# EVALUATING THE STRUCTURAL PERFORMANCE OF CERAMIC WASTE AS A PARTIAL SUBSTITUTE FOR COARSE AGGREGATE IN CONCRETE PROPERTIES

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**Abstract:** Various research studies have emerged in response to reducing the growing demand for crushed granite as coarse aggregate and protecting the environment from degradation. These studies aim to identify alternative materials that can provide the same purpose while minimizing environmental risks. This study evaluated the appropriateness of using waste ceramic tiles as a coarse aggregate in concrete and determined its strength compared to conventional crushed granite. Crushed waste ceramic tiles obtained from ceramic manufacturing businesses and construction sites were combined with crushed granite stones to partially substitute concrete. A concrete mixture with a ratio of 1 part cement, 1.11 parts sand, and 2.72 parts stones, known as notional C30 concrete, was created. The mixture included ceramic waste material, which replaced varying volumes of crushed granite (0%, 20%, 40%, 50%, and 100%). The water-cement ratio remained constant at 0.5. Concrete cubes of 150mm x 150mm x 150mm were manufactured and subjected to testing for compressive strength, density, and water absorption after 7 and 28 days. The findings demonstrated that discarded ceramic tiles can be used as a substitute for crushed granite in concrete manufacturing. However, it is advised to limit the replacement to a maximum of 20% to ensure the structural integrity of the concrete. Implementing this method of recycling ceramic debris can support the environment effectively.

## INTRODUCTION

The coarse aggregate, which constitutes the largest portion of concrete, is typically considered to be an inactive component in the concrete mixture. Aggregates constitute around 60% to 75% of the total volume in a standard concrete mixture (Maza et al., 2016). The coarse aggregate has a significant impact on the characteristics of both fresh and cured concrete. The aggregate's composition, shape, texture, size, and characteristics collectively influence concrete's strength, durability, and workability. Variations in gradation, maximum size, unit weight, and water absorption can all modify the nature and effectiveness of a concrete mixture. Coarse aggregates are often categorized as heavyweight aggregate, normal aggregate, and lightweight aggregate. The selection of each classification is determined by essential aspects that must be taken into account by the Structural Engineer. Heavyweight aggregates offer a cost-effective and efficient solution for utilizing concrete in radiation shielding. They provide the required protection against X-rays, gamma rays, and neutrons and for weight-coating submerged pipelines. The efficacy of heavyweight concrete, with a density ranging from 4000 kg/m$^3$ to 8500 kg/m$^3$, is contingent upon the aggregate type, size, and level of compaction. The standard aggregates are appropriate for most applications and yield concrete with a density that falls within the range of 2300 kg/m$^3$ to 2500 kg/m$^3$. Lightweight concretes have a density range from 1800 kg/m$^3$ to 2200 kg/m$^3$. Lightweight aggregates are utilized in many concrete products, including insulating screeds and reinforced or prestressed concrete. However, their primary application is in the production of precast concrete blocks. Lightweight aggregate-based concretes exhibit excellent fire resistance characteristics. (Kumar & Srivastava, 2023).

Indonesia needs substantial amounts of crushed rock aggregates to develop new infrastructure and restore old roads, highways, bridges, seaports, and private and governmental structures. This significantly strains the ecosystem since the rocks are only acquired from natural sources. The limited availability of crushed rock aggregate significantly impacts the cost of concrete. As a result, several researchers have proposed other materials that can be utilized as substitutes or partial replacements. Unutilized waste might be subjected to reprocessing to yield superior outcomes, surpassing the alternatives of abandonment or incineration. The combustion process raises a new issue, specifically widespread air pollution (Hadi Nugroho, 2022). Waste ceramic aggregate is a potential substitute for crushed rocks from quarry sites. Waste ceramic tiles are widely abundant at nearly every building site in the country. It is frequently observed that ceramic debris from building sites is often disposed of using it as filler material in depressions and open gaps in fields (Biney, 2020).

Indonesia's ceramic industry produces a significant amount of ceramic waste that needs to be better utilized. Ceramic waste aggregates possess a high specific gravity with a hard composition. They exhibit a rough surface on one side and a smooth surface on the other. They are also lighter than regular stone aggregates (Singh & Singla, 2015). The bricks are produced by combining clay, sand, and other natural materials, shaping them into the desired forms, and then subjecting them to intense heat in kilns, reaching temperatures ranging from 1000°C to 1250°C (Framinan et al., 2014). In addition to the favorable cost implications, using ceramic waste aggregate as coarse aggregates offers the advantage of being lighter in weight compared to traditional quarry stones. This characteristic will favorably affect the soil upon which the building is constructed. Furthermore, the ecology, which would otherwise face destruction, is safeguarded from degradation. This research evaluates waste ceramics' appropriateness and long-term viability as a partial replacement for coarse aggregate in concrete production, specifically in place of crushed granite stones. Additionally, it seeks to determine the optimal mix ratio of coarse aggregate to obtain the desired strength of the concrete.

## RESEARCH METHODS

### Materials and Procedure

The study utilized pit sand sourced from the Besuki Tulungagung Region of Indonesia, crushed granite from a quarry, regular Portland cement, pure water, and discarded ceramic tiles gathered from building sites and sales locations. The experiment involved replacing a portion of the crushed granite aggregate with waste ceramic aggregate at varying percentages (0, 20, 40, 50, and 100). This was done to create different concrete mixes with a nominal strength of C30 (using a mix ratio of 1:1.11:2.72) while maintaining a constant water-cement ratio of 0.5.

The aggregates' physical qualities and the fresh concrete's workability were assessed by material tests and slump tests, respectively. Subsequently, concrete cubes measuring 150mm x 150mm x 150mm were created from the different mixtures to conduct a compressive strength test on the 7th and 28th day. The test findings were subsequently compared to established benchmarks provided in the literature, while the specimens were measured in terms of weight to ascertain the density of the different mixtures.

### Tests on Materials

The British Standard Codes of Practice performed multiple tests (British Standards - BS 812-2, 1995) (Koksal, 2002),(Standard, 1881),(British Standards - BS 812-2, 1995) and the American Society for Testing Materials (United & Of, 1997). The tests were Gradation, Organic Matter, Moisture Content, Bulk Specific Gravity, Loss Angeles Abrasion (LAA), and Aggregate Impact Value (AIV).

**Sand**

The sand underwent several tests, including Gradation, Organic matter test, Moisture content test, and Bulk Specific Gravity, per the specifications outlined in BS 812, Part 112 (British Standards - BS 812-2, 1995).

**Crushed granite and ceramic tiles**

The study utilized crushed granite obtained from the Tulungagung Region of Indonesia as the standard coarse aggregate. Additionally, broken ceramic tiles with an average size of 20mm were collected from construction sites in Besuki Tulungagung. The engineering qualities of the materials were evaluated through tests including Gradation, Moisture content, Bulk Specific Gravity, Aggregate Impact Value, and Los Angeles Abrasion value. These tests were conducted according to the standards or requirements stated in BS 882 (Koksal, 2002).

## RESULTS AND DISCUSSION

The main focus of this study was to determine the compressive strength of the partial replacement of ceramic waste. This was done to identify the optimal percentage of replacement that may be recommended. Table 1 provides a detailed summary of the results obtained from the compression test. Meanwhile, Figure 1 visually illustrates the trend of the compressive strength for different mixtures.

Table 1. Compressive strength of concrete mixes

| No | % Ceramic Waste | Compressive Strenght (N/mm$^2$) | | |
|---|---|---|---|---|
| | | 7th Day | 28th Day | 28th day % Reduction |
| 1 | 0 | 19,78 | 30,99 | - |
| 2 | 20 | 18,35 | 30,26 | 2,37 |
| 3 | 40 | 17,00 | 27,61 | 10,93 |
| 4 | 50 | 15,50 | 26,81 | 13,49 |
| 5 | 100 | 13,07 | 23,60 | 23,85 |

Source: Primary Data Research (2023)

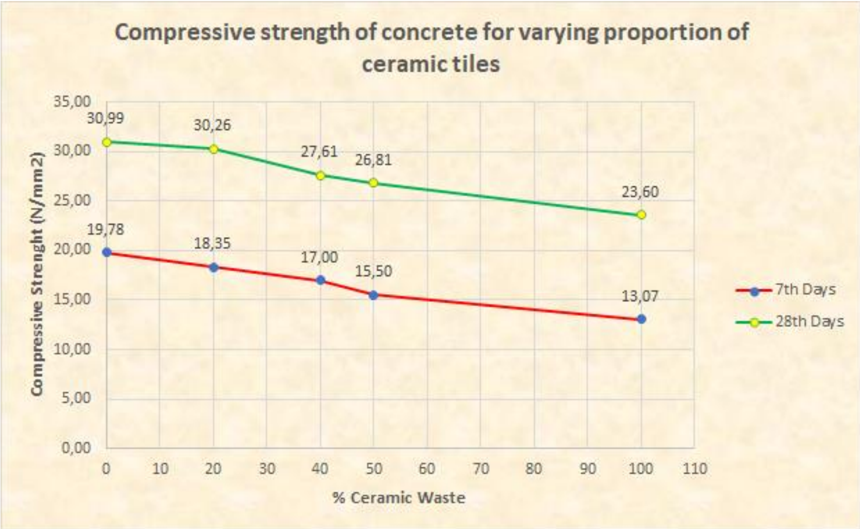


Fig. 1. Compressive strength of concrete for varying proportions of ceramic tiles
Source: Source: Primary Data Research (2023)

Overall, there was a reduction in the compressive strength of the concrete as the proportion of ceramic waste aggregate rose, regardless of whether the concrete specimens were 7 or 28 days old. For the 7-day specimen, the compressive strength decreased from 19,78 N/mm$^2$ in the control group to 13,07 N/mm$^2$ when 100% ceramic waste was replaced with crushed granite.

Similarly, the strength of a 28-day-old specimen decreased from 30,99 N/mm$^2$ (control) to 23,60 N/mm$^2$ (100% ceramic waste replacement for broken granite), which aligns with the findings of Singh and Singla (Singh & Singla, 2015). Based on the data in Table 1, the percentage reduction in 28th-day compressive strength of the different specimens was analyzed compared to the control specimen. It was found that the specimen with 20% replacement had the smallest percentage drop of 2.37%, followed by the specimen with 40% replacement. The specimen that underwent complete replacement had the highest percentage loss, 23.85%. The specimens with a replacement rate of 20% or less showed a reduction in percentage in the single digits. In contrast, the specimens with a replacement rate above 20% showed a reduction in percentage in the double-significant figures.

Hence, there was a notable decline in the strength of the concrete as the proportion of ceramic waste exceeded 20%. This may be attributed to the lower strength of ceramic waste aggregates in resisting compressive loads compared to crushed granite aggregate and a potential decrease in the binding between the cement matrix and waste ceramic tile.

However, the findings suggest that ceramic waste aggregates have the potential to be used as a partial substitute for crushed granite as coarse aggregate. Notably, the amount of ceramic waste aggregate in the mixture for heavy-duty concrete work should be at most 20% of the coarse aggregate. However, concrete with a strength of 23.60 $N/mm^2$, containing 100% ceramic waste coarse aggregate, could still be suitable for regular structural concrete components. This finding aligns with the results of Daniyal and Ahmad (Daniyal & Ahmad, 2015) and Tamanna and Sharma (Tamanna & Sharma, 2018), who concluded that the proportion of ceramic waste aggregate in concrete should not exceed 20% of the coarse aggregate content. However, it contradicts the findings of Kumar et al. (Ch et al., 2015), who suggested that a maximum of 10% ceramic waste replacement for the main aggregate was optimal (Maza et al., 2016).

## CONCLUSIONS AND RECOMMENDATIONS

This study aimed to assess the feasibility of substituting a portion of crushed granite aggregate with ceramic waste in structural concrete. Following the implementation of experimental techniques, it was determined that the ceramic waste generated by building sites and ceramic manufacturing businesses could be recycled by crushing it into different sizes of coarse aggregates and incorporating it into concrete mixtures. Nevertheless, the optimal proportion for achieving structural concrete's necessary strength and durability is to replace a maximum of 20% of the aggregate with ceramic waste.

Utilizing ceramic waste aggregate in concrete will mitigate environmental deterioration and preserve natural habitats while reducing the strain on limited quarry resources used for crushed granite.

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