

## Effect of Glass Bottle Waste and Granite Waste as Coarse Aggregate Substitutes on the Compressive Strength of Normal Concrete

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**Abstract**— The increase in waste from construction and daily human activities has raised environmental concerns, particularly the disposal of non-biodegradable materials such as glass and granite. This study investigates the potential use of glass bottle waste and granite waste as partial substitutes for coarse aggregates in normal concrete. The objective is to evaluate their influence on the compressive strength of concrete with a target strength of 20 MPa. Experimental tests were conducted using cylindrical specimens (15 cm × 30 cm), incorporating 3% glass waste and varying granite waste contents (3%, 5%, 8%, and 10%). A total of 45 specimens were tested at curing ages of 7, 14, and 28 days. The results show that the highest compressive strength of 25.20 MPa was achieved with 3% glass and 3% granite waste, surpassing the design strength. However, increasing granite content beyond 3% led to a gradual strength reduction. The findings indicate that limited substitution of both wastes is feasible without compromising structural performance. Future research should optimize mix design parameters to improve efficiency and explore higher substitution levels for environmental sustainability.

**Keywords:** glass waste, granite waste, compressive strength, coarse aggregate substitution, sustainable concrete

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### 1. Introduction

The accumulation of solid waste, particularly from glass and granite, has emerged as a pressing environmental concern in recent decades. Glass bottles and granite waste from households and construction projects are often discarded directly into the environment due to their non-biodegradable nature, contributing significantly to land pollution [1], [2]. At the same time, the construction industry remains heavily dependent on natural aggregates for concrete production, raising sustainability issues related to the depletion of natural resources [3], [4]. Concrete is a composite material widely used in civil engineering structures due to its strength, durability, and cost-effectiveness [5]. However, the continuous extraction of natural aggregates has motivated researchers to explore alternative materials derived from waste products [6]. Among these, waste glass has gained attention for its potential as a partial substitute in both fine and coarse aggregates. Several studies have demonstrated that waste glass, when properly processed, can improve concrete's compressive strength, durability, and workability [7]–[10].

In parallel, granite waste—typically generated from tile and countertop industries—has also shown promise as a substitute for coarse aggregate [11], [12]. The incorporation of granite and glass waste into concrete mixtures has been explored by multiple researchers with varying degrees of success. Some

studies have focused on using glass waste alone as aggregate or cementitious material [13]–[15], while others have investigated the effects of granite waste on mechanical properties and durability [16], [17]. Despite numerous studies, there is limited research examining the combined use of glass bottle waste and granite waste as dual substitutes for coarse aggregate in structural concrete. Previous investigations have generally focused on single-material substitution [18]–[20], leaving a gap in understanding the synergistic effects of combining two types of solid waste in one concrete mix. Furthermore, the interaction between particle size, substitution ratio, and curing age on compressive strength performance remains underexplored.

This research is urgently needed to address two converging challenges: the overreliance on natural aggregates and the underutilization of glass and granite waste in concrete applications. The novelty of this study lies in evaluating the mechanical performance of concrete incorporating 3% glass bottle waste and varying granite waste contents (3%, 5%, 8%, and 10%) as coarse aggregate substitutes. The study introduces a combined approach that is rarely examined in existing literature [21]–[24]. The objective of this study is to investigate the effect of simultaneous substitution of glass and granite waste on the compressive strength of normal concrete designed for 20 MPa target strength. This effort contributes to sustainable construction by reducing the environmental footprint of concrete materials while supporting the development of alternative aggregate sources [25]–[27].

## **2. Method**

This study employed an experimental research method to evaluate the compressive strength of concrete incorporating glass bottle waste and granite waste as partial substitutes for coarse aggregate. The control mixture was designed to achieve a target compressive strength of 20 MPa at 28 days, and experimental mixtures were prepared by replacing 3% of the coarse aggregate with glass waste and varying the granite waste content at 3%, 5%, 8%, and 10% by weight. A total of 45 cylindrical specimens, each with a diameter of 15 cm and a height of 30 cm, were cast for compressive strength testing at the ages of 7, 14, and 28 days. The experimental variables were designed to investigate the influence of the waste substitution ratio on the compressive strength performance of the concrete, based on findings from previous studies which indicated that granite waste could maintain acceptable compressive strength levels when used as aggregate replacement.

The concrete mix design followed the Department of Environment (DOE) method, adapted from the British mix design system and aligned with SNI 03-2834-2000 and SNI 2847-2013 standards. The assumed standard deviation was 3.5 MPa, and a quality control factor of 1.08 was used, resulting in a mix design margin of 3.78 MPa to ensure consistency in compressive strength. The target slump value for the fresh concrete was set at  $12 \pm 2$  cm. The constituent materials included ordinary Portland cement, natural sand as fine aggregate, crushed stone as natural coarse aggregate, recycled granite tile waste, and crushed glass bottle waste.

All aggregates had a maximum particle size of 25 mm and were tested for gradation, silt content, and organic impurities to ensure they met the requirements for structural-grade concrete. Clean water was used for both mixing and curing processes. The concrete mixtures were prepared using standard mixing procedures, followed by casting and compaction in cylindrical molds to minimize air voids and ensure uniform quality.

The specimens were demolded after 24 hours and cured in water tanks to maintain hydration. Curing durations were set at 7, 14, and 28 days to assess strength development over time. Compressive strength testing was conducted using a universal testing machine, where each specimen was centered accurately on the loading platform. A continuous load was applied at a rate of 0.14 to 0.34 MPa per second until failure occurred. The maximum load was recorded and used to calculate the compressive strength. This methodology enabled a systematic comparison between the control mix and those containing waste

substitutions, allowing the identification of the optimal proportion that meets both mechanical and environmental performance criteria.

### 3. Results and Discussion

The results of this study begin with the characterization of fine aggregates used in the concrete mixture. Based on the sieve analysis shown in Table 1 and illustrated in Figure 1, the fine aggregate had a fineness modulus (FM) of 2.57. This value meets the requirements specified in SNI 7656:2012, which mandates a fineness modulus range of 1.50 to 3.80, indicating that the aggregate is well-graded and suitable for concrete applications. The moisture content of the fine aggregate, as shown in Table 2, was found to be 6.9%, which is considered in the mix design adjustments to maintain the water-cement ratio. Furthermore, as presented in Table 3, the specific gravity of the fine aggregate in oven-dry, SSD, and apparent conditions were 2.55, 2.58, and 2.64 respectively, while the water absorption rate was 1.38%, falling within the acceptable range for use in structural concrete.

Table 1. Sieve Analysis Results of Fine Aggregate

| Sieve Size            | Retained Weight (g) | Percent Retained (%) | Cumulative Percent Retained (%) | Cumulative Percent Passing (%) |
|-----------------------|---------------------|----------------------|---------------------------------|--------------------------------|
| 3/8"                  | 0                   | 0                    | 0                               | 100                            |
| No. 4                 | 4                   | 0.4                  | 0.4                             | 99.6                           |
| No. 8                 | 20                  | 2                    | 2.4                             | 97.6                           |
| No. 16                | 148                 | 14.8                 | 17.2                            | 82.8                           |
| No. 30                | 311                 | 31.1                 | 48.3                            | 51.7                           |
| No. 50                | 418                 | 41.8                 | 90.1                            | 9.9                            |
| No. 100               | 81                  | 8.1                  | 98.2                            | 1.8                            |
| Pan                   | 18                  | 1.8                  | 100                             | 0                              |
| Total                 | 1000                | 100                  |                                 |                                |
| Fineness Modulus (FM) |                     |                      | 2.57                            |                                |

Table 2. Moisture Content of Fine Aggregate (SNI 1971-2011)

| Parameter                               | Value  | Unit |
|-----------------------------------------|--------|------|
| Weight of container + sample            | 11130  | g    |
| Weight of container only                | 130    | g    |
| Weight of moist sample (W1)             | 1000   | g    |
| Weight of container + oven-dried sample | 1065.5 | g    |
| Weight of oven-dried sample (W2)        | 935.5  | g    |
| Moisture Content                        | 0.069  |      |

Table 3. Specific Gravity and Water Absorption of Fine Aggregate (SNI 1970-2008)

| Parameter                           | Symbol | Value  | Unit |
|-------------------------------------|--------|--------|------|
| Saturated Surface Dry sample weight | S      | 500    | g    |
| Oven-dry sample weight              | A      | 493.2  | g    |
| Pycnometer + water                  | B      | 646.5  | g    |
| Pycnometer + sample + water         | C      | 953    | g    |
| Bulk specific gravity (dry)         | Sd     | 2.55   | -    |
| Bulk specific gravity (SSD)         | Ss     | 2.58   | -    |
| Apparent specific gravity           | Sa     | 2.64   | -    |
| Water absorption                    | Sw     | 0.0138 | -    |

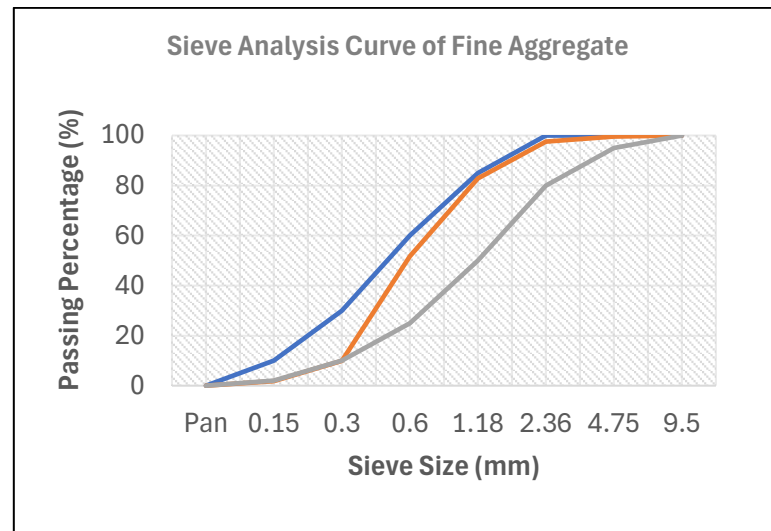


Figure 1. Sieve Analysis Curve of Fine Aggregate

The characteristics of coarse aggregate were also evaluated through sieve analysis, and the results are shown in Table 4. The aggregate conformed to ASTM C33 grading requirements, with a calculated fineness modulus of 7.8. The moisture content of the coarse aggregate was 1.3% as shown in Table 5. As indicated in Table 6, the specific gravity in oven-dry, SSD, and apparent states were 2.693, 2.642, and 2.564 respectively, with a water absorption value of 1.86%. These values confirm the suitability of the coarse aggregate for structural concrete use.

Table 4. Sieve Analysis of Coarse Aggregate (ASTM C33)

| Sieve Size       | Retained Weight (g) | Cumulative Retained (%) | ASTM C33 Limit (%) |
|------------------|---------------------|-------------------------|--------------------|
| 1"               | 73                  | 1.46                    | 100 max            |
| 3/4"             | 968                 | 20.85                   | 90–100             |
| 1/2"             | 2385                | 68.63                   | 20–55              |
| 3/8"             | 1209                | 92.85                   | 0–10               |
| No. 4            | 326                 | 99.38                   | 0–5                |
| No. 8–100 & Pan  | 31 (total)          | 100                     | 0                  |
| Fineness Modulus |                     | 7.8                     |                    |

Table 5. Moisture Content of Coarse Aggregate (SNI 1971-2011)

| Parameter                               | Value | Unit |
|-----------------------------------------|-------|------|
| Weight of container + moist sample      | 4210  | g    |
| Weight of container only                | 210   | g    |
| Moist sample weight (W1)                | 4000  | g    |
| Weight of container + oven-dried sample | 4160  | g    |
| Oven-dried sample weight (W2)           | 3950  | g    |
| Moisture Content                        | 0.013 |      |

Table 6. Specific Gravity and Water Absorption of Coarse Aggregate (SNI 1970-2008)

| Parameter                   | Symbol | Value | Unit |
|-----------------------------|--------|-------|------|
| Oven-dry weight             | A      | 5000  | g    |
| SSD weight                  | B      | 4907  | g    |
| Submerged weight            | C      | 3050  | g    |
| Bulk specific gravity (dry) | Sd     | 2.693 | -    |

| Parameter                   | Symbol | Value  | Unit |
|-----------------------------|--------|--------|------|
| Bulk specific gravity (SSD) | Ss     | 2.642  | -    |
| Apparent specific gravity   | Sa     | 2.564  | -    |
| Water absorption            | Sw     | 0.0186 | -    |

Granite waste used as a partial substitute for coarse aggregate was also tested for physical characteristics. As shown in Table 7, the specific gravity in oven-dry, SSD, and apparent states were 4.978, 4.888, and 4.568 respectively, with a water absorption rate of 1.80%. These values suggest that granite waste possesses higher density than natural aggregates, which could influence the overall weight and compaction behavior of the concrete mix.

Table 7. Properties of Granite Waste Aggregate (SNI 1970-2008)

| Parameter                   | Symbol | Value  | Unit |
|-----------------------------|--------|--------|------|
| Oven-dry weight             | A      | 5000   | g    |
| SSD weight                  | B      | 4910   | g    |
| Submerged weight            | C      | 3905.5 | g    |
| Bulk specific gravity (dry) | Sd     | 4.978  | -    |
| Bulk specific gravity (SSD) | Ss     | 4.888  | -    |
| Apparent specific gravity   | Sa     | 4.568  | -    |
| Water absorption            | Sw     | 0.018  | -    |

Concrete mix design calculations for the control mixture ( $f'_c = 20$  MPa) were established using DOE guidelines, and the key parameters are shown in Table 8. The mixture was designed with a slump target of 75–100 mm and maximum aggregate size of 25 mm. Table 9 provides the material quantities per cubic meter as well as for individual and grouped samples. The control mixture consisted of 279.71 kg/m<sup>3</sup> of cement, 153.3 kg/m<sup>3</sup> of water, 1092.06 kg/m<sup>3</sup> of coarse aggregate, and 886.46 kg/m<sup>3</sup> of fine aggregate, giving a total unit weight of 2411.5 kg/m<sup>3</sup>.

Table 8. Mix Design Parameters for Control Concrete ( $f'_c = 20$  MPa)

| Parameter                          | Value   | Unit              |
|------------------------------------|---------|-------------------|
| Target strength ( $f'_c$ )         | 20      | MPa               |
| Slump                              | 75–100  | mm                |
| Maximum aggregate size             | 25      | mm                |
| Water                              | 153.3   | kg/m <sup>3</sup> |
| Coarse aggregate (dry)             | 1609.03 | kg/m <sup>3</sup> |
| Concrete density                   | 2411.5  | kg/m <sup>3</sup> |
| Fineness modulus (sand)            | 2.57    | -                 |
| SSD specific gravity (fine agg.)   | 2.58    | -                 |
| SSD specific gravity (coarse agg.) | 2.64    | -                 |
| Water absorption (fine agg.)       | 0.0138  | -                 |
| Water absorption (coarse agg.)     | 0.0186  | -                 |

Table 9. Mix Composition for Control Concrete (1 and 9 Samples)

| Material | Mix/m <sup>3</sup><br>(kg) | Volume of 1<br>Specimen (m <sup>3</sup> ) | Weight per<br>Specimen (kg) | Weight for 9<br>Specimens (kg) |
|----------|----------------------------|-------------------------------------------|-----------------------------|--------------------------------|
| Water    | 153.3                      | 0.0053                                    | 0.81                        | 7.31                           |
| Cement   | 279.71                     |                                           | 1.48                        | 13.3                           |

| <b>Material</b>  | <b>Mix/m<sup>3</sup><br/>(kg)</b> | <b>Volume of 1<br/>Specimen (m<sup>3</sup>)</b> | <b>Weight per<br/>Specimen (kg)</b> | <b>Weight for 9<br/>Specimens (kg)</b> |
|------------------|-----------------------------------|-------------------------------------------------|-------------------------------------|----------------------------------------|
| Coarse Aggregate | 1092.06                           |                                                 | 5.79                                | 52.08                                  |
| Fine Aggregate   | 886.46                            |                                                 | 4.7                                 | 42.27                                  |
| Total            | 2411.5                            |                                                 | 12.78                               | 115                                    |

Table 10 presents the trial mix compositions for five different variations (TM1 to TM5), with TM1 being the control and TM2–TM5 representing mixes with 3% glass bottle waste and 3%, 5%, 8%, and 10% granite waste respectively. The materials were proportioned to maintain consistent fine aggregate, water, and cement content, while varying the substituted coarse aggregate volume. For each trial mix, nine cylindrical samples (15 cm × 30 cm) were cast, and the total volume required was calculated to be approximately 0.053 m<sup>3</sup> per variation. The exact material quantities used for each batch of nine samples are detailed in Table 11.

Table 10. Mix Composition of Trial Mixes (per m<sup>3</sup>)

| <b>Mix Code</b> | <b>Cement (kg)</b> | <b>Water (kg)</b> | <b>Fine Aggregate (kg)</b> | <b>Coarse Aggregate (kg)</b> | <b>Glass Waste (kg)</b> | <b>Granite Waste (kg)</b> |
|-----------------|--------------------|-------------------|----------------------------|------------------------------|-------------------------|---------------------------|
| TM1             | 428.16             | 214.43            | 666.33                     | 1031.17                      | 0                       | 0                         |
| TM2             | 363.94             | 182.27            | 666.33                     | 969.21                       | 30.93                   | 30.93                     |
| TM3             | 363.94             | 182.27            | 666.33                     | 948.59                       | 30.93                   | 51.55                     |
| TM4             | 363.94             | 182.27            | 666.33                     | 917.65                       | 30.93                   | 82.49                     |
| TM5             | 363.94             | 182.27            | 666.33                     | 897.03                       | 30.93                   | 103.11                    |

Table 11. Material Requirements for 9 Cylindrical Specimens (per Trial Mix)

| <b>Mix Code</b> | <b>Cement (kg)</b> | <b>Water (kg)</b> | <b>Fine Aggregate (kg)</b> | <b>Coarse Aggregate (kg)</b> | <b>Glass Waste (kg)</b> | <b>Granite Waste (kg)</b> |
|-----------------|--------------------|-------------------|----------------------------|------------------------------|-------------------------|---------------------------|
| TM1             | 22.7               | 11.37             | 35.33                      | 54.66                        | 0                       | 0                         |
| TM2             | 19.29              | 9.66              | 35.33                      | 51.38                        | 1.64                    | 1.64                      |
| TM3             | 19.29              | 9.66              | 35.33                      | 50.29                        | 1.64                    | 2.73                      |
| TM4             | 19.29              | 9.66              | 35.33                      | 48.65                        | 1.64                    | 4.37                      |
| TM5             | 19.29              | 9.66              | 35.33                      | 47.56                        | 1.64                    | 5.47                      |

The compressive strength of the concrete was tested at 7, 14, and 28 days. As shown in Figure 2, the compressive strength of the control concrete (TM1) at 7 days was 14.86 MPa, increasing to 19.16 MPa at 14 days and reaching 25.00 MPa at 28 days. These results confirm that the control mix exceeded the design strength of 20 MPa at 28 days.

The variation containing 3% glass and 3% granite waste (TM2) demonstrated a slightly improved performance, with compressive strengths of 16.19 MPa at 7 days, 21.63 MPa at 14 days, and 25.20 MPa at 28 days, as shown in Figure 3. These results indicate that the substitution of a small amount of both glass and granite waste can enhance early and ultimate strength due to improved particle packing and possible pozzolanic reactions from fine glass particles.

Subsequent mixtures with higher granite waste content, namely 5%, 8%, and 10%, showed decreasing compressive strength trends. At 28 days, these mixtures achieved 22.66 MPa, 21.90 MPa, and 20.43 MPa respectively. While all results remained above the 20 MPa target, the data suggest that excessive substitution may disrupt optimal gradation and reduce the interlocking of coarse particles, leading to lower mechanical resistance.

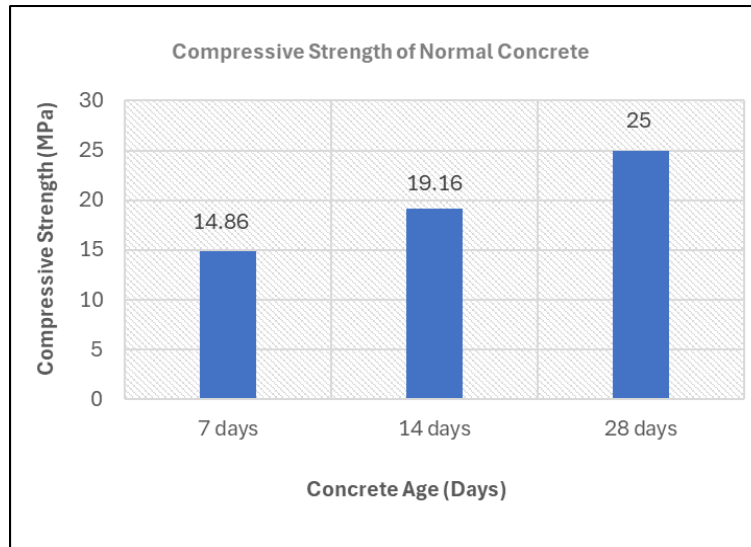


Figure 2. Compressive Strength of Normal Concrete at 7, 14, and 28 Days

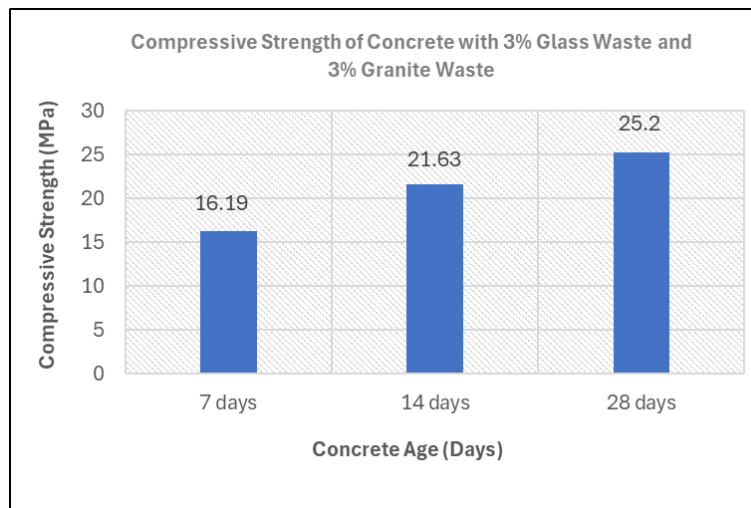


Figure 3. Compressive Strength of Concrete with 3% Glass Waste and 3% Granite Waste

In conclusion, the results demonstrate that glass and granite waste can effectively replace part of the coarse aggregate in normal concrete without reducing its structural performance. The highest strength was achieved using 3% glass and 3% granite waste, slightly outperforming the control mixture. These findings suggest that limited incorporation of such waste materials not only supports waste reduction strategies but also enhances concrete strength under optimized conditions.

#### 4. Conclusion

Based on the results of this experimental study, it can be concluded that partial substitution of coarse aggregate with 3% glass bottle waste and varying percentages of granite waste significantly affects the compressive strength of concrete. The control concrete mix designed for 20 MPa successfully reached an average compressive strength of 25.00 MPa at 28 days. The highest strength was observed in the mix with 3% glass and 3% granite waste, achieving 25.20 MPa, slightly higher than the control mix. This indicates that the combined use of limited amounts of glass and granite waste can enhance the mechanical performance of normal concrete, likely due to better particle packing and reduced voids.

However, increasing the granite waste content beyond 3% resulted in a gradual reduction in compressive strength, with values of 22.66 MPa, 21.90 MPa, and 20.43 MPa recorded for 5%, 8%, and 10% granite waste respectively. Although these values still exceeded the target strength, they highlight the importance

of optimizing replacement levels to maintain structural integrity. Slump test results also showed a slight decrease with higher granite content, indicating lower workability, yet all values remained within acceptable limits.

In general, the incorporation of 3% glass waste combined with up to 5% granite waste is recommended as the optimum substitution level to balance strength performance and sustainability. The use of recycled materials in concrete not only supports waste reduction but also demonstrates technical feasibility in meeting standard structural requirements. Further research is encouraged to evaluate long-term durability, microstructural behavior, and the effect of different curing regimes on similar mixtures.

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