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Deformation behavior of cement treated demolition waste with recycled masonry and concrete subjected to drying and temperature change

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ABSTRACT

Cement treated materials are widely used as road bases in pavements. Shrinkage of these materials due to moisture and temperature changes is a critical issue for determining shrinkage cracking in pavements. This paper presents the influence of four mixture variables (masonry content, cement content, water content and degree of compaction) on drying shrinkage and coefficient of thermal expansion (CTE) of cement treated demolition waste with recycled masonry and concrete (CTM_iG_r). The experimental results showed that the masonry content was the dominating factor affecting dry shrinkage and CTE of CTM_iG_r. Increasing the masonry content can not only lead to an obvious decrease of dry shrinkage of CTM_iG_r, but also a low CTE level. Dry shrinkage of CTM_iG_r increased as the increase of cement content as well as degree of compaction and water content. The CTE of CTM_iG_r was between $7.58 \times 10^{-6}/^{\circ}C$ and $10.22 \times 10^{-6}/^{\circ}C$, which was mainly determined by the masonry and cement content.

1. Introduction

Using a cement treated base (CTB) in a pavement is an option to obtain a high load spreading capacity for heavy traffic. As a result, many countries employ CTB as a semi-rigid course in pavements [1,2]. However, a disadvantage of the pavement with CTB is that CTB is a source of shrinkage cracks in the pavement [3,4]. Therefore, its susceptibility to dimensional change is a critical issue during its service life as a pavement layer.

In practice, a CTB layer is always subject to different or complicated conditions. Its dimensional change may occur as a result of cement hydration, variation of moisture content and change in temperature. Consequently, friction is developed between the CTB layer and the contact layers. Tensile stresses induced in the CTB layer as shrinkage happens can be defined according to Equation (1). If these stresses exceed the tensile strength of CTB, cracks will be initiated. Shrinkage cracks in some cases may appear after a few days whereas they can appear up to months or even years later in other cases [5].

$$\sigma(t) = -E(t)\cdot[S(t) - \varepsilon(t)] = -E(t)\cdot[S(t) - \alpha\cdot\Delta T] \quad (1)$$

Where, $\sigma(t)$ is the tensile stress induced in CTB at time$t$ due to shrinkage; E(t) is the elastic modulus of the CTB material at time t; S(t) is the shrinkage strain of the CTB material at time t due to cement hydration and moisture change; $\varepsilon(t)$ is the thermal strain of the CTB material at time t due to temperature change; α is coefficient of thermal expansion (CTE) of the CTB material and ΔT is the temperature change.

It is thus of great importance to know the deformation behavior of a CTB material for predicting the crack position and its width [6,7]. Then, techniques of controlling reflective shrinkage cracking in pavements can be technically chosen based on its cracking behavior. In practice, several factors including material characteristics, construction technique, traffic loading, and restraint imposed on the base by the contact layer contribute to the cracking development in a CTB layer. With regard to material characteristics, the dimensional change of CTB is influenced by the type of aggregates, cement content, degree of compaction, moisture content and so on. In addition, environmental conditions such as temperature, relative humidity and wind speed are very influential.

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Normally, CTB is produced by using high quality natural or crushed coarse aggregates [5]. Due to shortage of natural aggregates and environmental impacts of construction and demolition waste (CDW), recycled CDW has been widely crushed and reused as aggregates in a number of countries and has been now promoted as a sustainable road base/sub-base material. In the Netherlands, almost 90% of CDW materials consist of masonry and concrete, which is called mix granulates. Currently, more than 80% of the material used for road bases in the Netherlands is unbound recycled CDW [8,9]. Compared to unbound recycled CDW, cement treatment would be a good option to improve the properties of CDW as a road base layer with a higher load spreading capacity for pavements.

Authors have already reported the mechanical properties of cement treated mix granulates with recycled masonry and concrete (CTM_iG_r) [10,11]. This paper aims at experimentally exploring the deformation behavior of CTM_iG_r including dry shrinkage and CTE. So far no systematic information can be found in literature regarding dry shrinkage and CTE of cement treated demolition waste. Therefore, the influence of cement content, degree of compaction, recycled masonry content and water content on the deformation of CTM_iG_r was systematically investigated through a series of experimental tests in this study. Based on the obtained experimental data, the models to estimate the dry shrinkage level and CTE of CTM_iG_r were developed.

2. Experimental program

2.1. Materials

Since the recycled CDW is mainly composed of masonry and concrete, these two recycled aggregates collected from two Dutch companies, were used in this study. One consists of recycled concrete aggregates (RCA) produced by crushing recycled concrete rubbles and the other was made up of recycled masonry aggregates (RMA) produced by crushing recycled masonry waste. Both recycled aggregates were divided into six particle size ranges: 31.5–22.4 mm, 22.4–16.0 mm, 16.0–8.0 mm, 8.0–5.6 mm, 5.6–2.0 mm, <2.0 mm. Table 1 lists the physical properties of RMA and RCA. In addition to the recycled aggregates, the Portland cement of CEM I 42.5 N in accordance with BS EN 197-1 and tap water were used to prepare the specimens.

The aggregate gradation for the tested mix granulates was designed by Equation (2) (Fig. 1). This is in fact a Fuller curve, which was modified due to a lack of sufficient fine aggregates smaller than 0.063 mm in the collected recycled aggregates [12]. According to the real content of recycled fine aggregates, a parameter describing the shape of the curve, n = 0.45, was then used in this study.

$$P = (100 - F) \cdot \frac{d^n - 0.063^n}{D^n - 0.063^n} + F \quad (2)$$

Where,

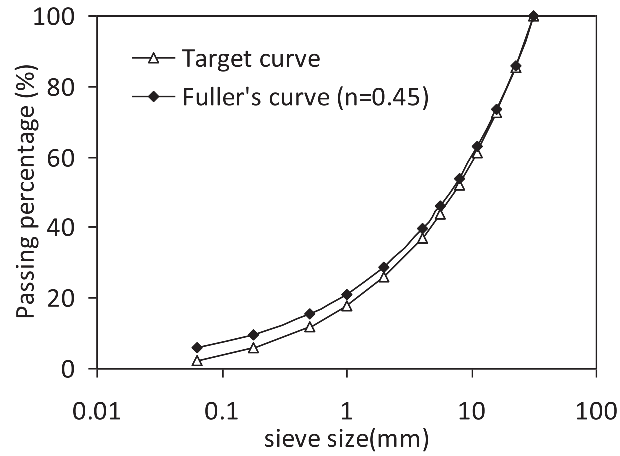

Fig. 1. Target gradation of mix granulates with RMA and RCA.

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 shape of the curve (n = 0.45 in this study)

2.2. Mixture design

Four mixture variables were selected in order to investigate their influence on the deformation behavior of the CTM_iG_r mixture subjected to drying and temperature change. They were:

- RMA content,
- cement content,
- degree of compaction, and
- water content.

Table 2 lists the considered variables and their application levels for the tested mixtures. The RMA and cement contents were obtained by mass of the total aggregates. Four different application levels of RMA were selected. Three application levels were chosen for the cement content and degree of compaction, which was based on the central composite design [13]. Fig. 2 illustrates the cross sections of CTM_iG_r specimens with different RMA contents.

2.3. Specimen preparation and deformation measurement

In the laboratory, all the constituents for CTM_iG_r were initially mixed by using a 100-L mixer. The water content was determined

Table 1
Physical properties of RMA and RCA.

Test items		Fractions (mm)					
		31.5–22.4	22.4–16.0	16.0–8.0	8.0–5.6	5.6–2.0	2.0–0.063
RMA	Apparent density (g/cm^3)	2.299	2.299	2.369	2.418	2.458	2.593
	Particle density (g/cm^3)	1.934	1.931	1.954	1.976	1.920	1.914
	Water absorption in 48 h (wt%)	8.19	8.27	8.98	9.26	11.40	13.67
RCA	Apparent density (g/cm^3)	2.533	2.512	2.555	2.583	2.597	2.596
	Particle density (g/cm^3)	2.354	2.313	2.322	2.336	2.311	2.046
	Water absorption in 48 h (wt%)	2.99	3.41	3.91	4.10	4.76	10.34