# Characterization of Wastewater Produced Concrete using Selected Mix Ratio of Crushed Waste Glass as Partial Replacement for Sand

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RESEARCH

**Abstract**— Concrete is a fundamental material in construction, but its widespread use raises environmental concerns due to the depletion of natural resources and high CO2 emissions. This study explores the sustainable integration of waste glass and domestic wastewater as partial replacements for fine aggregate and potable water in concrete production. The mechanical properties, durability, and workability of concrete incorporating varying proportions of crushed waste glass and wastewater were investigated. Benchmarking against similar studies was performed to validate the results. Regression and ANOVA analyses were employed to evaluate the relationships and significance of various factors affecting concrete performance. The findings indicate potential for using waste glass and domestic wastewater in concrete production, contributing to sustainable construction practices. This study provides a database on the effects of impurities in wastewater on concrete properties and promotes eco-friendly building methods, aligning with global sustainability goals. These findings can guide policymakers and construction professionals in adopting environmentally responsible practices.

**Keywords**— Concrete, ANOVA, Regression, Waste Glass, Sustainability, Replacement.

## 1 Introduction

Concrete, composed of cement, aggregates, water, and admixtures, is vital to construction due to its versatility, low maintenance, and durability (El-Nadoury, 2021). It is the second most consumed material after water (Alqahtani et al., 2021). However, its increasing demand depletes natural resources, necessitating sustainable practices. Sand, a key component in concrete, faces scrutiny due to environmental impacts associated with its extraction. As construction activities surge globally, alternative materials like recycled waste are crucial to reducing ecological damage (Garcia et al., 2022).

Several studies have explored the use of solid waste, such as crushed glass, in concrete production. These studies show that recycled materials enhance concrete's sustainability, promote efficient waste management, and reduce energy consumption (Akinwumi et al., 2016). For example, Ali and Al-Tersawy (2012) reported improved performance using glass in self-compacting concrete. However, limitations in existing studies such as inadequate examination of long-term durability and lack of focus on integrating wastewater with solid waste remain unaddressed.

This research seeks to fill these gaps by integrating crushed waste glass and domestic wastewater into concrete production. The study focuses on the mechanical properties and evaluates the sustainability of using waste materials, contributing to eco-friendly construction and waste reduction.

## 2 METHODOLOGY

### 2.1 MATERIALS

The materials used in this study were selected based on their relevance to sustainable concrete production. The primary materials include **crushed waste glass**, **ordinary Portland cement**, **river sand**, **coarse aggregate**, and **laundry wastewater**. All materials were evaluated to ensure compliance with relevant industry standards. The waste glass was sourced from local recycling facilities, cleaned, and finely crushed to serve as a partial replacement for sand. Laundry wastewater was collected from dry cleaners in the Shagari area, replacing potable water in some of the mixes. Portland cement of grade 42.5N from Dangote Industries was used as the binder.

**Table 1: Physical Properties of Cement**

| S/N | Physical Tests | Test Results Using Potable Water | Test Results Using Laundry Wastewater |
|---|---|---|---|
| 1 | Consistency Setting Time | 10 minutes | 10 minutes |

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| | | | |
|---|---|---|---|
| 2 | Initial Setting Time | 35 minutes | 45 minutes |
| 3 | Final Setting Time | 630 minutes | 660 minutes |
| 4 | Soundness Test | 3.55 minutes | 3.22 minutes |
| 5 | Finest Test | 2.0 minutes | 1.67 minutes |

The **coarse aggregate** used had a maximum particle size of 20 mm and was tested for specific gravity and water absorption. The **sand** was sourced from riverbeds and processed to a fine aggregate size.

**Table 2: Physical Properties of Coarse Aggregate**

| Physical property | Test Result | Range (test result comment) |
|---|---|---|
| **Specific Gravity Value** | 2.89 | 2.5 – 3.0 (Excellent) |
| **Aggregate Impact Value** | 20.03 | 20% - 30% (Satisfactory) |
| **Aggregate Crushing Value** | 27.97 | < 30% (Excellent) |

**Table 3: Physical Properties of Sand**

| TEST | Result |
|---|---|
| **Specific Gravity** | 2.79 |
| **Bulk Density** | 1,620 kg/m$^3$ |
| **Slit/Clay test** | 5% |
| **Moisture Content** | 3.87 |

## 2.2 Mix Proportion

In this study, concrete mixes were designed based on a consistent total volume of fine aggregate. **Crushed glass** was used as a partial replacement for river sand at percentages of 0%, 5%, 10%, 15%, 20%, 25%, and 30%. The **mix design** ratio of 1:2:4 was maintained for all batches.

**Table 4: Mix Proportion of Materials**

| % Replacement | Cement (kg) | Sand (kg) | Crushed Glass (kg) | Coarse Aggregate (kg) | Potable Water (kg) | Laundry Waste water (kg) |
|---|---|---|---|---|---|---|
| 0% | 20.00 | 40.00 | 0.00 | 80.00 | 9.00 | 11.00 |
| 5% | 20.00 | 38.00 | 2.00 | 80.00 | 9.00 | 11.00 |
| 10% | 20.00 | 36.00 | 4.00 | 80.00 | 11.00 | 12.00 |
| 15% | 20.00 | 34.00 | 6.00 | 80.00 | 11.00 | 13.00 |
| 20% | 20.00 | 32.00 | 8.00 | 80.00 | 12.00 | 13.00 |
| 25% | 20.00 | 30.00 | 10.00 | 80.00 | 12.00 | 13.00 |
| 30% | 20.00 | 28.00 | 12.00 | 80.00 | 12.00 | 15.00 |

## 2.3 Experimental Procedure

**Batching and Mixing:** Concrete batches were mixed by volume, with 182 cubes (150 x 150 x 150 mm) and 182 cylinders (100 x 200 mm) cast for the experiment. The control mix used potable water, while the experimental mix incorporated laundry wastewater. Each mix was carefully batched to ensure consistency in proportions.

**Curing Process:** After casting, the concrete specimens were demolded after 24 hours and cured in potable water for 7, 14, 21, and 28 days. After curing, they were tested for mechanical properties such as compressive and split tensile strengths.

**Figure 1: Curing Tank**

## 2.4 Test Methods

**Compressive Strength:** Compressive strength tests were conducted using a compression testing machine on the cube samples at 7, 14, and 28 days of curing.

**Split Tensile Strength:** Split tensile strength tests were performed on cylindrical specimens at the same intervals.

## 2.5 Analysis

**Regression Analysis:** A regression analysis was conducted to model the relationship between the percentage of waste glass used and the compressive strength of concrete. This analysis helped identify any significant trends in the data.

**ANOVA Analysis:** A one-way ANOVA was employed to determine if the variations in compressive strength across different mixes were statistically significant. This analysis



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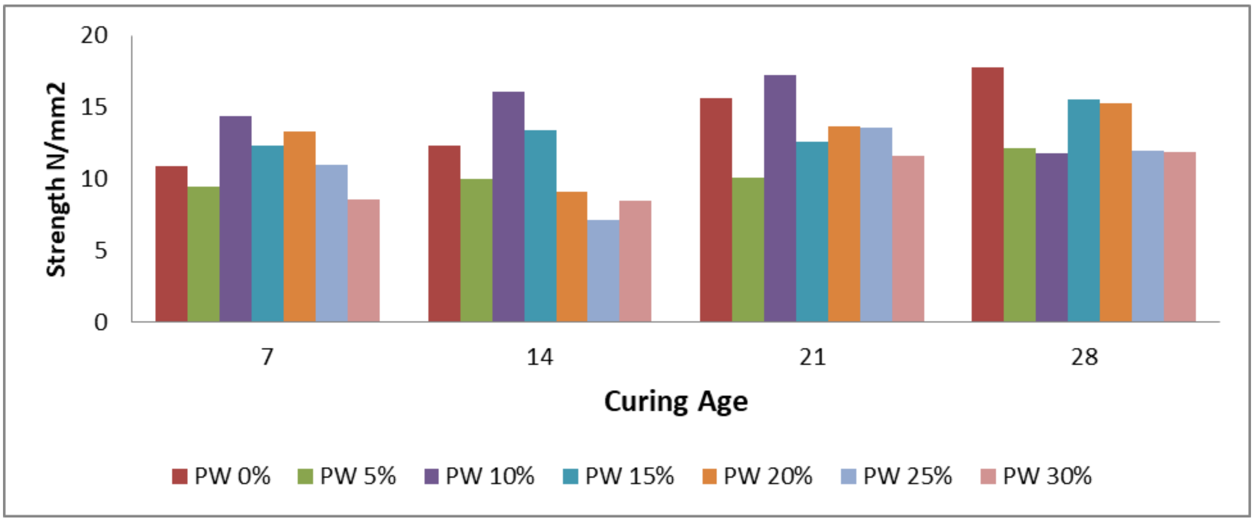


compared the means across various replacement levels and water types.

## 3 Results and Discussion

### 3.1 Compressive Strength

Figure 2 and 3 illustrates the compressive strength of concrete mixtures at various curing ages (7, 14, 21, and 28 days) with different percentages of potable water (PW) and Laundry Wastewater (LW) and replacement of Fine aggregate with Waste Glass(0%, 5%, 10%, 15%, 20%, 25%, and 30%).

### 3.1.2 ANOVA Analysis

A one-way ANOVA was conducted to compare the mean compressive strength across various glass replacement levels and water types. The ANOVA table below shows that there were no statistically significant differences (p = 0.500) between the groups, indicating that variations in the percentage of waste glass replacement did not substantially impact the compressive strength.

**Table 5: ANOVA Analysis Table**

**ANOVA**

**Compressive Strength**

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 0.315 | 6 | 0.052 | 0.904 | 0.500 |
| Within Groups | 2.845 | 49 | 0.058 | | |
| Total | 3.160 | 55 | | | |

The ANOVA results suggest that the observed differences in compressive strength among groups were likely due to random variability rather than the impact of the crushed glass or the type of water used. Thus, the inclusion of crushed glass and wastewater does not significantly affect the compressive strength under the conditions examined.

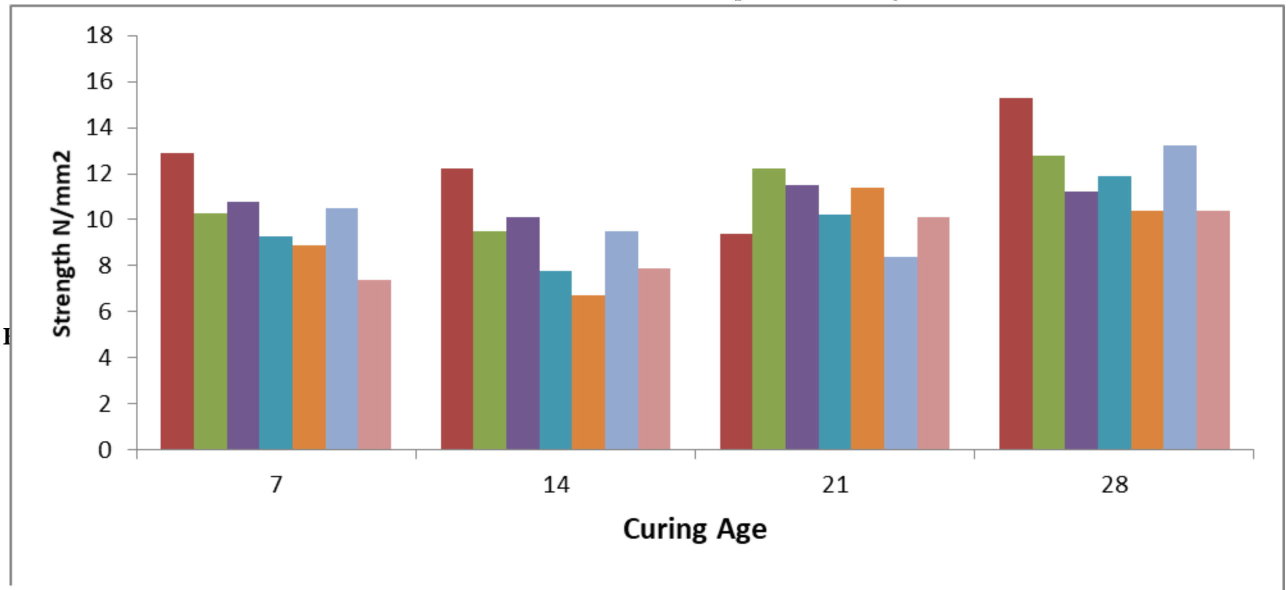


**Figure 3: Compressive Strength Using Laundry Wastewater**

 

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### 3.1.2 REGRESION ANALYSIS

A regression analysis was performed to explore the relationship between compressive strength, glass percentage, curing time, and water type. The analysis revealed a weak correlation between these variables, as evidenced by a low R-square value of 0.015.

**Table 6: Regression ANOVA Analysis Table**

**ANOVA**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 135.765 | 3 | 45.255 | 0.267 | 0.849[b] |
| | Residual | 8813.952 | 52 | 169.499 | | |
| | Total | 8949.717 | 55 | | | |

a. Dependent Variable: Compressive_Strength

b. Predictors: (Constant), Water_Type_Num, Curing_Time, Glass_Percentage

**Table 7: Regression Coefficient Table**

**Coefficients[a]**

| Model | | Unstandardized Coefficients B | Std. Error | Standardized Coefficients Beta | t | Sig. |
|---|---|---|---|---|---|---|
| 1 | (Constant) | 12.530 | 7.226 | | 1.734 | 0.089 |
| | Glass_Percentage | 0.073 | 0.174 | 0.058 | 0.422 | 0.674 |
| | Curing_Time | -0.151 | 0.222 | -0.093 | -0.678 | 0.501 |
| | Water_Type_Num | 1.407 | 3.480 | 0.056 | 0.404 | 0.688 |

a. Dependent Variable: Compressive_Strength

### 3.2 Split Tensile Strength

The results of the split tensile strength tests are shown in **Figure 4** and **Figure 5**, which illustrate the performance of concrete with different glass percentages and water types. The control mix again demonstrated the highest tensile strength, but the mixes with crushed glass showed only marginal reductions in strength, which is in line with expectations from previous studies.

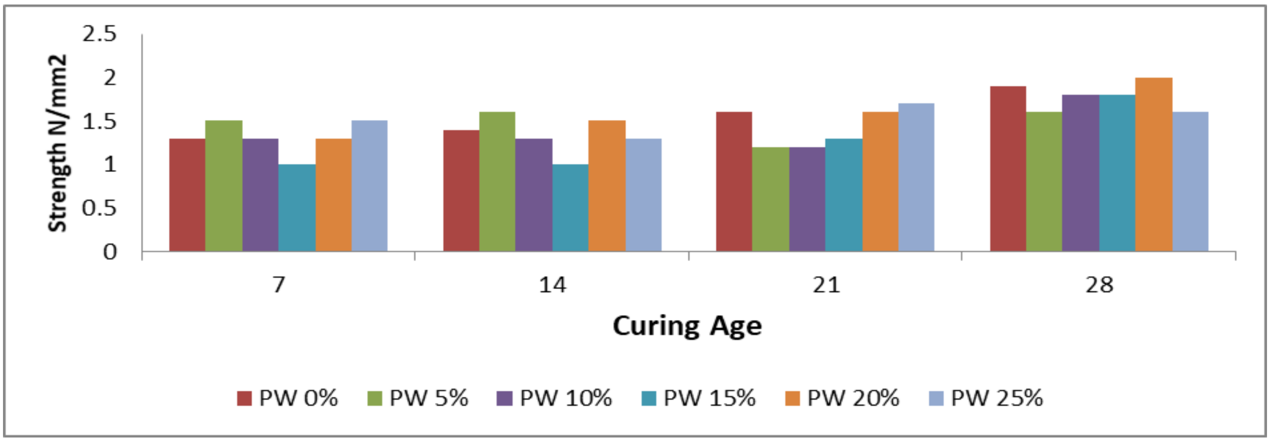


**Figure 4: Split Tensile Strength using Potable Water**

### 3.2.2 ANOVA Analysis

Similar to the compressive strength, a one-way ANOVA was conducted to evaluate the split tensile strength results across different levels of glass replacement.

**Table 8: ANOVA Analysis for Split Tensile Strength**

**ANOVA**

Split_Tensile_Strength

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | .315 | 6 | .052 | .904 | .500 |
| Within Groups | 2.845 | 49 | .058 | | |
| Total | 3.160 | 55 | | | |

The ANOVA results confirmed that there were no significant differences ($p = 0.500$) between the groups for split tensile strength, supporting the feasibility of using crushed glass as a partial replacement for fine aggregate.

### 3.2.3 Regression Analysis

**Table 9: Regression Analysis of Split Tensile Strength**

**Coefficients[a]**

| Model | Unstandardized Coefficients | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|

| | | B | Std. Error | Beta | | |
|---|---|---|---|---|---|---|
| 1 | (Constant) | 0.219 | 0.209 | | 1.049 | 0.300 |
| | Glass_Percentage | 0.000 | 0.001 | 0.010 | 0.194 | 0.847 |
| | Water_Type_Num | 0.009 | 0.027 | 0.018 | 0.320 | 0.750 |
| | Percentage_of_water_absorption | -0.002 | 0.004 | -0.024 | -0.527 | 0.601 |
| | Curing_Time | 0.001 | 0.001 | 0.021 | 0.425 | 0.672 |
| | Density | -2.664E-5 | 0.000 | -0.017 | -0.290 | 0.773 |
| | Slump | -.001 | 0.001 | -0.035 | -0.682 | 0.499 |
| | Load | 2.974E-5 | 0.000 | 0.950 | 18.049 | 0.000 |

a. Dependent Variable: Split_Tensile_Strength

The regression analysis showed no significant influence of glass percentage, curing time, or water type on split tensile strength. These findings are consistent with the results from the compressive strength analysis, suggesting that the inclusion of crushed glass and laundry wastewater does not drastically affect concrete performance under these conditions.

without drastically compromising concrete's structural properties.

However, future studies should focus on long-term durability and environmental impact assessments to further validate the use of crushed glass and wastewater in sustainable concrete production. Incorporating these materials could significantly reduce the environmental burden of construction by lowering the demand for natural resources and minimizing waste disposal.

## 4 Conclusion and Recommendation

This study demonstrates that the inclusion of crushed glass and wastewater in concrete does not significantly affect its mechanical properties, validating findings from previous studies. The regression and ANOVA analyses confirmed the robustness of the results, with no major deviations in compressive and tensile strength across different mixes. Future research should focus on long-term durability tests and environmental impact assessments to further validate the use of waste materials in concrete.

It is recommended that policymakers and construction professionals adopt these sustainable practices, given their environmental benefits and minimal impact on concrete properties. Expanding the use of waste glass and wastewater could substantially reduce resource depletion in construction.

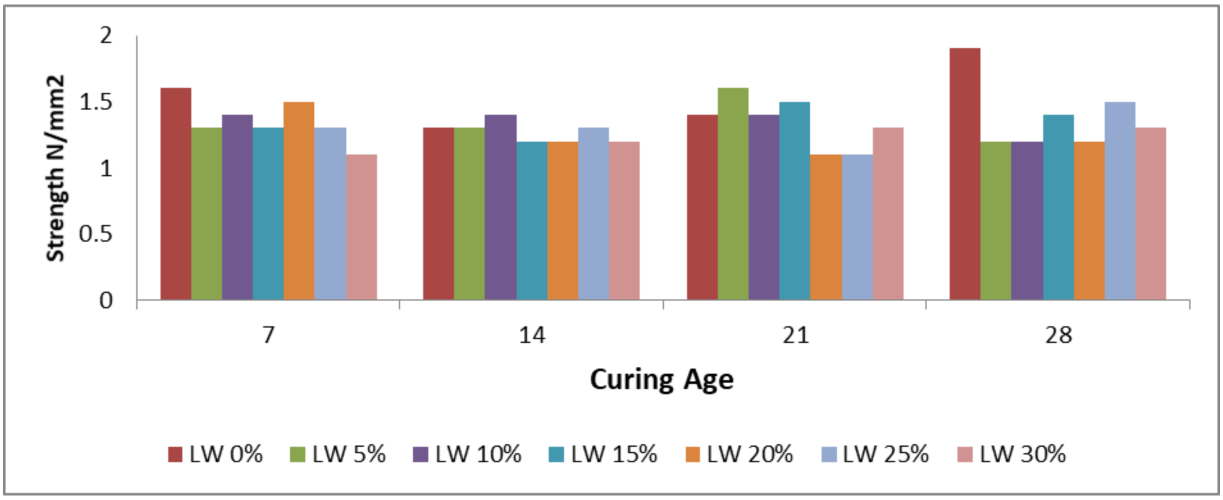


**Figure 5: Split Tensile Strength Using Laundry Wastewater**

### 3.3 Discussion of Results

The results of this study indicate that concrete incorporating crushed waste glass and laundry wastewater can maintain comparable compressive and tensile strengths to conventional concrete. While slight reductions in strength were observed, they were not statistically significant, suggesting that the use of these waste materials is feasible for producing eco-friendly concrete. These findings align with previous studies by Ali & Al-Tersawy (2012) and Olofinnade et al. (2017), which showed that recycled materials can be used

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