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Performance of self-compacting concrete incorporating recycled concrete fines and aggregate exposed to sulphate attack

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HIGHLIGHTS

- Two sizes of aggregates from crushing concrete wastes were used in the study.
- Concrete fines were used as a replacement to natural pozzolana.
- Addition of concrete fines up to 40% had improved the strength.
- Reusing recycled aggregate and fine recycled concrete has dual sustainability benefits.
- Full immersion sulphate attack tests can mislead.

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ABSTRACT

The present study investigates the performance of self-compacting concrete (SCC) and self-compacting sand concrete (SCSC) incorporating recycled concrete fines and aggregate under different sulphate environments. Similar mixtures incorporating natural aggregates and natural pozzolana were also tested for comparison. Different sulphate attack regimes (i.e. fully submerged and immersion-drying cycles) were applied. Compressive strength development/degradation under sulphate attack was monitored for all tested mixtures. Results indicate that the use of recycled materials did not significantly affect the strength development with respect to mixtures with natural materials. Moreover, mixtures incorporating recycled concrete aggregate and fine recycled concrete exhibited a better sulphate resistance behaviour than those with natural aggregates and natural pozzolana. In conclusion, the quality of the used recycled materials is a key factor in producing green and sustainable self-compacting concrete.

1. Introduction

As concrete structures are demolished or renovated, concrete recycling is an increasingly common method of utilizing the rubble. The use of recycling concrete assist in getting rid of various debris preserving the environment and reducing the construction costs. Moreover, it generates an additional source for aggregates. Recycled aggregates have essentially three major economic advantages: minimizing transportation expenses, as recycling facilities are often near construction sites, saving space in landfills and reducing the natural resources demand.

Recently, depletion of some natural deposits along with the high demands of major projects, increases the use of recycled aggregates which is considered as a sustainable development approach [1]. Therefore, many researchers had focused on optimizing the production and properties of concrete incorporating recycled aggregates [2–5]. Moreover, several international codes provide recommendations for the use of recycled coarse concrete aggregates as fully or partially replacement for natural coarse aggregates in new concrete [6,7].

Usually, recycled fine materials are discarded as it may modify concrete properties [8]. Previous study [9] showed that using 25% and up to 100% recycled fine materials as a replacement of sand induces a reduction in concrete compressive strength with about 15% and 30%, respectively. Conversely, Evangelista and de Brito [10] showed that the using up to 30% recycled fine materials will not affected concrete compressive strength significantly. The major effect of utilizing these recycled fine materials in concrete is the increase in drying shrinkage and the reduction in its durability [11,12].

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In general, it was reported by [13] that concrete made with RA exhibit less durability due to its high pore volume, leading to a higher permeability. This will be mainly influenced with the recycled aggregate gradation and replacement ratio. Many researchers showed that the use of supplementary cementitious materials (SCMs) can overcome this problem through improving the pore structure and reducing the volume of macro pores [14–17]. Another option that can assist in achieving higher packing density and lower permeability is to use different gradation of recycled concrete. Hence, besides coarse aggregate, fine recycled concrete aggregate and recycled fine materials can improve the durability and long term performance of concrete with recycled aggregate [18].

Therefore, the present study aims at strengthening the concept of sustainability in buildings through the use of recycled concrete aggregates and fine materials. In addition, it investigates and highlights the effect of using such materials on the long-term performance of concrete exposed to aggressive sulphate environments.

2. Experimental program

The experimental program was designed to study the sulphate resistance of self-compacting concrete and self-compacting sand concrete incorporating recycled concrete aggregates with different sizes obtained by crushing demolished concrete. A total of 8 different mixtures were produced and tested under different sulphate exposure conditions that simulate the real field condition. The performance of different mixtures were evaluated by visual inspection, mass changes, reduction in compressive strength along with advance analysis using Thermogravimetric Analysis (TGA) and Scanning electron microscope (SEM)

2.1. Materials

Portland cement type CEM II 42,5B meetings requirements of EN 197 [19] was used in all concrete mixtures. An Algerian natural pozzolan (NP), extracted from the Bouhamidi deposit in the Beni-Saf region (north-west of Algeria) was used in this study as a mineral admixture. This natural pozzolan composed mainly of silica and alumina (more than 60%) with a particle size less than 80 µm, resulting in a specific surface area of 300 m^2/kg. Fine recycled concrete (FRC) was obtained by grinding the crushed concrete residuals. Fig. 1 shows particle size distributions for FRC and cement. Chemical compositions for cement, mineral additive and FRC are also shown in Table 1. Both natural and recycled gravels with two size ranges (3–5 mm) and (5–15 mm) were used as coarse aggregates. Recycled concrete aggregates were obtained by crushing waste from the Laboratory of West Algeria Public Works with an average compressive strength of 40 MPa. Average specific gravity and water absorption for the used aggregate were 2.58 and 1.3% for natural gravel and 2.54 and 2.5% for recycled gravel, respectively. Fig. 2 illustrates the process of separating different sizes of the used recycled materials. Siliceous sand with a specific gravity of 2.56 and water absorption of 0.4% was used as a fine aggregate. A polycarboxylate-based high range water reducing admixture (HRWR) conforming to ASTM C494 [20] standard type F was also added to the mixtures. The solids content and specific gravity of the HRWR were 42% and 1.05. Several trial batches were produced for each mixture till the desired slump (700 ± 25 mm) flow was obtained by adjusting the dosage of the superplasticizer. The amount of HRWR ranged from (2.0% to 3.5%) of the cement weight was used. Air-entraining admixture (AEA) was added in the range of 35–65 ml/100 kg binder targeting a fresh air content of 5 ± 1%.

Eight concrete mixtures with a constant water-to-cement ratio (w/c) of 0.5 were prepared using natural aggregate, natural pozzolana, recycled aggregate and fine recycled concrete. Mixtures were divided into two groups: group A (conventional self-compacting concrete (SCC)) and group B (self-compacting sand concrete (SCSC) which is a special type of SCC characterized by using aggregates less than 5 mm). Table 2 shows the composition for each tested mixture.

Table 1
Chemical composition for the used cement, FRC and pozzolana.

Oxide (%)	Cement	FRC	Pozzolana
CaO	59.25	48.93	9.83
SiO_2	29.67	18.37	56.25
Fe_2O_3	1.80	2.13	8.57
Al_2O_3	3.74	2.69	16.98
MgO	1.15	1.93	1.81
SO_3	3.25	1.37	–
TiO_2	0.19	0.19	–
Na_2O	0.26	0.18	–
Cr_2O_3	0.12	0.12	–
Mn_3O_4	0.37	0.37	–
K_2O	0.79	0.42	–

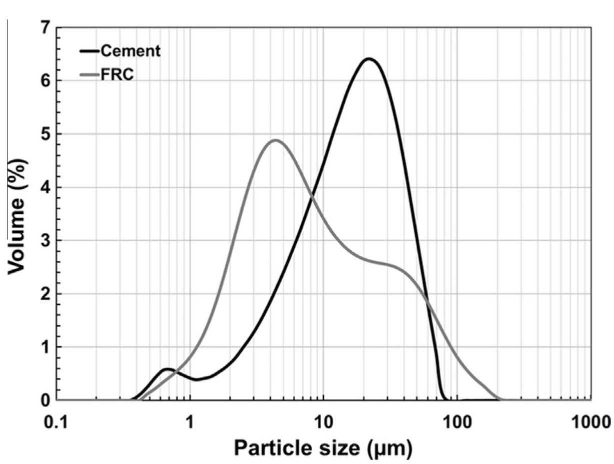

Fig. 1. Laser particle size distribution for the used cement and FRC.

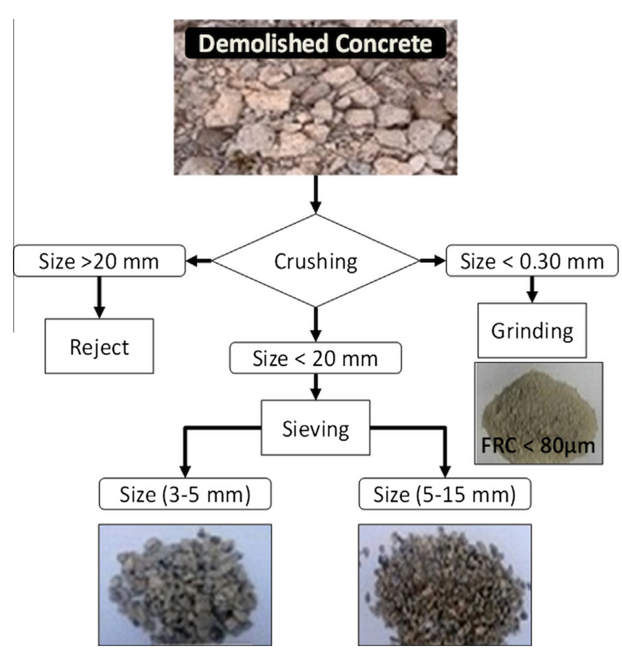

Fig. 2. Recycled materials separation from demolished concrete.