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Sustainable treatment methods for recycled concrete aggregate

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ABSTRACT

For a reasonable use of recycled aggregate in concrete applications, it is important to consider methods that can enhance the quality of these aggregates. The European Union-funded (Kolartic CBC) project "DeConcrete" attempted to identify some eco-efficient technologies that can be used for reusing concrete waste in construction materials. In this regard, different treatment methods for recycled aggregates have been studied, including heat treatment through microwaving, carbonation, and pozzolanic coating. The treatment methods are carefully chosen such that minimum secondary waste is produced, and thus, maximum material is recycled.

In this study, the water absorption capacity and dry density of the recycled aggregate were evaluated and compared with those of the treated aggregate. The carbonation method, which simply involved exposing the aggregate to CO_2, reduced the water absorption capacity by 10%. This method also facilitated CO_2 sequestration and made the material further sustainable and eco-efficient. Moreover, carbonation when applied after pozzolanic coating drastically boosted the interfacial transition zone of the concrete formed with recycled aggregate, which in turn increased the compressive strength. Hence, a combination of treatment methods is more effective than individual treatments. In particular, methods that do not produce any secondary waste yield the best results.

Keywords: Recycled concrete aggregate, Treatment, Carbonation, Pozzolanic coating, CO_2 sequestration.

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1. INTRODUCTION

In Europe, approximately 374 million tons of construction and demolition waste, excluding excavated soil, was produced in 2016 [1]. In Finland, out of the 800 metric tons of concrete recycled in earth constructions, approximately 200 metric tons is landfilled [2]. Although all the used concrete could be recycled for reuse with modern technology, approximately one-fourth of the concrete waste ended up in landfill sites, whereas the remaining was used in nonvalue-added applications. Thus, the application of effective concrete recycling on the field remains limited. One of the major reasons that hinder the recycling of concrete aggregate in the new concrete production is the decrease in the strength properties of the concrete [3,4]. Recycled concrete aggregate (RCA) incurs the major issue of adhered cement mortar from the old concrete, which is porous and increases water absorption in the concrete [5,6]. Moreover, the composition of these waste aggregates varies significantly, and their physical properties substantially influence the concrete properties [7]. According to RILEM recommendations, only 20% of the recycled coarse aggregate can be used for new concrete production, whereas the recycled fine aggregate cannot be used for structural concrete production at all. Hence, enhancing the properties of recycled aggregates using various treatment methods is essential to extend their application range [8,9].

The present study aims to determine the efficiencies of different treatment methods, such as abrasive action, carbonation, and microwaving, on RCA procured from the same demolition site in terms of the improvements achieved in RCA properties and the effects on the strength and water absorption capacity of the produced concrete.

2. MATERIALS AND METHODOLOGY

2.1 RCA

The recycled concrete used in this study was procured from a local Finnish building demolition site. The original material was a mixture of concrete and impurities such as metal pieces, plastic, and electric wires. Concrete pieces were carefully handpicked and crushed into 4–16-mm-diameter fractions by using a jaw crusher. Figure 1 shows the crushed RCA, which is ready to be treated.

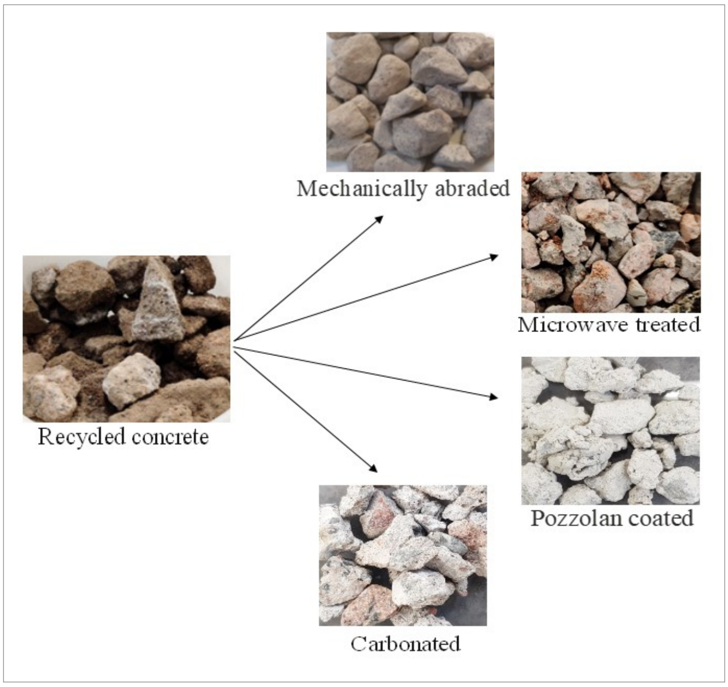

Figure 1: Treatment methods for the recycled concrete aggregate

2.2 Treatment methods

The treatment methods were designed to either remove the old mortar or to strengthen it. Removal of old mortar was facilitated through mechanical abrasion, which was performed using a bar mill (Wedag mill, 1 rpm, 300 s) without any crushing rod to avoid powdering of the recycled aggregate. The RCA was microwaved at 4 kW power and 2.45 GHz frequency for 600 s to loosen the old mortar. After the mechanical abrasion and microwave treatments, the treated RCA was sieved through a pore size of 4 mm to detach the old mortar from the parent material.

Two other treatments, pozzolanic coating and carbonation, were performed to strengthen the old mortar in the RCA. Pozzolanic coating was performed using a blast-furnace slag paste formed with a water-to-binder ratio of 2, where 1 kg of RCA was mixed with 1.2 l of the slag paste and maintained for 24 h. After this time, excess slurry was drained off and the coated RCA was sealed in a plastic bag until testing. Carbonation of RCA was performed under the conditions of 10% CO_2, 20°C temperature, and 60% relative humidity (RH) for 24 h. The RCA samples obtained from the four treatments are presented in Figure 1. In addition, a fifth treatment method was introduced, which combined pozzolanic coating with carbonation. In this treatment, the coated RCA sample obtained after 24 h was shifted to a carbonation chamber under the same conditions as those used for carbonation.

2.3 Tests conducted on RCA

The densities and water absorption capacities of the RCA samples were measured before and after the treatments. Density can be calculated as follows:

$$\rho = \frac{m}{V} \qquad \text{Equation (1)}$$

where ρ is the density (kg/m³), m is the mass of the RCA (kg), and V is the volume (m³) of the container.

The water absorption capacity can be calculated as follows:

Equation (2)

$$\text{Water absorption} = \frac{\text{(wet weight-dry weight)}}{\text{(dry weight)}} \times 100\%$$

where dry weight represents the mass of RCA dried at 105°C for 24 h and wet weight indicates the mass of RCA obtained after 24-h water immersion.

2.4 Production of alkali-activated concrete

The treated and untreated RCA samples were used to produce one-part alkali-activated concrete with blast-furnace slag and sodium hydroxide, where the binder-to-aggregate ratio was fixed at 1:2. In addition, the slag-to-sodium silicate ratio in the binder was set as 9:1 based on previous studies [10,11]. The aggregate was obtained as combination of 33% standard sand (fine aggregate) and 64% RCA (coarse aggregate). The water-to-binder ratio for different mixes was maintained constant at 0.35. Cubical specimens of dimensions 15 cm × 15 cm × 15 cm were developed to measure the compressive strength and water absorption capacity on the 7th day of curing age. The specimens were cured in a humidity chamber at 20°C and 100% RH until testing. The samples broken after the strength testing were preserved in isopropanol to be observed using a scanning electron microscope (SEM). The samples were mounted in epoxy resin and polished for SEM studies.

3. RESULTS AND DISCUSSION

3.1 Properties of RCA

The water absorption capacity of the concrete was found to be reduced with some of the treatments adopted, such as mechanical abrasion and carbonation (Figure 2). However, this was not the case for all methods, especially microwaving and pozzolanic coating. Mechanical abrasion removed some of the old mortar responsible for increased water absorption in RCA. In contrast, the microwave treatment loosened the old mortar but did not detach it from the aggregate. This can be the reason behind the increased absorption observed in microwaving. However, this contradicts the results obtained for a previous study conducted using microwave heating of RCA, which yielded approximately 1.4% reduction in water absorption capacity and a corresponding increase in density [12]. Thus, a combination of microwaving with mechanical abrasion was expected to yield improved performance.

Meanwhile, the pozzolan-coated RCA exhibited increased absorption values, which indicates that the applied pozzolan was not sufficiently hydrating and highly porous. This can be explained by the type of pozzolan used in the present study, as blast-furnace slag requires a co-binder for its activation. Hence, the coating enhanced the porosity of the aggregate, which resulted in increased water absorption. However, the density of the coated RCA was higher than that of the untreated RCA (Figure 2). Previous studies on RCA coating have shown significant improvement in concrete properties, though the properties of coated aggregate have not been reported [13,14]. In contrast, the carbonation of RCA significantly reduces the water absorption capacity. It strengthens the old mortar by forming calcium carbonate products, which seals the porosity of the mortar [15]. Thus, the combination of pozzolanic coating and carbonation performs well in reducing the water absorption capacity, which is also reflected in the increase in density (Figure 2).

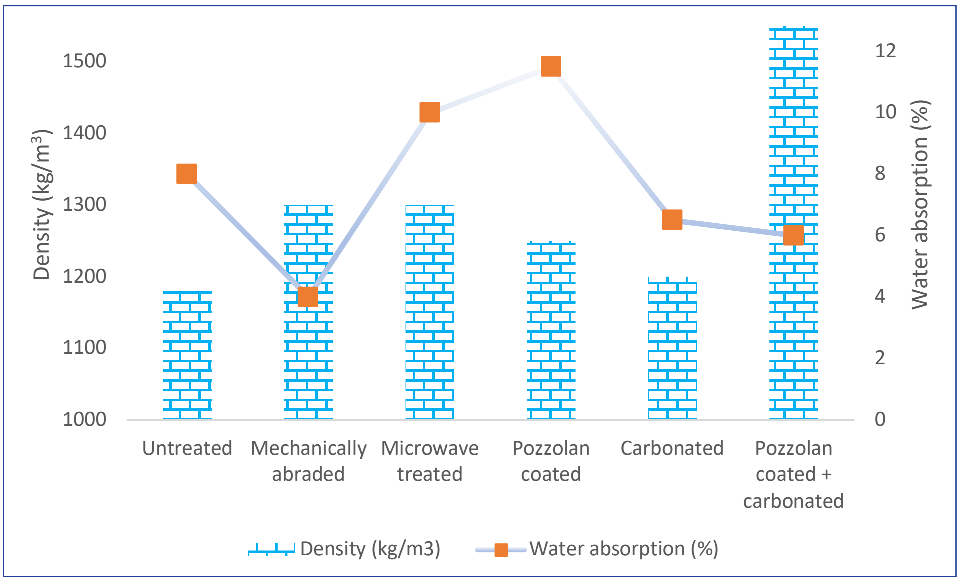

Figure 2: Properties of recycled concrete aggregate

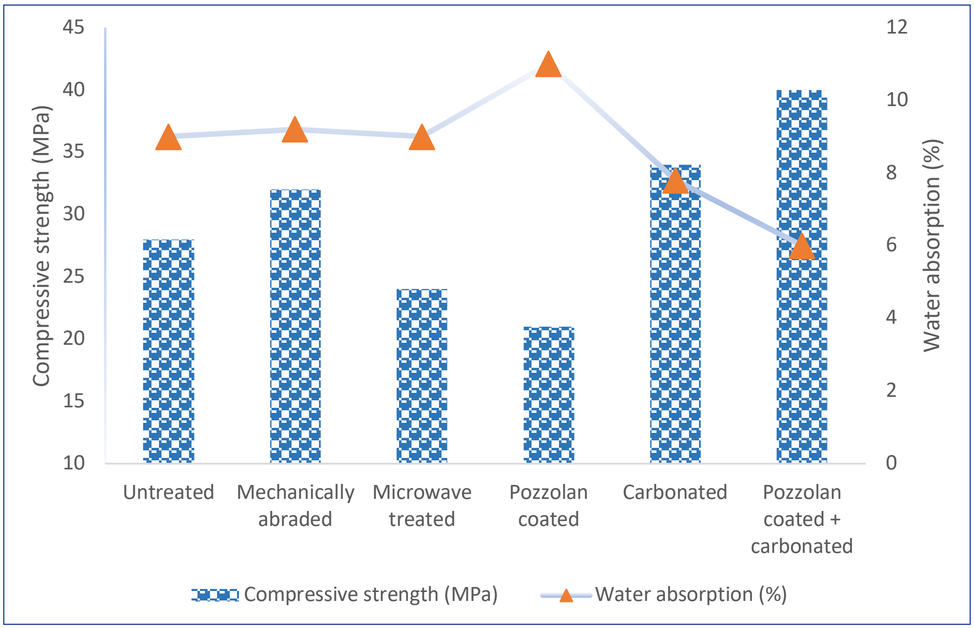

Figure 3: Properties of concrete with RCA

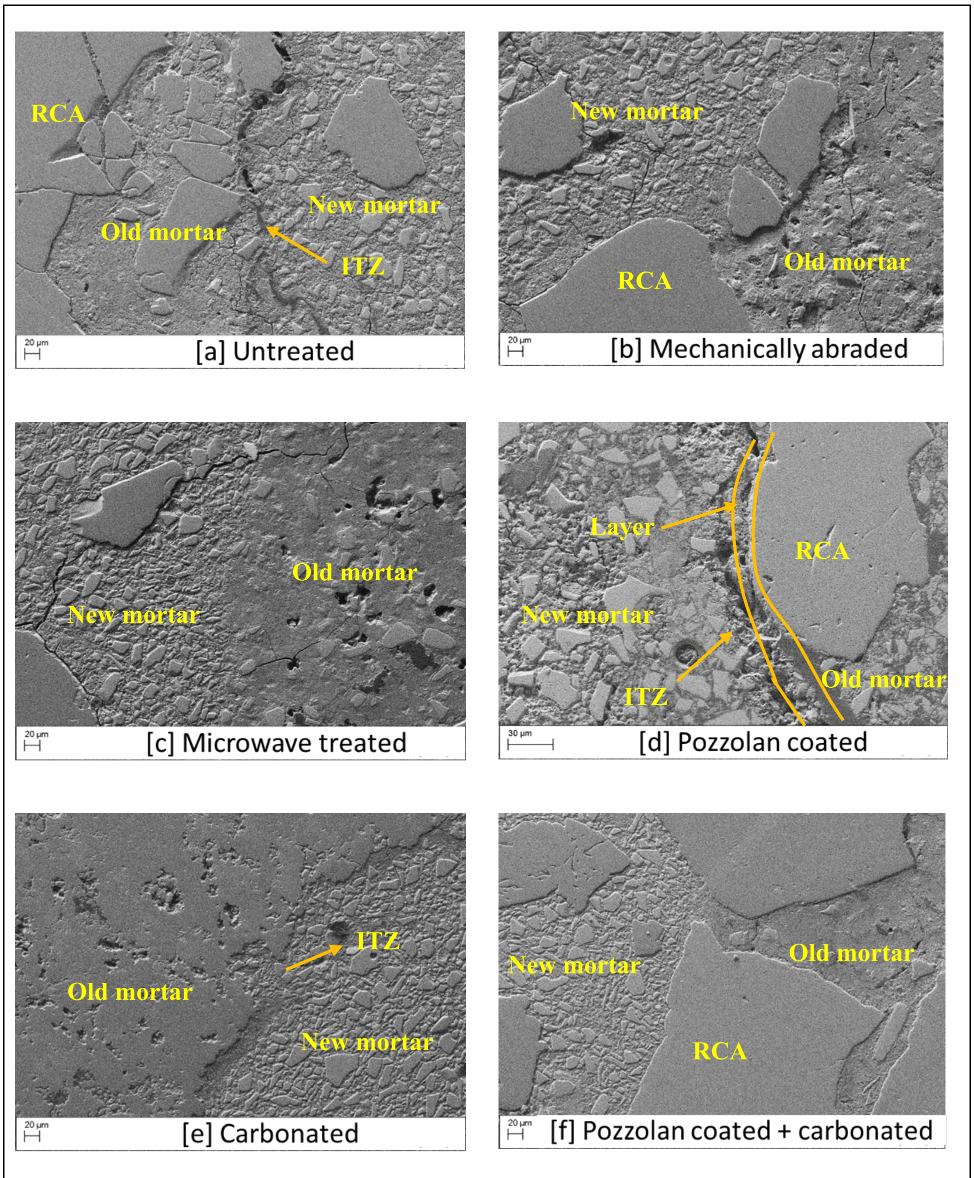

Figure 4: Representative microstructure of concrete produced with RCA

3.2 Properties of RCA

The compressive strength of the untreated and treated RCA samples is related to the aggregate properties discussed in section 3.1 (Figure 3). Mechanical abrasion improved the concrete strength by 17%, though there was no significant difference in the water absorption capacity. As expected, the microwave-treated and pozzolan-coated samples exhibited 14% and 28%, respectively, reduction in concrete strength. Although the water absorption capacity of the microwave-treated RCA increased substantially (Figure 3), this was not reflected in the water absorption capacity of the concrete produced with them. The strength of carbonated RCA increased by 21% (34 MPa), and even 42% (40 MPa), through the combination of microwave treatment with pozzolanic coating. According to previous research, pozzolanic slurry coating improved the workability of the concrete, whereas carbonation improved its the strength and durability properties [8]. Thus, the present study emphasized that RCA should be subjected to combined treatments to yield the benefits of different mechanisms involved in the different treatment methods.

PRIYADHARSHINI PERUMAL is working as a Postdoctoral Researcher in the Fibre and Particle Engineering Research Unit at University of Oulu, Finland. She is the project manager of De-Concrete project at the University of Oulu. She is also a recipient of the prestigious Marie-Curie Individual Fellowship from European Union. Her current research focuses on treatment methods to improve the quality and utilization of industrial waste (including mining, C&D and municipal solid waste) as an alternative for construction materials to achieve circular economy in industries.

4. CONCLUSIONS

In this study, different RCA samples obtained from a single source were treated using the following four treatment methods: mechanical abrasion, microwave treatment, pozzolan coating, and carbonation. To understand the effects of different combinations of treatment methods, carbonation was attempted on pozzolan-coated RCA samples. Among the different treatments, carbonation appeared promising for improving the RCA performance. Carbonation products filled the pores in the old mortar region of the RCA, which helped in improving the ITZ between the old and new mortar regions. This was reflected in the strength improvement of the concrete formed of carbonated recycled concrete. Pozzolanic coating did not perform well when applied alone; however, its combination with carbonation outperformed other methods. Hence, it is worthy to attempt different combinations of treatment methods to utilize their benefits. **CB**

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