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Comparative Evaluation of Potable Water and Laundry Wastewater on the Properties of Concrete Modified by Crushed Ceramic Waste

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ABSTRACT: The objective of this paper was to investigate a comparative evaluation of potable water and laundry wastewater on the properties of concrete modified by crushed ceramic waste using standard methods. Using various standard methods, slump, compaction factor, water absorption and compressive strength tests were carried out on the concrete samples. The slump test results indicated that potable water generally maintained consistent workability across different ceramic contents, while laundry wastewater achieved higher workability at 30% ceramic replacement. The compaction factor remained stable for potable water mixes (0.90 to 0.98), whereas laundry wastewater showed more variability (0.85 to 0.96). Water absorption tests revealed that potable water mixes have higher initial porosity but show decreased absorption with increased ceramic content, reaching a low of 1.1% at 15% replacement. Conversely, laundry wastewater mixes maintained lower absorption rates overall. Compressive strength tests indicated that potable water mixes consistently outperformed those made with laundry wastewater, although both exhibited reduced strengths at higher ceramic contents. These findings suggest that while laundry wastewater can be utilized in concrete production, careful optimization is necessary to ensure structural integrity. This research supports the sustainable use of alternative materials and water sources in concrete, aligning with contemporary efforts to enhance environmental sustainability in construction practices.

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The use of alternative materials and waste products in concrete production has garnered significant attention in recent years, driven by the need for sustainable construction practices (Nilimaa, 2023; Sangmesh *et al.*, 2023). The incorporation of waste materials, such as crushed ceramic tiles, as partial replacements for natural aggregates in concrete is being explored Bommisetty *et al.*, 2019; Sivakumar *et al.*, 2022). Researchers have found that ceramic waste can enhance certain properties of concrete due to its pozzolanic activity, which contributes to improved microstructure and mechanical properties. (Meena, 2022; Jwaida *et al*, 2024). Bommisetty *et al.* (2019) demonstrated that replacing natural coarse aggregates with up to 20% crushed waste ceramic tiles in concrete, enhanced the concrete's properties. In addition to the use of alternative aggregates, the substitution of potable water with wastewater in concrete batching has been investigated as a means to conserve freshwater resources (Ojo, 2019). Using different types of wastewater, such as treated sewage and greywater, have shown mixed results depending on the water's composition and treatment level (Varshney *et al.*, 2021). Soltanianfard *et al.* (2023)

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discovered that using wastewater for 25% and 50% replacement of potable water enhanced both compressive and tensile strengths of the concrete. However, there is limited research specifically focusing on the use of laundry wastewater, which could have unique implications due to the presence of detergents and other chemicals. The comparative analysis of fine aggregate-crushed ceramic-modified concrete batched with potable water and laundry wastewater addresses a novel and holistic approach to sustainability. Studies by Meena (2022) have indicated that replacing natural sand with crushed ceramics can reduce the environmental impact without significantly compromising the concrete's mechanical properties. Furthermore, investigations into using wastewater, such as those conducted by Maddikeari *et al.* (2024), suggest that with proper treatment, the performance of concrete can remain within acceptable limits. This study explores the use of crushed ceramic tiles as a sustainable partial replacement for fine aggregates in concrete. Additionally, the feasibility of using laundry wastewater instead of potable water for batching concrete is examined. By investigating various replacement levels and conducting comprehensive testing, this research aims to provide insights into the performance and potential benefits of this modified concrete.

MATERIALS AND METHODS

Materials: Ordinary Portland Cement (OPC) conforming to ASTM C150 was used as the binding material. Natural river sand served as the fine aggregate, while crushed granite stones were used as the coarse aggregate. Crushed ceramic tiles, procured from construction waste and processed to fine aggregate size, were employed as a partial replacement for the fine aggregates. Both potable water and laundry wastewater were utilized for batching. The potable wastewater was obtained from boreholes within the Federal University of Technology, Akure (FUTA) while the laundry wastewater was obtained from a laundry facility within FUTA.

Water Quality Analysis: The quality of both the potable water and laundry wastewater were determined in the laboratory. The water quality parameters determined include temperature, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), conductivity, nitrate concentration (NO^{3-}), sulfate concentration (SO_4^{2-}), chloride concentration, phosphate concentration (PO^{4-}), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), grease content, turbidity, and pH.

Mix Proportions: Concrete mix designs were prepared with fine aggregate replacements by crushed ceramic tiles at 0%, 5%, 10%, 15%, 20%, 25%, and 30% levels. Each mix was batched using both potable water and laundry wastewater to examine the impact on concrete properties.

Slump Test: The slump test was conducted according to ASTM C143/C143M to determine the workability of fresh concrete. A slump cone was placed on a flat, moist surface and filled with concrete in three equal layers. Each layer was tamped 25 times with a tamping rod. After filling, the cone was lifted vertically, and the slump was measured as the difference in height between the cone and the highest point of the concrete. The slump value was recorded in millimeters.

Compaction Factor Test: The Compaction Factor Test aimed to measure the degree of compaction of the concrete, following the BS 1881-103 standard. The weight of the cylindrical mould, W used for this experiment was 6kg. The concrete was placed into the upper hopper of the compaction factor apparatus and allowed to fall into the lower hopper by opening a trapdoor. The second trapdoor was then opened, allowing the concrete to fall into a cylinder. The weight of the partially compacted concrete (W_1) was measured. The cylinder was then filled with the same concrete in layers, with each layer being fully compacted, and the weight of the fully compacted concrete (W_2) was recorded. The compaction factor was calculated as the ratio of W_1 to W_2.

Water Absorption Test: The water absorption test determined the water absorption capacity of hardened concrete according to ASTM C642. Concrete specimens were dried in an oven at 105°C until a constant weight was achieved, then cooled to room temperature and weighed (W_{dry}). The specimens were immersed in water for 24 hours, surface-dried with a cloth, and weighed again (W_{wet}). The water absorption percentage was calculated using equation 1.

$$\frac{W_{wet} - W_{dry}}{W_{dry}} \, x \, 100 \quad (1)$$

Compressive Strength Test: To determine the compressive strength, concrete cubes were cast with the specified mixes and cured for 28 days following ASTM C39/C39M. After curing, the cubes were removed, excess water was wiped off, and they were tested in a compression testing machine. The load was applied gradually until the cube failed, and the maximum load (P) was recorded. The compressive strength was calculated using the formula P / A, where A is the cross-sectional area of the cube.

Profile Plot: A two-factor experimental design was employed to assess the interaction between crushed ceramic replacement levels and water type (potable and laundry wastewater) on concrete compressive strength. The mean values for compressive strength were plotted against ceramic replacement percentages and water type. The resulting profile plot was generated to visualize the interaction effects, enabling comparisons of compressive strength across different ceramic replacement levels and water sources.

RESULTS AND DISCUSSION

Potable Water and Laundry Wastewater quality: The analysis of laundry wastewater compared to potable water reveals notable differences in their composition, which can impact concrete strength characteristics when used in concrete production. The laundry wastewater had a higher temperature (33°C) compared to potable water (29°C). The Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) in the wastewater were higher, with TDS at 0.01650% and TSS at 0.00372%, compared to 0.01213% and 0.00400% in potable water, respectively. Conductivity was significantly higher in wastewater (133×10 µS cm) than in potable water (47×10 µS cm), indicating a higher ionic content. The wastewater contained elevated levels of nitrates (180.05 mg/L vs. 53.00 mg/L), sulfates (390.14 mg/L vs. 170.69 mg/L), chlorides (1597.50 mg/L vs. 556.17 mg/L), and phosphates (100.90 mg/L vs. 33.80 mg/L). It also showed much higher Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) values (9.50 mg/L and 1700.00 mg/L, respectively) compared to potable water (0.59 mg/L and 30.00 mg/L). Grease was present in wastewater (0.71 mg/L/Oil) but absent in potable water. The turbidity was slightly higher in wastewater (13.00 units) compared to potable water (10.50 units). The pH of wastewater (11.616) was considerably higher than that of potable water (8.963). These elevated concentrations of impurities in laundry wastewater, particularly high COD, chlorides, and pH, negatively affected the strength and durability of concrete, potentially leading to increased porosity, reduced compressive strength, and susceptibility to chemical attacks (Olonade, 2016).

Slump Test: Fig. 1 presents the Slump Test result of ceramic-modified concrete batched with potable water and laundry wastewater. The bar chart illustrates that workability varies with ceramic content. At 0% ceramics, both water sources yield a slump of 70 mm. For 5% ceramics, the slump decreases to 60 mm for both. At 10%, potable water results in an 80 mm slump while laundry wastewater shows 70 mm. At 15%, potable water maintains 80 mm while laundry wastewater drops to 50 mm. Both water sources show 50 mm at 20% ceramics. At 25%, potable water yields 70 mm and laundry wastewater 60 mm. Surprisingly, at 30%, laundry wastewater results in a higher slump of 80 mm compared to potable water's 60 mm, indicating that the water type significantly impacts workability, especially at higher ceramic content levels. These findings suggest that while potable water generally supports consistent workability, laundry wastewater becomes more effective at higher ceramic content, aligning with studies that show variable impacts of alternative water sources on concrete properties (Adeala and Adeala, 2021). This combined approach promotes recycling and sustainability in concrete production (Medina *et al.,* 2018).

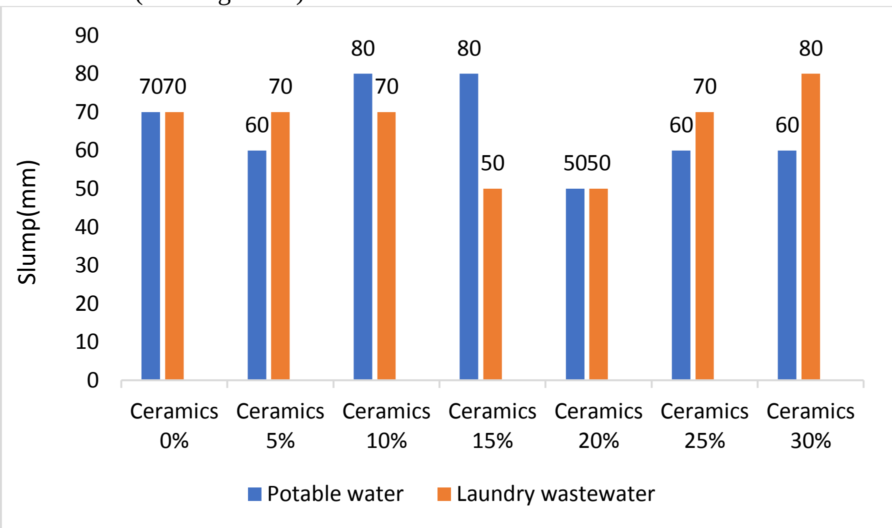

Fig. 1: Slump test

Compaction Factor Test: Fig. 2 depicts the compaction factor of concrete cubes batched with potable and laundry wastewater at varying percentages of fine aggregate replacement with crushed ceramic tiles (0%, 5%, 10%, 15%, 20%, 25%, and 30%). The compaction factor for concrete batched with potable water remains relatively consistent, ranging from 0.90 to 0.98, indicating good workability. Specifically, the highest compaction factor of 0.98 is observed at 30% ceramic replacement. In contrast, concrete batched with laundry wastewater shows more variability, with a compaction factor range from 0.85 to 0.96. At 20% replacement, the compaction factor dips to 0.85, indicating reduced workability. These results suggest that potable water generally leads to better workability in concrete mixtures, consistent with the literature that highlights the impact of water quality on concrete properties (Cayanan *et al*., 2024). Poor water quality can introduce impurities that affect the hydration process and subsequently the workability of the mix. These results further suggest that laundry wastewater mixes initially facilitate better compaction but face challenges at higher ceramic contents, aligning with studies on alternative water sources in concrete that indicate variable impacts on concrete properties (Mohe *et al*., 2022).

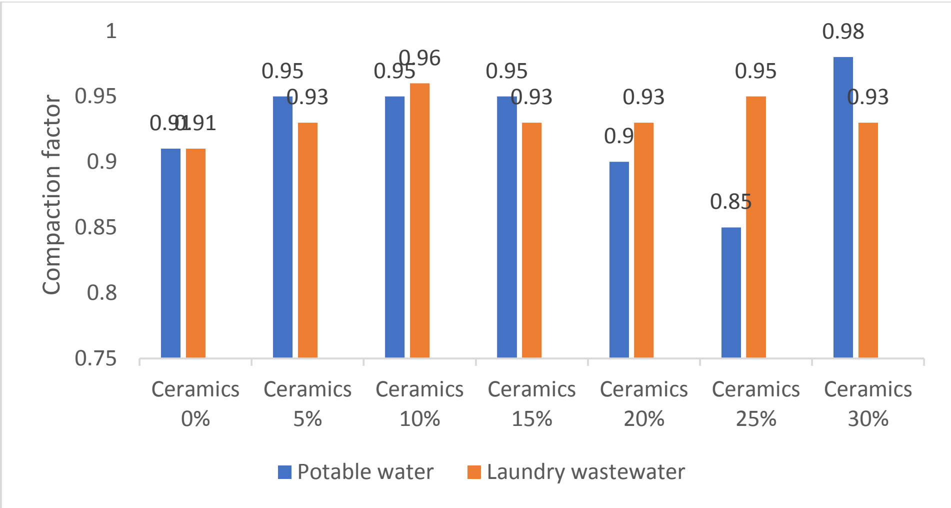

Fig. 2: Compaction factor test

Water absorption test of concrete: Fig. 3 shows the percentage water absorption test result at 28days of curing of ceramic-modified concrete cube and ceramic-modified concrete cylinder samples batched with potable water and laundry wastewater respectively. The water absorption test results for fine aggregate-crushed ceramic-modified concrete batched with potable water and laundry wastewater, as shown in the figure, indicate variations in porosity at different ceramic replacement levels. At 0% ceramic replacement, potable water mixes have a high absorption rate of 3.1%, while laundry wastewater mixes show a significantly lower absorption of 1.2%. As ceramic content increases, potable water mixes exhibit decreasing absorption rates, reaching a low of 1.1% at 15% replacement and remaining low at 30% (1.2%). Conversely, laundry wastewater mixes generally maintain lower absorption rates, peaking only at 25% replacement with 3.5%. The lowest absorption for laundry wastewater is also at 15% (1.1%). These findings align with previous research indicating that ceramic waste can reduce concrete porosity (Gautam *et al*., 2021), and that laundry wastewater can be effectively utilized in concrete production without significantly increasing water absorption, enhancing sustainability in construction practices.

Compressive strength test of concrete cubes: Fig. 4 presents the compressive strength of concrete cylinders after 28 days of curing, comparing the results for concrete produced with potable water and laundry wastewater across various percentages of crushed ceramic tile replacement. The compressive strength test results for fine aggregate-crushed ceramic-modified concrete batched with potable water and laundry wastewater, illustrated in the figure, demonstrate varying strengths at different replacement levels. At 0% ceramic replacement, potable water mixes showed a compressive strength of 17.6 N/mm² compared to laundry wastewater mixes (15.3 N/mm²). As ceramic content increases, both mixes experience a reduction in strength, with potable water mixes dropping to 12.1 N/mm² at 5% and reaching a low of 12.4 N/mm² at 20%. Laundry wastewater mixes exhibit a similar trend but generally have lower strengths, with a notable drop to 9.0 N/mm² at 15% replacement and the lowest strength of 8.2 N/mm² at 30% replacement. These results align with studies suggesting that while crushed ceramic tiles can enhance certain concrete properties, higher replacement levels may negatively impact compressive strength, particularly when alternative water sources like laundry wastewater are used (Awoyera *et al.,* 2018; Dauda *et al*., 2018). This indicates that while sustainable materials can be beneficial, careful optimization is necessary to maintain structural integrity

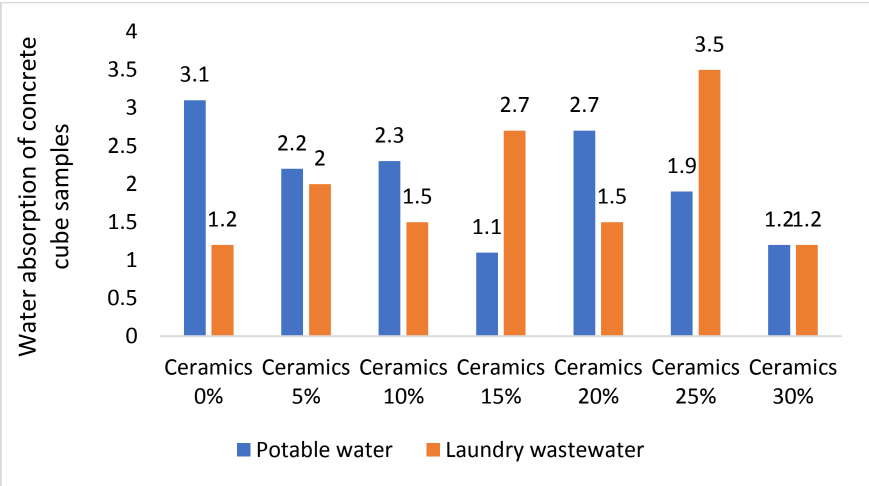

Fig. 3: Water absorption test result at 28 days curing age for concrete cubes produced with potable water and laundry wastewater

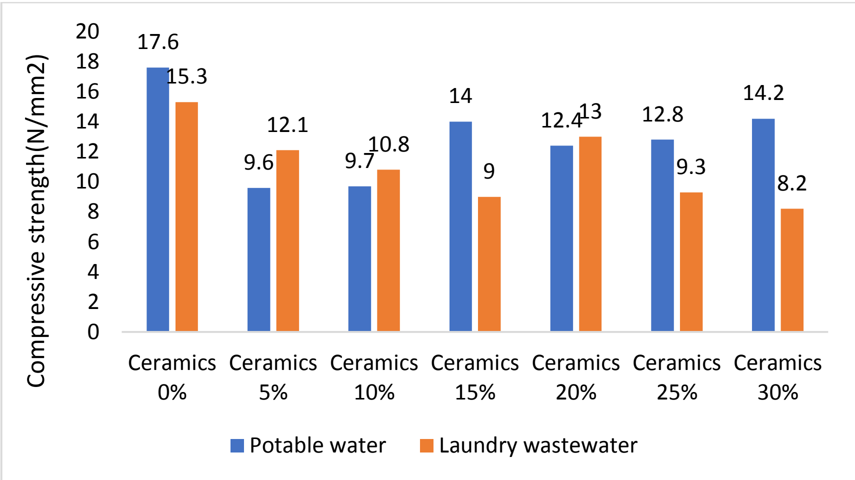

Fig. 4: Compressive strength at 28 days curing age for concrete cube produced with potable water and laundry wastewater

Profile plot: The profile plot (Fig. 5) depicts the mean values or estimated marginal mean values on the vertical axis, with the interaction of the percentage of crushed ceramics replaced and water type on the horizontal axis. This profile plot reveals that concrete cubes batched with potable water generally exhibit higher compressive strength compared to those batched with laundry wastewater, particularly at 0%, 15%, and 30% ceramic replacement levels. At 0% replacement, the compressive strength for potable water reaches approximately 17.5 MPa, while laundry wastewater is around 12.5 MPa. At 15%, potable water peaks at about 20 MPa, whereas laundry wastewater remains below 12.5 MPa. Conversely, at 30%, potable water shows an upward trend approaching 15 MPa, while laundry wastewater significantly decreases below 10 MPa. These findings are consistent with existing literature indicating that impurities in wastewater can adversely affect concrete strength (Azeem et al., 2023). Additionally, the variability in compressive strength across different percentages of ceramic replacement highlights the importance of optimizing material composition for enhanced concrete performance (Siddique *et al.,* 2017).

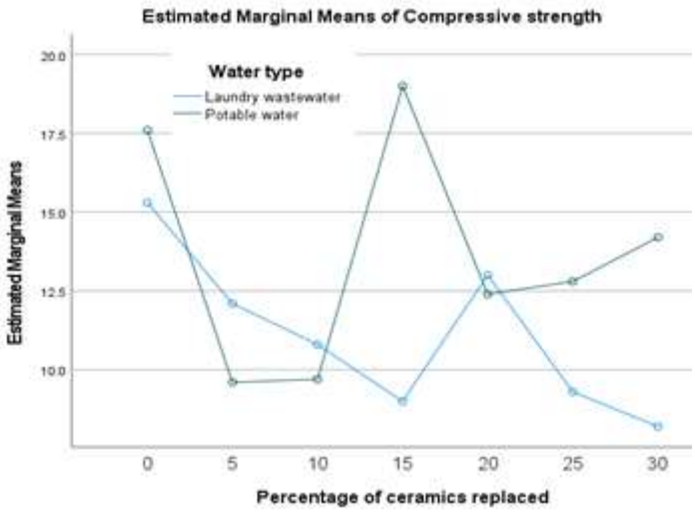

Fig. 5: Profile plot of compressive strength test of concrete cubes

*Conclusion***:** The study revealed that ceramic-modified concrete's workability, compaction, water absorption, and compressive strength are significantly influenced by the type of water used and the percentage of ceramic replacement. Potable water generally ensures better workability and compaction, maintaining higher compressive strengths and consistent low water absorption rates. Conversely, laundry wastewater shows more variability: while it can achieve comparable workability at higher ceramic replacement, it often results in lower compressive strengths and variable compaction factors. These findings underscore the need for careful optimization when using alternative materials and water sources to ensure the structural integrity and sustainability of concrete.

Declaration of Conflict of Interest: The authors declare no conflict of interest.

Data Availability Statement: Data are available upon request from the first author or corresponding author or any of the other authors.

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