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Influence of quality and variation of recycled masonry aggregates on failure behavior of cement treated demolition waste

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HIGHLIGHTS

- Investigation on the influence of quality and variation of the recycled masonry in CDW.
- The masonry content in CDW determining the properties of cement treated demolition waste.
- Fracture of cement treated demolition waste depends on the mechanical properties of masonry.

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ABSTRACT

Cement treatment of construction and demolition waste (CDW) is a good option as a road base layer with a higher load spreading capacity for pavements. However, the quality and variation of recycled masonry in CDW change considerably in practice and this certainly influences the mechanical properties of cement treated demolition waste. This paper presents the influence of quality and variation of recycled masonry aggregates on its failure and indirect tensile strength by carrying out experimental tests in the laboratory and employing lattice modeling to analyze the fracture process. Numerical analysis and experimental results indicate that the masonry content is an important factor to determine the mechanical properties of the mixture. The failure of cement treated demolition waste originates either in the bonding layer between aggregates and matrix or through some low-quality masonry particles along the loading direction.

1. Introduction

Recycling and reuse of construction and demolition waste (CDW) have become important issues due to its environmental impacts. In the past decades, CDW from demolished buildings has been applied as unbound road base or separately reused to produce new building materials [1,2]. In fact the application of recycled CDW as a road base material is an efficient method to consume much more demolition waste and prevent landfills. In the Netherlands currently over 80% of the material used for road bases is recycled CDW [3]. In China, the feasible reuse of recycled concrete and masonry aggregates as unbound road sub-base is also paid attention to [4].

In order to obtain a higher load spreading capacity for pavements, in comparison with unbound materials, cement treatment of CDW should be a good option. It is noticed that recycled CDW is mainly composed of recycled masonry and concrete. In the Netherlands, over 90% of CDW consists of masonry and concrete, named as mix granulates. Authors have done a series of researches on the structural properties of cement treated mix granulates with crushed recycled concrete and masonry (CTM_iG_r). The investigated structural properties include strength, elastic modulus and drying shrinkage behavior [5–8]. The experimental results indicated that reusing CDW in road bases or sub-bases when treated with cement has a great potential. Meanwhile, a real project in Spain using cement treated demolition waste as a road base has shown that it has good mechanical properties and can be successfully used in pavements [9].

In practice, however, quality and variation of the recycled masonry rubble in the CDW can change considerably [10]. The masonry content in CDW in one recycling factory is different from another recycling factory and varies from time to time as well as from one country to another country. Meanwhile, the mechanical properties of recycled masonry rubble also vary dramatically. This certainly will influence the failure behavior of CTM_iG_r. In the laboratory, extensive tests can be done in order to explore the influence

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of the masonry variation in CDW on the mechanical properties of CTM_iG_r, Meanwhile, there is another way to explore this by means of numerical simulation. In this paper the lattice model was employed to analyze the mechanical properties and fracture process of CTM_iG_r in combination with the corresponding experimental results in the laboratory.

2. Materials and methods

2.1. Materials

The investigated material in this research is cement treated CDW which is considered as a road base material. Because the recycled CDW is mainly composed of demolition masonry and concrete, these two recycled aggregates, recycled crushed concrete (RCA) and recycled crushed masonry (RMA), were used to prepare the cement treated CDW. Both recycled aggregates' gradation for the tested mix granulates was designed by Eq. (1) [11] and is shown in Fig. 1. This is in fact the Fuller curve but modified because of a lack of sufficient fines in the acquired recycled aggregates.

$$P = (100 - F) \cdot \frac{d^n - 0.063^n}{D^n - 0.063^n} + F \tag{1}$$

where P = percentage passing sieve size d (mm); D = maximum particle size (31.5 mm in this study); F = fines content (<0.063 mm) (F = 2.24, close to the fines in RCA); n = a parameter describing the gradation shape (n = 0.45 in this study).

2.2. Tested mixtures

Four types of researched mixtures for numerical analysis and experimental tests were composed of four levels of RMA contents by mass and 4% cement (Portland cement CEM I 42.5) by mass of the total aggregates. In the laboratory the CTM_iG_r mixture was firstly mixed by using a laboratory mixer. The water content was determined by the One-Point-Proctor test in accordance with EN13286-2. The proper water content is proportional to the RMA content, while the dry density decreases with the increase of the RMA content. Fig. 2 shows cross sections of CTM_iG_r specimens with different RMA contents. This implies the variation of RMA in the mixture.

2.3. Indirect tensile test

The monotonic indirect tensile test (ITT) of CTM_iG_r with a size of $\varnothing 150 \times 150$ mm in the laboratory was performed by using the set-up in Fig. 3. It was done by using a 150 kN MTS actuator in the displacement controlled mode. The displacement rate chosen for the ITT was 0.2 mm/s and was controlled by two Linear Variable Differential Transformers (LVDTs). The data of the force and the vertical deformation were automatically recorded. Five specimens of every tested mixture will be tested to get the mean indirect tensile strength.

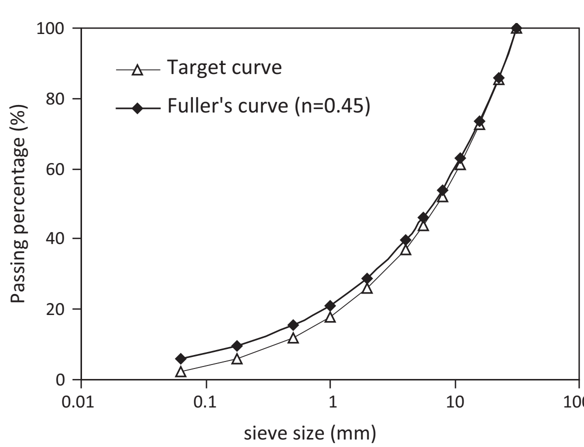

Fig. 1. Target gradation of mix granulates with RMA and RCA.

3. Construction of lattice model for simulation

3.1. Implementation of heterogeneity

Before constructing the lattice image for a real mixture, several steps were performed. Firstly, a cylindrical specimen with a diameter of 150 mm was impregnated with a green-color resin. And then a slice was cut from the real specimen and photographed by means of a digital camera with a high resolution (4000 × 3000 pixels) (see Fig. 4(a)). Based on the color differences, this image was manipulated by Adobe Photoshop CS4 to distinguish different aggregates (RCA and RMA), mortar and voids as shown in Fig. 4(b).

In this research the lattice analysis was conducted on this image with a diameter of 150 mm and with a thickness of 1 mm. The shape of the lattice beam was cylindrical. The mean length of the beam was equal to 1 mm. The radius of the beam was then calculated by:

$$\pi \cdot r^2 = 1 = 1 \ mesh \ area \tag{2}$$

By using the GLAK software developed at TU Delft [12], the random quadrangular mesh lattices were tagged on the specimen as shown in Fig. 5. Note that depending on the position of the phases in the mixture, each type of beam element is colorized. In fact there are six types of beam elements: the RMA, the RCA, the mortar with voids, the interface between RMA and mortar, the interface between RCA and mortar and the interface between RMA and RCA. The last one is bound by a thin layer of mortar, which is assumed to have similar properties as the mortar. Therefore, only five phases were evaluated.

3.2. Fracture criterion

In the lattice model all the beam elements have fixed connections in the nodes. Therefore, every beam can transfer a normal force, a shear force and a bending moment. Each beam is herein supposed to be linear elastic and brittle under tensile stress. Fracture is modeled by sequential removal of beam elements where the stress exceeds the tensile strength. The tensile stress of the beam elements can be derived from the Formula [13]:

$$\sigma_t = \frac{N}{A} + \alpha \cdot \frac{(|M_i|, |M_j|)_{\max}}{W} \tag{3}$$

where N stands for the normal force; A represents the area of the cross section; α is a bending factor; $|M_i|$, $|M_j|$ refer to the bending moments at both ends of a beam; W is the section modulus ($\pi D^3/32$, D is the diameter of the lattice beam).

4. Results and discussion

4.1. Mechanical properties of each phase

In order to be able to establish the relationship between composition and property of CTM_iG_r in a numerical way, it is first of all necessary to characterize the mechanical properties of every phase in CTM_iG_r and use these as input values for the numerical analysis. As shown in Fig. 5, there are six phases in the mixture of CTM_iG_r: the RMA, the RCA, the mortar composed of fine aggregates (less than 2 mm) and cement paste, the interface between RMA and mortar, the interface between RCA and mortar and the interface between RMA and RCA. The last phase is assumed to have similar properties with the mortar in the mixture. The properties of these five phases are therefore determined for a mixture with 65% RMA by mass, 4% cement by mass and 101% degree of compaction, which was cured for 28 days.