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# Assessing the mechanical and durability properties of concrete incorporating recycled clay masonry rubble bricks as fine aggregates

**Thilivhali M. Malima, Olatokunbo E. Omisakin, and Janina P. Kanjee**

School of Civil and Environmental Engineering, University of the Witwatersrand

**Abstract**

Construction and demolition waste is a significant environmental problem worldwide, with 58% of the 4.48 million tons of such waste ending up in landfills as reported by SAWIC in 2017. To mitigate this issue, this project aims to investigate the feasibility of incorporating 50% recycled clay masonry rubble bricks (CMRB) in place of natural fine aggregate in concrete, thereby reducing the environmental impact of construction waste. The study encompassed casting 84 100mm cubes utilising natural fine Andesite aggregate and 84 100mm cubes, replacing 50% of the fine aggregate with recycled CMRB. The cubes were cast using 14mm Andesite coarse aggregates and a water-to-binder ratio of 0.6. The compressive strength and durability properties (with respect to oxygen permeability, water sorptivity and chloride conductivity) were assessed at three ages, 28, 56 and 90 days. The results revealed that the incorporation of CMRB as fine aggregates in concrete reduced workability, but positively influenced the mechanical and durability properties of the 50% CMRB concrete mix. The improved properties can primarily be attributed to the calcinated clay present in the crushed recycled clay masonry rubble bricks, which exhibits pozzolanic behaviour. These findings suggest that using recycled clay masonry rubble bricks as a replacement for natural fine aggregate in concrete can lead to a reduction in environmental impact while also improving concrete properties.

**Keywords:** recycled clay masonry rubble bricks (CMRB); fine aggregates; compressive strength; durability.

## 1. INTRODUCTION

Construction and Demolition (C&D) waste refers to waste generated from the construction, remodelling, repair, and demolition of structures. C&D waste is a major contributor to environmental degradation and pollution, as well as occupying landfill space due to its non-biodegradable nature [1]. To address these issues, there is increasing pressure to find sustainable solutions, such as recycling C&D waste as fine aggregate in concrete [2]. Previous research has shown that incorporating recycled masonry rubble in concrete can enhance its compressive strength and durability in the short term, up to 28 days [3]. This study aimed to evaluate the mechanical and durability properties of finely recycled masonry clay rubble bricks as a replacement for natural fine aggregate in concrete, over a longer period of time. The objective was to reduce waste generation and the demand for natural fine aggregate while also determining the long-term performance of concrete with recycled clay masonry rubble bricks as fine aggregates.

## 2. MATERIALS AND TEST METHODS

### 2.1. CMRB as Fine Aggregates Replacement

The CMRB aggregates used in this study were obtained from clay masonry bricks collected from a construction site located at The University of the Witwatersrand. Unfortunately, the composition and age of the brickwork remain unknown. Prior to crushing the bricks, excess mortar and paint (physical impurities) were removed from the CMRB using a hammer and chisel. The CMRB were then mechanically crushed to produce particle size and grading characteristics that closely matched those of the control fine Andesite aggregates utilized in this study. A grading profile, depicted in Figure 1, was used to determine the amount of masonry rubble aggregate required to achieve a grading profile that was comparable to the one produced using natural fine Andesite aggregate, as described in SANS 1083 [4], in terms of fraction size and mass.

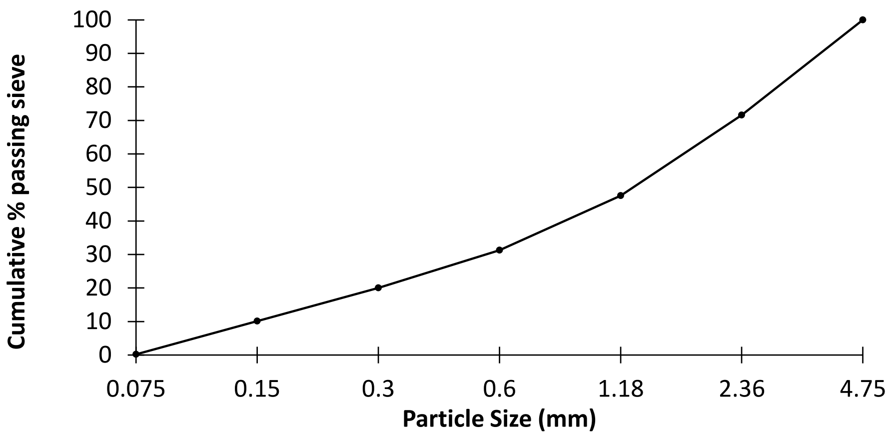


***Figure 1: Grading profile for natural fine Andesite aggregate***

### 2.2. Concrete Mix Design

Two concrete mixes were designed with a w/b ratio of 0.6, with one mix having 0% CMRB aggregate replacement and the other having 50% CMRB aggregate replacement. Table 1 provides a summary of the details of these mix designs.

*Table 1: Concrete proportions in kg/m³*

| Constituents | 0% CMRB | 50% CMRB |
|---|---|---|
| PC (CEM I 52.5 R) | 251 | 251 |
| Fly Ash (FA) | 107 | 107 |
| Andesite stone content | 761 | 761 |
| Andesite sand content | 1077 | 538.5 |
| CMRB sand content | 0 | 538.5 |
| Water | 215 | 215 |
| Admixture (Superplasticiser) | 0 | 1.25 |

### 2.3. Testing Approach

**i. Slump tests**

To measure the workability of fresh concrete, slump tests were conducted in line with SANS 5862-1:2006 [5].

**ii. Compressive strength tests**

100 mm concrete cubes samples were prepared, water cured and tested in accordance with SANS:5863[6]. The cubes were loaded using a cube machine which had a maximum loading capacity of 2 000 KN. The compressive strength of the concretes was determined at 28, 56 and 90 days after casting.

**iii. Durability test**

Three durability index (DI) tests namely the oxygen permeability, water sorptivity and chloride conductivity tests were performed. These tests measure the resistance of the cover concrete to the transportation of ions and fluids through the concrete thus affecting deterioration. The tests produce reliable indices for the characterization of concretes.

The DI test specimens were prepared in accordance with SANS 3001: CO3-1 [7]. The oxygen permeability index (OPI) test was conducted according to SANS:3001-CO3-2 [8]. The water sorptivity test was conducted in accordance with the Durability Index Manual [9]. The chloride conductivity test was conducted according to SANS:3001-CO3-3[10].

## 3. RESULTS AND DISCUSSION

The investigation into the mechanical and durability properties of concrete made using CMRB as fine aggregates was conducted over a period of three months. The results are outlined and further discussed below.

### 3.1. Slump Test

The slump tests results in Figure. 2, showed that the use of CMBR resulted in a decrease in the workability of the concrete.

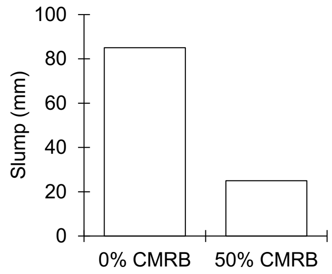


***Figure 2: Slump results for concrete made using 0, 50% CMRB as fine aggregate.***

The slump results for 0% and 50% CMRB were 85 mm and 25 mm respectively, as shown in the figure above. The high porosity of the rubble can be attributed to the absorption of some of the mixing water leading to the decrease in the workability, hence a decrease in slump [11].

### 3.2. Compression Strength

In general, the compressive strength is observed to increase with the incorporation of fine CMRB aggregates, for all three testing ages as seen in Figure 3.

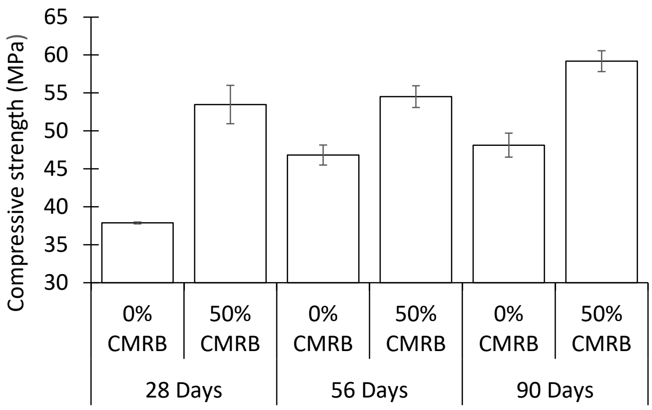


***Figure 3: Compressive strength of concrete made using 0, 50% CMRB as fine aggregates at 28, 56 and 90 days.***

At ages 28, 56, and 90 days, the compressive strengths of 50% CMRB were 53.5, 54.5, and 59.2 MPa respectively. In comparison, the compressive strengths of 0% CMRB at the same ages were 37.9, 46.8, and 48.1 MPa respectively. After 28 days, the average compressive strength of the replacement mix was found to be 41.2% higher than that of the control mix. This difference was further observed to be 16.5% and 23% at ages 56 and 90 days, respectively. The findings indicate that the 50% CMRB mix, which is a blend of 50% recycled CMRB and 50% fine Andesite aggregates, exhibited higher compressive strength compared to the control mix consisting of 100% fine Andesite aggregates.

The observed increase in strength can be primarily attributed to the calcinated clay present in the crushed recycled clay masonry rubble bricks, which exhibit pozzolanic behaviour [12].

### 3.3. Durability Index Testing

The durability of concrete can be measured by the oxygen permeability index, water sorptivity and porosity, and chloride conductivity tests. All three durability indices were obtained to determine the overall durability of concrete incorporating fine CMRB aggregates.

#### 3.3.1. Oxygen permeability index

The Oxygen Permeability Index (OPI) is indirectly proportional to permeability. The value of OPI indicates the resistance of a given concrete to the ingress of gases. A high value of the OPI corresponds to a high resistance to gaseous ingress.

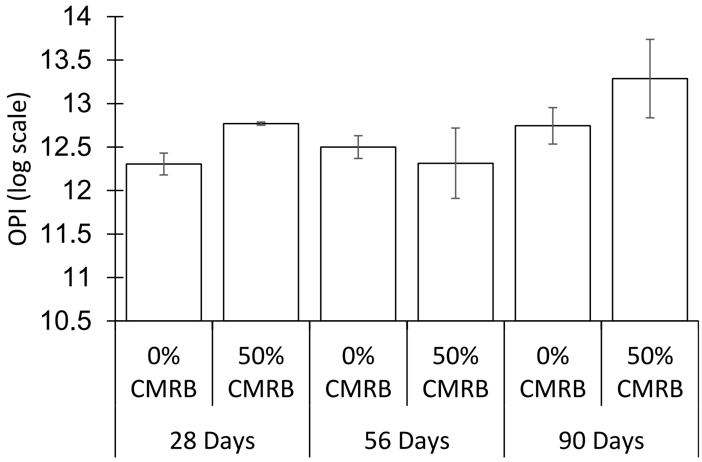


***Figure 4: OPI for concrete made using 0 and 50 % CMRB as fine aggregates at 28, 56 and 90 days.***

At ages 28, 56, and 90 days, the OPI for 50% CMRB were 12.8, 12.3, and 13.3 respectively. In comparison, the OPI for 0% CMRB at the same ages were 12.3, 12.5, and 12.7 respectively. Figure 4 displays a general trend where the OPI value increases with the incorporation of fine CMBR aggregates at 28 and 90 days. However, at 56 days, the replacement mix showed a lower OPI value compared to the control mix, which can be regarded as an outlier. The increase in permeability can be attributed to the pozzolanic reactivity of the crushed recycled clay masonry rubble bricks, resulting in the formation of cementitious hydration products [13].

#### 3.3.2. Water sorptivity index

Ingress of moisture in concrete by capillary suction is obtained using this index. A higher value of WSI implies a decreased resistance to the ingress of liquids in a given concrete specimen.

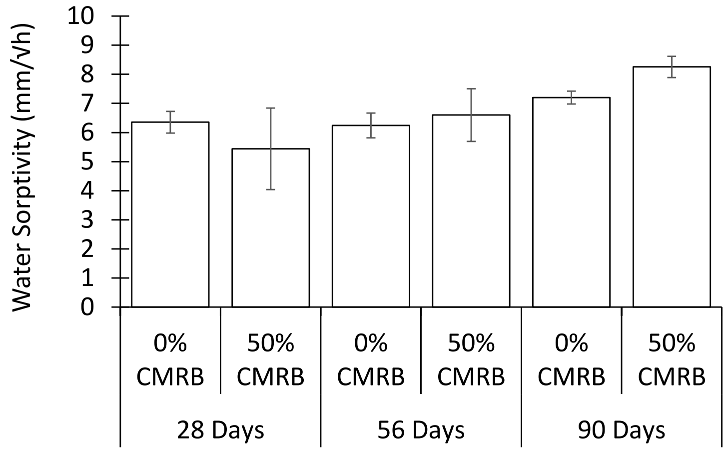


***Figure 5: Water sorptivity for concrete made using 0 and 50 % CMRB as fine aggregates at 28, 56 and 90 days.***

At ages 28, 56, and 90 days, the WSI for 50% CMRB were 5.4, 6.6, and 8.3$mm/\sqrt{h}$ respectively. In comparison, the WSI for 0% CMRB at the same ages were 6.4, 6.2, and 7.23$mm/\sqrt{h}$ respectively. Figure 5 indicates that the 50% CMBR mix exhibited a higher WSI value at 56 and 90 days compared to the control mix. This can be attributed to the porous nature of the fine CMBR aggregates, resulting in a higher absorption of moisture.

### 3.3.3. Chloride conductivity index

Chloride Conductivity Index (CCI) indicates the resistance of concrete to the ingress of chloride. A higher CCI value suggests a decreased resistance to chloride ingress.

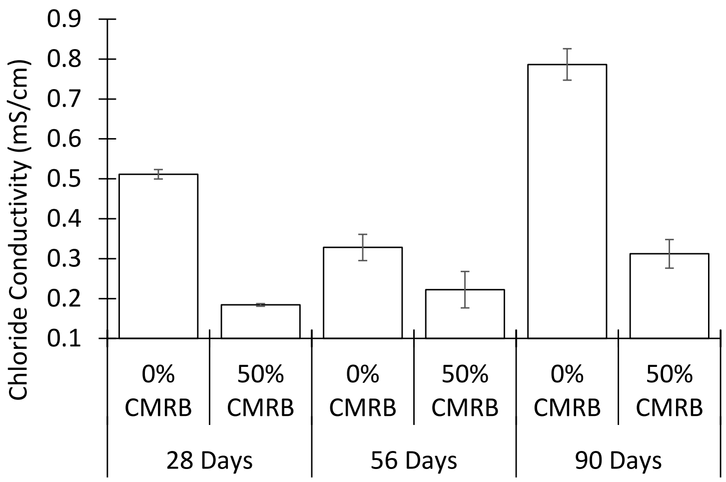


***Figure 6: Chloride Conductivity for concrete made using 0 and 50 % CMRB as fine aggregates at 28, 56 and 90 days.***

At ages 28, 56, and 90 days, the CCI for 50% CMRB were 0.18, 0.22, and 0.31mS/cm respectively. In comparison, the CCI for 0% CMRB at the same ages were 0.51, 0.33, and

0.79mS/cm respectively. The results of the chloride conductivity tests showed that the replacement mix exhibited greater resistance to chloride penetration than the control mix at 28, 56, and 90-day ages. At 28 days, the replacement mix was approximately 65% better than the control mix, whereas at 56 and 90 days, the percentage difference was found to be 33% and 61%, respectively. This result may be attributed to the presence of a clay mineral, such as kaolinite, in the masonry bricks used during production. This mineral is known to bind with chloride ions, forming stable compounds that effectively reduce the amount of chloride ions that can penetrate the concrete [14].

## 4. CONCLUSION

The effects of replacing fine Andesite aggregate with fine CMRB aggregate on the mechanical and durability properties of concrete was assessed in this study. Two concrete mixes were investigated: 0% CMRB (the control mix) and 50% CMRB (the replacement mix). The properties tested include workability, compressive strength, and South African durability index of each concrete mix produced. The results are summarised below:

- The slump test results obtained indicate that the incorporation of fine CMRB aggregates in the concrete mixture reduced its workability. The high porosity of the rubble can be attributed to the absorption of some of the mixing water leading to the decrease in the workability.
- The compressive strength is observed to increase with the incorporation of fine CMRB aggregates, for all three testing ages. This result is attributed to the calcinated clay present in the crushed recycled clay masonry rubble bricks, which exhibit pozzolanic behaviour.
- For both the 0 and 50 % CMRB mixes, three durability indices were assessed. OPI results revealed a general trend where the OPI value increases with the incorporation of fine CMBR aggregates at 28 and 90 days. The increase in permeability can be attributed to the pozzolanic reactivity of the crushed recycled clay masonry rubble bricks, resulting in the formation of additional cementitious hydration products.
- WSI indicates that the 50% CMBR mix exhibited a higher WSI value at 56 and 90 days compared to the control mix. This can be attributed to the porous nature of the fine CMBR aggregates, resulting in a higher absorption of moisture.
- The CCI tests yielded conclusive results in which the 50% CMBR had the lower CCI values at all three testing ages compared to the control mix. These results may be attributed to the presence of a clay mineral, which is known to bind with chloride ions, forming stable compounds that effectively reduce the amount of chloride ions that can penetrate the concrete.

In summary, the results suggest that recycled CMBR has the potential to be used as a substitute for natural fine Andesite aggregates in concrete. However, further testing is necessary to assess the long-term mechanical properties of the concrete incorporating 50% CMBR, such as shrinkage and creep.

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