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Evaluation of various treatment methods for enhancing the physical and morphological properties of coarse recycled concrete aggregate

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HIGHLIGHTS

- Various methods to enhance the coarse recycled concrete aggregate properties are studied.
- Heat treatment has negative effects when done at very high temperatures (above 500 °C).
- The use of weak acid is an effective and safe way, thus, preferable than the strong acid.
- Heat treatment at 350 °C followed by short mechanical treatment led to the best results.
- Increase density and surface homogeneity whereas decrease Ca/Si ratio within microstructural level.

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ABSTRACT

The main objective of this research is to enhance the physical and morphological properties of coarse recycled concrete aggregate (CRCA) by combining different types of treatment methods. Heat treatments included various temperatures (250 °C, 350 °C, 500 °C and 750 °C). Presoaking method involved the use of strong acid HCl and weak acid $C_2H_4O_2$, whereas short mechanical treatment included the utilization of a Micro-Deval device. In order to investigate the surface morphology and chemical composition for both treated and untreated CRCA, Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Analyzer (EDAX) analyses were also conducted. The obtained results indicated that the combination of heat treatment at 350 °C and short mechanical treatment led the best performance for enhancing physical properties, with more than 27% lowering of water absorption. The use of weak acid treatment is an effective, safe and more preferable may than strong acid. Heat treatment appears to have negative effects when used at higher temperatures (500 °C and 750 °C). A large microstructure enhancement was obtained that particularly includes increased density, increased surface homogeneity and a reduced Ca/Si ratio. Physical properties of CRCA including porosity and water absorption are strongly related to the durability characteristics in terms of resistance to freezing and thawing and resistance to abrasion loss under impact of heat treatment. Mineralogical characteristics in terms of Ca/Si ratio are strongly correlated with durable and mechanical properties including abrasion loss and adhered mortar loss under influence of heat treatment.

1. Introduction

The growing quantities and types of waste materials, shortage of landfill spaces, and lack of natural sources all indicate the urgency of finding innovative ways of recycling and reusing waste materials. Construction waste materials are increasing due to the rising demand for new highways, commercial buildings, housing developments and infrastructure projects. Unless recycled properly, these large amounts of waste end up in landfills every year, and natural resources are being depleted rapidly because of a tremendous demand for raw materials [1]. Nowadays, recycled concrete aggregate (RCA) obtained from construction and demolition waste has become a valuable resource as an alternative solution to natural aggregates [2]. Due to the lack of natural aggregates, the use of recycled concrete in different civil construction works

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has become widespread in Europe and countries such as Singapore, Japan and Australia for more than 20 years [3]. Thus, the innovative use of recycled materials makes an important contribution to overall sustainability and economic benefits [4].

RCA is a composite material, where in natural aggregates (65–70%) are coated by cement mortar (30–35%) and can be produced from the crushing of the hunks of concrete into smaller pieces [3,5,6]. The types of crushing method can have an influence on the shape and texture of the produced RCA [7]. However, RCA is generally rough, porous, flat and irregular. Compared to the natural aggregates, RCA shows the following characteristics: high water absorption, lower bulk and specific gravity, high abrasion loss, easy to grind into small fractions, and other source dependent influences [8,9]. Using RCA provides an environmentally friendly solution in the construction industry; however, the drawback comes when it relates with an inferior properties that are mainly responsible for the limited use of RCA. Therefore, the improvement of RCA physical properties has been one of the considerable issues that noticeably attracts many researchers worldwide. Consequently, the present study attempts to research different possible solutions to enhance the physical properties of RCA.

2. Literature review

The main difference between RCA and natural aggregate is the presence of residual aged cement paste (adhered mortar) on the surface of recycled aggregates [3,10,11]. The adhered mortar has usually higher porosity and lower density than the virgin crushed stone, which is known to be the major reason behind the unsatisfactory quality of RCA [9,11–13]. Adhered mortar can be found to be 20–70% by weight of RCA [14]. The particle size, the strength of the original concrete and the crushing process have an impact on the percentage of old mortar in RCA [14,15]. The quality and the amount of adhered mortar are also main factors, which may have an effect on the physical properties of RCA [15]. In addition, tiny cracks that appear during the crushing process, and weak adhesion between mortar and aggregate are the other important factors [9,12]. These factors play then an important role in making RCA a poor quality substitute compared to natural aggregate [9,13].

Due to the diverse influence of adhered mortars on the RCA quality, numerous researchers [6,9,12,14,16–20] have investigated various approaches and techniques to improve the characteristics of RCA. However, these approaches and techniques can be fundamentally classified into two categories [21,22]. The first category mainly includes removing the adhered mortar on the surface, whereas the second category is extensively focused on modifying and improving the quality of adhered mortar. The adhered mortar can be removed by using different treatments that include ball milling [23], heating and then rubbing [24,25], ultrasonic cleaning method [26]. The modification of the quality of adhered mortar includes surface coating with different materials such as water glass [27], pozzolanic materials such as fly-ash and silica fume [27–29], polyvinyl alcohol emulsion [30] and biodeposition [31].

Recently, the use of pre-soaking in acidic solutions to remove the adhered mortar has attracted much research interest. Tam et al. [12] investigated RCA soaking in three different strong acids solutions: hydrochloric acid (HCl), sulfuric acid (H_2SO_4) and phosphoric acid (H_3PO_4) at low concentration of 0.1 mol at 20 °C for 24 h. The obtained results indicated that there was a considerable decrease in water absorption, improved mechanical properties, and there was no adverse influence from chloride and sulfate ions on the RCA. Butler [32] investigated the effect of nitric acid at a high concentration (20% volume) and moderate temperature (85 °C) for two to three hours. It was observed that the acid removed the outer layer of RCA; however, there were dyed yellowish spots on the RCA surface. Ismail & Ramli [6] tested the effect of various concentrations (0.1, 0.5, and 0.8 M) of hydrochloric acid (HCl) with different immersion times (1, 3, and 7 days) on treating the RCA to improve its performance. The findings showed a linear correlation between the amounts of mortar loss with increasing concentration of acid while there was no significant effect for immersion time. Purushothaman et al. [21] tested the influence of different approaches to decrease the adhered cement paste from RCA. Chemical treatment included pre-soaking in two acidic solutions, namely, hydrochloric acid (HCl) and sulfuric acid (H_2SO_4) at low concentration 0.1 mol for 24 h. Mechanical method consisted of mechanical scrubbing and heating-scrubbing which included heating RCA by hot air at 300 °C, followed by scrubbing. The outcomes of the study indicated that the H_2SO_4 treatment method was more effective than HCl acid whereas heating and scrubbing was more successful in enhancing RCA and its properties. The two successful methods also showed improved long term performance that includes water absorption and loss of weight on drying.

Much research has focused on using heat treatment at higher temperatures. Wong et al. [33] applied the calcination process to RCA, which involved increasing temperatures gradually up to 950 °C for 2 h, then decreasing temperatures to 27 °C in order to transform calcium carbonate (calcite) to free lime (calcium oxide). The study concluded that lime can be produced through the calcination procedure, which ultimately enhances the rutting and low temperature cracking performance of hot mix asphalt. However, there was some concrete particle breakdown as well as mass loss because of exposure to higher temperature. Zega & Di Maio [34] examined the influence of heating at high temperature (500 °C) for 1 h on the performance of different concretes prepared with RCA. In concrete mix design, two different water-cement ratios and different coarse natural aggregates (granitic crushed stone, siliceous gravel, and quartzitic crushed stone) were used. It was found that the conventional and recycled concrete specimens prepared with quartzitic crushed stone showed better performance after the heat treatment than that of granitic crushed stone and siliceous gravel. Vieira et al. [35] examined the effects of heating of RCA at three different temperatures (400, 600 and 800 °C) for 1 h on the concrete samples with replacement of natural aggregates by RCA at different percentages (20%, 50% and 100%). The study reported that there was no heat influence on mechanical behaviour of concrete which contained RCA compared to conventional concrete. Gupta et al. [18] examined the influence of heating at ranges between moderate and elevated temperatures (200 °C, 400 °C, 600 °C, 800 °C, 1000 °C) for 6 h on the mechanical and micro structural properties of concrete contained mixed RCA with natural aggregate and fly ash as a replacement of cement. The study concluded that treated and untreated RCA samples exhibited poor behaviour at various higher temperatures in comparison with natural aggregate. Also, concrete suffers from broad degradation after exposure to higher temperatures because of concrete microstructure becoming rougher and increasing total pore volume resulting in higher strain and lower compressive strength. Sui & Mueller [17] investigated the effect of the combination of heat treatment at various temperatures (100 °C–600 °C) for 30 min and mechanical treatment in a ball mill at different milling times on RCA properties. The obtained results indicated that the adhered mortar can be removed by heating at a temperature range of 250 °C–300 °C, if it was followed by strong and sufficient mechanical treatment and resulted in comparable properties to that of virgin aggregate.

The implementation of these approaches and techniques resulted in partial or total removal of adhered mortars. However, there are many economic and ecological challenges associated with these methods such as the need for a special mechanical