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FULL LENGTH ARTICLE

Properties of paving units incorporating crushed ceramic

Dina M. Sadek, Hanan A. El Nouhy *

Housing and Building National Research Center, Cairo, Egypt

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Abstract The aim of this study is to investigate the effects of using crushed ceramic in the production of interlocking paving units. Eight mixes were cast. The first mix was the control mix, in which natural aggregates were used in the upper and lower layers. In the second and third mixes, coarse crushed ceramic was used in the lower layer replacing 50% and 100% of crushed stone, respectively. In the fourth and fifth mixes, fine crushed ceramic was used in the lower layer replacing 50% and 100% of natural sand, respectively. In the sixth mix, coarse and fine crushed ceramic were used in the lower layer replacing 50% of crushed stone and 50% of natural sand, respectively. Finally, in the seventh and eighth mixes, fine crushed ceramic was used in the upper layer replacing 50% and 100% of natural sand, respectively while natural sand was used in the lower layer. Tests were carried out in order to investigate the properties of the manufactured specimens after 28 days of curing. Compressive strength and abrasion resistance were determined according to the American Society for Testing and Materials (ASTM C 140 and ASTM C418, respectively). Water absorption, split tensile strength, abrasion resistance, as well as, skid resistance were determined according to both Egyptian Standard Specifications (ESS 4382) and European Standard (EN 1338). The Egyptian standard is identical with the European standard. The results indicate that it is feasible to use fine crushed ceramic in the manufacture of paving blocks.

Introduction

Concrete which contains at least 20% of waste products as aggregates is called "Green Concrete" [1]. The major sources of ceramic waste are ceramic industry, buildings construction and buildings demolition. In building construction, ceramic waste is generated due to transportation to the building site, and during the execution of construction elements [2]. Research studies have been conducted to study the viability of replacing limestone aggregate with ceramic coarse aggregate on the production of concrete pavement slabs. In the

* Corresponding author. Tel.: +20 224484729.
E-mail addresses: Construction_20001@yahoo.com (D.M. Sadek), hanan_elnouhy@yahoo.com (H.A. El Nouhy).
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study, it was shown that there is a potential for the use of ceramic aggregates in elements in which the primary requirement is not compressive strength but tensile strength and abrasion resistance. Strength decreased as the quantity of ceramic aggregates in concrete increased, as they are lighter and less resistant than the primary limestone aggregates. Furthermore, the abrasion resistance of concrete made with ceramic recycled aggregates was higher than that of concrete made with limestone aggregates. Also, the results showed that water absorption tests (either by capillarity or by immersion) increase very regularly and significantly with the proportion of ceramic aggregates [2,3]. Binici studied the suitability of ceramic industrial wastes and basaltic pumice as a possible substitution for conventional crushed fine aggregates. Experiments were carried out to determine abrasion resistance, chloride penetration depths and compressive strengths of concrete with crushed ceramic waste and basaltic pumice fine aggregates and to compare them with those of conventional concretes. Test results indicated that ceramic wastes and basaltic pumice concretes had good workability. Furthermore, it was found that abrasion resistance of crushed ceramic (CC) and crushed basaltic pumice (CBP) concretes was lower than that of conventional concretes. Results showed that CC and CBP could be conveniently used for low abrasion and higher compressive strength concretes [4]. Research works were carried out to study the replacement of 20% of cement as well as the replacement of both fine and coarse aggregates by ceramic waste. Results showed that although concrete with ceramic waste powder had a minor strength loss, it still possessed durability performance due to the pozzolanic properties. It was also shown that replacement of traditional sand by ceramic sand is a good option as it does not imply strength loss and has superior durability performance. As for the replacement of traditional coarse aggregates by ceramic coarse aggregates, the results were promising but underperformed slightly in water absorption, and water permeability, meaning that the replacement of sand by ceramic is a better option [5]. Jimenez et al. evaluated the performance of both fresh and hardened masonry mortar manufactured using fine recycled aggregate from ceramic partition wall rubble. It was shown that the replacement ratios up to 40% by volume did not significantly affect the properties of both fresh and hardened mortar, with the exception of density and workability [6]. Another study was conducted in which the chloride ion penetration tests were carried out on mortars made of ceramic waste (which was crushed and grounded to various sizes prior to the replacement of fine aggregates). From the results, it was found that the mortars containing ceramic waste were more effective in the resistance of chloride ion penetration than a typical mortar made of river sand [7].

Materials and methods

Cement

The cement used was Portland cement CEM I 52.5N in accordance to ESS 4756-1/2007. Physical and mechanical properties of cement are shown in Table 1, while the chemical composition is shown in Table 2.

Natural aggregates

Siliceous sand and crushed limestone were used in this research program as fine and coarse aggregates, respectively. The sieve analysis curves of natural sand and crushed limestone are shown in Figs. 1 and 2, respectively. Table 3 gives the properties of both fine and coarse aggregates.

Recycled aggregates

Crushed ceramic was used as recycled fine and coarse aggregates. The fractions passing from sieve 2.36 were used as fine aggregate, while fractions passing from 10 mm sieve and retained on 2.36 mm sieve were used as coarse aggregate. The sieve analysis curves of fine and coarse crushed ceramic are shown in Figs. 3 and 4, respectively. Table 4 presents the properties of fine and coarse crushed ceramic.

Testing methods

All concrete paving blocks were prepared using pressure (200 bars) and vibration until complete compaction was obtained from the compaction machine.

The absorption test was carried out in accordance to ASTM C140 [8]. The specimens were immersed in potable water at a temperature of (15.6–26.7 °) for 24 h. Then they were weighed to obtain the initial mass. After that, the specimens were dried in a ventilated oven at (100–115 °) for a minimum period of 24 h. The specimens were then allowed to be cooled to room temperature before they were weighed to obtain the final mass.

Abrasion resistance was determined according to both ESS 4382 [9] and BSEN 1338 [10]; annex G by the Wide Abrasion test. The wearing machine is essentially made of a wide abrasion wheel, a storage hopper with a control to regulate the output of the abrasive material, a flow guidance hopper, a clamping trolley and a counterweight. Immediately before testing, the surface to be tested is cleaned with a stiff brush and covered with a surface dye to facilitate measuring the groove (e.g. painting with a marker pen). The hopper is filled with corundum (abrasive material) and the specimen is brought into

Table 1 Physical and mechanical properties of cement.

Property	Description	Test results	Standard requirements
Setting time (min)	Initial	150	Not less than 45 min
	Final	195	–
Soundness (mm)		1	Not more than 10
Compressive strength (MPa)	2 days	23.5	Not less than 20
	28 days	55.2	Not less than 52.5