Construction and Building Materials 113 (2016) 586–595

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Secondary aggregates and seawater employment for sustainable concrete dyke blocks production: Case study

Miren Etxeberria *, Jesus Manuel Fernandez, Jussara Limeira

Department of Construction Engineering, The Polytechnic University of Catalonia, Barcelona, Spain

HIGHLIGHTS

- Concrete with 50% MRA mixed with 50% SA was the most adequate for dyke block production.
- Concrete employing high % of MRA (without SA) must be in a saturated state.
- Seawater (SW) reduced the concrete's setting time and its accessible porous.
- SW increased of compressive strength at early age and its Density and Elastic Modulus.
- Laboratory results and technical know-how can be transferred to large scale projects.

ARTICLE INFO

Article history:
Received 3 October 2015
Received in revised form 11 March 2016
Accepted 19 March 2016
Available online 24 March 2016

Keywords:
Sustainable concrete
Recycled aggregates
Steel slags
Sea water
Concrete block
Case study
Cores
Properties

ABSTRACT

The main objective of this research work was to validate the on site real scale production of dyke blocks employing coarse mixed recycled aggregates, steel slag aggregates and seawater. A laboratory experimental phase (Phase 1) was carried out prior to real scale concrete block production within Barcelona's port (Phase 2). According to the results, the concretes produced with a combined mixture of 50% coarse mixed aggregates and 50% of coarse steel aggregates achieved the most adequate properties for use in dyke block manufacturing. The concrete produced employing high percentages of coarse mixed recycled aggregates (without steel slag aggregates) could achieve adequate properties in its saturated state. The use of seawater instead of freshwater reduced the concrete's setting time as well as the porosity of the concretes produced, resulting in both the reduction of water penetration and the capillary water absorption capacity of the concretes. The use of seawater increased concrete's compressive strength at early age. It was also concluded that the results obtained in the laboratory studies and the technical know-how achieved can be transferred to large scale projects.

1. Introduction

The use of recycled aggregates (obtained from the treatment of construction and demolition waste) and steel slag industrial by-products as coarse aggregate in normal concrete mixes is primordial in reducing the environmental problems created by the dumping of these materials, thus helping to maintain sustainability of the environment by reducing the opening of new quarry developments for concrete production.

Due to its diverse content, i.e. large amounts of ceramic material and other impurities besides concrete and raw aggregates, the resulting recycled aggregate sourced from the C&DW treatment plants is commonly designated as mixed recycled aggregate (MRA) [1–3].

Concretes produced with high percentages of MRA suffer a decrease of density, and mechanical and durability properties with respect to those of conventional concrete [2,4–7].

However it is well-known that concrete produced with steel slag aggregates achieve a higher density as well as higher mechanical properties than those of conventional concrete [8–10]. This is due to both their high density and rough surface which results in an effective ITZ [11,12].

The use of steel slag aggregates together with recycled aggregates can produce better structural concrete [13]. The percentage reduction in compressive strength is greater than that of the flexural strength when recycled concrete aggregates are incorporated. However, the strength reduction in mixes containing slag aggre-

* Corresponding author.
E-mail address: miren.etxeberria@upc.edu (M. Etxeberria).

http://dx.doi.org/10.1016/j.conbuildmat.2016.03.097
0950-0618/

gates is much less resulting in the production of a better structural concrete.

Additionally, the use of freshwater in concrete production causes a serious impact on those areas in which freshwater is a scarce resource. The substitution of freshwater for seawater could play a key role in the obtaining of more sustainable environments, especially with regard to those construction projects near to coastal areas, where there would be a notable reduction in transportation costs.

Seawater is, as other research work has shown, suitable for use in plain un-reinforced concrete production [14]. Several studies agree that concrete mixed with seawater increases early-age strength and reduces setting time in comparison with concretes mixed with freshwater [15–18]. The chloride-ion content produces an acceleration of the cement setting and early hardening of the concrete. According to Shi et al. [19] at a given age, the content of cement hydrates were found to be higher in seawater mixed concretes due to the hydration acceleration via $CaCl_2$. However, long-term studies revealed contradictory conclusions over the influence that seawater had on these higher percentages.

The major preoccupation concerning seawater use in concrete mixing is over the negative influences on durability properties, as the resulting concrete could suffer from a chemical attack, or reaction [20] caused by dissolving chloride, sulphate, sodium and magnesium in seawater. As part of a complex series of chemical reactions and physical changes in the concrete microstructure, magnesium and sulphates affect the durability of concrete by producing expansions whilst chlorides affects reinforcement by accelerating corrosion [21].

The main objective of this research work was to determine the properties of on site real scale dyke blocks produced using coarse mixed recycled aggregates, steel slag aggregates and seawater. Two experimental phases were carried out: Phase 1 was developed at laboratory level and Phase 2 was developed within the Port of Barcelona where concrete blocks were produced on site. The properties of the concrete dyke blocks were analysed via means of concrete specimens as well as extracted cores from the dyke blocks themselves after being exposed to a sea environment for 1 year.

Four different types of concretes were produced in the laboratory and in the Port of Barcelona, using separately freshwater or seawater. The mixes are referred to as: CC (conventional concrete), CRA-50 (concrete produced with 50% of natural coarse aggregate and 50% of coarse recycled aggregate), CRS (concrete produced with 50% of coarse recycled aggregate and 50% of steel slag gravel) and CRA-100 (concrete produced with 100% coarse recycled aggregate). The fine aggregate employed in all concretes was 100% natural sand. The results obtained by concretes produced with recycled and slag aggregates using seawater were evaluated with respect to those obtained from the conventional concrete. The results obtained from the laboratory test samples were compared with the results of the core samples extracted from the real scale manufacture of the concrete blocks.

2. Experimental phase

2.1. Materials

2.1.1. Cement

Type I Portland cement, CEM I 42.5 N/SR, sulphate resistant cement was used in all concretes mixtures. Table 1 shows the chemical compositions of the cement.

2.1.2. Aggregates

Three types of aggregates were used; natural limestone aggregate divided into three fractions (0/5 mm, 5/10 mm and 10/20 mm), two fractions of coarse steel slag aggregates (SA, 5/10 mm and 10/20 mm) and one fraction of coarse mixed recycled aggregate (RA, 5/20 mm). Particle size distributions of all aggregates were determined as described in the UNE EN 933-1:2012 regulation (see Fig. 1). The results of the density and water absorption of the aggregates were determined according to the UNE EN 1097-6:2001 regulation. The SA aggregates density was higher than those of the natural or recycled aggregate (see Table 2). All fractions of aggregates satisfy the requirements specified by the Spanish Standard of Structural Concrete EHE-08.

The composition of the recycled aggregate was carried out according to the UNE EN 933-11:2009 regulation. The composition is described as: 46.96% concrete; 21.18% bricks-tiles; 26.25% Natural aggregates; 3.36% Asphalt; 1,77% gypsum; 0.48% plastic and glass. Due to the high percentage of concrete and bricks composition, the water absorption capacity of mixed recycled aggregates was much higher than that of natural or slag aggregates. The soluble SO_3 was 1.47%. In addition, the gypsum impurity was also high, however, the use of SR cement minimizes the sulphate attack that may be produced by gypsum within the aggregate, a fact which has been demonstrated in a previous work [22].

2.1.3. Water

Two types of water were used for concrete production, water from the city's mains supply network (W-freshwater), and seawater (SW) extracted directly from the Port of Barcelona. Table 3 shows the chemical properties of both the waters employed.

2.1.4. Admixture

An admixture with a polycarboxylates base was employed in all concrete productions in order to obtain the same slump.

2.2. Concrete manufacture

A laboratory experimental phase (Phase1) was carried out prior to real scale concrete block production within the port. The onsite production of blocks was nominated as phase 2 of the experimental work. In both phases recycled aggregates were used together with natural aggregates and steel slag for concrete production. The results obtained from the recycled concretes were compared to those obtained from the conventional concrete.

2.2.1. Laboratory experimental phase, Phase 1

Four types of concretes were produced using different kinds of coarse aggregates; CC (concrete produced employing 100% natural aggregates), CRS (concrete produced using 100% natural sand, 50% recycled aggregate, 50% steel slag gravel); CRA-50 (concrete produced using 100% natural sand, 50% natural coarse aggregate and 50% recycled aggregate); CRA-100 (concrete produced with 100% natural sand and 100% recycled aggregate). Natural limestone sand was used in all concrete mixes. Table 4 shows mix proportions of all produced concretes. Freshwater (W) and seawater (SW) were used in each mixture.

The total water-cement (w/c) ratio of 0.5 was set up for the conventional concrete. Following Neville's [20] definition of effective water in the mix (amount of water which occupies space outside the aggregate particles), the effective water-cement ratio was of 0.45 and was kept constant in all mixtures. The reason for keeping the effective water-cement ratio constant in all concretes production was in order to achieve the same conditions with respect to the hydration of the cement paste caused by the high absorption of RA (mixed recycled aggregate). RA was used with high moisture content, nearly saturated surface-dry conditions (80–90% of water absorption capacity), in order to avoid bleeding or water surface layers influencing the mechanical properties of the concrete [23]. RA moisture content was measured prior to its use and the dosages were adjusted according to the remaining effective water absorption capacity (the effective water absorption of the aggregates was determined by submerging them in water for 20 min) of the RA, steel slag and natural aggregates.

After 24 h of casting, the concretes specimens were demolded and stored in the humidity room at 22 °C and 90% of humidity, until they were tested at 7 days, 28 days and 1 year.

Table 1
Chemical composition of cement.

Composition	Fe_2O_3	MnO	TiO_2	CaO	K_2O	P_2O_5	SiO_2	Al_2O_3	MgO	Na_2O
CEM I 42.5 SR (%)	4.58	0.02	0.20	63.88	0.78	0.10	20.71	4.22	1.68	0.17