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Properties of concrete incorporating fine recycled aggregates from crushed concrete wastes

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HIGHLIGHTS

- Two types of FRAs (R1 and R2) from crushing concrete wastes were used in the study.
- Crushing processes have significantly influence on the quality of FRAs.
- FRA replacement ratio is an important factor affecting the properties of the resulting concrete.
- Concrete specimens containing R2 have a superior quality than that containing same amount of R1.

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ABSTRACT

Fine recycled aggregates produced by crushing concrete wastes can be used as a replacement for fine natural aggregates for manufacturing concrete. Two methods were adopted for production of fine recycled aggregates from crushed concrete wastes: first, produces coarse as well as fine aggregates (R1); second, produces only fine aggregate (R2). Test results demonstrate that the fine recycled aggregate replacement ratio is an important factor affecting the physical, mechanical and durability of resulting concrete. Furthermore, concrete specimens containing R2 have a superior quality than concrete specimens containing same amount of R1.

1. Introduction

Aggregate produced by crushing concrete waste can be used as a replacement for natural aggregate in the manufacture of concrete. This can help to conserve natural resources and promote a more sustainable infrastructure. Numerous studies have detailed the use of coarse recycled aggregate (CRA) from crushed concrete waste as a replacement for coarse natural aggregate (CNA) in the manufacture of structural material [1–6]. The properties of concrete produced from CRA have been thoroughly investigated and a number of researchers have begun exploring the use of fine recycled aggregate (FRA) from crushed concrete waste. Khatib [7] conducted experiments in which 0%, 25%, 50%, 75%, or 100% of fine natural aggregate (FNA) was replaced by FRA, which resulted in a density of 2340 kg/m^3 and water absorption of 6.25%. At replacement ratios of 25% and 100%, compressive strength of concrete was reduced by 15% and 30%, respectively. Evangelista and de Brito [8] tested the mechanical properties of concrete in which 0%, 10%, 20%, 30%, 50%, and 100% of FNA was replaced by FRA, which resulted in a density of 2165 kg/m^3 and water absorption of 13.1%. Based on the above findings, it is reasonable to assume that the use of FRA does not jeopardize the mechanical properties of concrete, at replacement ratios of up to 30%.

Pereira et al. [9] added two types of superplasticizer to concrete, in which 0%, 10%, 30%, 50%, or 100% of FNA was replaced by FRA, which resulted in a density of 2230 kg/m^3 and water absorption of 10.9%. Experiment results demonstrate that the mechanical performance of the concrete produced using recycled aggregate in conjunction with superplasticizer exceeded that of the reference

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concrete with no admixture and of conventional concrete with lower performance superplasticizer.

Khoshkenari et al. [10] produced concrete using CRA or FRA, which resulted in materials with a density of 2310 and 1970 kg/m^3 and water absorption of 6.87% and 14.05%, respectively. They discovered that concrete produced from CRA or FRA has lower compressive and splitting tensile strength than the control group. Furthermore, they found that the negative effect on splitting tensile strength was more pronounced. Nonetheless, strength could be improved by incorporating FNA of 0–2 mm size. The positive effect of the FNA was particularly evident on compressive strength of normal-strength concrete and on splitting tensile strength of high-strength concrete.

Cement paste adhering to the surface of FRA has been shown to affect the properties of concrete. Thus, recent researches have been conducted to investigate the effect of production process of FRA on the properties of concrete. Sim and Park [11] applied an advanced recycling process employing water floatation and air blowing in production of FRA. Concrete specimens with various proportions of FNA were tested. Increase in FRA replacement ratio would reduce compressive strength of concrete. Song and Ryou [12] also introduced a washing process to produce FRA. The washing process was shown to enhance the physical properties of the resulting FRA. Koshiro and Ichise [13] demonstrated the effectiveness of heat grinder system for processing concrete waste from a demolished building to produce high-quality FRA. Lee [14] used a jaw crusher or an impact crusher to produce two types of FRA, RF-A and RF-B, with specific gravity of 2.39 and 2.28 and absorption of 6.59% and 10.35%, respectively. Various combinations of FNA and FRA were used to produce specimens for testing. Specimens with FNA replaced entirely by RF-A presented higher density and better compressive strength in comparison with specimens made from RF-B. Test results also indicated that absorption of FRA influences the properties of specimens with higher replacement ratios.

Florea et al. [15] investigated the influence of crushing method on particle size distribution and the density of recycled concrete aggregate. Concrete with compressive strength of 60 MPa were crushed by applying three methods: RC-1, recycled concrete aggregate from concrete waste by one-time jaw-crushing before being screened; RC-2, recycled concrete aggregate by ten-time jaw-crushing before being screened and RC-3, recycled concrete aggregate produced from three consecutive crushing processes using a Smart Crusher. RC-3 presented particle size distribution between 125 and 200 μm, with a density of 2500 kg/m^3. Optimal crushing process was concluded to enhance the quality of the resulting concrete. Ulsen et al. [16] produced a variety of FRAs using a jaw crusher in conjunction with a vertical shaft impact (VSI) crusher with various rotational speeds. The resulting aggregates were as follows: CDW-sand, FRA produced using a jaw crusher; VSI-55~VSI-75, FRA produced using a jaw crusher followed by a VSI crusher with various rotation speeds prior to screening. Test results indicated that the rotational speed of VSI crusher had no effect on particle shape or particle size distribution of FRA, however, absorption and porosity were affected.

Fan et al. [17] investigated the effects of two types of FRA (R1 and R2) from crushed concrete waste on the properties of mortar. Mortar specimens with various proportions of FRA were tested. Test results revealed that R2 has lower porosity, higher density and lower absorption than R1, which indicating the superior quality of R2 and demonstrating the effect of crushing process on quality of resulting concrete. Current study was aimed to explore how the properties of concrete are affected when FNA is replaced by various percentages of FRA produced from same concrete waste.

2. Experimental design

2.1. Materials

Type I Portland cement and natural river aggregate comprising clay slate were used. Two types of fine recycled aggregates (FRA: R1, R2) were produced as shown in Fig. 1. Fine recycled aggregate (R1) was produced simultaneously with recycled coarse aggregate production by crushing concrete waste. Fine recycled aggregate (R2) was produced by repeating crushing process until required particle size. Table 1 lists the physical properties of used materials.

2.2. Mix proportions

Table 2 lists the mix proportions of concrete in this study. The water/cement ratios were set at 0.35 and 0.55. Concrete from former trial mix displayed poor workability; therefore, type G superplasticizer (1% weight of the cement) was added to improve workability. The replacement levels of FNA by R1 and R2 were set at volume fractions of 0%, 25%, 50%, and 100%. Only FNA was used in control concrete. The cement/FNA weight ratio of control mix was 1:2 and the FNA/aggregate ratio was set at 0.5. The details of mix proportions are listed in Table 2.

2.3. Fabrication of specimens

The FRA used in this study has higher water absorption than does FNA. We therefore applied pre-wetting to all aggregates for 24 h. Surface moisture (ASTM C70 [20]) was measured and water was adjusted prior to mixing in order to achieve saturated-surface-dry (SSD) condition. Mixing was performed according to the designed proportion and the resulting concrete from each mixture was used in the production of the following specimens: nine cylindrical specimens with a diameter of 100 mm and height of 50 mm, and fifteen cylindrical specimens with a diameter of 100 mm and height of 200 mm. After casting, the specimens were covered with plastic sheeting to prevent evaporation. The specimens were held in the laboratory for 24 h before being de-molded and immersed in saturated lime water for curing at an average temperature of 23 ± 2 °C until testing.

2.4. Testing

The following tests were performed to characterize the attributes of the concrete: slump tests, density tests, absorption tests, compressive strength tests, ultrasonic pulse velocity (UPV) tests, resistivity tests, and initial surface absorption tests. Slump testing was performed in accordance with ASTM C143 [21]. We then measured slump by determining the vertical difference between the top of the mold and the displaced original center at the top surface of the specimen. Density testing was performed using cylindrical specimens with a diameter of 100 mm and height of 50 mm, in accordance with ASTM C642 [22]. The specimens were weighed at 28 days in SSD conditions. The specimens were weighed after being suspended in boiling water for 5 h and again after being removed from the water that had cooled to 25 °C. Absorption testing was performed using cylindrical specimens with a diameter of 100 mm and height of 50 mm, in accordance with ASTM C642 [22]. Specimens at 28 days were first placed in an oven at 105 ± 5 °C and dried until they achieved constant weight. They were then soaked in water to achieve SSD conditions before being weighed. Compressive strength testing was performed using cylindrical specimens with a diameter of 100 mm and height of 200 mm, in accordance with ASTM C39 [23]. Specimens were retrieved, dried, and tested at 7 days, 14 days, and 28 days. UPV testing was performed using cylindrical specimens with a diameter of 100 mm and height of 200 mm, in accordance with ASTM C597 [24]. The measurement device used in this test was the Pundit Plus, manufactured by CNS Farnell Limited. Converters were placed at both ends of the specimens at 7 days, 14 days, and 28 days, with the ultrasonic frequency was set to 54 kHz. Wave velocities were measured twice and averaged to obtain the UPV. Resistivity testing was performed using cylindrical specimens with a diameter of 100 mm and height of 200 mm. The specimens were dried and tested using the Proceq resistivity meter at 7, 14, and 28 days after production. The four electrodes were equi-spaced as per the Wenner arrangement. The cylinders were measured with the probe centered along the longitudinal direction, with the specimen rotated 90° with each measurement for a total of four readings in each round of measurements. The resistivity of each specimen was calculated as the average of the results from four rounds of testing. Initial surface absorption testing was performed using cylindrical specimens with a diameter of 100 mm and height of 50 mm, in accordance with BS 1881-208 [25]. Specimens at 28 days were first placed in an oven at 105 ± 5 °C and dried until they achieved a constant weight. This test is intended to measure the permeability of concrete and its ability to absorb water in a prescribed period of time (ranging between 10 min and 2 h) under a head of 200 mm (8 in.). The rates of absorption of water at 10, 30, 60 and 120 min from the start of test were recorded. The rate of initial surface absorption is expressed in milliliters per square meter per second (ml/m^2 s).