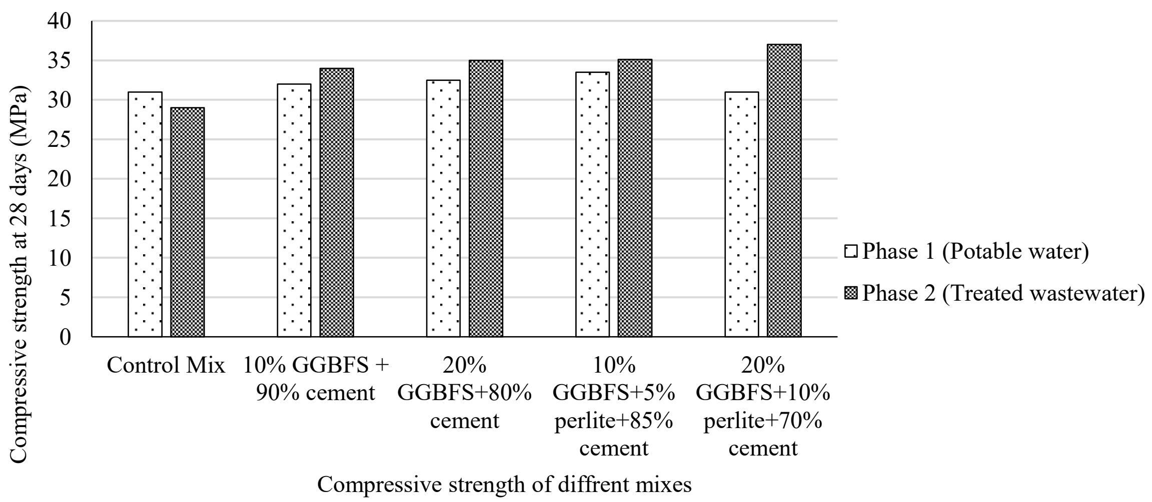

Figure 3. Compressive strength of different mixes.

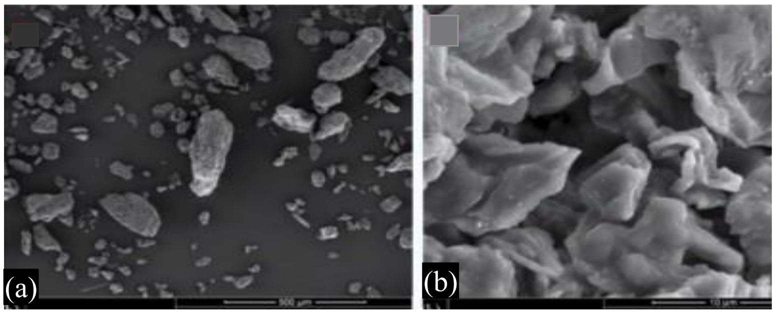

Figure 4. Microstructure Analysis for treated dyeing water cube.

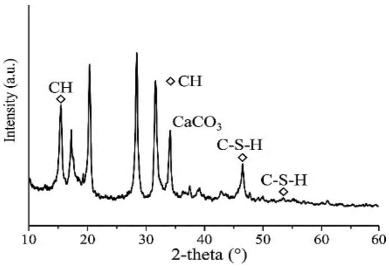

Figure 5. XRD Analysis for treated dyeing water cube.

CONCLUSION

This work examined the use of treated textile dyeing wastewater as mixing water in concrete, along with partial replacement of cement by GGBFS and perlite. Untreated wastewater was not suitable because of its high alkalinity, salt content, and organic impurities. After treatment, the water quality met the limits specified in IS 456:2000 and could be used in concrete mixing. Concrete prepared with the treated wastewater showed workability and compressive strength close to those of mixes made with potable water over the curing periods studied. Strength at later ages improved in mixes containing GGBFS, likely due to continued hydration. The inclusion of perlite reduced the unit weight, while the reduction in strength remained small within the selected replacement levels. Water absorption results indicated a comparatively less permeable matrix in these mixes. Microstructural observations followed the same trend. XRD results showed a lower presence of calcium hydroxide and a higher proportion of binding phases. SEM images indicated a more compact internal structure with fewer connected pores. The mix containing 20% GGBFS and 10% perlite with treated wastewater showed the most consistent performance among the combinations examined. These results indicate that treated dyeing wastewater can be used as mixing water in blended cement systems when its quality is controlled. The approach may help reduce freshwater use and cement consumption, although performance will depend on the characteristics of the wastewater and the replacement levels adopted.

REFERENCES

1. Micheal A, Abd El Salam H. Reliability of using secondary and tertiary treated wastewater in concrete mixing and curing. Environment Development and Sustainability. 2024;26:9875–9894. https://doi.org/10.1007/s10668-023-03245-4
2. Soltanianfard MA, Abuhishmeh K, Al-Fahdawi O. Sustainable concrete made with wastewater from different stages of filtration. Construction and Building Materials. 2023;402:133231. https://doi.org/10.1016/j.conbuildmat.2023.133231
3. Salehi A, Asadollahfardi G, Nematzadeh M. Impact of propylene fibers and industrial wastewater on the properties of self-compacting concrete. Scientific Reports. 2025;15:11876. https://doi.org/10.1038/s41598-025–11876-x
4. Harishbabu J, Saboo N, Chandrappa AK. Assessing the use of treated wastewater for pavement quality concrete and dry lean concrete layers in rigid pavements: Future-proofing infrastructure. Journal of Materials in Civil Engineering. 2025;37(7):04025XXX.
5. Kim JS, Oh SE, Kim SY, Pyeon G, Maeng S, Chung SY. Effects of treated wastewater from

recycled aggregate processing on the microstructure and mechanical properties of cement mortar. Construction and Building Materials. 2025;494:142945. https://doi.org/10.1016/j.conbuildmat.2025.142945
6. Dinesh S, Adinarayanan A, Selvakumar V, Paventhan R. Recent Advancements and Layering Techniques in Nanoparticle-Reinforced Hybrid Composites: A Comprehensive Analysis. Journal of Polymer and Composites. 2024; 13(01):83–89. https://journals.stmjournals.com/jopc/article=2024/view=0
7. Bodur B, Bayraktar OY, Akpinar P, et al. Effect of using wastewater from the ready-mixed concrete plant on the performance of one-part alkali-activated GBFS/FA composites: Fresh, mechanical, and durability properties. Journal of Building Engineering. 2023;66:105839. https://doi.org/10.1016/j.jobe.2023.105839
8. Alrowais R, Shakeel K, Alyousef R, Alabduljabbar H, Alaskar A, Mohamed AM. Utilizing marble wastewater in cement pastes and mortars for enhanced physico-mechanical and microstructural properties. Buildings. 2024;14(8):2451. https://doi.org/10.3390/buildings14082451
9. Rathinam V., Ganeshkumar A., Arul M., Dinesh S., Adinarayanan A., Ida G. Recent Developments in Hybrid and Nanostructured Basalt Fiber Composites: A Review of Mechanical and Processing Innovations. Journal of Polymer and Composites. 2025; 13(06):885–894. https://journals.stmjournals.com/jopc/article=2025/view=233481
10. He Z, Yang Y, Zhang Y, Liu J, Wang H, Li X. Recycling hazardous water treatment sludge in cement-based construction materials: Mechanical properties, drying shrinkage, and nano-scale characteristics. Journal of Cleaner Production. 2021;287:125048. https://doi.org/10.1016/j.jclepro.2020.125048
11. Rawat S, Zhang YX, Li Q. Development of sustainable engineered cementitious composite with enhanced compressive performance at elevated temperatures using high-volume GGBFS. Journal of Cleaner Production. 2024;433:139912. https://doi.org/10.1016/j.jclepro.2023.139912
12. Omer B, Saeed NM, Ahmed R. Evaluating the long-term strength of GGBFS-blended cement across various water-to-binder and superplasticizer ratios under heating/cooling cycles. PLoS ONE. 2025;20(7).
13. Sivakumar M., Thirumoorthy P., Narasimman V., Sreedevi S.L., Karthikeyan T., Dinesh S.. AI-Driven Multi-Objective Optimization of Conductive Polymer Composites for High-Performance Flexible Electronics. Journal of Polymer & Composites. 2025; 13(06):734–745. https://journals.stmjournals.com/jopc/article=2025/view=234533
14. Shaikh A, Tandel Y, Patel R. Mechanical, hydraulic, and durability characteristics of sustainable pervious concrete incorporating GGBFS and PPF. Discover Civil Engineering. 2025;6:215.
15. Baldermann A, Preissegger V, Mittermayr F, et al. Uptake of aqueous heavy metal ions (Co^{2+}, Cu^{2+} and Zn^{2+}) by calcium–aluminium–silicate–hydrate gels. Cement and Concrete Research. 2021;149:106588. https://doi.org/10.1016/j.cemconres.2021.106588
16. Izuo H, Nakarai K, Nishida T. Twenty-two-year investigation of strength development and surface deterioration of cement-treated clay in an in-situ field test. Cement and Concrete Composites. 2022;132:104629. https://doi.org/10.1016/j.cemconcomp.2022.104629
17. He ZS, He C, Li Y, Performance assessment of partially corrosion-damaged RC segment incorporating the spatial variability of steel corrosion. Construction and Building Materials. 2023;362:129769. https://doi.org/10.1016/j.conbuildmat.2022.129769
18. Narasimharajan M, Dinesh S. Development and evaluation of a sustainable hybrid epoxy composite reinforced with treated natural fabrics and agro-waste nanoparticles for structural applications. Materials and Technology. 2025 Aug;59(4):621-630. https://doi.org/10.17222/mit.2025.1456.

