Effect of Recycled Crushed Brick Waste as Fine Aggregate Replacement on Mechanical Properties of Green Concrete

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Abstract. Both the sand mining industry and the construction trade have a negative impact on the environment. Excessive sand mining activity and disposal of brick waste from construction industry is harmful to the environment. To reduce these effects, crushed brick waste has been a potential substitute for sand in concrete production. The objective of this paper is to investigate the effect of crushed brick wastes as fine aggregates on workability, compressive strength, flexural strength and water absorption of concrete. Concrete mixtures were prepared by substitution of sand content at 0, 5, 10, 15, 20 and 25%. All specimens were subjected to water curing. Four types of testing were conducted, namely the slump test, compressive strength test, flexural strength and water absorption test. The results indicated that use of crushed brick waste in concrete affects the workability, compressive strength and flexural strength. Water absorption of concrete increased when a higher percentage of crushed brick waste was used as sand replacement. On overall, up to 10% replacement of crushed brick can be integrated in concrete production. Conclusively, channelling the brick waste for the use as sand replacement in concrete promotes river sand saving and contributes towards a cleaner environment.

1 Introduction

Concrete formed through a combination of cement, aggregates and water, remains the most widely used building material globally due to its versatility, strength, and affordability. It is the backbone of modern infrastructure, with annual production increasing by 10 billion tons to support the rapid growth of urbanization and infrastructure [1]. This high demand creates a significant need for its main components, especially natural river sand. Natural river sand is highly valued for its qualities in concrete production, but over-extraction causes significant environmental damage, such as riverbed depletion and ecosystem disruption [2]. These twin issues highlight the urgent need for more sustainable practices in the industry. At the same

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time, the growing construction sector generates large amounts of construction and demolition (C&D) waste, like concrete, stone, and plastics that often end up in landfills. This waste stream, accounting for approximately 30% to 40% of C&D, is rapidly increasing worldwide, posing challenges such as higher waste management costs and environmental harm due to landfill overuse [3-5]. In Malaysia, the construction industry generates around 25,600 tons of C&D waste daily, contributing significantly to environmental challenges and requiring improved waste management strategies [6]. Despite efforts to promote sustainable waste practices, issues such as a lack of awareness and weak policy enforcement, and constraints have limited progress have delayed these efforts. Addressing these challenges through improved management systems, policy support, and industry engagement is essential to advance sustainability and reduce the environmental impacts of both resource extraction and waste disposal in Malaysia's construction sector [7 - 8]. These issues highlight the urgent need for sustainable resource management and waste reduction strategies within the construction industry.

A promising solution to this challenge lies in the concept of a circular economy, whereby waste materials are transformed into a resource. One key approach is the development of ‘green concrete’, which incorporates recycled materials to reduce its environmental footprint. In this context, the use of recycled fine aggregates (RFA), sourced from C&D waste, has received considerable attention. The utilization of RFA would be able to support the effort to conserve natural resources while simultaneously reducing the amount of waste sent to landfills. Researchers have explored various types of RFA to determine their feasibility as a replacement for natural sand in concrete production [9]. Past researcher, Nováková and Buyle [10] concluded that replacing natural aggregates with fine recycled concrete aggregates at ratios of up to 40% has no significant negative impact on either the fresh or hardened properties of concrete. Another researcher elsewhere Belebchouche et al., [11], concrete containing up to 40% recycled content can achieve compressive strengths exceeding 20 MPa after 28 days of curing. In certain cases of partial replacement approach of using 25% RFA resulted in increment of compressive, flexural and split tensile strength [12]. The inclusion of RFA which has dissimilar properties as compared to natural aggregate which commonly used also has effect on the water absorption properties of concrete. The use of RCBA at higher replacement level led to stiffer mixes with lower workability [13]. According to Rifa et al [9], the water absorption levels of concrete containing RFA remain within acceptable limits when the replacement level is maintained between 15% and 45%. The mechanical properties of concrete incorporating recycled fine aggregates (RCA) is strongly influenced by the replacement level and physical properties of the recycled materials. However, a critical agreement from the literature is that performance is highly dependent on the replacement ratio and the specific type of RFA used.

Much of the existing research focuses on recycled concrete aggregate, leaving a gap concerning the performance of fine aggregates derived specifically from crushed cement-sand bricks. Therefore, this study aims to systematically evaluate the effect of incorporating recycled crushed cement-sand brick aggregate (RCBA) as a partial replacement for natural fine aggregate. The research evaluates its effects on the fresh properties (workability), mechanical strengths (compressive and flexural), and water absorption of concrete, providing crucial data for its effective utilization in sustainable construction. In response to the environmental challenges of sand mining and construction waste, this research explores the viability of using RCBA as a partial substitute for natural fine aggregate in concrete production. The RCBA used in this study was derived from local crushed cement-sand bricks.se 170 x 250 mm paper size (W x H mm) and adjust the margins to those shown in the Table 1. The final printed area will be 130 x 210 mm. Do not add any page numbers.

2 Introduction

The experimental work consists of three main phases. First of all, materials required for concrete specimen preparation were attained. Then, the specimens for testing were prepared at the concrete laboratory. All tests were conducted adhering to the existing standards.

2.1 Materials

The primary materials included ordinary Portland cement (OPC), tap water, coarse aggregate, natural river sand (fine aggregate), and recycled crushed cement-sand brick aggregate (RCBA) as an alternative fine aggregate were used. Local river sand with a fineness modulus of 2.86 was used as the natural fine aggregate, providing a baseline for comparison. The recycled cement-sand brick waste was sourced from a local supplier, crushed using a jaw crusher, then sieved to obtain particles passing the 4.75 mm sieve and retained on the 75 µm sieve. The RCBA exhibited a fineness modulus of 3.08, indicating a slightly coarser grading compared to the natural sand. Figure 1 presents the physical appearance of both the natural river sand and RCBA.

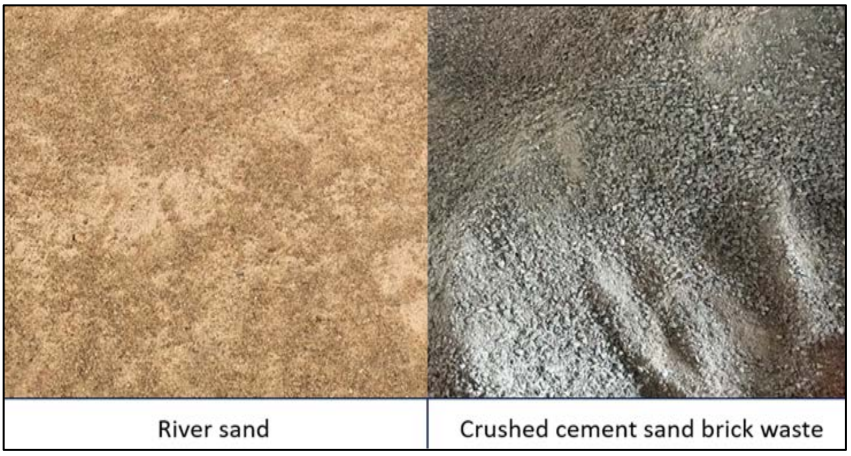

Fig. 1. River sand and crushed cement sand brick waste used

2.2 Mix proportion

In this research, six concrete mixes were prepared to assess the effects of partially replacing natural river sand with RCBA as a fine aggregate. The control mix used 100% river sand, providing a baseline for comparison. The experimental mixes were designed to maintain the same proportions of cement, water, and coarse aggregate as the control, ensuring consistent conditions for evaluating the influence of RCBA replacement. The replacement levels for river sand with RCBA were varied at 0%, 5%, 10%, 15%, 20%, and 25% by weight. The water-to-cement ratio was maintained at 0.35 for all mixes. This controlled variation aimed to isolate the impact of RCBA while minimizing other variables. The composition of the concrete mix proportion is tabulated in Table 1.

Table 1. Mix proportion of concrete mixes.

Mix designation	Cement	Sand	RCBA	Coarse Aggregate	Water
RCBA - 0	425	0	755	1182	150
RCBA – 5	425	38	717	1182	150
RCBA - 10	425	75	680	1182	150
RCBA – 15	425	113	642	1182	150
RCBA - 20	425	151	604	1182	150

2.3 Specimen preparation and testing method

The concrete specimens were prepared, including 150 mm cubes and 150 mm x 150 mm x 600 mm prisms. The quantities of ingredients required for the concrete mix, namely, cement, fine aggregate, coarse aggregate, RCBA, and water, were weighed accurately using a digital scale. The preparation of the concrete mix and mixing procedures were conducted using clean apparatus. The ingredients were then mixed using a clean mechanical concrete mixer until a homogeneous mixture was obtained. Each mould was filled with concrete in three layers and compacted with a vibrating table to ensure proper consolidation at each layer. After filling the mould, the specimens were covered with a wet gunny sack and left overnight for curing before being demoulded the following day. All hardened concrete specimens were immersed in a water tank for 7 and 28 days for curing purposes.

Four types of testing were conducted for fresh and hardened concrete specimens. The fresh properties of the concrete mixes containing different percentages of RCBA were determined through the slump test in accordance with BS EN 12350-2 [14]. The machines used to conduct compressive strength test and flexural strength test are shown in Figure 2. The compressive strength test and flexural strength test were carried out following the standard BS EN 12390-3[15] and BS EN 12390-5:[16], respectively. The water absorption test for concrete was carried out in accordance with BS 1881-122:[17].

Fig. 2. Machine used for compressive strength test machine and flexural strength test.

3 Results and Discussion

On overall, the use of RCBA as fine aggregate replacement has influence on the fresh and hardened properties of concrete.

3.1 Workability

Figure 3 displays the findings of slump values, which assess the workability of fresh concrete mixes. A pattern can be seen in which the slump value gradually decreases as the RCBA content increases. The control mix contained 100% natural river sand, exhibited the highest workability (160 mm). However, when RCBA was incorporated, the slump values progressively decreased, reaching approximately 125 mm at 25% RCBA. The physical properties of RCBA are directly attributed to the decrease in workability of RCBA mixes. Compared to natural sand, RCBA particles often have rough, angular surfaces and greater porosity. The porous structure of RCBA particles absorbs some of the mixing water, which contributes to the fluidity of the cement paste, even though the amount of mixing water is kept constant for all mixtures. Slump values of the mix containing up to 15% of RCBA remained within a workable range enabling it to be used for concreting work. Mixes consisting beyond the replacement need to be improved its workability through integration of water reducing mixture or higher content of mixing water. Studies by Liu et al. [18] and Li et al. [19] using different porous recycled aggregates have also reported this phenomenon.

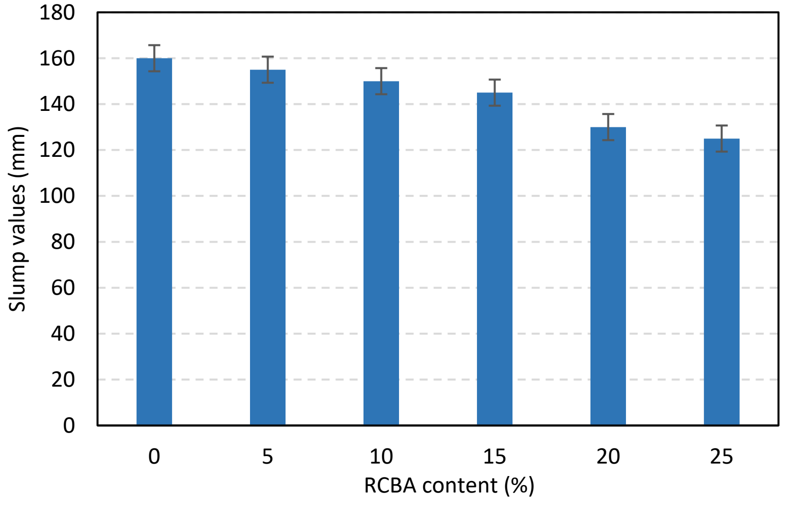

Fig. 3. Effect of RCBA on workability of fresh concrete.

3.2 Compressive strength

The compressive strength of concrete with varying RCBA percentages is presented in Figure 4. It was found that the continuous cement hydration process increased the compressive strength of all mixes from 7 to 28 days. However, the findings demonstrated a negative relationship between compressive strength and RCBA content. At 7 and 28 days, the control concrete (0% RCBA) reached strengths of about 29 MPa and 41 MPa, respectively. Both early-age and later-age strengths decreased with the incorporation of RCBA, with the lowest values recorded at 25% replacement, which is approximately 23 MPa at 7 days and 34 MPa at 28 days. The strength loss was small with 5% and 10% RCBA replacement, however, the 28-day compressive strength remained close to 40 MPa as recorded by the control mix. The RCBA concrete specimens showed a significant decrease to about 36 MPa, 35 MPa and 34 MPa, respectively, at 28 days when the RCBA level increased above 15%. According to a recent meta-analysis, the normalized 28-day compressive strength decreased by 0.19 % for every 1% increase in coarse RCA replacement and by 0.24 % for fine RCA [20].

The reason for these decreases is that RCBA particles are weaker and more permeable than natural river sand. Kisku et al. [21] identified that recycled coarse aggregate (RCA) particles are often weaker and more porous than natural fine aggregate. When subjected to load, these weaker particles can be the starting point of failure in the concrete matrix. Additionally, the old mortar on RCBA particles absorbs more water than natural river sand, which could affect the water-to-cement ratio around the particles. Evidently, compared to other values documented in the literature, the magnitude of the strength reduction observed is acceptable and modest. Recent studies have shown that treated RCA can reach up to 87% of the compressive strength of concrete made with natural aggregates, although untreated RCA usually exhibits a more noticeable decrease [13]. Particularly at lower replacement level of 5%, the study's comparatively modest strength loss indicates that the RCBA utilized had acceptable quality features as it able to meet the targeted compressive strength.

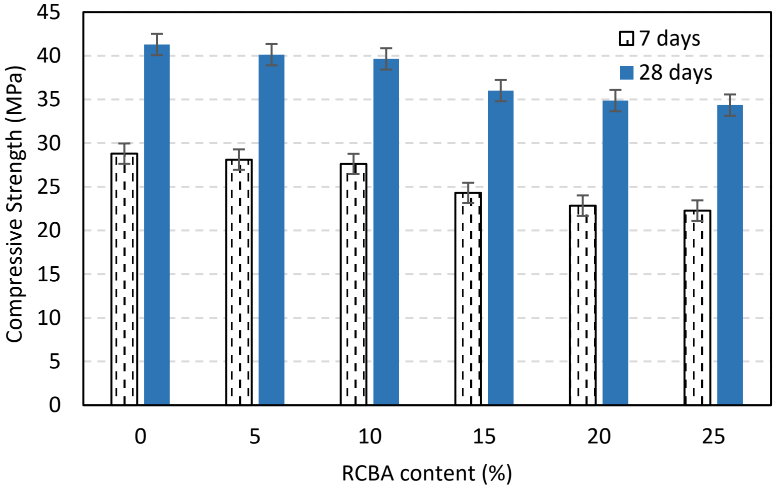

Fig. 4. Compressive strength of RCBA concrete.

3.3 Flexural strength

Figure 5 depicts the flexural strength of concrete with different levels of RCBA replacement. Clearly, the flexural strength decreases with increasing RCBA content, following a pattern similar to the compressive strength. This is typical behavior in concrete containing porous aggregate. It demonstrates that the strength of the bond between the RCBA particles and the cement paste has a significant impact on flexural strength. Furthermore, the strength increased for all mixtures, indicating continued hydration of the cement from 7 to 28 days of curing. The findings clearly showed that the flexural strength at 28 days was superior to the strength tested at 7 days for control concrete and those containing RCBA. The ongoing cement hydration process is directly responsible for this gradual increase in strength.

It was also found that the reduction in flexural strength was influenced by the RCBA content. The dense natural sand particles in the control mix (0% RCBA) provided the interfacial transition zone with a solid foundation to grow without competition for water,

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resulting in more significant strength growth. In contrast, less significant increases were seen in combination with higher levels of RCBA (20% to 25%). This may be explained by some of the mixing water being absorbed by the porous RCBA particles [12]. This internal absorption may create a small area surrounding the aggregate particles where there is not enough water for full cement hydration. Although strength typically increases with age, mixtures with higher levels of replacement exhibit lower 28-day flexural strength in comparison to reference concrete produced using 100% natural river sand as fine aggregate. This effect is also influenced by the reduced workability related to greater RCBA percentages, as was previously mentioned. Because it is more difficult to completely compact a less workable mix, there may be more micro-voids and honeycombing in the matrix. The tensile resistance of the concrete is greatly decreased by these internal defects, which serve as stress concentration locations. Past studies by Debieb & Kenai [22] on the use of other recycled materials in concrete have observed this connection between flexural strength, porosity, and workability. Similar observation has been reported by past researcher, Gan et al. [23].

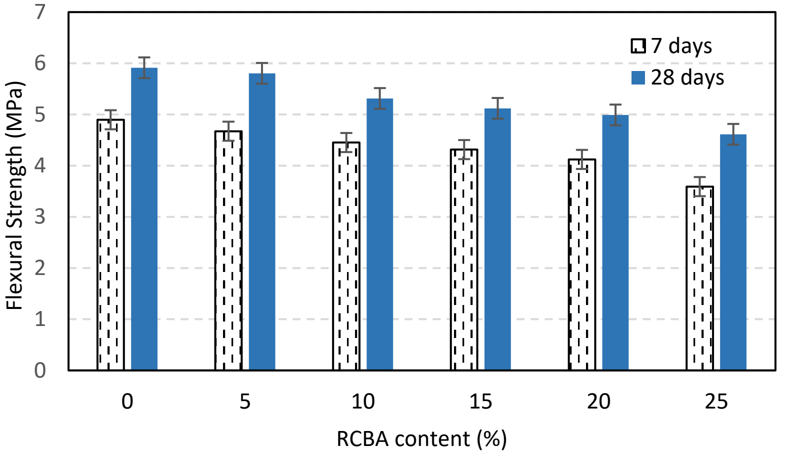

Fig. 5. Flexural strength of RCBA concrete.

3.4 Water absorption

The water absorption for all series of concrete specimens is presented in Figure 6. On overall, all the mixtures examined in this study had water absorption values that were within acceptable limits, which are often considered to be between 5% and 7% by mass. Those values are consistent with the requirements for high-quality concrete [17]. The findings show a distinct pattern where higher percentages of RCBA used as a replacement for natural sand are associated with an increase in water absorption. The characteristics of RCBA are directly responsible for this increase in water absorption. In contrast to dense natural sand particles, RCBA has more porosity. The integration of porous RCBA particles to the mix, increase existence of more voids in the concrete that results in increases the amount of water that can be absorbed and held by the hardened concrete.

Moreover, this effect is significantly influenced by the decrease in workability observed at higher levels of RCBA replacement. Even with vibration, the concrete mix becomes more difficult to fully compact, which may lead to a less dense matrix with more trapped air voids. These voids open up more channels for water to enter. The observed increase in water absorption is ultimately due to the porous aggregate and the microstructure, which may be less dense. Similar trend has been reported by previous researchers, Khalaf and DeVenny [24], Xiao et al., [25] and Jagadesh et al. [26] who integrated recycled aggregate derived from cement based composite material waste as fine aggregate replacement in concrete.

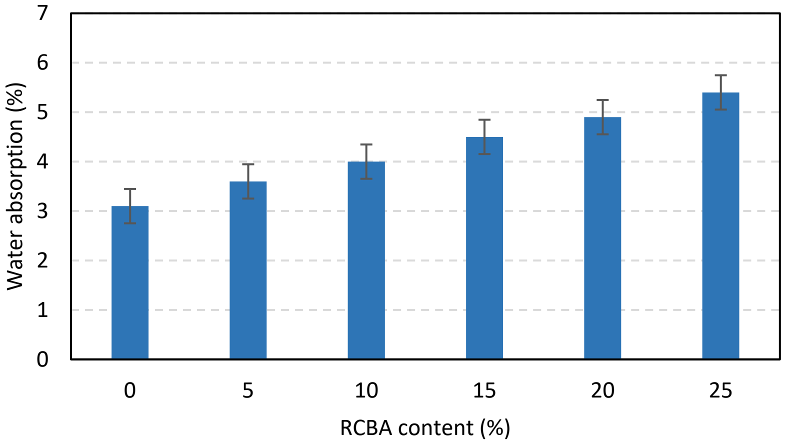

Fig. 6. Water absorption of RCBA concrete.

4 Conclusion

The introduction of RCBA as an alternative material in concrete had a significant impact on the fresh and mechanical properties of concrete. It was observed that as the RCBA content increases, the workability of fresh concrete continues to decrease. The high porosity of the RCBA particles and their water absorption capacity are the main reasons for this decrease. Additionally, it demonstrated a rise in water absorption as the RCBA percentage rose, indicating that the addition of RCBA enhanced the concrete matrix's overall porosity and interconnected pore network. To achieve a balance between acceptable mechanical performance and environmental benefits, a replacement level of up to 10% is advisable. This places RCBA-mixed concrete as a promising partial replacement material for sustainable construction.

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Author contribution statement. Muhammad Hafiz Nasuha Mat Yasim- Investigation, Writing. Khairunisa Muthusamy: Conceptualization, Methodology, Editing. Mohamed A. Ismail – Editing. Mohd Faizal Md Jaafar - Editing

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