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SUSTAINABLE USE OF CONCRETE AGGREGATES IN ARGENTINA

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Abstract

Córdoba province (Argentina) produces important quantities of aggregates, especially for concrete structures. Low quality materials can decrease structure's life and increment environmental liabilities and the use of quartz-bearing rocks can develop alkali-silica reactions (ASR) which affect concrete durability. Rocks reactivity from Córdoba was evaluated through standardized methods showing good behaviour due to their favorable textural and microstructural characteristics.

Introduction

The province of Córdoba (Argentina) is one of the main crushed stone producers in the central-east region of the country and this material is in second place in the production of this province, after natural aggregates [5]. Additionally, Córdoba is responsible of about 40% of the national crushed stones [6].

Although quarries from Sierras de Córdoba exploit monolithological materials and polilithological materials [17], and in some cases the gravel fraction of alluvial deposits which is also crushed [5], metamorphic rocks lead with around 60% to 70% of the total volume of production [5,9,20].

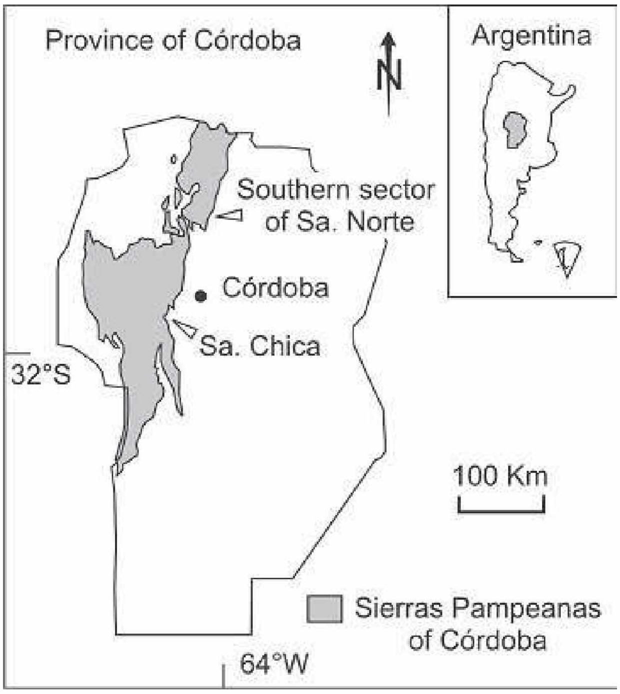

Figure 1. Geological sketch of the ***Sierras Pampeanas of Córdoba***.

The eastern sector of the Sierras Pampeanas of Córdoba (Figure 1) is the main source of crushed rocks and the construction industry consumes a great part of the aggregates to develop concrete structures such as dams, highways, bridges, etc.

Lithological and structural heterogeneities of the material produced in this region are product of the geological processes which affect this igneous-metamorphic complex [4,16] of basically Lower Cambrian age [19]. It requires a constant monitoring by producers as well as inspectors and the lack of a correct advice given by specialized professionals, inevitably impacts on the quality of the produced material [17]. This situation causes an increment in environmental liabilities due to demolition processes and waste accumulations.

The use of recycled aggregate concrete from demolition structures [e.g. 15] is a good strategy for minimizing the environmental impact. However, searching new areas with high quality materials [e.g. 20] could prevent concrete deterioration due to bad aggregates performance.

Alkali-silica reaction (ASR) is a well-known process which is developed when certain types of silica in the aggregates get in contact with the alkalis in the concrete pore solution producing gels which increase its volume in water presence producing internal stresses in the concrete and affecting its durability [21].

Quartz-bearing rocks from Córdoba have been affected by deformation processes [16], producing microstructures in quartz (like dislocations) which cause a partial loss of continuity in the crystal structure, and create unstable sites that are susceptible to being attacked by the alkaline concrete pore solution [12]. It is a well known process which contributes to ASR [e.g. 7,11,23]. Quartz in myrmekites is another unstable site and could also contribute to the reaction [18].

Recently, reactivity of a set of rocks from Sierras de Córdoba was evaluated [13,14] concluding that the higher the quartz content in the rock is, the more marked its foliation, the larger the number of microstructures in the strained quartz and the smaller the grain size, the greater aggregate expansion results.

The objective of this work is to evaluate the potential alkali reactivity of a second set of rocks from the eastern Sierras Pampeanas de Córdoba and compare the results with those previous studies.

Materials and Methods

Monolithological samples from potential areas (chloritized garnet-bearing gneiss "A", amphibolite "B", slightly deformed tonalite "D", porphyric granite "F" and granite "G") and polilithological samples from quarries ("C" and "E") were studied. They come from Sierra Chica and the southern sector of Sierra Norte (Figure 1), province of Córdoba (Argentina). Sample C is a mixture of crushed pyroxenitic orthogneisses (Figure 2a) with minor quantities of granatiferous paragneisses and granitic intrusives. Sample E is a mixture of Hbl-bearing orthogneisses, amphibolites and minor quantities of granitic intrusives.

Petrographic analysis of the samples was performed [1], focusing on their mineralogy, relative amounts of each face, alterations, texture and structures, quartz grain size and microstructural features in quartz crystals.

Potential alkali reactivity was determined by the accelerated mortar bar test method [3]. It consists of moulding cement and sand bars (25 x 25 x 285 mm) with grain sizes, proportions, w/c ratio and mixing determined according to the aggregates to be evaluated. The bars are first cured in a fog room (24 h), then demoulded and immersed in water at 23°C in a sealed container and placed in a heater at 80°C (24 h). Once the length (initial) has been measured, they are immersed in a 1 N NaOH solution at 80°C for 14 days and the rest of the readings are taken. Expansions below 0.10% at 16 days indicate aggregates of innocuous performance, and expansions above 0.20% a potentially deleterious behaviour. Expansions between 0.10% and

0.20% are considered as marginal and it is recommended supplementary information be gathered or further studies be made to discriminate between innocuous and deleterious aggregates. Some authors [e.g. 8] suggest diminish the limit to 0.07% or 0.08% at 16 days or extend the test until 28 days for identify slow-reacting rocks such as granitic rocks.

Dissolved silica values were determined as prescribed in the chemical test method [2]. It consists of crushing a fraction of the aggregate to be evaluated (between 300 μm and 150 μm in size) and placement of this fraction in a sealed container with a 1 N NaOH solution at 80°C for 24 h; the solution is then filtered and the dissolved silica in the liquid phase is determined.

Finally, studies with a stereomicroscope and by polarization microscopy on thin sections once the test time had elapsed were performed.

Results

Petrographical characteristics of samples are summarized in Table 1 (measures and observations were realized under petrographic microscope). Mineral abbreviations are according to Whitney and Evans [22].

Samples were tested according to chemical test method [2] for 24 hours and accelerated mortar bar test method [3] extending the lectures until 28 days. Results are summarized in Table 2 and Figure 3.

Expansion tests were extended up to 28 days as suggested by Hooton and Rogers [10] and Falcone et al. [8] because strained quartz-bearing rocks react in a slower manner than rocks with amorphous silica which react in a faster way.

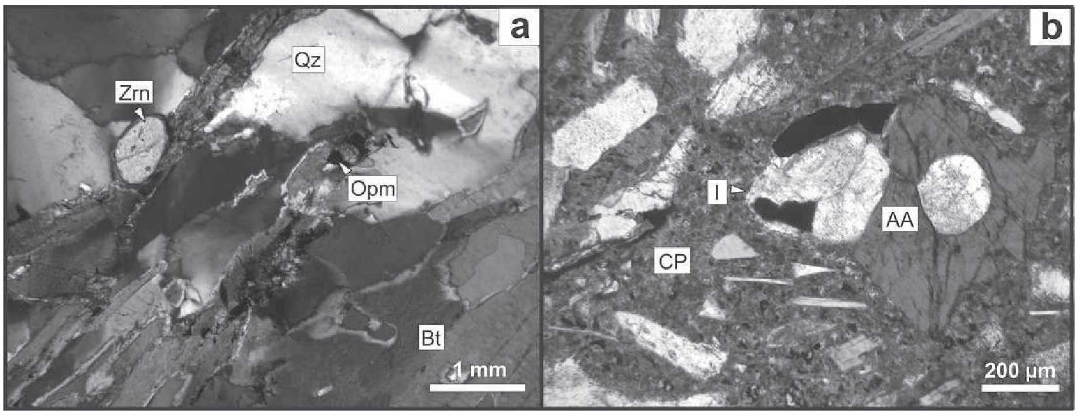

Figure 2. Photomicrographs. a) Sample C. b) Mortar bar tested. I: aggregate-cement paste interface. AA: amphibolitic aggregate. CP: cement paste. Abbreviations according to Whitney and Evans [22]

Table 2.
Dissolved silica values at 24 hours [2] and length variation in mortar bars [3] up to 28 days.

Samples	Dissolved silica	Length variation (%) in mortar bars at different ages (days)					
	mg/100 ml	4	7	11	16	21	28
A	5.1	0.003	0.004	0.021	0.036	0.060	0.082
B	5.8	0.003	0.007	0.010	0.015	0.053	0.069
C	5.0	0.010	0.015	0.036	0.058	0.079	0.103
D	7.5	0.000	0.003	0.008	0.016	0.059	0.074
E	5.2	0.009	0.014	0.022	0.037	0.051	0.058
F	5.7	0.006	0.014	0.016	0.020	0.023	0.030
G	5.3	0.004	0.006	0.008	0.008	0.015	0.019

After accelerated test, mortar bars show no important cracks, empty or partially filled entrained air voids and good aggregate-paste bonding (Figure 2b). Sometimes a uniform, transparent to white film lining air voids is observed and in other cases white plates and transparent needles are also observed under stereomicroscope. Microscopically, cement paste shows no cracks except for samples C and E. In this samples little perigranular and intragranular cracks (~2 μm in thick) partially filled with a low interference color material and linked to aggregates with strained quartz are observed.

Table 1.
Petrographic characteristics of the samples.

Sample	*Mineralogy**	*Alteration*	*Texture -structure*	*Q (∅)*	*M*
A	Qz (45%) - Pl (30%) - Bt, Chl, Ser, Opm (15%) - Grt (5%) - Ms, Zrn, Cal, oxides (~5%)	Bt and Grt to Chl - Pl to Ser and Cal - Opm oxidized	Grano-lepidoblastic. Marked foliation.	Grains: 6 mm-100 μm	Undulate extinction (abundant), deformation bands (scarce), subgrains and recrystallized grains (locally produced)
B	Amp (50%) - Cpx (20%) - Qz (15%) - Bt (5%) - Pl (5%) - Ser, Kfs, Ms, Zrn, Ttn, Opm, Cal, Ep (~5%)	Pl to Ser, Ep and Cal	Nematoblastic. Minerals are grouped in domains.	Grains: 1-0.5 mm Subgrains: ~100 μm	Undulate extinction, deformation bands and fluid inclusions (abundant). Subgrains (scarce)
C (Fig. 2a)	Monomineralic particles: Bt (29%), Qz (29%), Pl (13%), Amp (3%), Grt (2%), Kfs, Hyp, Ms, Cal, Ep, Ser, Opm, oxides (~5%) Polim. particles: gneissic ag. (19%)	Pl to Ser - Opm oxidized	Gneissic aggregate (predominant): Grano-lepidoblastic. Marked foliation.	Grains: 1 mm-200 μm Subgrains: 10-40 μm	Undulate extinction, deformation bands and subgrains (scrace). Some aggregates (< 1%) present quartz crystals with strong subgraining and recrystallized grains. Mirmekites (scarce)
D	Pl (50%), Qz (30%), Amp, Bt, Chl, Opm (10%), Kfs (5%), Ser, Ep, Cal, Zrn, Ap (~5%)	Pl to Ser, Ep and Cal - Bt and Amp to Chl	Holocrystalline with anhedral quartz phenocrysts.	Grains: 4 mm-100 μm (abundant), ~1.5cm (scarce)	Undulate extinction, blocky extinction, deformation bands and fluid inclusions (abundant).
E	Monomineralic particles: Amp (29%), Qz (11%), Pl (11%), Bt (10%), Kfs, Ms, Ttn, Chl, Cal, Ep, Ser, Opm, oxides (~5%) Polim. particles: Hbl-bearing aggregate (20%), granitic ag. (14%)	Pl to Ser and Cal - Opm oxidized - Bt and Amp to Chl	Hbl-bearing aggregate (predominant): Grano-nematoblastic. Marked foliation.	Grains: 3 mm-100 μm Subgrains: 40-10 μm Pulverized quartz due to brittle defromation: ≤ 10 μm	Undulate extinction (abundant), deformation bands and subgrains (scrace). Some aggregates (~3%) present quartz crystals with strong subgraining and recrystallized grains. Mirmekites (scarce)
F	Pl (50%), Kfs (25%), Qz (20%), Bt, Ap, Zrn, Ep, Cal, Kln, Opm, oxides (~5%)	Pl to Ser, Cal and Ep - Kfs to Kln - Bt to oxides	Holocrystalline and porphyric texture with Pl and Kfs phenocrysts.	Grains: ≤ 6mm	Undulate extinction and deformation bands (localized). Mirmekites (abundant)
G	Qz (35%), Pl (35%), Kfs (25%), Ser, Ap, Ep, Cal, Chl, Bt, Ms, Opm (~5%)	Pl to Ser, Cal and Ep - Bt to oxides or Chl	Holocrystalline and equigranular. Contact between Pl and Kfs is sometimes recrystallized.	Grains: ≤ 2mm	Undulate and blocky extinction (scarce). Mirmekites (scarce)

*Approximate content of each phase. *Q(∅)*: Quartz grain size (apparent diameter). M: Microstructural features identified in quartz crystals.

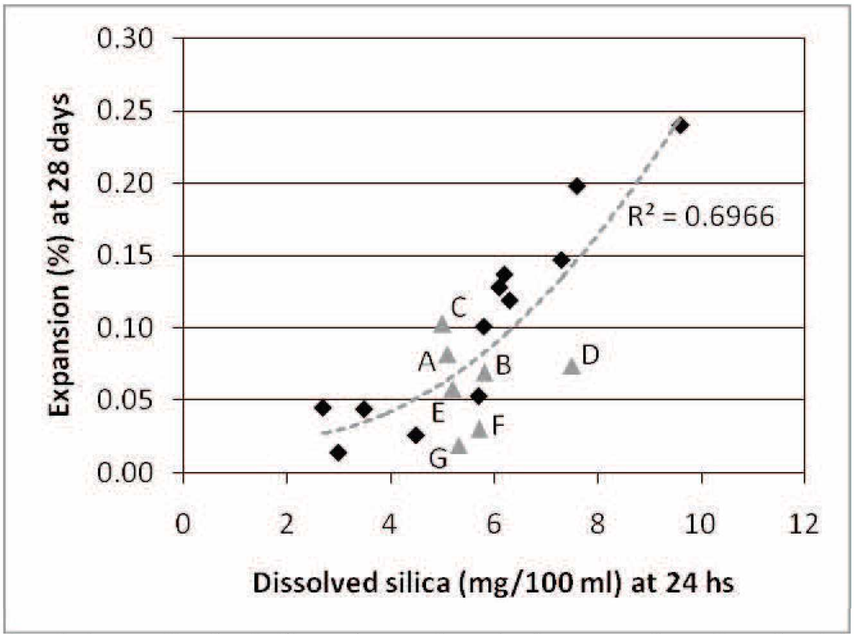

Figure 3. Comparison between dissolved silica values and mortar bar expansions. Samples A to G (grey triangles). Black diamonds: data from Locati et al. [13,14]).

Discussion

None of the samples show expansions greater than 0.10% at 16 days, so they are classified as no alkali-reactive and possibly a good option to produce a more durable concrete. This good behaviour is mainly due to the intensity of the deformation processes which slightly affected the rocks.

However producers must be very careful selecting areas for production because the intensity of the deformation processes can vary in a few meters especially in shear zones, producing important modifications in the fabric of rocks and in their alkali-reactive behaviour [12].

In previous studies [13] a good correlation between dissolved silica and expansion values was found (R^2 ~0.87). In Figure 3 we compare those values with values obtained in this work. Though the coefficient obtained is smaller (R^2 ~0.70), an acceptable correlation was found (with a quadratic polynomical distribution), and the statistic of the value was improved.

Conclusions

All samples studied show a good behaviour respect to the ASR. Granitic aggregates (Samples F and G) have shown the best performance respect to the ASR due to its textural, mineralogical and microstructural favorable characteristics.

An acceptable correlation between dissolved silica and expansion values (R^2 ~0.70) was observed. Higher expansion values are accompanied by higher dissolved silica values with a quadratic polynomical distribution. However more results are needed to confirm this tendency.

Comparing values from different standardized methods and other non-standardized analysis, like studies with stereomicroscope and polarization microscopy on mortar bars tested, result in a good strategy to evaluate the potential alkali-reactivity of the rocks in an integral way.

Acknowledgements

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THE THERMO-EFFECT ON THE SHEAR BANDING IN SATURATED SOILS

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Abstract: *The thermal effects on the shear banding in saturated sand under high-speed deformation were discussed. The initiation conditions by considering the generation and diffusion of the heat and the pore pressure were discussed. The instability initiates once the heat and pore pressure softening effects overcome the strain-hardening effects. Heat is trapped inside the shear band to cause the rapidly increase of the pore pressure. Thus uninhibited sliding motion on a small-friction or frictionless base occurs.*