Petrographic Characterization of Waste Rocks: Applicability as Concrete Aggregates

Maria del Pilar Durante Ingunza, Antonio Carlos Galindo,
and Ana Beatriz Azevedo de Medeiros

Abstract

Petrographic characterization showing mineralogical, textural and structural aspects of rocks is an essential technique in the study of the performance of concrete aggregates, specifically on the investigation of the alkali-aggregate reaction (AAR). The assessment of this deleterious reaction, considered as one of the most important pathologies, is a required test in the waste utilization programs. In this paper, waste rock samples of a feldspar mine were studied by optical microscopy, approaching aspects related to morphology, texture and alteration degree to determine the potential alkali reactivity for use as aggregates in cementitious mixtures. The rock studied shows characteristics that make it susceptible to be a reactive aggregate, due to, mainly, the strained quartz and the microcrystalline quartz. However, these results must be confirmed by standard mechanical test methods.

Keywords

Petrographic characterization • Waste rocks • Concrete aggregates

1 Introduction

Nowadays, sustainable mining is increasingly considered as a more accessible challenge. To include mining waste in sustainable management practices is a global consensus.

Mining industry produces a large amount of waste rocks with different properties related to formation processes. Specifically, crystalline rocks are widely used as ornamental stone and as raw material in civil construction, mainly as concrete aggregate, due to their suitable properties.

ASTM defines aggregates as granular materials of mineral composition such as sand, gravel, shell, slag or crushed stone used with a cementing medium to form mortars or concrete (ASTM Standard 2016a). The use of aggregates for concrete is widely regularized by ASTM Standard (2009, 2011, 2013, 2014a, b, c, 2016b).

On the other hand, alkali-aggregate reactivity (AAR) is considered one of the most important pathologies in civil construction. Two types of Alkali-aggregate reactivity are commonly defined, the alkali-silica reaction (ASR), where there are two variants, depending on the velocity of the reaction and the alkali-carbonate reaction (ACR). Both are complex reactions of aggregates and alkali hydroxides in concrete that create expansion processes, and provoke, potential structural damages.

Although ASR pathologies in structures have been reported around the world related to crystalline aggregates (Ian Sims and Poole 2017) these materials are commonly used in civil construction, having obtained successful results.

Table 1 summarizes the main reactive minerals and the respective occurrence rocks. Clearly, potential reactive minerals occur in just about all the common rocks, which emphasizes the importance of accurate analysis in aggregates.

The U.S. Department of Transportation (2012) defines the combination of petrographic examination, expansion testing and field performance as required actions to confirm the non-deleteriously-reactive nature of the aggregates.

Petrographic description of aggregates is a very well known method to identify its reactivity. It is due, basically, to the reliability and quickness that this technique provides. However, it is strongly recommended to confirm the results by other methods, specifically mechanical tests as the accelerated mortar test (ASTM Standard 1994).

Recently, Sanchez et al. (2017) have stood out microscopic techniques as important complementary tools in the AAR assessment. In addition, microscopic examination is

M. del Pilar Durante Ingunza (✉) · A. C. Galindo ·
A. B. A. de Medeiros
Federal University of Rio Grande do Norte (UFRN), Natal, RN
59078-970, Brazil
e-mail: durante@ct.ufrn.br

A. Shakoor and K. Cato (eds.), *IAEG/AEG Annual Meeting Proceedings, San Francisco, California, 2018—Volume 3*, https://doi.org/10.1007/978-3-319-93130-2_9

Table 1 Some potential reactive minerals

Reactive material	Occurrence rocks
Chalcedony, micro and cryptocrystalline quartz Macrogranular strained quartz, rich in inclusion, intensely fractured with microcrystalline quartz in grain contacts	Volcanic rocks with devitrified glass or cryptocrystalline Igneous rocks: granite, granodiorite and charnockite Sedimentary Rocks: sandstone, grauvaque, siltite, argillite, shale, phyllite and slate Metamorphic rocks: gneiss, shale, quartzite, phyllite and slate

Modified from ABNT (2008)

highlighted as the appropriated measurement of deformation intensity (Murlidhar et al. 2016).

Specifically for rocks with quartz, the undulatory extinction in quartz is a criterion strongly used for identifying potentially alkali-reactive reactions (Dolar-Mantuani 1981). Consequently, rocks with micro and cryptocrystalline quartz moderately to strongly strained are considered as susceptible to AAR (ABNT 2008; CSA 1994).

The amount of strained and microcrystalline quartz needed to provoke potential reactivity reaction is variable. There are no defined values, consensually. Many factors can contribute to ASR-induced damage; consequently, cases should be studied separately. In this way, Brazilian norm suggested values of 5% of strained quartz, 3% of chalcedony, 1% of tridymite-cristobalite, 3% volcanic glass, 0.5% opal. Under these values, the aggregate is considered potentially innocuous. These values can be changed by petrographer considerations (ABNT 2008).

The aim of this paper is to evaluate the applicability as concrete aggregates of waste rocks by petrographic characterization I n the context of sustainable mining.

2 Materials and Methods

Locally, the study area is geologically inserted in the Structural Province of Borborema (Fig. 1), with composition and organization essentially Neoproterozoic (Brasiliano Domain). The stratigraphic units in this area are predominantly composed by formations inserted in the Seridó Group, associated to the Brasiliano/Pan-African Orogeny, including the Itaporanga intrusive suite, resulting of a Brasiliano plutonism (Angelim 2007).

Tectonically, the Seridó Group experienced three deformational events causing compositional banding, geological folds and NNE-SSW foliation, respectively. The last one corresponding to the Brasiliano transcurrent Kinematic, with shear areas (Jardim de Sá 1984, 1987, 1994).

Samples of waste rocks from feldspar mining at Parelhas/RN, Brazil were collected. The samples are included in the intrusive suite Itaporanga. Geologically, the rock is classified as granite gneiss. Petrographic examination of samples was performed according to Brazilian norm (ABNT 2008) based in international standards (ASTM Standard 2012) with a Polarizing Microscope Nikon Eclipse E200MV POL. Table 2 shows the procedures followed.

3 Results and Discussion

Figures 2, 3, 4, 5 and 6 show thin sections of the rock samples. The minerals identified are quartz, k-feldspar, plagioclase, biotite, opaques, apatite, and zircon. Mostly, the rock presents a medium-grained texture, inequigranular, with the largest crystals of quartz, without a clear out mineral orientation, although biotite crystals show slightly preferential orientation (Fig. 2).

The predominant mineral is quartz (Table 3) appearing essentially, as xenomorphic crystals, clear and colourless, with undulatory extinction and with fractures, which are occasionally filled by fine micaceous material, with bright birefringence colours (Fig. 3).

The second most abundant mineral, K-feldspar, appears as xenomorphic-hypidiomorphic microcline crystals, with characteristic cross-hatched twinning. The crystals are of varied size, generally larger than 0.3 mm, some crystals reaching 1.0–1.5 mm (Fig. 4). Further, some K-feldspar crystals show some characteristic textures as string perthite (Fig. 5).

Plagioclase arises generally as hypidiomorphic crystals, usually with twin lamellae, polysynthetic, showing a low degree of alteration and, commonly composing aggregates with triple junction contacts (Fig. 6).

The mafic mineral in the rock is, predominantly, biotite (Fig. 2) which occurs in general as hypidiomorphic crystals, with pallet shapes showing, discreetly, preferential orientation. Its colour is yellow with pleochroism in brown tones. Biotite shows low degree of secondary alteration. In addition, biotite crystals contain apatite, zircon and opaques inclusions.

Opaques occur as small crystals (<0.3 mm) with dark colours, usually idiomorphic, in quadratic sections, suggestive of being magnetite.

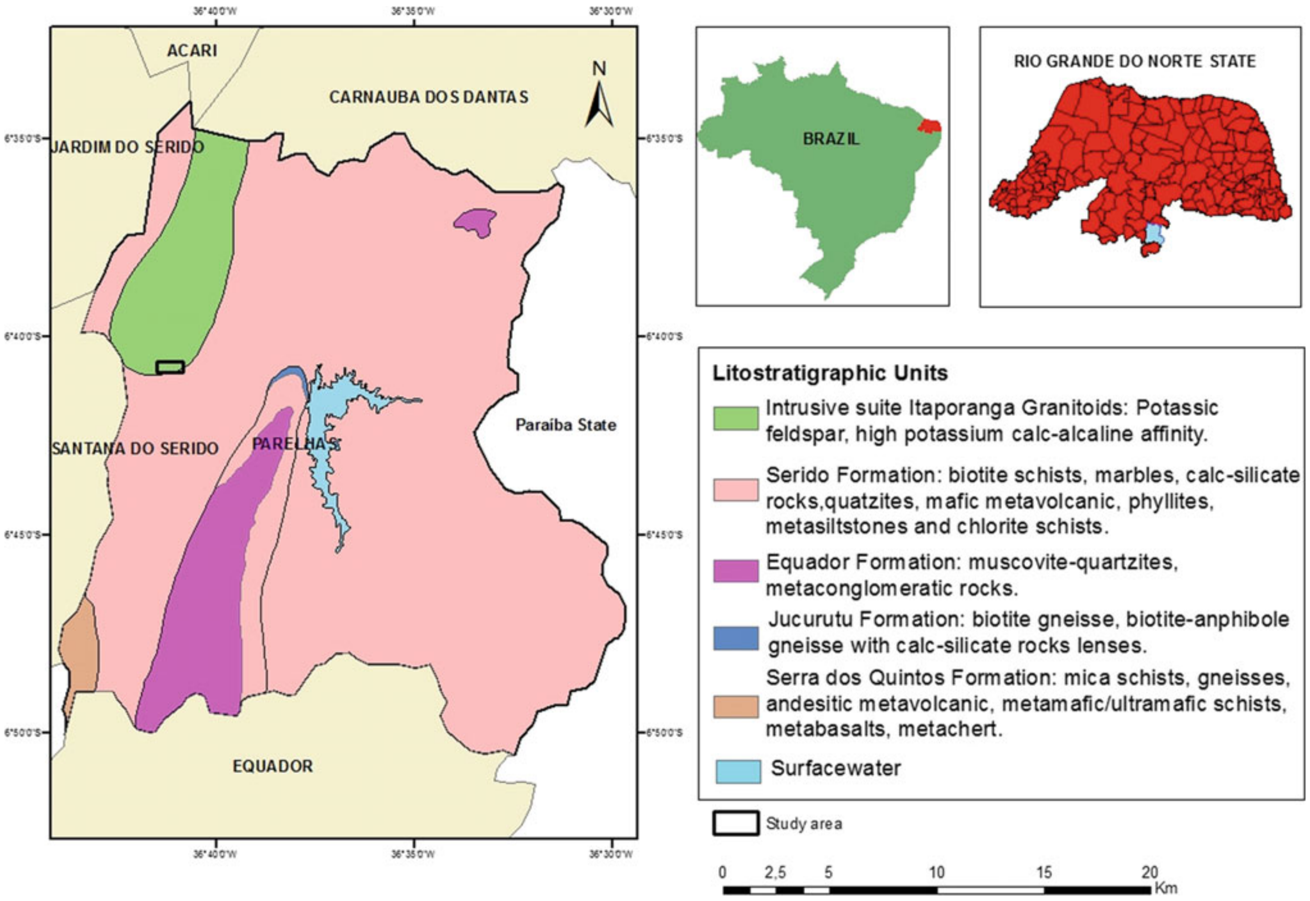

Fig. 1 Location and geological characterization of the study area. *Source* Modified from Angelim et al. (2006)

Table 2 Procedures in thin sections

Characteristic	Observations
Mineralogical composition	Description of main and subordinate minerals. Including opaques Percentages (estimative)
Texture	Identification of myrmekite and perthitic textures
Granulation	Classification: fine-medium-coarse
Deleterious minerals ([a])	Description of deleterious mineral and phases Percentages (estimative)
Microfractures	Classification: low-moderate-high
Alteration degree	Description of altered minerals

Modified from ABNT (2008)
([a]) as described in Table 1

Apatite and Zircon are present in lower amounts (1%) and small crystals (<0.1 mm) essentially idiomorphic and included in biotite. Apatite is colourless and high relief with rounded hexagonal crystals.

Zircon is slightly colourful, quadratic to prismatic elongated, with strong birefringence colours.

4 AAR Reactivity

Two types of deleterious minerals have been found: strained quartz, as shown in Fig. 3 and microgranular quartz. The maximum undulatory extinction angle was 17°.

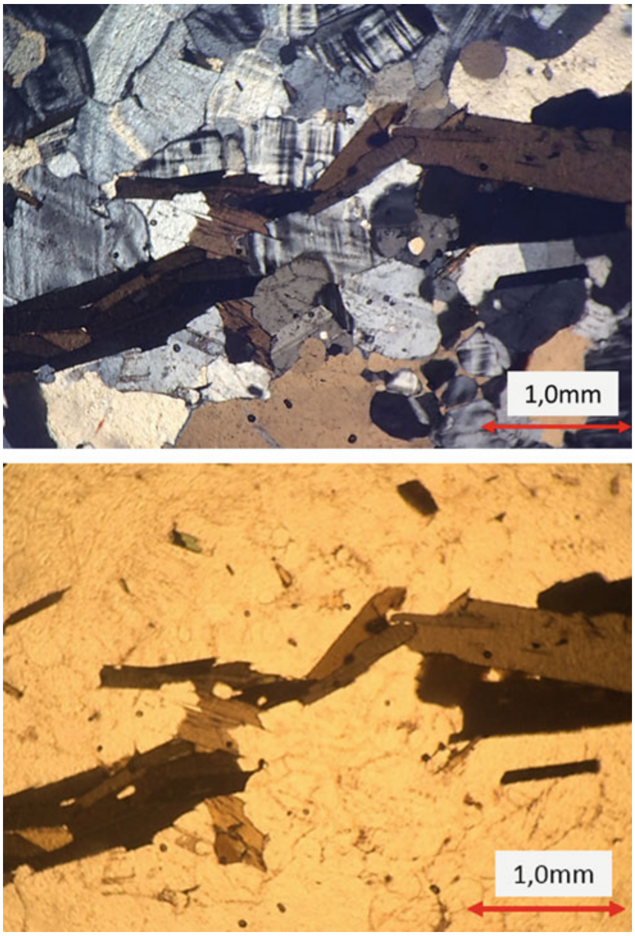

Fig. 2 General overview. Biotite crystals show, slightly, preferential orientation. Crossed polarized light (upper photograph), plane-polarized light (lower photograph).

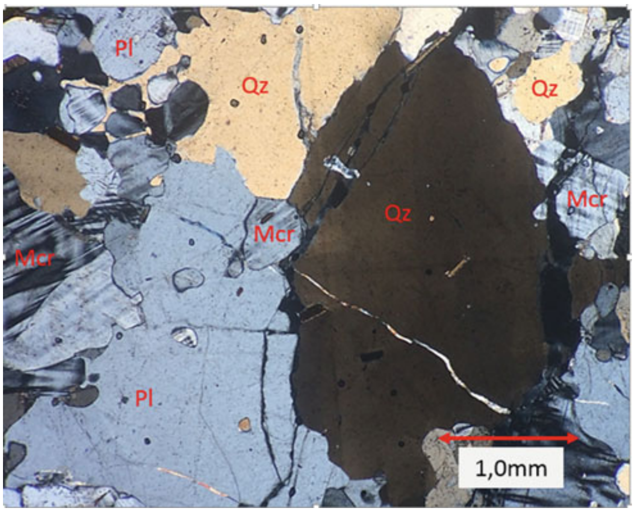

Fig. 3 Xenomorphic crystals of quartz, with undulatory extinction and micaceous material filling a fracture, with bright birefringence colours (crossed polarized light). Qz: quartz; Mcr: microcline; Pl: plagioclase

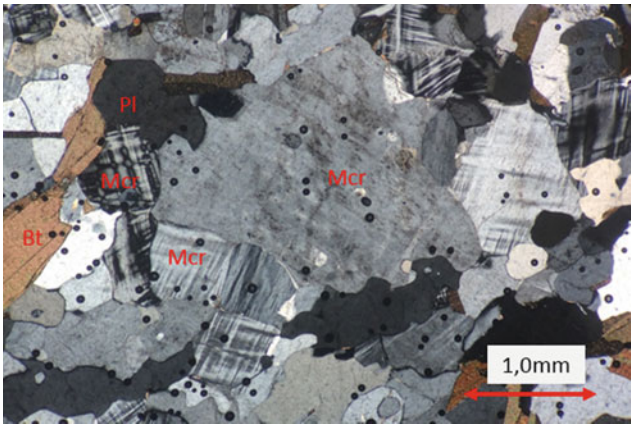

Fig. 4 Xenomorphic-hypidiomorphic microcline crystals showing cross-hatched twinning (crossed polarized light). Bt: biotite; Mcr: microcline; Pl: plagioclase

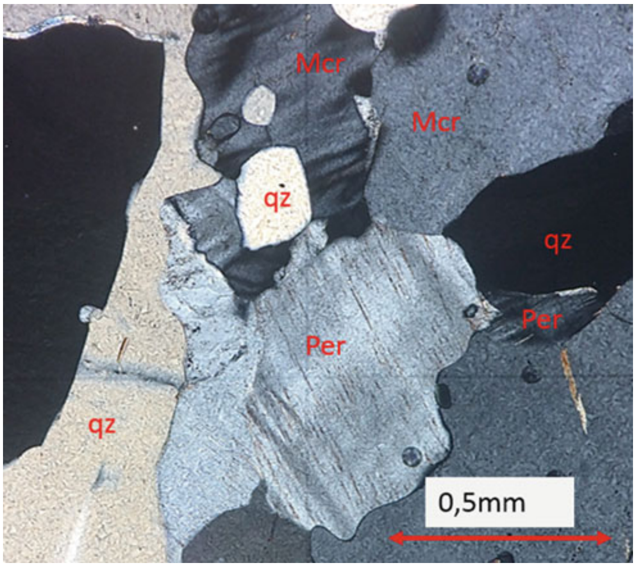

Fig. 5 Large alkali feldspars with string perthite (crossed polarized light). Per: perthite; qz: quartz; Mcr: microcline

The percentage found for strained quartz was 15%, which transcends the recommended values in Brazilian standards of 5% (ABNT 2008). Regarding to microcrystalline quartz, the percentage found was 1%.

Perthitic texture is considered potentially reactive for AAR in the specific case of flame Perthite, as it indicates deformation processes. In all the samples studied, there is no evidence of that specific texture. However, string perthite—not suggestive of AAR—is commonly found (Fig. 5).

The textural and mineralogical characteristics of the protolith—probably a syenogranite—due to the high amount of K-feldspar and low percentage of mafics—have certainly influenced on the potential alkali-aggregate reactivity of the

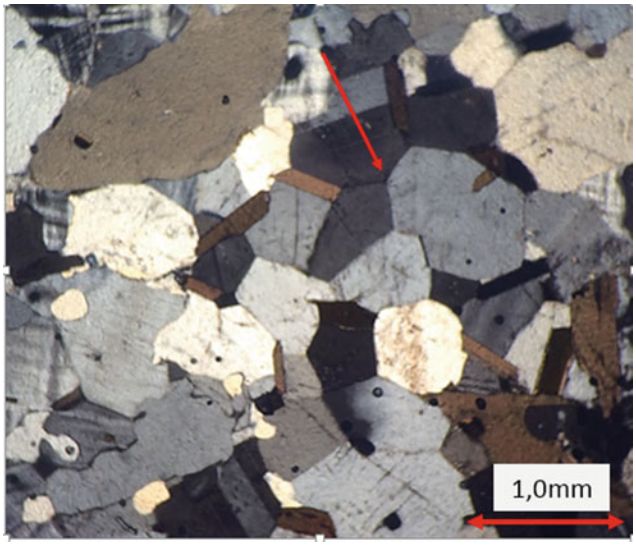

Fig. 6 Crystals of plagioclase with slight alteration and triple junctions (crossed polarized light)

Table 3 Modal percentage of minerals

Mineral	Modal percentage (%)
Quartz	40
K-Feldspar	30
Plagioclase	17
Biotite	10
Opaques	2
Apatite, Zircon	1

samples studied. In this respect, petrographic description indicates stability of the protolith.

The rock is classified as potentially reactive due to the percentage of strained quartz and the undulatory extinction angle, with low degree by Brazilian Standards (ABNT 2008). However, these results must be confirmed by standard mechanical test methods.

5 Conclusions

The rock studied shows characteristics that make it susceptible to be a reactive aggregate mainly, strained quartz, undulatory extinction angle and microcrystalline quartz. Furthermore, the materials show slight alteration processes, which also have to be considered.

In addition, the rock formation processes and the protolith characteristics have influenced, considerably, the low potential reaction degree of the rock.

Finally, as established in international standard norms, these results must be confirmed by standard mechanical tests (ASTM Standard 1994).

References

ABNT (Brazilian Association of Standards Specification) Standard ABNT NBR 15577, 1-5, 2008: Alkali Reactivity of Aggregates. ABNT, Rio de Janeiro, Brazil, (2008)

Angelim, L.A.A.: Geology and Mineral Resources of Rio Grande do Norte State (Brazil). Scale 1:500.000. Recife: CPRM–Braziliam Geological Service (2007)

Angelim, L.A.A., Medeiros, V.C., Nesi, J.R.: Braziliam Geology Program. Geology and Mineral Resources of RN Project. Geological Map of RN State. Scale 1:500.000. Recife: CPRM/FAPERN (2006)

ASTM Standard C1260, 1994: Test method for potential alkali reactivity of aggregates (mortar bar method). ASTM International, West Conshohocken, PA. www.astm.org (1994)

ASTM Standard C332, 2009: Specification for Lightweight Aggregates for Insulating Concrete. ASTM International, West Conshohocken, PA. www.astm.org (2009)

ASTM Standard C144, 2011: Specification for Aggregate for Masonry Mortar. ASTM International, West Conshohocken, PA. www.astm.org (2011)

ASTM Standard C295/C295M, 2012: Standard Guide for Petrographic Examination of Aggregates for Concrete. ASTM International, West Conshohocken, PA. www.astm.org (2012)

ASTM Standard C33/C33M, 2013: Specification for Concrete Aggregates. ASTM International, West Conshohocken, PA. www.astm.org (2013)

ASTM Standard C330/C330M, 2014: Specification for Lightweight Aggregates for Structural Concrete. ASTM International, West Conshohocken, PA. www.astm.org (2014a)

ASTM Standard C331/C331M, 2014: Specification for Lightweight Aggregates for Concrete Masonry. ASTM International, West Conshohocken, PA. www.astm.org (2014b)

ASTM Standard C637, 2014: Specification for Aggregates for Radiation-Shielding Concrete. ASTM International, West Conshohocken, PA. www.astm.org (2014c)

ASTM Standard D8, 2016: Terminology Relating to Materials for Roads and Pavements. ASTM International, West Conshohocken, PA. www.astm.org (2016a)

ASTM Standard C1797, 2016: Specification for Ground Calcium Carbonate and Aggregate Mineral. ASTM International, West Conshohocken, PA. www.astm.org (2016b)

CSA (Canadian Standard Association) A23.2–4, 1994: Appendix B Alkali-Aggregate Reaction: Concrete Materials and Methods Of Concrete Construction, Toronto, Ont. (1994)

Dolar-Mantuani, L.M.M.: Undulatory extinction in quartz used for identifying potentially alkali-reactive rocks. In: Proceedings on International conference on alkali-reaction in concrete, 5. Cape Town, Pretoria (1981)

Ian Sims, I., Poole, A.B. (ed.): Alkali-Aggregate Reaction in Concrete: A World Review. CRC Press (2017)

Jardim de Sá, E.F.: Seridó Region geology: data compilation. In: Symposium of Northeast Geology, Natal, Brazil (1984)

Jardim de Sá, E.F.: Proterozoic granitoids in a polycyclic setting: the Seridó region, NE Brazil. In: International Symposium on Granites and Associated Mineralizations-ISGAM, 1, Salvador (1987)

Jardim de Sá, E.F.: Seridó faixe (Borborema Province) geodinamical meaning on Braziliam/Pan-African System. Doctoral thesis. Brasília, 803 p (1994)

Murlidhar, B.R., Mohamad, E.T., Armaghani, D.J.: Potential alkali silica reactivity of various rock types in an aggregate granite quarry. Measurement **81**, 221–231 (2016)

Sanchez, L.F.M., Fournier, B., Jolinb, M., Mitchell, D., Bastien, J.: Overall assessment of alkali-aggregate reaction (AAR) in concretes presenting different strengths and incorporating a wide range of reactive aggregate types and natures. Cem. Concr. Res. **93**, 17–31 (2017)

U.S. Department of Transportation; Federal Highway Administration: Alkali-aggregate reactivity (AAR) workshops for engineers and practitioners reference manual (2012)