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Comparisons of natural and recycled aggregate concretes prepared with the addition of different mineral admixtures

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ABSTRACT

This paper presents the results of a laboratory study on the performance of natural and recycled aggregate concrete prepared with the incorporation of different mineral admixtures including silica fumes (SF), metakaolin (MK), fly ash (FA) and Ground granulated blast slag (GGBS). The compressive and splitting tensile strength, drying shrinkage, chloride ion penetration and ultrasonic pulse velocity (UPV) of the concrete mixtures were determined. The test results, in general, showed that the incorporation of mineral admixtures improved the properties of the recycled aggregate concretes. SF and MK contributed to both the short and long-term properties of the concrete, whereas FA and GGBS showed their beneficial effect only after a relatively long curing time. As far as the compressive strength is concerned, the replacement of cement by 10% of SF or 15% of MK improved both mechanical and durability performance, while the replacement of cement by 35% FA or 55% GGBS decreased the compressive strength, but improved the durability properties of the recycled aggregate concretes. Moreover, the results show that the contributions of the mineral admixtures to performance improvement of the recycled aggregate concrete are higher than that to the natural aggregate concrete.

1. Introduction

The possible use of recycled aggregates (RA) derived from construction and demolition (C&D) wastes have received increasing interest, due to its potential to be used in environmentally friendly concrete structures. Moreover, the shortage of supply of natural aggregates in some parts of the world leads to the need to develop recycled aggregate as an alternative source of aggregate. The issue of recycling rubbles from building demolition in the concrete industry has been widely discussed by many researchers [1–3]. A number of previous publications [4–7] studied the mechanical behavior of concretes containing RA. The results showed how the strength loss caused by recycled concrete aggregate at equal water to cement ratio (W/C) could be reduced if better concrete was used as coarse recycled aggregate and if a lower proportion of fine recycled aggregate was added.

Although it is environmentally beneficial to use RA, the current specifications and experience in many parts of the world are not able to support and encourage the recycling of C&D waste [8]. Also, some technical problems, including the lack of information on the interfacial transition zone between cement paste and RA, increase in porosity and presence of traverse cracks within RA, high levels of sulphate and chloride contents, the presence of impurities and attached cement mortar on the RA, poorer grading, and high variations in quality, render the use of RA, especially in structural concrete difficult [9–20].

Mineral admixtures such as fly ash (FA), silica fume (SF), metakaolin (MK) and Ground granulated blast slag (GGBS) have been utilized for many years either as supplementary cementitious materials in Portland cement concretes or as a component in blended cement [21–25]. Generally, due to their high pozzolanic activity, the inclusion of MK and SF improves the mechanical and durability properties of the concrete [26–33]. The use of GGBFS as a partial replacement of ordinary Portland cement improves strength and durability of the concrete by creating a denser matrix and thereby would increase the service life of the concrete structures. It is well known that the incorporation of FA and GGBS with normal fineness reduces the early strength of concrete, but they have long term advantages, such as improved long-term strength and durability, increased workability, reduced permeability and porosity, and reduced alkali-silica reaction expansion [34–39].

Preliminary studies have been conducted on the mechanical and durability properties of recycled aggregate concrete made with mineral admixtures. Berndt [40] reported that the recycled aggregate concrete mixtures containing 50% slag gave the best overall performance. Slag was particularly beneficial for concrete with recycled aggregate and could reduce strength losses. Durability

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tests indicated slight increases in coefficient of permeability and chloride diffusion coefficient when using recycled aggregate in concrete. However, values remained acceptable for durable concrete and the chloride diffusion coefficient was improved by incorporation of slag in the mixture. Corinaldesi and Moriconi [41] conducted experiments on concrete specimens that were manufactured by completely replacing fine and coarse aggregates with recycled aggregates using FA and SF as partial cement replacements. They found that satisfactory concrete properties can be developed with proper selection and proportioning of the mineral materials in the concrete. Ann et al. [42] found that the corrosion rate of recycled aggregate concretes made with 30% PFA and 65% GGBS was kept at a lower level after corrosion initiation, compared to the control specimens, presumably due to the restriction of oxygen and water access. However, it was less effective in increasing the chloride threshold level for steel corrosion.

The authors have published a number of papers on the use of FA in concrete prepared with recycled aggregates [43–45]. The advantages of using FA as an additional cementitious material in recycled aggregate concretes prepared by suitably combining coarse recycled aggregate particles were quantified.

This paper reports the results of a systematic study on the effect of different mineral admixtures in the strength, drying shrinkage, chloride ion penetration and UPV of recycled aggregate concrete. In the concrete mixtures, the replacement levels of cement were chosen at 10% SF, 15% MK, 35% FA and 55% GGBS, which are the common levels used in practice.

2. Materials and experiments

2.1. Materials

The cementitious materials used in this study were Portland cement (PC) equivalent to ASTM Type I, metakaolin (MK) named MetaStar 450 obtained from Imerys Minerals; and condensed silica fume (SF) named Force 10,000D microsilica obtained from W. Grace. ASTM Class-F fly ash obtained from CPL in Hong Kong and Ground granulated blast slag (GGBS) obtained from China mainland. The chemical compositions and physical properties of the cement, SF, MK, FA and GGBS are listed in Table 1.

Natural and recycled aggregates were used as the coarse aggregate in the concrete mixtures. In this study, crushed granite was used as the natural aggregate and recycled aggregate sourced from a recycling facility in Hong Kong was used (the RA contained more than 90% crushed recycled rubbles). The nominal sizes of the natural and recycled coarse aggregates were 20 and 10 mm and their particle size distributions conformed to the requirements of BS 882 (1985). The physical and mechanical properties of the coarse aggregate are shown in Table 2. The porosity of the aggregates was determined by using mercury intrusion porosimetry (MIP). River sand was used as the fine aggregate in the concrete mixtures. All aggregates were used at air dried condition. Regular tap water was used as mixing water.

2.2. Specimen preparation and curing

Three series of concrete mixtures were prepared in the laboratory using a Pan mixer. The absolute volume method was used in calculating the mixture proportions. SF, MK, FA and GGBS were used as cement replacements on a weight basis. In all concrete mixtures, a constant water/binder ratio at 0.50 was used. Series I concrete mixtures used natural aggregate as the coarse aggregate and the mixes were designated with the following codes: C (control, natural aggregate with 100% OPC), C-SF10 (natural aggregate with 10% SF), C-MK15 (natural aggregate with 15% MK), C-FA35 (natural aggregate with 35% FA) and C-GGBS55 (natural aggregate with 55% GGBS). In Series II and Series III, recycled aggregates were used to replace 50% and 100%, respectively of natural coarse aggregate. The mixtures were designated with the following codes: R50-SF10, R100-SF10 (50% or 100% recycled aggregate with 10% SF), R50-MK15, R100-MK15 (50% or 100% recycled aggregate with 15% MK), R50-FA35, R100-FA35 (50% or 100% recycled aggregate with 35% FA) and R50-GGBS55, R100-GGBS55 (50% or 100% recycled aggregate with 55% GGBS). The mixture proportions of the concrete are presented in Table 3.

The workability of the concrete mixtures were measured using the slump cone test according to ASTM C143-89a [46]. Each slump value reported in this paper is the average of three readings obtained from three different specimens in the same conditions.

The test specimens prepared were concrete cubes with sizes of 100 and 150 mm for compressive strength and UPV tests. In addition, concrete cylinders with 100 mm (diameter) and 200 mm (height), and $75 \times 75 \times 285$ mm prism were cast for tensile splitting strength, chloride ion penetration and drying shrinkage test, respectively. The specimens were cast in accordance with ASTM C192-88 [47] Plastic sheets were used to cover the specimens to prevent the water from evaporating. All concrete specimens were first cured for 24 h in laboratory conditions. After which the specimens were demoulded and placed in a water curing tank at 27 ± 2 °C until the test ages.

2.3. Compressive and tensile splitting strength test

The 100 mm cubes and concrete cylinders with 100 mm (diameter) by 200 mm (height) were used for the determination of the compressive and tensile splitting strength, respectively at 1, 4, 7, 28, and 90 days according to BS 1881 Part 116 and Part 117 [48,49]. The compression load was applied using a compression

Table 1
Physical and chemical properties of cement, fly ash, silica fume, GGBS and metakaolin.

Contents	Cement	Fly ash	Silica fume	Metakaolin	GGBS
SiO_2	21.0	56.79	85–96	53.2	44.6
Al_2O_3	5.9	28.21	–	43.9	13.3
Fe_2O_3	3.4	5.31	–	0.38	0.9
CaO	64.7	<3	–	0.02	33.8
MgO	0.9	5.21	–	0.05	4.8
Na_2O	–	–	–	0.17	1.0
K_2O	–	–	–	0.10	–
TiO_2	–	–	–	1.68	–
SO_3	2.6	0.68	0.3–0.7	–	1.3
Loss on ignition (%)	1.2	3.90	3.5	0.50	0.2
Specific gravity (g/cm^3)	3.15	2.31	2.22	2.62	2.98
Fineness (>45 μm)	–	–	3–5	–	–
Specific surface (cm^2/g)	3520	3960	18,650	12,680	5350