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Properties of high performance concrete made with recycled fine ceramic and coarse mixed aggregates

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HIGHLIGHTS

- High performance concrete (HPC) were produced with natural and recycled aggregates.
- Fine ceramic (FCA) and coarse mixed (CMA) recycled aggregates were employed.
- Physical, mechanical and durability properties of HPC were investigated.
- Concretes made with FCA improve the properties of conventional HPC.
- Concrete made with 50% of CMA achieved adequate durability properties.

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ABSTRACT

There are various means of obtaining waste for the production of recycled aggregates. In this study the waste material has been obtained from building demolition and also from the ceramic industry (known for the production of large amounts of rejected ceramic wastes). High performance concretes (HPC) was produced using fine ceramic aggregates (FCA) in substitution of 15% and 30% of natural sand, and using 20%, 50% and 100% of coarse mixed aggregates (CMA) on substitution of natural coarse aggregates. The physical, mechanical and durability properties of the recycled aggregate concretes were determined and compared to those of the results of conventional concrete. The results showed that concrete produced with up to 30% of FCA achieved similar or improved mechanical and durability properties to those of conventional concrete. Concrete made with up to 20% of CMA achieved similar compressive strength to High Performance conventional Concrete of 100 MPa. At 180 days of curing the concretes produced with up to 50% CMA obtained low corrosion risk.

1. Introduction

Southern European countries have maintained a long tradition of using ceramic materials, such as tiles, bricks and blocks, in the construction industry. Ceramic waste which is produced by the ceramic manufactures during production can also be found in the demolition of existing buildings [1]. Ceramic waste represent an important amount of the construction and demolition waste that reaches recycling and treatment plants. Unfortunately this waste is usually combined with waste from other inorganic materials that have a negative effect on their properties results in mixed recycled aggregates with lower technical properties. It is evident that selective demolition will represent a more appropriate recycling method of achieving a more efficient and sustainable reuse of ceramic materials [2].

High performance concrete (HPC) is designed to have better mechanical properties and a higher resistance to aggressive chemicals than traditional concrete [3]. Some wastes have been successfully used in the manufacture of conventional concrete and even in HPC [4–6]. The use of recycled ceramic aggregates in high performance concrete have been examined in relatively few studies [7,8] and experimental data is limited. De Brito et al. [1] stated that the disparity in water absorption between ceramic and natural aggregates points towards the main difficulty of the use of ceramic aggregates in the production of concrete that does not lose in strength, workability or durability. However, pre-saturation is a way of minimising these consequences [1] or even improving mechanical properties when internal stress is required such as in HPC [7]. The use of ceramic waste material as fine admixtures has positive values as an additional binder that could

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be very useful in HPC. If ceramic minerals are mixed with calcium hydroxide and water, pozzolanic reactions can form new compounds thus increasing the strength and durability properties of the concrete [8].

The suitability of ceramic recycled aggregates for use in different applications with a low or moderate degree of requirement (lower compressive strength than that defining HPC, 62 MPa according to ACI [9]), has been extensively tested and proved by many authors [10–19]. In most cases the ceramic materials were used as aggregates, however their use as cementitious materials has also been studied [8,18]. According to some research works the recycled concrete could achieve the properties of conventional concrete when the replacement of natural aggregates by ceramic aggregates are: up to 50% for fine aggregate [16,19] and up to 40% for coarse aggregate [7,12]. Certain authors [7,8] suggested that the use of recycled ceramic materials could enhance HPC, offering an additional value to the ceramic waste.

Suzuki et al. [7] used porous coarse ceramic waste aggregates for the internal curing of high performance concrete. Their research exposed that there was a high effectiveness of the ceramic aggregates in reduction and even complete elimination of autogenous shrinkage. The incorporation of 40% of coarse mixed aggregate led to a non-shrinking HPC that was accompanied by a significant increase of compressive strength.

Torkittikul and Chaipanich [16] and Khatib [19] studied the mechanical properties of concrete made with fine ceramic aggregates (FCA). Torkittikul and Chaipanich [16] established 50% of FCA as the optimum replacement ratio in order to maintain similar workability and compressive strength to those of conventional concrete. Khatib [19] extended the statement to long-term compressive strength, recommending the use of 50% of FCA in the substitution of natural sand for concrete production. However, Khatib [19] affirmed that even at 100% of fine aggregate replacement the reduction in strength was only 10% and indicated that this could be due to cementing action in the presence of FCA. Pacheco and Jalali [13] found that concrete mixtures employing ceramic aggregates achieved durable concrete.

Heidari and Tavakoli [19] studied the mechanical properties of ceramic powder as an addition in concrete production. Their results showed that the replacing 20% of cement for ceramic powder did not have a significantly negative effect on the compressive strength of concrete. Similarly, the experimental results of Vejmelkova et al. [8] showed that 20% of ceramic powder substitution for cement was satisfactory for achieving adequate mechanical properties, and 40% was adequate for chemical resistance.

In this research work high performance recycled aggregate concretes were produced and their properties were compared to the properties of conventional concrete which was defined by a precast and prestressed high performance concrete railway sleeper manufacturer. The production of high performance concrete was carried out using a coarse mixed recycled aggregate (CMA) obtained from a Spanish Construction and demolition treatment plant. A substitution ratio of 20%, 50% and 100% of natural coarse aggregates for coarse mixed recycled aggregates was employed. Fine ceramic aggregate (FCA) obtained from crushing rejected bricks from the ceramic industry, in substitution of 15% and 30% of natural fine aggregate, was also used in order to verify its applicability in HPC. High performance concretes were produced in the laboratory and the physical (density, absorption, volume of permeable pore space and ultrasonic pulse velocity), mechanical (compressive, splitting tensile, flexural strengths and modulus of elasticity) and durability (capillary water absorption, electrical resistivity and chloride ion penetrability) properties were assessed. The obtained results were compared to those of conventional concrete (CC) and the minimum requirements specified by Spanish railway sleeper technical specification [20].

2. Experimental details

2.1. Materials

2.1.1. Cement and additive

ASTM Type I Portland cement (CEM I 52.5R) was used in all concrete mixtures. The high strength and rapid hardening cement presented low alkali content and a specific surface of 4947.8 cm^2/g. Rapid hardened cement was used in order to achieve concretes with 1-day compressive strength higher than 46 MPa meeting the requirements defined for railway sleeper concretes [20]. The chemical properties of the cement are given in Table 1.

A high performance admixture (superplasticizer type) was used for concrete production as a constant percentage of the cement weight (1.5%) following the manufacturer's recommendations. The super plasticizer was a high range water reducer based on polycarboxylate ether (PCE) with a specific gravity of 1.08. It is indicated for the production of concrete that require high early strength and high workability.

2.1.2. Aggregates

Two types of coarse natural aggregates (NA) and two types of river sands were used for the production of the conventional concrete. The mixture proportioning followed that used in HPC for sleeper manufacture.

The two types of coarse natural aggregates (NA) were, crushed dolomite and river gravel. The use of river sand improved the workability and toughness of the concrete. Moreover, one type of coarse mixed recycled aggregate (CMA) was used as a replacement for the natural coarse aggregates. The CMA containing 67% ceramic waste was sourced from a treatment plant located in Catalonia (Spain). The composition of the CMA is given in Table 2 following the specification EN-933-11. CMA composition did not fulfill the requirements of the RILEM [21] and DIN standards [22] to be classified as ceramic aggregate (>90% or >80% of ceramic content, respectively). The mixed aggregate category was adopted to define the CMA composition in spite of showing a high proportion of ceramic components.

The nominal sizes of the coarse natural aggregate and the CMA were 10 and 12.5 mm, respectively, and their particle size distributions are shown in Fig. 1. The NA and CMA were found to have a similar size grading. Therefore no grading adjustments were carried out before NA replacement. Physical and mechanical properties of the coarse aggregate were determined according to EN specifications. As Table 3 shows, the natural aggregate had a higher density and lower absorption capacity than CMA. CMA showed a water absorption capacity of 16.45% due to the 67% high proportion of ceramic material (see Table 2). CMA had much lower percentages of natural and concrete aggregates with 9.8% and 22.2% respectively. The Los Angeles Index of all the aggregates was lower than 30%, which indicated

Table 1
Chemical composition of cement.

Cement composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Cl^-	SO_3	LOI
(%)	21.75	3.38	4.55	64.65	1.63	0.64	0.01	2.66	0.91

Table 2
Composition of recycled aggregates following UNE-EN 933-11:2009.

Composition (%)	Concrete products	Unbound aggregates	Masonry products	Bituminous products	Glass products	Others (wood, plastics and gypsum)
CMA	22.2	9.8	67.3	0	0.1	0.7
FCA	0	0	100	0	0	0