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Microwave-assisted beneficiation of recycled concrete aggregates

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ABSTRACT

The presence of mortar has been reported as the main factor causing the lower quality of recycled concrete aggregates (RCA) when compared to natural aggregates (NA). A novel microwave-assisted technique to increase the quality of RCA by partially removing the mortar adhering to RCA particles and breaking up the lumps of mortar present in RCA is introduced in this paper. The technique takes advantage of the difference in the electromagnetic properties of the adhering mortar and natural aggregates to generate high thermal stresses within the mortar, especially at the interface with the embedded natural aggregates, to cause delamination. The stresses generated also result in the breaking up of the lumps of mortar into smaller pieces. The results of an experimental study conducted to investigate the capability of the microwave-assisted RCA beneficiation technique and to compare its efficiency with other beneficiation methods proposed in available literature are presented. Moreover, the effects of incorporating various amounts of un-treated and microwave-treated coarse RCA on the mechanical properties of concrete are investigated. The temperature distribution and stresses developed in RCA when subjected to microwave heating during the beneficiation process are numerically calculated for a better understanding of the processes involved.

1. Introduction

Recycled concrete aggregates (RCA) are produced by reducing the size of concrete debris through multiple crushing stages. Depending on the size, the crushed concrete particle may comprise one or more particles of natural coarse aggregate held together and surrounded fully or partially by a layer of mortar (Fig. 1a and b). In the present study, such RCA particles are referred to as Type I RCA. Moreover, as can be seen in Fig. 1c, after sieving into the respective aggregate size grades, recycled coarse aggregates which are essentially lumps of mortar with varying proportions of smaller size natural aggregates embedded are also present. In this paper, the RCA particles comprising entirely of mortar are referred to as Type II RCA. There is as-yet no practical method to separate the lumps of mortar from the RCA particles with the embedded natural coarse aggregates in a recycling plant. Therefore, batches of RCA usually comprise varying proportions of both types.

The presence of mortar in RCA has been identified as the most important factor lowering the quality of recycled concrete aggregates [1]. The presence of cementitious mortar has been reported to result in a lower density, higher water absorption, lower Los Angeles abrasion resistance and higher soundness loss of RCA when compared to natural aggregates [2–5]. This has limited the use of RCA in the structural concrete to only small replacement percentages of the natural aggregates (up to 30%) [6] because the differences in the properties of RCA and natural aggregates will in turn affect the fresh, mechanical and long term properties of the concretes made using RCA; e.g. lowering the density, workability, compressive strength, tensile strength, modulus of elasticity, frost resistance, chloride penetration, and increasing the creep and shrinkage. when compared to natural aggregate concrete [3,7–15].

The volume percentage of old mortar in RCA may vary between 20% and 70% [16,17], depending on the grain size, strength of the parent concrete and the crushing process used [16,18,19]. The undesirable effect of the mortar on the properties of RCA particles has been found to be proportional to its content [1].

A number of RCA beneficiation methods have been recently proposed to enhance the quality of RCA through reduction of the mortar present. In these methods, one or a combination of mechanical, thermal and chemical treatments is usually used to remove the mortar. However, these methods are either too time and energy consuming or do not adequately increase the quality of RCA produced [1].

A new microwave-assisted beneficiation method to reduce the mortar content of RCA is presented in this paper. This method takes advantage of the differences in electromagnetic properties, water absorption and the tensile strength of natural aggregates and mortar to break up and separate the mortar without damaging

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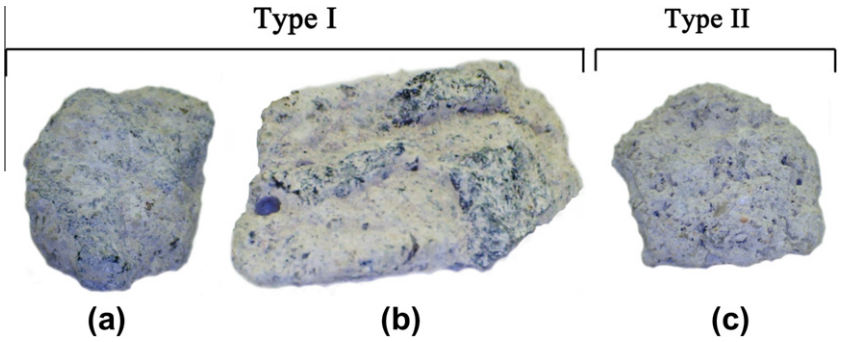

Fig. 1. Various types of RCA comprising (a) a granite particle surrounded by adhering mortar, (b) three granite particles held together and surrounded by mortar, (c) only mortar.

the natural aggregates. The process involved is twofold. First, microwave heating is used to generate high differential thermal stresses concentrated in the adhering mortar (AM), especially at its interface with the embedded natural aggregates (ENA), to cause delamination of the adhering mortar present in Type I RCA particles. Next, further microwave heating is used to break up the mortar delaminated from Type I particles as well as the mortar lumps present (Type II) to smaller pieces that can be easily collected through sieving.

The capability of the microwave-assisted beneficiation method to increase the quality of RCA through reduction of the total mortar content is experimentally investigated and compared with the acid pre-soaking, conventional heating, mechanical rubbing and "heating and rubbing" methods as proposed in available literature. Furthermore, the efficacy of using the combined "microwave heating and mechanical rubbing" processes is examined. Numerical modeling of the microwave-RCA interaction is used to estimate the temperature distribution and the thermal stresses developed in an idealized RCA particle when exposed to microwaves for a better understanding of the phenomena involved. In addition the effects of incorporating various amounts of un-treated RCA and microwave-treated RCA (MRCA) on the compressive strength, modulus of elasticity and flexural strength of concrete are experimentally investigated.

2. Previously proposed RCA beneficiation methods

2.1. Conventional heating (thermal beneficiation)

In this method, RCA particles are heated at about 500 °C for a duration of about two hours. The thermal stresses generated through thermal expansion are used to fracture and thereby remove the mortar present [20]. Moreover, according to Shima et al. when concrete is heated at temperatures higher than 300 °C, mortar is made brittle due to dehydration; lowering its resistance against the thermal stresses developed [21]. It is believed that saturating the mortar before heating can increase the efficiency of this method because it can lead to pore pressure development which may result in the faster removal of mortar. It has also been reported that immersing the heated aggregates in cold water immediately after heating can lead to higher mortar removal yields through increasing the differential thermal stresses developed [1].

2.2. Mechanical beneficiation

In this technique, mechanical forces are used to grind and remove the mortar. Two techniques have been proposed in Japan; eccentric-shaft rotor [22] and mechanical grinding [23]. In the eccentric-shaft rotor method, crushed concrete lumps are passed downward between an outer cylinder and an inner cylinder that rotates eccentrically at a high speed to separate the coarse aggregate from the mortar through grinding. In the mechanical grinding method, a drum is divided into small sections with partitions. The mortar portion of the RCA is removed by rubbing against the iron balls placed in each of the rotating partitioned sections of the drum.

2.3. Thermal–Mechanical beneficiation

In this method a combination of the thermal stresses generated through conventional heating at temperatures from 300 °C to 500 °C and the mechanical stresses generated through rubbing is used to remove mortar from the RCA particles. In 1999, Shima et al. proposed a thermal–mechanical RCA treatment technique known as "heating and rubbing" [24]. In this technique, concrete debris are first heated at 300 °C in a vertical furnace to render the cement paste brittle due to dehydration. To remove the mortar, the heated concrete debris are fed into the rubbing equipment. In the equipment, the heated concrete is rubbed against steel balls and the mortar portion that is dislodged is discharged through the screening system provided [21]. Inventors of this method claimed that it can increase the quality of RCA to comply with the JCI (Japan Concrete Institute) standards for high quality recycled concrete aggregates [25].

2.4. Acid Soaking beneficiation

More recently, Tam et al. proposed a new method to remove the mortar by pre-soaking RCAs in 0.1 M acidic solutions for 24 h [26]. Three different acidic solutions (HCl, H_2SO_4, H_3PO_4) were considered in this study. They reported that the water absorption of RCA after treatment reduced, showing improvements in the range of 7.27–12.17%. A major drawback of this method is the increase in the chloride and sulfate content of the aggregates respectively after treatment with hydrochloric and sulfuric acids. The increase in the chloride and sulfate content of aggregates may cause durability problems.

2.5. Chemical–Mechanical beneficiation

Abbas et al. proposed to use combined chemical degradation through exposure of RCA to sodium sulfate solution and mechanical stresses created through subjecting RCA to freeze-and-thaw action to separate mortar from RCA [27]. However, the main objective of this study was focused on quantifying the amount of mortar present for use in RCA classification. The technique "as is", is not suited for full scale RCA production.