Fresh concrete properties

The use of different types of natural coarse aggregates in SCC design

The shape and texture of coarse aggregate affect the properties of fresh and hardened concrete. However, there is limited information about the effects of aggregate characteristics on self-compactability, which can be relevant in countries like Argentina, where a large variety of aggregates is available even in the same region. This paper analyzes the effect of shape and texture of coarse aggregate on self-compacting concrete (SCC) properties. Four different types of coarse aggregate were selected: granitic crushed stone, quartzitic crushed stone, basaltic crushed stone and siliceous river gravel. The granitic and basaltic crushed stone presents irregular shape, rough texture and low absorption. The quartzitic crushed stone also has irregular shape and rough texture, but it has high water absorption. Finally, the natural siliceous river gravel is composed by strong particles with smooth surface and low porosity. Slump-flow, V-funnel and J-Ring tests were carried out in order to evaluate SCC properties. The influence of the mixing volume was also studied. The homogeneity of the coarse aggregate distribution was evaluated along vertical cuts on 1 m in height tubes and along a U-tube with 1.80 m height, measuring the ultrasonic pulse velocity and the unit weight in different sections. In addition, the compressive strength and modulus of elasticity were determined. From the results, was concluded that, as expected, the shape and texture of coarse aggregate modify the flowability, but also the mixing energy can strongly affect the viscosity of SCC.

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Self-compacting concrete (SCC) is a high performance concrete which presents both economic and technological benefits. SCC reduces labor and equipment with no need form vibration, reduces noise on the job site, permits more flexibility form detailing reinforced bars and presents a high quality surface. Filling ability, passing ability and resistance to segregation have been accepted as the main requirements for self-compactability [1, 2]. Typical values of engineering tests such as slump-flow or V-funnel time have been recommended for different SCC classes [3].

The SCC design based on previous mortar tests to achieve the adequate properties of fluidity and viscosity, optimizing powder combination and verifying the superplasticizer compatibility, allows the selection of the necessary volume of paste considering the characteristics and content of the fine particles of the sand [4 - 6].

Mc Bride J. and Mukai D. J. analyzed the effect of coarse aggregate in filling and passing capability [7]. Concretes were made employing for all experiences a crushed stone with a very angular shape, three aggregate gradations and two maximum sizes (13 and 19 mm). Slump-flow, horizontal flow box and a specially designed passing ability test were performed while stereology was used to determine the aggregate spacing. The results showed that both mixtures with lowest aggregate content and with lowest maximum size, achieved the highest slump-flow. Horizontal flow box tests showed that concrete with the lowest aggregate content had the highest filling percentage. On the other side, mixtures with similar coarse aggregate content, with more sand and less cement, showed filling ability decreases.

Saak et. al., have proposed a methodology to design self-compacting concrete considering the yield stress and viscosity of cement paste, defining a self-flow zone, where aggregate segregation is avoided [8]. Bui et. al., have expanded this model including the effect of aggregate interaction [4]. In this new model, the fine-coarse aggregate ratio, the aggregate shape and the particle size distribution are considered by means of the void content and the average diameter of aggregate particles. The study determined a minimum paste flow and a minimum apparent viscosity and an optimum flow-viscosity ratio to get enough deformability and filling capability avoiding segregation. This is related to the average aggregate diameter of particles (Dav) and the aggregate average spacing (Dss). However, the surface characteristics of the aggregates were not considered in this model.

As in normal vibrated concrete, the shape and texture of coarse aggregate modify the properties of fresh and hardened SCC. However, there is limited information comparing the effects of coarse aggregate characteristics on self-compactability, which can be relevant in countries like Argentina, where a large variety of aggregates is available even in the same region. This paper analyzes the influence of coarse aggregate type in SCC properties.

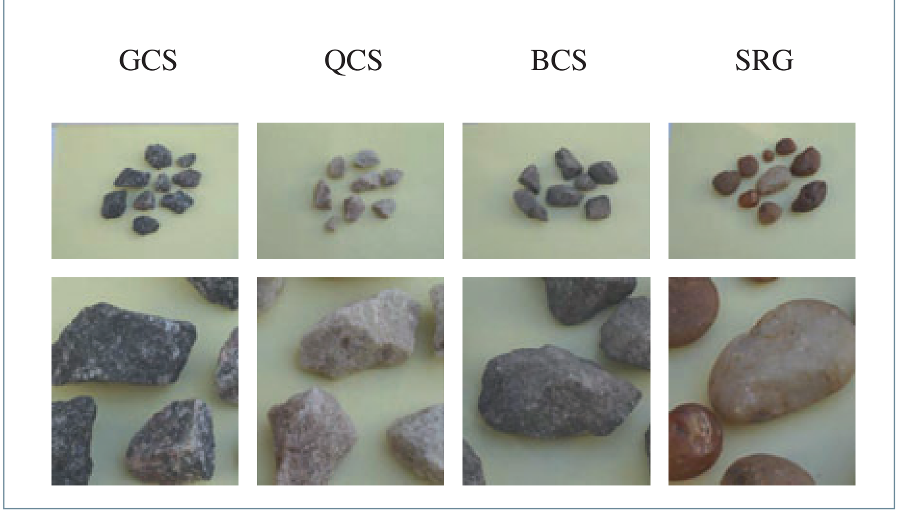


Fig. 1: Coarse aggregates

Experimental research

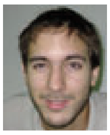
Materials

Four types of coarse aggregates with similar particle size distribution (maximum size 19 mm) were selected: granitic crushed stone (GCS), quartzitic crushed stone (QCS), basaltic crushed stone (BCS) and siliceous river gravel (SRG). The granitic and the basaltic crushed stone present irregular shape, rough texture and low absorption. The quartzitic crushed stone also has irregular shape and a rough texture (with coarser grains), but it has high water absorption. Finally, the siliceous river gravel is composed by strong particles with smooth surface and low porosity. Fig. 1 shows these aggregates. Properties of the aggregates are detailed in Table 1. It can be seen that GCS, BCS and QCS have similar void content, and that it is higher than in the SRG. The BCS the highest density.

All concretes were prepared with a portland cement (which incorporates 19 % of calcareous filler, Blaine surface area 337 m^2/kg, density 3.11), and additional calcareous filler (density 2.8) as powder materials. A polycarboxilate superplasticizer (density 1.09, solid content 18 %) was used. A natural siliceous sand with a modulus of fineness of 2.38, 0.4 % particles smaller than 0.075 mm and voids content 30 %, was used.

Series

Four concretes were prepared with the different coarse aggregates using the same mixture proportions. In all cases the same volume of coarse aggregate (31 % of total concrete volume) was used, changing the coarse aggregate weight. The coarse



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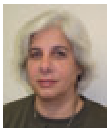

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aggregate was used in a saturated dry surface condition in order to avoid significant water absorption. Concretes were identified in accordance with the used coarse aggregate as C-G, C-Q, C-B and C-S.

Batches of 40 liters were made. Slump-flow, V-funnel and J-ring were measured as well as the air content in the fresh state. In order to measure compressive strength, modulus of elasticity and splitting-tensile strength, 100 x 200 mm cylinders were cast. They were cured in a moist room until the age of testing. The mixture proportions and the

Tab. 1: Coarse aggregate properties

Coarse aggregate	GCS	QCS	BCS	SRG
Density	2.76	2.49	2.93	2.58
Absorption (%)	0.4	2.1	1.0	0.2
Fineness modulus	6.53	6.73	6.46	6.59
Unit weight (kg/m^3)	1440	1300	1520	1600
Unit weight-compacted (kg/m^3)	1580	1430	1720	1660
Voids content (%)	48	49	48	38
Voids content-compacted (%)	43	42	41	36
Shape	Irregular	Irregular	Irregular	Round
Texture	Rough	Rough	Rough	Smooth
Elongation index (%)	27	17	24	23
Flakiness index (%)	19	24	22	2

Tab. 2: Mixture proportions and properties of fresh concrete

Concrete	C-G	C-Q	C-B	C-S	C*-G	C*-B	C#-S
Cement (kg/m³)	332						317
Filler (kg/m³)	299						285
Water (kg/m³)	166						158
Sand (kg/m³)	745						710
Coarse aggregate (kg/m³)	856	772	905	800	856	905	875
Coarse aggregate volume (%)	31						34
Superplasticizer (kg/m³)	4,6				5,5		4,4
Properties of fresh concrete (batches of 40 l)							
t_{50} (s)	3,1	3,6	2,2	2,3	2,3	1,7	1,6
Spread diameter, D_f (mm)	605	655	610	685	710	750	700
V-funnel flow time Tv (s)	11,0	14,2	8,6	6,8	7,1	4,4	6,1
J-Ring spread diameter, D_j (mm)	525	650	600	650	680	660	670
D_f - D_j (mm)	80	5	10	35	30	10	30
Air content (%)	–	4,5	2,5	5,0	5,7	2,5	2,0

Tab. 3: Estimated aggregate spacing for the used combinations of fine and coarse aggregates

	GCS	QCS	BCS	SRG	SRG#
Paste volume (liters)	384	384	384	384	366
Coarse / fine aggregate ratio (in volume)	1,08	1,08	1,08	1,08	1,24
Modulus of fineness	4,60	4,59	4,62	4,56	4,70
Average aggregate diameter, D_{av} (mm)	6,4	6,7	5,9	6,5	6,8
Unit weight-compacted (kg/m³)	2095	1980	2210	2075	2070
Void content-compacted (%)	22,1	22,5	20,5	20,2	20,4
Aggregate average spacing D_{ss} (mm)	0,517	0,530	0,527	0,584	0,540

properties of fresh concrete are given in Table 2. As can be observed in Table 2, both C-G and C-B achieved a spread diameter Df lower than the other SCC. To verify if it is possible to achieve a higher Df, only by the increase of the superplasticizer dosage and without segregation, two other concretes C*-G and C*-B were prepared.

The shape and texture of coarse aggregate lead to differences in the spacing between the aggregate particles, even using the same particle size distribution. A good example appears when SRG is considered. Table 3 summarizes the main properties of the combination of coarse and fine aggregates, including the average aggregate diameter of particles (Dav) and the aggregate average spacing (Dss) [4]. It can be seen that all concretes have the same Dss with the exception of C-S. Increasing the volume of SRG from 31 to 34 % a Dss value of 0.54 was obtained. Then, concrete C-S# was prepared.

Finally, with the aim of analyzing the effect of the mixing, some concretes were repeated changing the mixer and the volume of the batch (100 l).

Discussion

Effect of the coarse aggregate properties on selfcompactability

Comparing SCC with the same mixture proportions and superplasticizer dosage (C-G, C-Q, C-B, C-S), the results of slump-flow (spread diameter Df and T_{50} time), V-funnel flow time (TV), J-Ring (spread diameter Dj) (see Table 2), show the effect of the type of coarse aggregate on selfcompactability. The highest slump-flow was obtained using the river gravel, due to its rounded and smooth particles. The lowest values of Df correspond to C-B and C-G, where the slump-flow were 610 and 605 mm respectively, BCS and GCS are composed by particles of higher sharpness and density, than the QCS.

The V-funnel times varied from 7 to 14 s for these mixtures. The highest Tv was obtained with the QCS and the lowest with the SRG. C-Q had also the highest t50 value. From these results it can be inferred that concrete C-Q has a higher viscosity than the others. Note that QCS is the coarse aggregate with the lowest density of particles.

The J-Ring test determines the passing ability of SCC. The difference between the slump-flow and J-Ring spread diameters can be used as an indication of the passing ability. A difference smaller than 25 mm indicates good passing ability while a difference greater than 50 mm means noticeable to extreme blocking. From the results, it can be noted that all concretes presented an acceptable performance, except C-G.

With the aim to compare the effect of coarse aggregate in SCC with a similar range of slump flow diameter (Df = 700 ± 50 mm) C*-G and C*-B were prepared increasing the dosage of superplasticizer by 0.9 kg/m³. Comparing the Tv and t_{50} values (Table 2) an important reduction in the viscosity of both concretes can be observed. However it must be mentioned that C*-B showed some signs of segregation. This risk of segregation can be associated with the presence of heavier particles immersed in a less viscous matrix. It is important to note that it was not necessary to correct the mortar previously selected. The water/cement ratio, the relative volume of paste and the superplasticizer dosage was kept.

In order to evaluate the degree of suspension of coarse aggregate particles in the matrix the average aggregate spacing (Dss) was calculated. Although, as mentioned, the average aggregate diameter was similar for all used aggregates, the Dss was higher in C-S. Increasing the coarse aggregate content from 31 % (C-S) to 34 % (C*-S) only minor changes in fresh concrete properties were found (a very light reduction in t_{50} and Tv and an increase in Df smaller than the own variability of the method).

Regarding the effect of the change in volume and mixing energy, Table 4 presents the properties of concretes C*-G, C-Q, C-S corresponding to batches of 40 and 100 liters. As can be seen, the fluidity of concrete was not affected but there were significant changes in the viscosity. When higher mixing energy was used both the Tv and the t50 were similar in all SCC mixes, reducing

Tab. 4: Effect of mixing

Concrete	Batches of	t_{50} (s)	D_f (mm)	Tv (s)	Air content (%)
C*-G	40 l	2,3	710	7,1	5,7
	100 l	1,4	700	4,8	6,5
C-Q	40 l	3,6	655	14,0	4,5
	100 l	1,5	680	5,2	6,0
C-S	40 l	2,3	685	7,0	5,0
	100 l	1,5	680	4,6	4,5

Tab. 5: Mechanical properties

Concrete		C-Q	C-S	C*-G	C*-B	C#-S
f'cm (MPa)		42,7	37,0	41,6	-	-
E (GPa)	7 (days)	25,4	32,6	30,1	-	-
f_t (MPa)		3,6	3,1	3,7	-	-
f'cm (MPa)		48,2[a]	42,4[a]	47,5[a]	55,1	46,3
E (GPa)	28 (days)	27,1[a]	34,9[a]	32,5[a]	36,8	36,8
f_t (MPa)		-	-	-	4,6	3,3

[a] Batches of 100 l

the influence of the type of aggregate. According to ASTM C1611 the Visual Stability Index Values (VSI) for all concretes were equal to 0, which corresponds to a highly stable concrete with no evidence of segregation or bleeding. The effect of mixing shall be considered as main aspect in the production of SCC, and it must be taken in consideration during the mixing design.

Properties of the hardened concrete

Table 5 shows the mechanical properties of the concretes. Differences in compressive strength, modulus of elasticity and tensile strength are mainly related to the changes in the interface bond strength and the stiffness of the coarse aggregates. In this sense the observed effects of coarse aggregate on the properties of hardened SCC agrees with the results obtained on previous studies on normal and high strength concrete [9]. Fig. 2 shows the fractured surfaces obtained after the splitting tests. In the case of the C-Q a plane surface can be observed, where all aggregate particles have been fractured. On the contrary, in concrete with SRG a tortuous broken surface with most aggregate particles debonded was seen. This difference can be explained considering the high strength of gravel particles added to the weaker interfaces produced by a rounded shape and smooth texture. Concretes with GSC and BCS present both debonded and fractured particles.

Concretes achieved 7 day compressive strengths higher than 35 MPa. The lowest strength was obtained with SRG. C-Q achieved high compressive strength, similar to C*-G, but had the lowest modulus of elasticity, which is in accordance with the stiffness of the rock. The lowest value of splitting tensile strength corresponds to C-S and there were no differences between C*-G, C*-B and C-Q.

As the stability is a very important aspect to be considered in SCC, especially when coarse aggregates of different densities are used, the homogeneity of hardened concrete was evaluated. Tubes of different height and shape were cast to analyze segregation resistance. With the small batches tubes 1 m height and 0.1 m diameter were filled, and after 7 days they were sawn alongside to survey coarse aggregate distribution. Fig. 3 shows the sawn surfaces. All mixtures showed a homogeneous distribution of coarse aggregate particles along the height of the tubes. In the case of 100 l batches, tubes with U shape of 1.80 m height, 0.70 m base, and 0.10 m diameter were cast. After 28 days they were sawn in transversal direction obtaining specimens of 0.40 m length for the determination of the ultrasonic pulse velocity (UPV) and the unit weight (UW). Fig. 4 shows the variation of UPV and UW measured on different sections of the U-tubes. As it can be seen, no significant

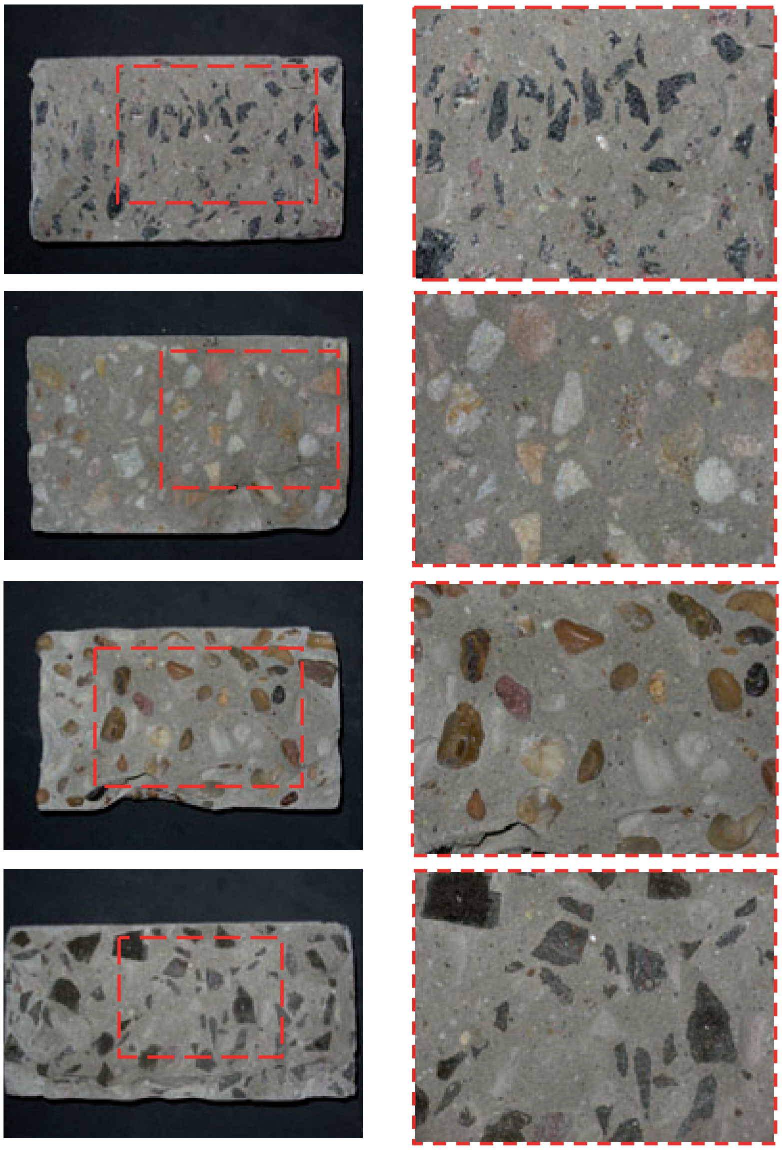

Fig. 2: Fractured surfaces obtained from the splitting tests.

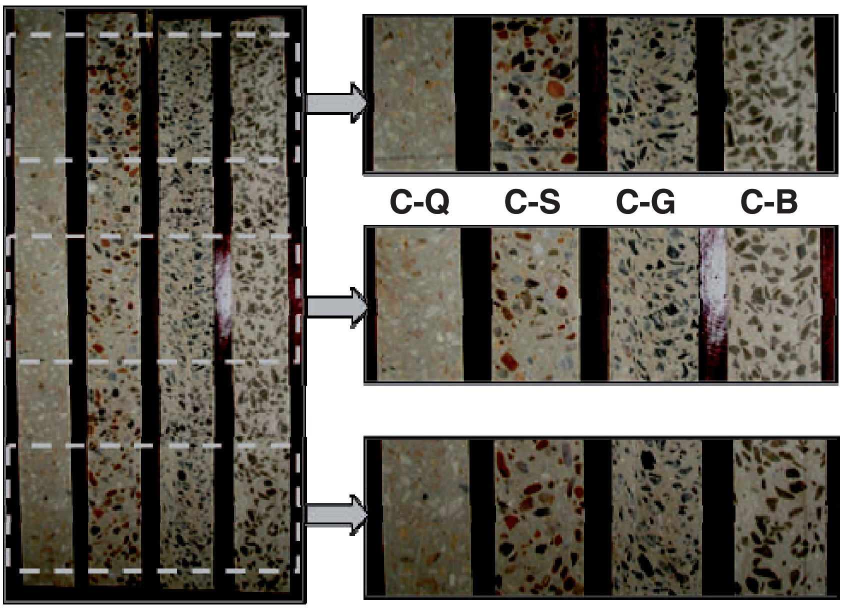

Fig. 3: Sawn surfaces of the specimens

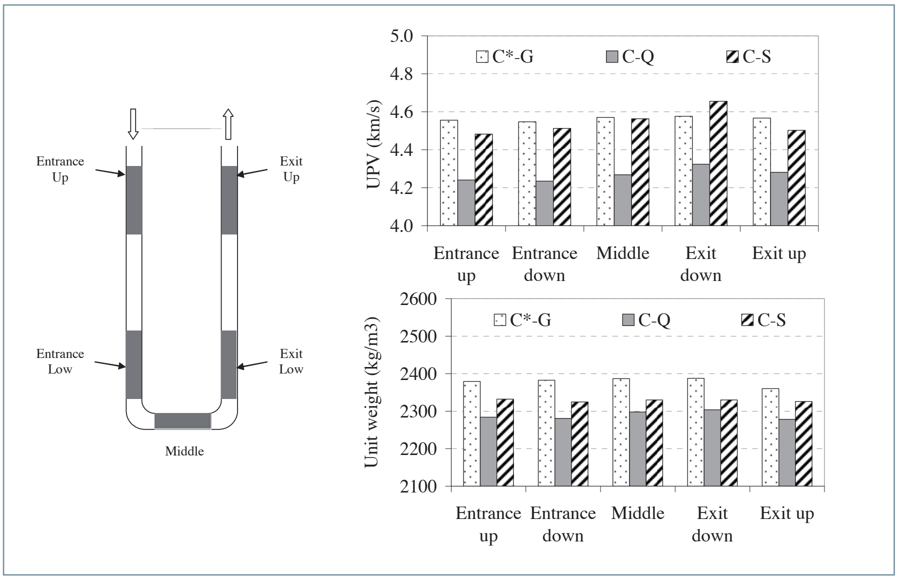

Fig. 4: Study of homogeneity: variation of the ultrasonic pulse velocity (UPV) and the unit weight along the length of U- tubes

differences (smaller than 3 %) between the sections considered were found. As expected the UPV varies with the type of coarse aggregate. Mean values of 4.56, 4.54 and 4.27 km/s were obtained on C*-G, C-S and C-Q respectively. The very small variation reflects the excellent filling ability of these SCC mixes.

Conclusions

This paper studied the influence of coarse aggregate type on the properties of SCC. The following conclusions are drawn:

- Based on the slump-flow and V-funnel tests on mortars it was possible to obtain SCC using 20 mm coarse aggregates with marked differences in shape and texture.
- The shape and texture of the coarse aggregate affected the flowability of SCC. Granitic and basaltic crushed stones required higher dosage of superplasticizer than the other aggregates to achieve the same slump flow class. In addition, it was observed that concrete with river gravel showed the lowest values of V-funnel time.
- An important influence of mixing energy was observed. The main differences seem to be related to the viscosity of concrete. Concretes with similar slump flow showed important reductions in the t_{50} and V-funnel time when bigger batches were prepared.
- The analysis of sections of SCC tubes showed that all concretes present a homogeneous distribution of coarse aggregate particles along the height, indicating a high stability and segregation resistance.
- The effect of coarse aggregate type on the properties of hardened SCC agrees with the behavior previously observed in normal and high strength concretes.

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