



# Carbon dioxide sequestration of concrete slurry waste and its valorisation in construction products

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## HIGHLIGHTS

- Concrete slurry waste was recycled and reused in construction products.
- Concrete waste was considered as CO<sub>2</sub> capture and storage medium.
- Carbon capture construction products were made of concrete wastes.
- The strength of carbonated mixture was as a power function of CO<sub>2</sub> uptake.

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## ABSTRACT

This paper aimed to investigate the CO<sub>2</sub> sequestration potential of concrete slurry waste (CSW) and its valorisation with fine recycled concrete aggregates (FRCAs) for the production of sustainable construction products by direct gas-solid mineral carbonation. Concrete slurry waste (CSW) with rich calcium and silicate phases is a by-product waste generated from concrete production in concrete batching plants. The CO<sub>2</sub> sequestration extent achievable by CSW, FRCAs and their mixture, as well as the mechanical and durability properties of the mixture were evaluated in this study. It was found that the gas-solid carbonation mechanism of CSW and its mixture followed unreacted core model where a fast kinetically controlled process initially took place, then followed by a slow diffusion-controlled reaction process. Over 75% of the experimental CO<sub>2</sub> uptake by CSW, FRCAs and their mixture occurred in less than 3-h carbonation and the CSW was able to sequester 110 g CO<sub>2</sub> per kg dry mass after 7 days. Subjected to mineral carbonation, the mixture prepared with CSW and FRCAs quickly gained strength in a few hours and suffered lower drying shrinkage. Its strength development followed a power function of CO<sub>2</sub> uptake, which was attributed to the gradual reduction in porosity with mineral carbonation. Furthermore, lifecycle assessment indicated that the production of the studied mixture as partition wall blocks was carbon neutral and environmentally sustainable due to CO<sub>2</sub> capture and storage in concrete wastes.

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## 1. Introduction

Concrete, the second-most-consumed substance on Earth after water, is so ubiquitous that its currently global production per year is approximately 2.0 tonne per capita [1]. The concrete industry is therefore very concerned with its impact on the global environmental footprint. Moreover, the essential binding agent in concrete, cement, is highly energy-and-emissions intensive and accounts for about 5–8 percent of current anthropogenic carbon dioxide (CO<sub>2</sub>) emissions [2]. Furthermore, the construction sector generates a huge quantity of waste with respect to concrete

production and demolition of old concrete structures [3]. Consequently, a careful selection of low environmental impact materials in the construction sector is becoming great important [4].

Owing to the rich calcium and silicates phases in concrete, their possible mineral carbonation is of great interest and has been recognized by researchers to be able to capture and store CO<sub>2</sub> as well as to improve the properties of recycled concrete aggregates and concrete products [5–9]. Normally, carbonation is known as a naturally occurring process in which CO<sub>2</sub> reacts with cement components (e.g. C<sub>3</sub>S, C<sub>2</sub>S, C<sub>3</sub>A, C<sub>4</sub>AF) and hydration products (e.g. C-S-H gel, Ca(OH)<sub>2</sub>, Aft) to form thermodynamically stable calcium carbonate [10,11]. In the solid phases, ionized carbon dioxide induces the release of calcium ions, which are then re-precipitated in the pore space of the concrete mixture as CaCO<sub>3</sub>,

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forming a densified product. In terms of CO<sub>2</sub> uptake and improvement of microstructure, mineral carbonation of concrete wastes would have potential for making value-added construction products. This idea has been implemented on some waste materials such as cement kiln dust, recycled concrete aggregates, steel slag, MSW IBA etc. [7,12–16].

Although much research interest has been concerned on recycled aggregates from demolished concrete buildings, the possible recycling of waste arising from the fresh concrete production is relatively paid less attention to [17]. One type of fresh concrete wastes associated with the concrete production in concrete batching plants, named as concrete slurry waste (CSW), is normally discarded at landfills in some countries [18]. CSW, the suspended solid in the wastewater, is deposited in the sedimentation pit and generated from the reclaiming system of concrete batching plants, where over-ordered/unrequired fresh concrete is washed out to retrieve the aggregates and concrete mixer trucks are cleaned up as shown in Fig. 1. In Europe, the loss of fresh concrete, because of over ordering, transportation, poor workmanship and change of mix design, is in the range of 1.0–4.0 wt% of the total processed concrete [19]. In Hong Kong, the average fresh concrete waste level is about 1.5 wt% of the total produced concrete. When the water reclaiming system is adopted to recycle the water, the quantity of CSW collected from the sedimentation tank is estimated at about 0.8 wt% of the total concrete produced.

In order to facilitate the management of CSW, some potential techniques aiming to recycle and reuse it have been reported by a few research works [14,16–24]. Recycling and reusing of CSW may be conducted by solid phase or aqueous phase. Due to its intrinsic cementitious nature, CSW can become hardened in a few months' time, and may be further crushed and used as recycled fine/coarse aggregates to replace natural aggregates in concrete or concrete products [20,21]. Moreover, by means of drying pre-treatment and grinding, the dried CSW powder has been considered as a cementitious material which can be used in mortars or as a soil stabilizer in road bases [19,22,23]. But it has been noticed that using solid phase CSW requires more energy and involves high treatment costs, and it is more economical to directly recycle and reuse the as-received CSW in aqueous phase. Although attempts have been made to reuse the slurry wastewater from the sedimentation tank in new concrete production, careful monitoring and control of the amount of suspended solids should be made [17,24]. In addition, studies has been made to reuse CSW as a sorbent of chemicals, but advanced and mature techniques are yet to be developed [25–27]. Therefore there is a need to effectively reuse the reclaimed CSW in view of the increasing volume of concrete produced for the construction industry.

As CSW is a by-product waste from concrete production containing rich calcium and silicate phases, this study aimed to investigate its potential of CO<sub>2</sub> sequestration and its valorisation as construction materials in new construction products. To improve the viability of mineral carbonation technique for application on an industrial scale, attempts were made in this study to conduct the mineral carbonation process at ambient temperature and a

slightly positive pressure at 0.1 bar. The CO<sub>2</sub> uptake achievable by CSW as well as the mechanical and durability properties of the mixture prepared with CSW and recycled concrete aggregates as partition wall blocks were examined through a series of experiments.

## 2. Materials and experimental methods

### 2.1. Materials

Ten batches of fresh CSWs were randomly collected from ready-mixed concrete plants in Hong Kong in 2014. They were stored in airtight plastic bags and delivered to the laboratory on the generation day. Fig. 2 shows the appearance of the fresh CSW before and after mixing in a laboratory mixer. The collected fresh CSW was initially like dewatered pellets (cakes) generated by the filter press process of the reclaiming system. After mixing in the mechanical mixer, they became re-workable and had a flow value above 150 mm tested in accordance with BS EN 1015-3. They could remain workable for 3–7 days since the generation day, depending on the water content. The average water content in the collected fresh CSWs, determined by the water loss at 105 °C in the oven, was about 50% and the maximum particle size of the dried solid particles was 0.15 mm.

FRCAs with the size <5.0 mm were collected from a construction waste recycling plant in Hong Kong. FRCAs had a specific density of 2.661 g/cm<sup>3</sup>, particle density of 2.075 g/cm<sup>3</sup> and 24-h water absorption of 10.6%. ASTM Type I Portland cement, which had a specific gravity of 3.15 g/cm<sup>3</sup> and a specific surface area of 3960 cm<sup>2</sup>/g, was used.

### 2.2. Preparation of the mixture for a type of partition wall blocks

This study aimed to produce a type of concrete partition wall blocks using the above two concrete waste materials. The mix proportion of the designed concrete mixture is listed in Table 1. After homogeneously mixing all the constituents in a mixer, the fresh mixture was firstly cast into the steel moulds (cylinder:  $\varnothing 53.5 \times 50$  mm and prism:  $25 \times 25 \times 285$  mm) and manually pre-compacted using a hammer in three equal layers. Then a pressure of 30 MPa by a hydraulic compression machine was applied and held for 30 s on the specimens. Once the compaction was finished, the specimens from the cylindrical moulds were demoulded immediately, while the prism specimens were demoulded after one day. This fabrication procedure was followed those we developed before [28]. The aim was to achieve similar compaction as that in the industrial production of concrete blocks. And all the specimens were then pre-treated in the environmental chamber at  $50 \pm 5\%$  relative humidity (RH) and  $23 \pm 3$  °C for 6 h before accelerated mineral carbonation. The purpose of such drying pre-treatment was to improve the degree of carbonation of the carbonated specimens [29].

### 2.3. Gas-solid mineral carbonation

Representative samples of CSWs and FRCAs as well as the concrete mixture specimens mentioned above were subject to accelerated mineral carbonation for evaluating their CO<sub>2</sub> sequestration potential. For the preparation of CSW samples, the fresh CSWs were first pre-conditioned in an environmental chamber at  $50 \pm 5\%$  relative humidity (RH) and  $23 \pm 3$  °C for 6 h. And the processed CSWs were further manually crushed to a size of <5.0 mm. Furthermore, they were spread in steel trays to a thickness of <10 mm and further pre-dried in the environmental chamber for another 6 h. After the above pre-treatment procedure, the

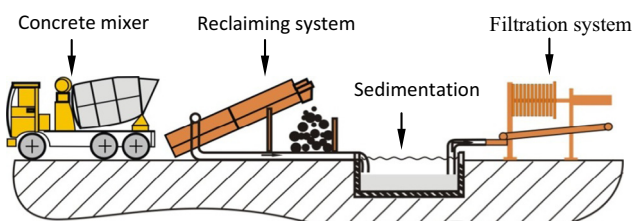


Fig. 1. Fresh concrete waste reclaiming system in a ready-mixed concrete plant.

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