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Influence of recycled aggregates on properties of self-consolidating concretes

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HIGHLIGHTS

- It is feasible to incorporate crushed concrete powder in order to achieve maximum use of the recycled concrete.
- The influence of admixtures must be studied not only in fresh mixtures but also in hardened concrete.
- Petrographic studies revealed that the incorporation of crushed concrete powder makes the mortar matrix denser.

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ABSTRACT

Recycled aggregates are made from crushed waste concretes and can be used as a replacement of natural aggregates in concrete production. Despite having lower density and higher absorption than natural aggregates, they can be used to manufacture conventional concretes with good performance if they are added in the proper amounts. To make self-consolidating concretes, the same aggregates used to manufacture conventional concretes can be used, but in order to increase segregation resistance and keep mix cohesion, a large amount of fine aggregates and a suitable admixture are required. The main goal of this work is to study the influence of recycled aggregates on self-consolidating concrete. Concretes were mixed with 50% of the coarse aggregate replaced by recycled aggregates (Patagonia gravel) and with 20% of the fine aggregate (natural sand) replaced by crushed concrete powders. Fresh concrete properties were tested, and physical and mechanical properties were determined in the hardened state. The petrographic composition of the concrete was examined to assess the interfacial transition zone and the contribution of the powders to the mortar microtexture. The results vary depending on the type of admixture and aggregate. However, it is shown that the inclusion of these crushed aggregates to make good self-consolidating concrete is feasible.

1. Introduction

Self-consolidating concrete (SCC) is a special concrete that flows under its own weight, taking the formwork shape and filling all the empty spaces. The same aggregates are used to make SCC and conventional concretes (CC). However, the fine particles and type of admixture govern self-compactness properties in SCC fresh mixtures. To increase segregation resistance and keep cohesion, a large amount of fine aggregates is required in order to generate a higher water demand in the concrete due to the increase in the aggregate specific surface. In SCC, this effect is compensated for by using the latest generation of water-reducing admixtures.

Recycled aggregates are obtained by crushing waste concrete and then, the coarse fraction of crushed aggregates can be used to replace natural coarse aggregates in the concrete production process. The advantages and disadvantages of using recycled aggregates have been extensively studied [1–3]. It was demonstrated that the mechanical behavior does not change significantly in concretes with a 75% replacement of their natural aggregates by recycled ones [4]. In spite of presenting lower density and higher absorption than natural aggregates, it is feasible to make concretes with good performance by mixing the proper amount of each concrete component [5]. The use of recycled aggregates has a significant environmental impact since fewer natural resources are exploited and construction industry wastes may be used.

In the crushing process, there is a remaining fine fraction that can be incorporated during the concrete elaboration to replace part of the natural fine aggregates [6]. Several authors have stated that

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up to a 30% replacement does not substantially modify the mechanical properties or the durability of concrete [7,8]. This can be attributed to a lower effective water/cement ratio of the recycled concrete compared to the conventional one and to the angular shape and rough surface texture of the recycled aggregate particles forming a better paste–aggregate interfacial transition zone than in the natural aggregate [8]. One of the most significant differences between CC and concrete made with recycled aggregates is the presence of two different types of interfaces: one transition zone between the old mortar and the natural aggregate and the other between the new mortar and the natural aggregate. The failure mechanism of concretes containing recycled aggregates under mechanical loads depends on the quality of the two interface zones, the new and the old one [9].

Mineral additives such as calcareous filler, fly ash or granulated blast furnace slags modify the interfacial transition zone structure and/or reduce its thickness. The analysis of SEM images of SCC microstructure revealed that the calcareous filler decreases the interfacial transition zone porosity, enhances the adherence between the aggregate and the matrix, and reduces internal bleeding [10]. Even the use of treated sediments incorporated in SCC as a replacement of limestone filler and aggregates results in a dense solid matrix and a homogeneous material. The fine particles enhance the hydration process and the nucleation of hydrated products [11].

In Europe, India and other parts of the world filler materials such as fly ash and silica fume are available at little or no cost. However, in the regions where these materials are not available, the cost of SCC increases, thus making it uneconomical. Therefore, all attempts to develop SCC with alternative locally available materials will always be welcome in order to make SCC more economical [12].

In this work, the possibility of incorporating the remaining fine fraction from the crushing process to complete the SCC fine content required was examined. The utilization of all the fractions of recycled concrete allows the maximum use of crushed concrete, i.e., the coarse and fine fractions, and the crushed concrete powder.

Therefore, self-consolidating concretes were mixed with 50% of the coarse aggregate replaced by recycled aggregates (Patagonia gravel) and with 20% of the fine aggregate (natural sand) replaced by crushed concrete powders. Two experimental high-range water-reducing admixtures were used; they are both compatible with the cement used and allow making concretes denominated as "self-consolidating." The self-compactability of fresh concrete was evaluated, and the physical and mechanical properties were studied in the hardened state to evaluate the influence of recycled aggregates on self-consolidating concrete. Also, the petrographic composition of the concrete was studied to assess the interfacial transition zone and the contribution of the powders to the mortar microtexture.

2. Materials and methods

2.1. Materials and mixtures

The following materials were used to make the different mixtures:

- Normal Portland cement (CPN 40) (Type I, ASTM Standards) supplied by a manufacturer located in Buenos Aires area (Argentina).
- Water taken from the local water supply network at Bahía Blanca city (province of Buenos Aires, Argentina).
- Two types of aggregates:
  a) Natural: composed of sand with a fineness modulus of 2.42 and gravel with a maximum nominal size of 12.5 mm. Both meet grading specifications set by local IRAM standard 1627 [13] and come from a quarry located in the south of the province of Buenos Aires.
  b) Recycled: made from crushing concrete with gravel as coarse aggregate from construction works in the Bahía Blanca area. The material to recycle was ground using a jaw crusher. During the grinding process, 80% of the coarse fraction was obtained. The remaining 20% of the fine fraction has 5% of crushed concrete powder passing through sieve No. 100. The coarse fraction was separated from the fine one in order to obtain a recycled coarse aggregate of maximum nominal size similar to that of the boulder (12.5 mm) and a recycled fine aggregate with a fineness modulus of 3.77. Both fractions were sprinkled with water before adding to concrete.

Table 1
Size distribution of natural sand and recycled fine aggregate.

Sieve	Cumulative retained (%)	
	Natural sand (NS)	Recycled fine aggregate
N° 4 (4.75 mm)	–	–
N° 8 (2.36 mm)	20	45
N° 16 (1.18 mm)	32	69
N° 30 (600 μm)	41	80
N° 50 (300 μm)	55	88
N° 100 (150 μm)	94	95

Table 2
Size distribution of gravel and recycled coarse aggregate.

Sieve	Cumulative retained (%)	
	Gravel (G)	Recycled coarse aggregate
1″ (25 mm)	–	–
3/4″ (19 mm)	2	4
1/2″ (12.5 mm)	28	38
3/8″ (9.5 mm)	66	74
N° 4 (4.75 mm)	100	100

To complete the SCC fine content required, calcareous filler and crushed concrete powder, passing through a 149 μm mesh size (sieve No. 100 – ASTM Standards), obtained as remaining fraction during the concrete crushing process, were used.

The size distributions of natural and recycled aggregates are shown in Tables 1 and 2.

These materials were used to make six different concretes with a water/cement ratio of 0.50 (water/cementitious materials ratio of 0.40). Two "experimental" high-range water-reducing admixtures (water-based modified polycarboxylate) called "S" and "H", were used to make two different groups of 3 samples each. In both groups, a reference concrete made with rounded gravel and natural sand (SP and HP) was used. Then, a concrete with a replacement of 50% by volume of the natural coarse aggregate by a recycled one (SRG and HRG) was prepared. Finally, 20% of the natural fine aggregate was replaced by recycled fine aggregate (SRGF and HRGF). The designations and characteristics of each sample are shown in Table 3 and the mixture proportions in Table 4.

From Table 3, it can be noticed that to achieve the same consistency, it was necessary to increase the amount of both admixtures (% by cement weight) for the samples that contained recycled coarse aggregate and crushed sand.

Due to the amount and types of fine aggregates and admixtures, SCC always required a greater kneading time than CC to be able to achieve proper mixture homogeneity.

2.2. Experimental

2.2.1. Admixture/cement compatibility

To optimize the admixture amount to be used in pastes, the saturation dosage for the water/cement/admixture system was determined by the Marsh cone test. The use of an admixture amount beyond the saturation point does not modify paste fluidity and could have negative effects (delaying setting times, segregation) besides increasing concrete costs [14]. This test also allows evaluating other effects of the superplasticizers such as the loss of fluidity in cement pastes with time.

In the present study, a Marsh cone with a nozzle of 8 mm diameter was used; 800 ml of paste was poured into the cone and the time taken by 200 ml to flow was determined. The flow time was measured at 5 and 60 min after the pastes were prepared. The longer the flow time is, the lower the fluidity results. The saturation point can be determined applying this procedure with different amounts of admixtures. This point indicates the optimum admixture dosage beyond which the flow time does not decrease appreciably [15]. A water/cement ratio of 0.45 was used, and the superplasticizer dosage varied from 0.1% to 2% by cement weight.

To establish the water content contributed by admixtures, in order to deduct it from the mixing water amount, the solid content [16] of each of them was determined. For admixture "H" it was 49% and for admixture "S", 41%. These values were taken into account when mixing the pastes for the Marsh cone test.