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Review

Addition of quartzite residues on mortars: Analysis of the alkali aggregate reaction and the mechanical behavior

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HIGHLIGHTS

- Mortars containing more than 80% of quartzite wastes were produced.
- No other study focused on the potentiality of ASR of quartzite waste.
- Alkalis in the wastes do not react with silica in mortars containing pozzolan.

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ABSTRACT

The recycling of ornamental rock residues for use in mortars has been a widespread technique throughout the world. However, most studies do not verify if these residues, used as aggregates, can maintain their integrity when subjected to the action of aggressive agents. This work has the objective of studying the recycling of the quartzite residue in mortars with focus on the alkali-aggregate reaction and their mechanical behavior. We characterized the quartzite residues and executed the accelerated mortar bar test according to the ASTM C1260. The results reveal that these are non-reactive when incorporated into mortar and presented suitable mechanical behavior.

Contents

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1. Introduction

Millions of tons of ornamental rock residues are produced throughout the world every year. These residues are improperly discarded in the environment, causing serious public health problems, since they release a powder into the atmosphere. When inhaled, these substances cause respiratory complications [1,2]. Some studies state that the proper management of these residues is a matter of high technological, environmental and economic importance [3,4].

Studies conducted in developing countries suggest the incorporation of these residues into cement matrices, for use in mortar, as a way to achieve their sustainable management [5–8]. However, in order to conduct such studies, it is necessary to evaluate the durability of the aggregates generated by the ornamental rock residues with respect to the alkali-aggregate reaction (AAR). The AAR is a complex chemical process that may occur in the hardened mortar when some mineralogical components and alkaline hydroxides (sodium and potassium hydroxides from the cement, water, external agents, etc.) start chemical reactions that develop in the pores of the mortar, compromising its quality and durability [9–11].

The durability of mortar compositions incorporated with ornamental rock residues is affected by the occurrence of alkali-aggregate reactions, which have a strongly expansive character, and which leads to the appearance of tensions inside the material, and consequent cracking, frequently followed by the appearance of efflorescences and exudations to the surface [12].

The alkali-aggregate reaction may occur in three distinct ways: alkali-silica reactions, alkali-silicate reactions and alkali-carbonate reactions. The alkali-silica reaction involves the presence of amorphous silica or certain types of natural and artificial glass; the alkali-silicate reaction has the same nature of the alkali-silica, but with a slower process, involving some silicates present in the feldspars, clay shales, certain igneous metamorphic and sedimentary rocks, deformed quartz (tensioned) and expansive minerals; and the alkali-carbonate reaction, which occurs between certain dolomitic limestones and the alkaline solutions present in the pores of concrete [10].

Studies on the performance of mortar incorporated with ornamental rock residues as alternative raw matters have been highlighted in literature [13–16]. However, those studies do not mention the behavior of these residues with respect to the alkali-aggregate reaction. We must also point out that studies on the use of quartzite residues as alternative raw matters for the production of mortar, specially concerned with the relation between durability and the occurrence of alkali-aggregate reactions, was not found in literature. Therefore, the present work is intended to study the recycling of quartzite residues through their incorporation into mortar, as well as their durability related to the alkali-aggregate reactions.

2. Materials and methods

2.1. Materials

The binders used in this research work were: a CP IV 32 RS cement (ABNT NBR 5736 [17]) and a hydrated lime. The chemical composition of the cement is presented in Table 1. The cement used contain approximately 25% of pozzolanic material. It is similar to the American type-III cement, according to the ASTM C 150 [18]. The lime used presents in its composition a percentage of calcium oxide above 90% with respect to the remaining total oxides, being classified by the ABNT NBR 6453 standard [19] as calcitic. Its mineralogical composition comprises 87% of portlandite ($Ca(OH)_2$), 11% of calcite ($CaCO_3$) and 2% of free water.

The wastes were collected in a Brazilian company that process and sell ornamental stones. They were used as thin aggregate, and were of two types: quartzite sand, produced from scrapes, in the form of sand (quartzite sand), named in this work as QS; and in the form of powder (quartzite powder), resulting from the sawing of plates, named in this work as QP. The QS waste was used such as collected in the industry and the QP waste was deagglomerated in a ball mill, because it is produced as a mud in the sawing of tiles and plates and need deagglomeration before use.

2.2. Methods

2.2.1. Characterization

The characterization of the quartzite wastes was performed by the following techniques: determination of the specific mass, particle size distribution, by sieve method in the case of QS and by laser diffraction (Cilas 1064 equipment), X-ray fluorescence (Shimadzu EDX 720 device), XRD (Shimadzu XRD 6000 device), Scanning Electron Microscopy (Tescan SEM VEGA 3 equipment), Energy-dispersive Spectroscopy (Oxford EDS act20 device).

2.2.2. Alkali-aggregate reaction

The alkali-aggregate reaction (AAR) of mortar incorporated with quartzite residues was executed according to the ASTM standard C1260 [20], using the accelerated mortar bar test (AMBT) with prismatic test specimens dimensions 25 mm × 25 mm × 285 mm.

In the development of the formulations, changing the amount of quartzite wastes (and particle size distribution), cement and lime, a {3,2} centroid simplex-lattice design of mixture experiment, augmented with interior points, was used to define the mixtures of quartzite wastes (QP and QS), cement and hydrated lime that present proper mechanical strength for application in masonry. The mixture experiment was performed with the following constraints: maximum amount of cement of 50%, maximum amount of lime of 50%, minimum amount of QS of 50% and maximum amount of QP 15%. These constraints were based on data obtained from the literature and on the processing characteristics of the formulations. The statistical design was carried out with two replicates (three independent batches), using the Statistica 7.0 software.

In order to obtain a standard spread in all compositions, the amount of water to achieve a spread of 260 ± 10 mm was determined for each composition according to ASTM methodology (ASTM C230, 2008) [21] to determine the consistency of mortars.

Test specimens (10 cylindrical specimens for each composition replica – 50 mm in diameter and 100 mm in height) were produced after mechanical mixture of raw materials and use of a predetermined amount of water. After molding, the specimens were cured for 24 h in humid chamber, with 100% of relative humidity, for a period of 28 days. After 28-day curing period, the simple compressive strength ASTM C 780 standard [22]) (CS) was determined using a universal mechanical-tests machine (SHIMADZU AG-IS). The CS results were used to calculate the coefficients of the regression equations iteratively until statistically relevant models and response surfaces were obtained, relating the CS with the amount of wastes, cement and lime. According to the results of the strength, formulations were chosen for the alkali-aggregate reaction analysis.

Table 1
Chemical composition of Portland cement, quartzite sand waste (QS) and quartzite powder waste (QP).

Material	CaO	SiO_2	MgO	Al_2O_3	Fe_2O_3	SO_3	K_2O	TiO_2	P_2O_5	OO[a]	LOI[b]
Cement (%)	45.1	28.2	2.2	8.1	3.1	5.4	2.1	0.3	1.3	0.2	4.0
QS (%)	1.2	67.5	1.6	17.3	2.2	0.4	7.2	–	–	0.6	2.0
QP (%)	0.8	77.9	0.9	11.9	1.2	0.3	4.8	–	–	0.6	1.6

[a] OO: Other oxides.
[b] LOI: Loss on Ignition.