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Mechanical properties and durability of bio-blocks with recycled concrete aggregates

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HIGHLIGHTS

- Bio-blocks were produced with recycled concrete aggregates and natural aggregates.
- Bio-blocks were produced using microbially induced calcite precipitation (MICP).
- Durability and mechanical properties of the bio-blocks were studied.
- The use of MICP to produce bio-blocks resulted in the reduction of water absorption.
- Replacement of NA by RCA resulted in relatively similar properties and durability.

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ABSTRACT

Harnessing bio-processes to improve the mechanical properties of building materials have gained interest in developing green construction. One of the bio-processes utilized to improve the mechanical properties of building materials is the bio-mineralization of calcium carbonate by the activity of the urease-positive bacterium. In this research, the recycled concrete aggregates, as one of the main constituents of construction and demolition wastes, were used to produce bio-blocks by the bio-mineralization of $CaCO_3$ and the results were compared to bio-blocks produced with natural aggregates. Furthermore, the durability and mechanical properties of both types of bio-blocks were investigated. The difference in compressive strengths of bio-blocks made with both aggregates was less than 10%. The results showed that bio-mineralization reduced the water absorption of the RCA bio-blocks, which is one of the drawbacks of recycled concrete aggregates. In addition, durability tests revealed that the bio-blocks maintained their strength under freeze thaw cycles and high temperatures.

1. Introduction

Considering the world and its inhabitants as a single system gives man a vision that helps achieve sustainable development. Therefore, there is a need to conserve natural resources for future generations and halt notorious phenomena such as global warming [1]. One of the fields that need more attention is construction. Increase in construction contributes to generating more construction and demolition (C&D) wastes, and this increasingly contributes to global warming by the CO_2 footprint in industries such as Portland cement production. These factories produce one ton of CO_2 for each ton of Portland cement produced, which accounts for up to 10% of the CO_2 production of the world [2,3]. Different researchers have attempted to develop novel materials and methods to compensate for this unsustainable approach in construction. Alternatives, such as alkali-activated materials [4], geopolymers [5], or inorganic polymer concretes [6] have been developed instead of energy-intensive materials like Portland cement. The sustainability and CO_2 reduction efficiency of these methods are doubtful owing to their dependency on ordinary cement and energy intensive by-products such as blast furnace slag and fly ash [7]; therefore, the demand for the development of new methods and materials is increasing.

Different bio-derivatives and methods are being used in building materials because of their sustainability [8–12]. One of these methods, which promises to be sustainable and can be utilized in constructing building materials is microbially induced calcite precipitation (MICP) [13]. The most efficient form of MICP used in this research is the urea-hydrolyzed based MICP [14]. In this method, hydrolyzed urea is catalyzed by the metabolism of urease-positive bacterium according to the following equation:

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$$CO(NH_2)_2 + 2H_2O \xrightarrow{Urease} 2NH_4^+ + CO_3^{2-} \quad (1)$$

Then, calcium carbonate crystals precipitate in the presence of calcium ions:

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3 \downarrow \quad (2)$$

When these calcium carbonate crystals precipitate, they bridge the targeted particles together and improve their mechanical properties. One of the first applications of this process was to reduce the permeability of soil for use in oil industries [15]; this aroused discussions on the use of bio-processes in geotechnical engineering [16]. The use of MICP in geotechnical engineering has been investigated in different applications, such as to increase soil strength, and promised a proper method of soil improvement [17–19]. Furthermore, the application of this method has been investigated in different fields of construction such as in the improvement of concrete properties [20,21] and making bio-bricks [12].

As C&D wastes are one of the largest contributors to municipal solid wastes (e.g., up to 23% in USA [22]), it is important to find a sustainable method to reuse such materials. These wastes, especially concrete wastes, have proved to be good sources of aggregates for building materials and can be used for the manufacture of new concrete [23]. Therefore, this study aims to use recycled concrete aggregates (RCA), which is the main constituent of C&D wastes, to produce and study the engineering properties of bio-blocks made with RCA by the novel method of MICP. Finally, the results were compared to those produced with natural aggregates (NA) and their durability was evaluated in terms of water absorption, resistance to high temperature, and resistance to thermal cycles. The study would be advantageous for the future of green construction.

2. Materials and methods

2.1. Aggregates and sample preparation

Natural aggregates were sieved [24] and the particle size gradation curve (Fig. 1) was obtained. Then, the same gradation curve was utilized to prepare the RCA and eliminate the effect of gradation size. To prepare the RCA, concrete blocks were crushed to sizes smaller than 40 mm in the laboratory and sieved to be prepared according to the particle gradation curve of the NA. The soil can be classified as well graded sand according to unified classification.

The specimens were prepared by pouring the aggregates into the concrete molds (dimension 100 × 100 × 100 mm) by the air pluviation method with a constant elevation to reach a density of 1650 kg/m^3. The molds were made of Plexiglass sheets cut to the desired shapes and assembled with a sealant glue. Moreover, they were designed with drain holes at their bottom as well as with a tube to inject and drain the cementation solution (Fig. 2).

2.2. Microorganism and culture conditions

To induce the precipitation of calcium carbonate, indigenous urease-positive bacterium was isolated from a soil sample and identified as Staphylococcus Pasteurii, registered in the EMBL by the accession number of FR839669 [25]. The bacterium was cultured in a medium containing 10 g/l yeast extract (identified as an optimum medium for this bacterium) at 37 °C and at a shaking rate of 180 rpm to an optical density of 2 (OD_{600}).

2.3. Cementation solution and cementation method

The solution injected to induce calcium carbonate precipitation was named as cementation solution (CS). The mixture of CS contained one volume of bacterial solution and one volume of 1 equimolar $CaCl_2$-Urea solution. An injection with post stop flow condition (i.e., the CS was retained in the mold for a specific time after the injection) was utilized to saturate the samples and create a uniform cementation all over the bio-blocks. With every injection, the prepared sample was saturated with CS and was retained in the mold for 18 h. Then, the mold was depleted and prepared for the next injection.

2.4. Unconfined compressive strength and calcium carbonate measurements

The unconfined compressive strength (UCS) of samples was measured according to the BS EN 12390 (EN 2009). After the UCS test, the calcium carbonate content was measured by washing the specimens with HCl acid. The dry weight of samples was measured before acid washing, then the samples were rinsed with 5 M HCl until the $CaCO_3$ was completely dissolved. Subsequently, the acid-washed samples were rinsed with deionized water and dried. Next, the dry weight of samples was measured and the calcium carbonate content was measured as the difference of the two dry weights. It should be noted that the reduction of weights of the RCA after the acid washing was measured three times for non-cemented aggregates and the average was considered as the weight loss.

2.5. Thermal stability test

To investigate the thermal stability, a series of samples were heated in a high-temperature oven for 2 h at 200, 400, 800, and

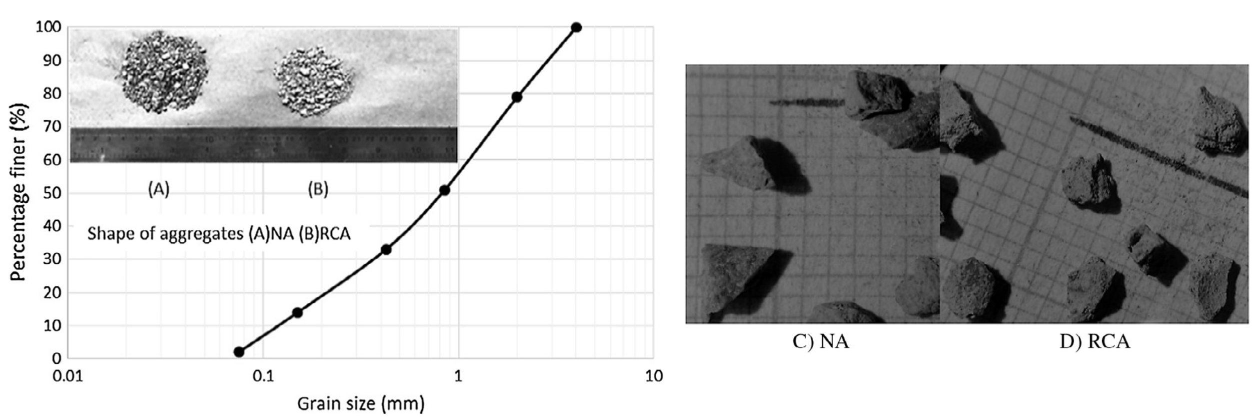

Fig. 1. Particle size distribution of NA and RCA (on the left) and magnified shape of aggregates (on the right).